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HUMBOLDT'S COSMOS.

COSMOS:

A SKETCH

OF A

PHYSICAL DESCRIPTION OF THE UNIVERSE.

BY

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TRANSLATED FROM THE GERMAN,

BY

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Naturæ vero rerum vis atque majestas in omnibus momentis fide caret, si quis modo partes ejus ac non totam complectatur animo.—Plin., *Hist. Nat.* lib. vii. c. 1.

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GENERAL SUMMARY OF CONTENTS

OF

VOLUME V. OF COSMOS.

CORRECTIONS AND ADDITIONS

BY THE AUTHOR.

PAGE 32. LINE 12.

A far more important result in reference to the density of the earth than that obtained by Baily (1842) and Reich (1847—1850) has been brought out by Airy's experiments with the pendulum, conducted with such exemplary care in the Mines of Harton, in the year 1854. According to these experiments, the density is 6·566, with a probable error of 0·182 (Airy in the *Philos. Transact. for* 1856, p. 342). A slight modification of this numerical value, made by Professor Stokes on account of the effect of the rotation and ellipticity of the earth, gives the density for Harton, which lies at 54° 48′ north latitude, at 6·565, and for the Equator at 6·489.

PAGE 76. LINE 10.

Arago has left behind him a treasury of magnetical observations (upwards of 52,600 in number) carried on from 1818 to 1835, which have been carefully edited by M. Fedor Thoman, and published in the *Œuvres Complètes de François Arago* (t. iv, p. 498). In these observations, for the series of years from 1821 to 1830, General Sabine has discovered the most complete confirmation of the decennial period of magnetic declination, and its correspondence with the same period, in the alternate frequency and rarity of the solar spots (*Meteorological Essays,* London, 1855, p. 350). So early as the year 1850, when Schwabe published at Dessau his notices of the periodical return of the solar spots (*Cosmos,* vol. iv, p. 397), two years before Sabine first showed the decennial period of magnetic declination to be dependent on the solar spots (in March, 1852, *Phil. Tr.* for 1852, p. i, pp. 116—121; *Cosmos,* vol. v, p. 76, *note*), the latter had already discovered the important result, that the sun operates on the earth's magnetism by the magnetic power proper to its mass. He had discovered (*Phil. Tr.* for 1850, p. i, p. 216, *Cosmos,* vol. v, p. 140), that the magnetic intensity is greatest, and that the needle approaches nearest to the vertical direction, when the earth is nearest to the sun. The knowledge of such a magnetical operation of the central body of our planetary system, not by its heat-producing quality, but by its own magnetic power, as well as by changes in the Photosphere (the size and frequency of funnel-shaped openings), gives a higher cosmical interest to the study of the earth's magnetism and to the numerous magnetic observatories (*Cosmos,* vol. 1, p. 184; vol. v, p. 73) now planted over Russia and Northern Asia, since the resolutions of 1829, and over the colonies of Great Britain since 1840—1850. (Sabine, in the *Proceedings of the Roy. Soc.* vol. viii, No. 25, p. 400; and in the *Phil. Trans. for* 1856, p. 362).

PAGE 85. LINE 9.

Though the nearness of the moon in comparison with the sun does not seem to compensate the smallness of her mass, yet the already well ascertained alteration of the magnetic declination in the course of a lunar day, the *lunar-diurnal magnetic variation* (Sabine, in the *Report to the Brit. Assoc.* at Liverpool, 1854, p. 11, and for Hobart-town in the *Phil. Tr.* for 1857, Art. i, p. 6), stimulates to a persevering observation of the magnetic influence of the earth's satellite. Kreil has the great merit of having pursued this occupation with great care, from 1839 to 1852, (see his treatise *Ueber den Einfluss des Mondes auf die horizontale Component der Magnetischen Erdkraft,* in the *Deukschriften der Wiener Akademie der Wiss. Mathem. Naturwiss. Classe,* vol. v, 1853, p. 45, and *Phil. Trans.* for 1856, Art. xxii). His observations, which were conducted for the space of many years, both at Milan and Prague, having given support to the opinion that both the moon and the solar spots occasioned a decennial period of declination, led General Sabine to undertake a very important work. He found that the *exclusive* influence of the sun on a decennial period, previously examined in relation to Toronto in Canada, by the employment of a peculiar and very exact form of calculation, may be recognised in all the three elements of terrestrial magnetism (*Phil. Trans.* for 1856, p. 361), as shown by the abundant testimony of *hourly observations* carried on for a course of *eight years* at Hobart Town, from January 1841 to December 1848. Thus both hemispheres furnished the same result as to the operation of the sun, as well as the certainty "that the lunar-diurnal variation corresponding to different years shows no conformity to the inequality manifested in those of the solar-diurnal variation. The earth's inductive action, reflected from the moon, must be of a very little amount." (Sabine, in the *Phil. Tr.* for 1857, Art. i, p. 7, and in the *Proceedings of the Royal Soc.* vol. viii, No. 20, p. 404). The magnetic portion of this volume having been printed almost three years ago, it seemed especially necessary, with reference to a subject which has so long been a favourite one with me, that I should supply what was wanting by some additional remarks.

INTRODUCTION.

SPECIAL RESULTS OF OBSERVATION IN THE DOMAIN OF TELLURIC PHENOMENA.

In a work embracing so wide a field as the Cosmos, which aims at combining perspicuous comprehensibility with general clearness, the composition and co-ordination of the whole are perhaps of greater importance than copiousness of detail. This mode of treating the subject becomes the more desirable because, in the Book of Nature, the generalization of views, both in reference to the objectivity of external phenomena and the reflection of the aspects of nature upon the imagination and feelings of man, must be carefully separated from the enumeration of individual results. The first two volumes of the Cosmos were devoted to this kind of generalization, in which the contemplation of the Universe was considered as one great natural whole, while at the same time care was taken to show how, in the most widely remote zones, mankind had, in the course of ages, gradually striven to discover the mutual actions of natural forces. Although a great accumulation of phenomena may tend to demonstrate their causal connection, a General Picture of Nature can only produce fresh and vivid impressions when, bounded by narrow limits, its perspicuity is not sacrificed to an excessive aggregation of crowded facts.

As in a collection of graphical illustrations of the surface and of the inner structure of the earth's crust, general maps precede those of a special character, it has seemed to me that in a physical description of the Universe it would be most appropriate, and most in accordance with the plan of the present work, if, to the consideration of the entire Universe from general and higher points of view, I were to append in the latter volumes those special results of observation upon which the present condition of our knowledge is more particularly based. These volumes of my work, must, therefore, in accordance with a remark already made (*Cosmos*, vol. iii, pp. 2—6), be considered merely as an expansion and more careful exposition of the General Picture of Nature (*Cosmos*, vol. i, pp. 62—369), and as the uranological or sidereal sphere of the Cosmos was exclusively treated of in the two last volumes, the present volume will be devoted to the consideration of the telluric sphere. In this manner the ancient, simple, and natural separation of celestial and terrestrial objects has been preserved, which we find by the earliest evidences of human knowledge to have prevailed among all nations.

As in the realms of space, a transition to our own planetary system from the region of the fixed stars, illumined by innumerable suns, whether they be isolated or circling round one another, or whether they be mere masses of remote nebulæ, is indeed to descend from the great and the universal to the relatively small and special; so does the field of our contemplation become infinitely more contracted when we pass from the collective solar system, which is so rich in varied forms, to our own terrestrial spheroid, circling round the sun. The distance of even the nearest fixed star, *a* Centauri, is 263 times greater than the diameter of our solar system, reckoned to the aphelion distance of the comet of 1680; and yet this aphelion is 853 times further from the sun than our earth (*Cosmos*, vol. iv, p. 546). These numbers, reckoning the parallax of *a* Centauri at 0.″9187, determine approximately both the distance of a near region of the starry heavens from the supposed extreme solar system and the distance of those limits from the earth's place.

Uranology, which embraces the consideration of all that fills the remote realms of space, still maintains the character it anciently bore, of impressing the imagination most deeply and powerfully by the incomprehensibility of the relations of space and numbers which it embraces; by the known order and regularity of the motions of the heavenly bodies; and by the admiration which is naturally yielded to the results of observation and intellectual investigation. This consciousness of regularity and periodicity was so early impressed upon the human mind that it was often reflected in those forms of speech, which refer to the ordained course of the celestial bodies. The known laws which rule the celestial sphere excite perhaps the greatest admiration by their simplicity, based as they solely are, upon the mass and distribution of accumulated ponderable matter and upon its forces of attraction. The impression of the sublime, when it arises from that which is immeasurable and physically great, passes almost unconsciously to ourselves beyond the mysterious boundary which connects the metaphysical with the physical, and leads us into another and higher sphere of ideas. The image of the immeasurable, the boundless, and the eternal, is associated with a power which excites within us a more earnest and solemn tone of feeling, and which, like the impression of all that is spiritually great and morally exalted, is not devoid of emotion.

The effect which the aspect of extraordinary celestial phenomena so generally and simultaneously exerts upon entire masses of people, bears witness to the influence of such an association of feelings. The impression produced in excitable minds by the mere aspect of the starry vault of heaven is increased by profounder knowledge, and by the use of those means which man has invented to augment his powers of vision, and at the same time enlarge the horizon of his observation. A certain impression of peace and calmness blends with the impression of the incomprehensible in the universe, and is awakened by the mental conception of normal regularity and order. It takes from the unfathomable depths of space and time those features of terror which an excited imagination is apt to ascribe to them. In all latitudes man, in the simple natural susceptibility of his mind, prizes "the calm stillness of a starlit summer night."

Although magnitude of space and mass appertains more especially to the sidereal portion of cosmical delineation, and the eye is the only organ of cosmical contemplation, our telluric sphere has, on the other hand, the preponderating advantage of presenting us with a greater and a scientifically distinguishable diversity in the numerous elementary bodies of which it is composed. All our senses bring us in contact with terrestrial nature, and while astronomy, which, as the knowledge of moving luminous celestial bodies is most accessible to mathematical treatment, has been the means of increasing in the most marvellous manner the splendour of the higher forms of analysis, and has equally enlarged the limits of the extensive domain of optics; our earthly sphere, on the other hand, by its heterogeneity of elements, and by the complicated play of the expressions of force inherent in matter, has formed a basis for chemistry, and for all those branches of physical science which treat of phenomena, that have not as yet been found to be connected with vibrations generating heat and light. Each sphere has, therefore, in accordance with the nature of the problems which it presents to our investigation, exerted a different influence on the intellectual activity and scientific knowledge of mankind.

All celestial bodies, excepting our own planet and the aerolites which are attracted by it, are, to our conception composed only of homogeneous gravitating matter, without any specific or so-called elementary difference of substances. Such a simple assumption is, however, not by any means based upon the inner nature and constitution of these remote celestial orbs, but arises merely from the simplicity of the hypotheses, which are capable of explaining and leading us to predict the movements of the heavenly bodies. This idea arises, as I have already had occasion frequently to remark (*Cosmos*, vol. i, pp. 44—49 and pp. 124—125; vol. iii, pp. 2, 18, and 22—28), from the exclusion of all recognition of heterogeneity of matter, and presents us with the solution of the great problem of celestial mechanics, in which all that is variable in the uranological sphere is subjected to the sole control of dynamical laws.

Periodical alternations of light upon the surface of the planet Mars do indeed point, in accordance with its different seasons of the year, to various meteorological processes, and to the polar precipitates excited by cold in the atmosphere of that planet, (*Cosmos*, vol. iv, p. 504). Guided by analogies and reasoning, we may indeed here assume the presence of ice or snow (oxygen and hydrogen), as in the eruptive masses or the annular plains of the moon we assume the existence of different kinds of rock on our satellite, but direct observation can teach us nothing in reference to these points. Even Newton ventured only on conjectures regarding the elementary constitution of the planets which belong to our own solar system, as we learn from an important conversation which he had at Kensington with Conduit (*Cosmos*, vol. i, p. 120). The uniform image of homogeneous gravitating matter conglomerated into celestial bodies has occupied the fancy of mankind in various ways, and mythology has even linked the charm of music to the voiceless regions within the realms of space (*Cosmos*, vol. iv, pp. 431—434).

Amid the boundless wealth of chemically varying substances, with their numberless manifestations of force—amid the plastic and creative energy of the whole of the organic world, and of many inorganic substances—amid the metamorphosis of matter which exhibits an ever-active appearance of creation and annihilation, the human mind, ever striving to grasp at order, often yearns for simple laws of motion in the investigation of the terrestrial sphere. Even Aristotle in his Physics states, that "the fundamental principles of all nature are change and motion; he who does not recognise this truth recognises not nature herself" (*Phys. Auscult.* iii, 1 p. 200 Bekker), and referring to the difference of matter ("a diversity in essence"), he designates motion in respect to its qualitative nature, as a metamorphosis, ἀλλοίωσις, very different from mere mixture, μίξις, and a penetration which does not exclude the idea of subsequent separation (*De Gener. et Corrupt.* i, 1 p. 327).

The unequal ascent of fluids in capillary tubes—the endosmosis which is so active in all organic cells, and is probably a consequence of capillarity—the condensation of different kinds of gases in porous bodies (of oxygen in spongy platinum, with a pressure which is equal to a force of more than 700 atmospheres, and of carbonic acid in boxwood charcoal, when more than one-third is condensed in a liquid state on the walls of the cells)—the chemical action of contact-substances which, by their presence occasion or destroy (by *catalysis*) combinations without themselves taking any part in them—all these phenomena teach us that bodies at infinitely small distances exert an attraction upon one another, which depends upon their specific natures. We cannot conceive such attractions to exist independently of motions, which must be excited by them although inappreciable to our eyes.

We are still entirely ignorant of the relations which reciprocal molecular attraction as a cause of unceasing motion on the surface, and very probably also in the interior of the earth's body, exerts upon the attraction of gravitation, by which the planets as well as their central body are maintained in constant motion. Even the partial solution of this purely physical problem would yield the highest and most splendid results that can be attained in these paths of inquiry, by the aid of experimental and intellectual research. I purposely abstain in these sentences from associating (as is commonly done) the name of Newton with that law of attraction, which rules the celestial bodies in space at boundless distances, and which is inversely as the square of the distance. Such an association implies almost an injustice towards the memory of this great man, who had recognised both these manifestations of force, although he did not separate them with sufficient distinctness, for we find—as if in the felicitous presentiment of future discoveries—that he attempted in the Queries to his *Optics* to refer capillarity and the little that was then known of chemical affinity to *universal gravitation* (Laplace, *Expos. du Syst. du Monde*, p. 384. *Cosmos*, vol. iii, p. 23).

As in the physical world, more especially on the borders of the sea, delusive images often appear which seem for a time to promise to the expectant discoverer the possession of some new and unknown land; so, on the ideal horizon of the remotest regions of the world of thought, the earnest investigator is often cheered by many sanguine hopes, which vanish almost as quickly as they have been formed. Some of the splendid discoveries of modern times have undoubtedly been of a nature to heighten this expectation. Among these we may instance contact-electricity—magnetism of rotation, which may even be excited by fluids, either in their aqueous form or consolidated into ice—the felicitous attempt of considering all chemical affinity as the consequence of the electrical relations of atoms with a predominating polar force—the theory of isomorphous substances in its application to the formation of crystals—many phenomena of the electrical condition of living muscular fibre—and lastly, the knowledge which we have obtained of the influence exerted by the sun's position, that is to say, the thermic force of the solar rays, upon the greater or lesser magnetic capacity and conducting power of one of the constituents of our atmosphere, namely, oxygen. When light is unexpectedly thrown upon any previously obscure group of phenomena in the physical world, we may the more readily believe that we are on the threshold of new discoveries, when we find that these relations appear to be either obscure, or even in opposition to already established facts.

I have more particularly adduced examples in which the dynamic actions of attracting forces seem to show the course by which we may hope to approximate towards the solution of the problem of the original, unchangeable, and hence named the *elementary* heterogeneity of substances (for instance, oxygen, hydrogen, sulphur, potassium, phosphorus, tin, &c.), and of the amount of their tendency to combine, in other words, their chemical affinity. Differences of form and mixture are, I would again repeat, the only elements of our knowledge of matter; they are the abstractions under which we endeavour to comprehend the all-moving universe, both as to its size and composition. The detonation of the fulminates under a slight mechanical pressure, and the still more formidable explosion of terchloride of nitrogen, which is accompanied by fire, contrast with the detonating combination of chlorine and hydrogen, which explodes when the sun's rays fall directly upon it (more especially the violet rays). Metamorphosis, union, and separation afford evidence of the eternal circulation of the elements in inorganic nature no less than in the living cells of plants and animals. "The quantity of existing matter remains however the same, the elements alone change their relative positions to one another."

We thus find a verification of the ancient axiom of Anaxagoras, that created things neither increase nor decrease in the Universe, and that that which the Greeks termed the destruction of matter was a mere separation of parts. Our earthly sphere, within which is comprised all that portion of the organic physical world, which is accessible to our observation, is apparently a laboratory of death and decay; but that great natural process of slow combustion, which we call decay, does not terminate in annihilation. The liberated bodies combine to form other structures, and through the agency of the active forces which are incorporated in them a new life germinates from the bosom of the earth.

RESULTS OF OBSERVATION IN THE TELLURIC PORTION OF THE PHYSICAL DESCRIPTION OF THE UNIVERSE.

In the attempt to grasp the inexhaustible materials afforded by the study of the physical world—or in other words—to group phenomena in such a manner as to facilitate our insight into their causal connection, general clearness and lucidity can only be secured where special details — more particularly in the long and successfully cultivated fields of observation—are not separated from the higher points of view of cosmical unity. The telluric sphere, as opposed to the uranological, is separable into two portions, namely, the inorganic and the organic departments. The former comprises the size, form, and density of our terrestrial planet; its internal heat; its electro-magnetic activity; the mineral constitution of the earth's crust; the reaction of the interior of the planet on its outer surface which acts dynamically by producing earthquakes, and chemically by rock-forming, and rock-metamorphosing processes; the partial covering of the solid surface by the liquid element—the ocean; the contour and articulation of the upheaved earth into continents and islands; and lastly the general external gaseous investment (the atmosphere). The second or organic domain comprises not the individual forms of life which we have considered in the Delineation of Nature, but the relations in space which they bear to the solid and fluid parts of the earth's surface, the geography of plants and animals, and the descent of the races and varieties of *man* from one common, primary stock.

This division into two domains belongs to a certain extent to the ancients, who separated from the vital phenomena of plants and animals such material processes as change of form and the transition of matter from one body to another. In the almost total deficiency of all means for increasing the powers of vision, the difference between the two organisms[1] was based upon mere intuition, and in part upon the dogma of self-nutrition (Aristot. *de Anima*, ii, 1 t. i, p. 412, a 14,

[1] See *Cosmos*, vol. iii, p. 54.

Bekker), and of a spontaneous incentive to motion. This kind of mental comprehension which I have named intuition, together with that felicitous acumen in the power of combining his ideas, which was so characteristic of the Stagyrite, led him to the assumption of an apparent transition from the inanimate to the living, from the mere element to the plant, and induced him even to adopt the view that in the ever ascending processes of plastic formation there were gradual and intermediate stages connecting plants with the lower animals (Aristot. *de part. Animal.* iv, 5, p. 681, a 12, and *hist. Animal.* viii, 1, p. 588, a 4, Bekker). The history of organisms (taking the word history in its original sense, and therefore in relation to the faunas and floras of earlier periods of time) is so intimately connected with geology, with the order of succession of the superimposed terrestrial strata and with the chronometrical annals of the upheaval of continents and mountains; that it has appeared most appropriate to me, on account of the connection of great and widely diffused phenomena, to avoid establishing the natural division of organic and inorganic terrestrial life as the main element of classification in a work treating of the Cosmos. We are not here striving to give a mere morphological representation of the organic world, but rather to arrive at bold and comprehensive views of nature, and the forces which she brings into play.

I.

Size, Configuration, and Density of the Earth.—The Heat in the interior of the Earth, and its distribution.—Magnetic Activity, manifested in changes of Inclination, Declination, and Intensity of the force under the influence of the Sun's position in reference to the Heat and Rarefaction of the Air.—Magnetic Storms.—Polar Light.

That which in all languages is comprehended under etymologically differing symbolical forms by the expression *Nature*, and which man, who originally refers everything to his own local habitation, has further designated as Terrestrial Nature is the result of the silent co-operation of a system of active forces, whose existence we can only recognise by means of that which they move, blend together, and again dissever; and which they in part develope into organic tissues (living organisms), which have the power of re-producing like structures. The appreciation of nature is excited in the susceptible mind of man through the profound impression awakened by the manifestation of these forces. Our attention is at first attracted by the relations of size in space exhibited by our planet, which seems only like a handful of conglomerated matter in the immeasurable universe. A system of co-operating forces, which either tend to combine or separate (through polar influences), shows the dependence of every part of nature upon other parts, both in the elementary processes (as in the formation of inorganic substances), and in the production and maintenance of life. The size and form of the earth, its mass, that is to say, the quantity of its material parts, which when compared with the volume determines its density, and by means of the latter, under certain conditions, both the constitution of the interior of the earth and the amount of its attraction, are relations which stand in a more manifest, and a more mathematically demonstrable dependence upon one another than we observe in the case of the above named vital processes, in the distribution of heat, in the telluric conditions of electro-magnetism, or in the chemical metamorphoses of matter. Conditions, which we are not yet able to determine quantitatively on account of a complication of phenomena, may nevertheless be present, and may be demonstrated through inductive reasoning.

Although the two kinds of attraction, namely, that which acts at perceptible distances, as the force of gravity (the gravitation of the celestial bodies towards one another), and that which is manifested at immeasurably small distances, as molecular or contact-attraction, cannot in the present condition of science be reduced to one and the same law, yet it is not on that account the less credible that capillary attraction and endosmosis, which is so important in reference to the ascent of fluids, and in respect to animal and vegetable physiology, may be quite as much affected by the force of gravitation and its local distribution as electro-magnetic processes and the chemical metamorphosis of matter. To refer to extreme conditions, we may assume that if our planet had only the mass of the moon, and therefore almost six times less intensity of gravity, the meteorological processes, the climate, the hypsometrical relations of upheaved mountain chains and the physiognomy of the vegetation would be quite different from what they now are. The absolute size of our planet which we are here considering, maintains its importance in the collective economy of nature merely by the relations which it bears to mass and rotation ; for even in the universe, if the dimensions of the planets, the quantitative admixture of the bodies which compose them, their velocities and distances from one another, were all to increase or diminish in one and the same proportion, all the phenomena depending upon relations of gravitation would remain unchanged in this ideal macrocosmos, or microcosmos.[2]

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a. *Size, Figure, Ellipticity, and Density of the Earth.* (Expansion of the Picture of Nature, *Cosmos,* vol. i, pp. 154—164.)

The earth has been *measured* and *weighed* in order to determine its form, density, and mass. The accuracy which has been incessantly aimed at in these terrestrial determinations, has contributed, simultaneously with the solution of the problems of astronomy, to improve instruments of measurement, and methods of analysis. A very important part

[2] "The law of reciprocal attraction which acts inversely as the square of the distance is that of emanations, proceeding from a centre. It appears to be the law of all those forces, whose action is perceptible at sensible distances, as in the case of electrical and magnetic forces. One of the remarkable properties of this law is that, if the dimensions of all the bodies in the universe, together with their mutual distances and their velocities, were proportionally increased or diminished, they would still describe curves precisely similar to those which they now describe ; so that the universe, after being thus successively reduced to the smallest conceivable limits, would still always present the same appearance to the observer. These appearances are consequently independent of the dimensions of the universe, as in virtue of the law of the ratio which exists between force and velocity, they are independent of absolute movement in space."—Laplace, *Exposition du Syst. du Monde* (5ème éd.), p. 385.

of the process involved in the measurement of a degree is strictly astronomical, since the altitudes of stars determine the curvature of the arc, whose length is found by the solution of a series of triangles. The higher departments of mathematics have succeeded, from given numerical data, in solving the difficult problems of the figure of the earth, and the surface of equilibrium of a fluid homogeneous, or dense shell-like heterogeneous mass, which rotates uniformly round a solid axis. Since the time of Newton and Huygens, the most distinguished geometricians of the eighteenth century have devoted themselves to the solution of these problems. It is well that we should bear in mind that all the great results which have been attained by intellectual labour and by mathematical combinations of ideas, derive their importance not only from that which they have discovered and which has been appropriated by science, but more especially from the influence which they have exerted on the development and improvement of analytical methods.

"The *geometrical* figure of the earth, in contradistinction to the *physical*,[3] determines the surface which the superficies of water would assume in passing through a net-work of canals, connected with the ocean, and covering and intersecting the earth in every direction. The geometrical surface intersects the directions of the forces vertically, and these forces are composed of all the attractions emanating from the individual particles of the earth, combined with the centrifugal force, which corresponds with its velocity of rotation.[4] This surface must be generally considered as approximating very closely to an oblate spheroid, for irregularities in the distribution of the masses in the interior of the earth will also, where the local density is altered, give rise to irregularity in the geometrical surface, which is the product of the co-operation of unequally distributed elements. The physical surface is the direct product of the surface of

[3] Gauss, *Bestimmung des Breitenunterschiedes zwischen den Sternwarten von Göttingen und Altona*, 1828, s. 73. (These two observatories, by a singular chance, are situated within a few yards of the same meridian.)

[4] Bessel, *Ueber den Einfluss der Unregelmässigkeiten der Figur der Erde auf geodätische Arbeiten und ihre Vergleichung mit astronomischen Bestimmungen, in Schumacher's Astron. Nachr.* Bd. xiv, No. 329, s. 270, and Bessel and Baeyer, *Gradmessung in Ostpreussen*, 1838, s. 427—442.

the solid and fluid matter on the outer crust of the earth." Although while it is not improbable, judging from geological data, that the incidental alterations which are readily brought about in the fused portions of the interior of the earth, when they are moved by a change of position of the masses, may even modify the *geometrical* surface by producing curvature of the meridians and parallels in small spaces, and at very widely separated periods of time; the *physical* surface of the oceanic parts of our globe is periodically subjected to a change of place in the masses, occasioned by the ebbing and flowing (or in other words the local depression and elevation) of the fluid element. The inconsiderable amount of the effects of gravity in continental regions may indeed render a gradual change inappreciable to actual observation; and according to Bessel's calculation, in order to increase the latitude of a place by a change of only 1″, it must be assumed that there is a transposition in the interior of the earth of a mass, whose weight (its density being assumed to be that of the mean density of the earth) is that of 7296 geographical cubic miles.[5] However large the volume of this transposed mass may appear to us when we compare it with the volume of Mont Blanc, or Chimborazo, or Kintschindjinga, our surprise at the magnitude of the phenomenon soon diminishes when we remember that our terrestrial spheroid comprises upwards of 1696 hundreds of millions of such cubic miles.

Three different methods have been attempted although with unequal success for solving the problem of the *figure of the earth* whose connection with the geological question of the earlier liquid condition of the rotating planetary bodies was known at the brilliant epoch of Newton, Huygens and Hooke.[6] These methods were the geodetico-astro-

[5] Bessel, *Ueber den Einfluss der Veränderungen des Erdkörpers auf die Polhöhen*, in Lindenau und Bohnenberger, *Zeitschrift für Astronomie*. Bd. v, 1818, s. 29. "The weight of the earth, expressed in German pounds $=9933\times10.^{21}$, and that of the transposed mass $=947\times10.^{14}$."

[6] The theoretical labours of that time were followed by those of Maclaurin, Clairaut, and d'Alembert, by Legendre and by Laplace. To this latter period we may add the theorem advanced by Jacobi, in 1834, that ellipsoids of three unequal axes may, under certain conditions, represent the figures of equilibrium no less than the two previously-indicated ellipsoids of rotation.—See the treatise of this writer, whose

nomical measurement of a degree, pendulum experiments, and calculations of the inequalities in the latitude and longitude of the moon. In the application of the first method two separate processes are required, namely, measurements of a degree of latitude on the arc of a meridian, and measurements of a degree of longitude on different parallels.

Although seven years have now passed since I brought forward the results of Bessel's important labours, in reference to the dimensions of our globe, in my General Delineation of Nature, his work has not yet been supplanted by any one of a more comprehensive character, or based upon more recent measurements of a degree. An important addition and great improvements in this department of inquiry may, however, be expected on the completion of the Russian geodetic measurements, which are now nearly finished, and which, as they extend almost from the North Cape to the Black Sea, will afford a good basis of comparison for testing the accuracy of the results of the Indian survey.

According to the determinations published by Bessel in the year 1841, the mean value of the dimensions of our planet was, according to a careful investigation[7] of ten mea

early death has proved a severe loss to science, in Poggendorff's *Annalen der Physik und Chemie.* Bd. xxxiii, 1834, s. 229—233.

7 The first accurate comparison of a large number of geodetic measurements (including those made in the elevated plateau of Quito, two East Indian measurements, together with the French, English, and recent Lapland observations) was successfully effected by Walbeck, at Abo, in 1819. He found the mean value for the earth's ellipticity to be $\frac{1}{302.781}$, and that of a meridian degree 57009.758 toises, or 324,628 feet. Unfortunately his work, entitled *De Forma et Magnitudine Telluris* has not been published in a complete form. Excited by the encouragement of Gauss, Eduard Schmidt was led to repeat and correct his results in his admirable Handbook of Mathematical Geography, in which he took into account both the higher powers given for the ellipticity, and the latitudes observed at the intermediate points, as well as the Hanoverian measurements and those which had been extended as far as Formentera by Biot and Arago. The results of this comparison have appeared in three forms, after undergoing a gradual correction, namely, in Gauss's *Bestimmung der Breitenunterschiede von Göttingen und Altona* 1828, s. 82; in Eduard Schmidt's *Lehrbuch der Mathem. und Phys. Geographie*, 1829, Th. 1, s. 183, 194—199; and lastly in the preface to the latter work (s. 5). The last result is, for a meridian degree 57008.655 toises, or 324,261 feet; for the ellipticity, $\frac{1}{297.479}$. Bessel's first work of 1830 had been immediately preceded by Airy's treatise on the *Figure of the Earth,*

surements of degrees, as follows :—The semi-axis major of a rotating spheroid, a form that approximates most closely to

in the Encyclopædia Metropolitana. Ed. of 1849, pp. 220—239. (Here the semi-polar axis was given at 20,853,810 feet=3949.585 miles, the semi-equatorial axis at 20,923,713 feet=3962.824 miles, the meridian quadrant at 32,811,980 feet, and the ellipticity at $\frac{1}{298.33}$). The great astronomer of Königsberg was uninterruptedly engaged, from 1836 to 1842, in calculations regarding the figure of the earth, and as his earlier works were emended by subsequent corrections, the admixture of results of investigations at different periods of time has, in many works, proved a source of great confusion. In numbers, which from their very nature are dependent on one another, this admixture is rendered still more confusing from the erroneous reduction of measurements; as, for instance, toises, metres, English feet, and miles of 60 and 69 to the equatorial degree; and this is the more to be regretted since many works, which have cost a very large amount of time and labour, are thus rendered of much less value than they otherwise would be. In the summer of 1837, Bessel published two treatises, one of which was devoted to the consideration of the influence of the irregularity of the earth's figure upon geodetic measurements, and their comparison with astronomical determinations, whilst the other gave the axes of the oblate spheroid, which seemed to correspond most closely to existing measurements of meridian arcs (Schum. *Astr. Nachr.* bd. xiv, No. 329, s. 269, No. 333, s. 345). The results of his calculation were 3271953.854 toises for the semi-axis major; 3261072.900 toises for the semi-axis minor; and for the length of a mean meridian degree, that is to say, for the ninetieth part of the earth's quadrant (vertically to the equator), 57011.453 toises. An error of 68 toises, or 440.8 feet, which was detected by Puissant, in the mode of calculation that had been adopted, in 1808, by a Commission of the National Institute for determining the distance of the parallels of Montjouy, near Barcelona, and Mola in Formentera, led Bessel, in the year 1841, to submit his previous calculations regarding the dimensions of the earth to a new revision. (Schum. *Astr. Nachr.* Bd. xix, No. 438, s. 97—116). This correction yielded for the length of the earth's quadrant 5131179.81 toises, instead of 5130740 toises, which had been obtained in accordance with the first determination of the metre; and for the mean length of a meridian degree, 57013.109 toises, which is about 0.611 of a toise more than a meridian degree, at 45° lat. The numbers given in the text are the result of Bessel's latest calculations. The length of the meridian quadrant, 5131180 toises, with a mean error of 255.63 toises, is therefore=10000856 metres, which would therefore give 40003423 metres, or 21563.92 geographical miles, for the entire circumference of the earth. The difference between the original assumption of the *Commission des Poids et Mesures*, according to which the metre was the forty-millionth part of the earth's circumference, amounts for the entire circumference to 3423 metres, or 1756.27 toises, which is almost two geographical miles, or more accurately the irregular figure of our earth, was 3272077.14 toises, or 20,924,774 feet; the semi-axis minor, 3261139.33 toises, or 20,854,821 feet; the length of the earth's quadrant, 5131179.81 toises, or 32,811,799 feet; the length of a mean meridian degree, 57013.109 toises, or 364,596 feet; the length of a parallel degree at 0° latitude, and consequently that of an equatorial degree, 57108.52 toises, or 365,186 feet; the length of a parallel degree at 45°, 40449.371 toises, or 258,657 feet; the ellipticity of the earth, $\frac{1}{299.152}$; and the length of a geographical mile, of which sixty go to an equatorial degree, 951.8 toises, or 6086.5 feet.

The table (page 17) shows the increase of the length of the meridian degree from the equator to the pole, as it has been found from observations, and therefore modified by the local disturbances of attraction

The determination of the figure of the earth by the measurement of degrees of longitude on different parallels requires very great accuracy in fixing the longitudes of different places. Cassini de Thury and Lacaille employed, in 1740, powder signals to determine a perpendicular line at the meridian of Paris. In more recent times, the great trigonometrical survey of England has determined, by the help of far better instruments and with greater accuracy, the lengths of the arcs of parallels and the differences of the meridians between Beachy Head and Dunnose, as well as between Dover and Falmouth. These determinations were, however. only made for differences of longitude of 1° 26′ and 6° 22′.[8] By far the most considerable of these surveys is the one that was carried on between the meridians of Marennes, on the western coast of France, and Fiume. It extends over the western chain of the Alps, and the plains of Milan and Padua, in a direct distance of 15° 32′ 27″, and was executed under the direction of Brousseaud and Largeteau, Plana and Car-

speaking, 1.84. According to the earliest determinations, the length of the metre was determined at 0.5130740 of a toise, while according to Bessel's last determination it ought to be 0.5131180 of a toise. The difference for the length of the metre is, therefore, 0.038 of a French line. The metre has, therefore, been established by Bessel as equal to 443.334 French lines, instead of 443.296, which is its present legal value (Compare also, on this so-called natural standard, Faye, *Leçons de Cosmographie*, 1852, p. 93).

[8] Airy, *Figure of the Earth* in the *Encycl. Metrop.* 1849, pp. 214—216.

Countries.	Geographical latitude of the middle of the measured arc.	Length of the measured arc.	The length of a degree for the latitude of the middle arc as obtained from observations, and given in feet.	Observers.
Sweden	66° 20′ 10″	1° 37′ 19″.6	365473.4	Svanberg.
	66 19 37	0 57 30.4	365882.1	Maupertuis.
Russia	56 3 55.5	8 2 28.9	365368.0	Struve, Tenner.
Prussia	54 58 26.0	1 30 29.0	365396.0	Bessel, Baeyer.
Denmark	54 8 13.7	1 31 53.3	365087.0	Schumacher.
Hanover	52 32 16.6	2 0 57.4	365400.0	Gauss.
England	52 35 45.0	3 57 13.1	365071.2	Roy, Mudge, Kater.
	52 2 19.4	2 50 23.5	364951.1	
France	44 51 2.5	12 22 12.7	364671.5	Delambre, Méchain, Biot, Arago.
North America	39 12 0	1 28 45.0	363785.1	Mason, Dixon.
East Indies	16 8 21.5	15 57 40.7	363044.0	Lambton, Everest.
	12 32 20.8	1 34 56.4	362950.6	Lambton.
Quito (s. l.)	1 31 0.4	3 7 3.5	363625.2	La Condamine, Bouguer.
Cape of Good Hope (s.l.)	33 18 30	1 13 17.5	364819.2	Lacaille.
	35 43 20	3 34 34.7	364160.0	Maclear.

lini, almost entirely under the so-called mean parallel of 45°. The numerous pendulum experiments which have been conducted in the neighbourhood of mountain chains, have confirmed in the most remarkable manner the previously-recognised influences of those local attractions which were inferred from the comparison of astronomical latitudes with the results of geodetic measurements.[9]

In addition to the two secondary methods for the direct measurement of a degree on meridian and parallel arcs, we have still to refer to a purely astronomical determination of the figure of the earth. This is based upon the action which the earth exerts upon the motion of the moon, or in other words upon the inequalities in lunar longitudes and latitudes. Laplace, who was the first to discover the cause of these inequalities, has also taught us their application by ingeniously showing how they afford the great advantage which individual measurements of a degree and pendulum experiments are incapable of yielding, namely, that of showing in one single result the mean figure of the earth.[10] We would

[9] Biot, *Astr. Physique,* t. ii, p. 482, and t. iii, p. 482. A very accurate geodetical measurement, which is the more important from its serving as a comparison of the levels of the Mediterranean and Atlantic, has been made on the parallel of the chain of the Pyrenees by Coraboeuf, Delcros, and Peytier.

[10] *Cosmos,* vol. i, p. 160. "It is very remarkable that an astronomer without leaving his observatory, may merely by comparing his observations with analytical results, not only be enabled to determine with exactness the size and degree of ellipticity of the earth, but also its distance from the sun and moon—results that otherwise could only be arrived at by long and arduous expeditions to the most remote parts of both hemispheres. The moon may, therefore, by the observation of its movements render appreciable to the higher departments of astronomy, the ellipticity of the earth, as it taught the early astronomers the rotundity of our earth by means of its eclipses" (Laplace, *Expos. du Syst. du Monde,* p. 230). We have already in *Cosmos,* vol. iv, pp. 481—532, made mention of an almost analogous optical method suggested by Arago, and based upon the observation that the intensity of the ash-coloured light, that is to say the terrestrial light in the moon, might afford us some information in reference to the transparency of our entire atmosphere. Compare also Airy in the *Encycl. Metrop.* pp. 189, 236, on the determination of the earth's ellipticity by means of the motions of the moon, as well as at pp. 231—235, on the inferences which he draws regarding the figure of the earth from precession and nutation. According to Biot's investigations, the latter determination would only

here again refer to the happy expression of the discoverer of this method "that an astronomer without leaving his observatory may discover the individual form of the earth in which he dwells, from the motion of one of the heavenly bodies." After his last revision of the inequalities in the longitude and latitude of our satellite, and by the aid of several thousand observations of Bürg, Bouvard, and Burckhardt,[11] Laplace found by means of his lunar method a compression amounting to $\frac{1}{306}$, which is very nearly equal to that yielded by the measurements of a degree of latitude ($\frac{1}{299}$).

The vibrations of the pendulum yield a third means of determining the figure of the earth (or in other words the relation of the major to the minor axis, on the supposition of our planet being of a spheroidal form), by the elucidation of the law according to which gravity increases from the equator towards the pole. The Arabian astronomers, and more especially Ebn-Junis, at the close of the tenth century, and during the brilliant epoch of the Abbassidian Califs[12], first employed these vibrations for the determination of time, and after a neglect of six hundred years the same method was again adopted by Galileo, and Father Riccioli at Bologna.[13] The pendulum in conjunction with a system of wheels used to regulate the clocks (which were first employed in the imperfect experiments of Sanctorius at Padua in 1612, and then in the more perfect observations of Huygens in 1656), gave the first material proof of the different intensity of gravity at different latitudes in Richer's comparison of the beats of the same astronomical clock at Paris and Cayenne, in 1672. Picard was indeed engaged in the equipment of this important voyage, but he does not on that account assume to himself the merit of its first suggestion. Richer left Paris

give, for the earth's ellipticity, limiting and widely differing values ($\frac{1}{304}$ and $\frac{1}{578}$). *Astron. Physique*, 3ème éd. t. ii, 1844, p. 463.

[11] Laplace, *Mécanique Celeste*, éd. de 1846, t. v. pp. 16, 53.

[12] *Cosmos*, vol. i, p. 158. Edward Bernard, an Englishman, was the first who recognised the application of the isochronism of pendulum-oscillations in the writings of the Arabian astronomers. (See his letter, dated Oxford, April, 1683, and addressed to Dr. Robert Huntington, in Dublin. *Philos. Transac.* vol. xii, p. 567.)

[13] Fréret *de l'Etude de la Philosophie Ancienne* in the *Mém. de l'Acad. des Inscr.* t. xviii (1753), p. 100.

in October, 1671, and Picard in the description of his measurement of a degree of latitude, which appeared in the same year[14] merely refers to "a conjecture which was advanced

[14] Picard, *Mesure de la Terre*, 1671, Art. 4. It is scarcely probable that the conjecture which was advanced in the Paris Academy even before the year 1671, to the effect that the intensity of gravity varies with the latitude (Lalande, *Astronomie*, t. iii, p. 20 § 2668) should have been made by the illustrious Huygens, who had certainly presented his *Discours sur la Cause de la Gravité* to the Academy in the course of the year 1669. There in no mention made in this treatise of the shortening of the seconds-pendulum, which was being observed by Richer at Cayenne, although a reference to it occurs in the supplements to this work, (one of which must have been completed after the publication of Newton's *Principia*, and consequently later than 1687). Huygens writes as follows:—"Maxima pars hujus libelli scripta est, cum Lutetiæ degerem (to 1681) ad eum usque locum, ubi de alteratione, quæ pendulis accidit e motu Terræ." See also the explanation which I have given in *Cosmos*, vol. ii, p. 736. The observations made by Richer at Cayenne were not published until 1679, as I have already observed in the text, and therefore not until fully six years after his return, and what is more remarkable, the annals of the *Académie des Inscriptions* contain no notice during this long period of Richer's important double observations of the pendulum clock and of the simple seconds-pendulum. We do not know the time when Newton first became acquainted with Richer's results, although his own earliest theoretical speculations regarding the figure of the earth date farther back than the year 1665. It would appear that Newton did not become acquainted until 1682 with Picard's geodetic measurement, which had been published in 1671, and even then "he *accidentally* heard of it at a meeting of the Royal Society, which he was attending." His knowledge of this fact as Sir David Brewster has shown (*Memoirs of Sir I. Newton*, vol. i, p. 291), exerted a very important influence on his determination of the earth's diameter, and of the relation which the fall of a body upon our planet bears to the force which retains the moon in its orbit. Newton's views may have been similarly influenced by the knowledge of the spheroidal form of Jupiter which had been ascertained by Cassini prior to 1666, but was first described in 1691 in the *Mémoires de l'Académie des Sciences*, t. ii, p. 108. Could Newton have learnt anything of a much earlier publication, of which some of the sheets were seen by Lalande in the possession of Maraldi? (Compare Lalande, *Astr.* t. iii, p. 335, § 3345, with Brewster, *Memoirs of Sir I. Newton*, vol. i, p. 322, and *Cosmos*, vol. i, p. 156.) Amid the simultaneous labours of Newton, Huygens, Picard, and Cassini, it is often very difficult to arrive, with any certainty, at a just appreciation of the diffusion of scientific knowledge, owing to the tardiness with which men at that day made known the result of their observations, the publication of which was moreover frequently delayed by accidental circumstances.

by one of the members, at a meeting of the Academy, according to which the weight of a body must be less at the equator than at the pole, in consequence of the rotation of the earth." He adds doubtfully, that although it would appear from certain experiments made in London, Lyons, and Bologna, as if the seconds-pendulum must be shortened the nearer we approach to the equator; yet on the other hand he was not sufficiently convinced of the accuracy of the measurements adduced, because at the Hague, notwithstanding its more northern latitude, the pendulum lengths were found to be precisely the same as at Paris. The periods at which Newton first became acquainted with the important pendulum results that had been obtained by Richer as early as 1672, although they were not printed until 1679, and at which he first heard of the discovery that had been made by Cassini, before the year 1666, of the compression of Jupiter's disc, have unfortunately not been recorded with the same exactness, as the fact of his very tardy acquaintance with Picard's measurement of a degree. In an age so remarkable for the successful emulation that distinguished the cultivators of science, and when theoretical views led to the prosecution of observations, which by their results reacted in their turn upon theory, it is of great interest to the history of the mathematical establishment of physical astronomy, that individual epochs should be determined with accuracy.

Although direct measurements of meridian and parallel degrees (the former especially in the case of the French measurement of a degree[15] between the latitudes 44° 42′ and 47° 30′, and the latter by the comparison of points lying to the east and west of the Italian and Maritime Alps),[16] exhibit great deviations from the mean ellipsoidal figure of the earth, the variations in the amount of ellipticity given by pendulum lengths (taken at different geographical points and in different groups) are very much more striking. The determination of the figure of the earth obtained from the

[15] Delambre, *Base du Syst. Métrique*, t. iii, p. 548.

[16] *Cosmos*, vol. i, p. 159. Plana, *Opérations Géodésiques et Astronomiques pour la Mesure d'un Arc du Parallèle Moyen*, t. ii, p. 847; Carlini in the *Effemeridi Astronomiche di Milano per l'anno* 1842, p. 57.

increase or decrease of gravity (intensity of local attraction), assumes that gravity at the surface of our rotating spheroid must have remained the same as it was at the time of our earth's consolidation from a fluid state, and that no later alterations can have taken place in its density.[17] Notwithstanding the great improvements which have been made in the instruments and methods of measurement by Borda, Kater, and Bessel, there are at present in both hemispheres, from Spitzbergen in 79° 50′ N.L., to the Falkland Islands, in 51° 35′ S.L., where Freycinet, Duperrey, and Sir James Ross successively made their observations, only from 65 to 70 irregularly scattered points,[18] at which the length of the simple pendulum has been determined with as much accuracy as the position of the place in respect to its latitude, longitude, and elevation above the level of the sea.

The pendulum experiments made by the French astronomers on the measured part of a meridian arc, and the observations of Captain Kater in the trigonometrical survey of Great Britain concurred, in showing that the results do not individually admit of being referred to a variation of gravity proportional to the square of the sine of the latitude. On this account the English Government determined, at the suggestion of the Vice-President of the Royal Society, Davies Gilbert, to fit out a scientific expedition, which was entrusted to my friend Edward Sabine, who had accompanied Captain Parry on his first polar voyage in the capacity of astronomer. In the course of this voyage, which was continued through the years 1822 and 1823, he coasted along

[17] Compare Biot, *Astronomie Physique*, t. ii, 1844, p. 464, with *Cosmos*, vol. i, p. 160, and vol. iv, p. 427, where I have considered the difficulties presented by a comparison of the periods of rotation of planets, and their observed compression. Schubert (*Astron.* Th. iii, s. 316) has also drawn attention to this difficulty, and Bessel in his treatise *On Mass and Weight* says expressly, that the supposition of the invariability of gravity at any one point of observation has been rendered somewhat uncertain by the recent experiments made on the slow upheaval of large portions of the earth's surface.

[18] Airy in his admirable treatise on the *Figure of the Earth* (*Encycl. Metropol.* 1849, p. 229) reckoned fifty different stations where trustworthy results had been obtained up to the year 1830, and fourteen others, (those of Bouguer, Legentil, Lacaille, Maupertuis and La Croyère), which however do not bear comparison with the former in point of accuracy.

the western shores of Africa, from Sierra Leone to the Island of St. Thomas, near the Equator, then by Ascension to South America, from Bahia to the mouth of the Orinoco, on his way to the West Indies and the New England States, after which he penetrated into the Arctic regions as far as Spitzbergen, and a hitherto unexplored and ice-bound portion of East Greenland (74° 32′). This brilliant and ably conducted expedition had the advantage of being mainly directed to one sole object of investigation, and of embracing points which are separated from one another by 93° of latitude.

The field of observation in the French expedition for the measurements of degrees was more remote from the equinoctial and arctic zones; but it had the great advantage of presenting a linear series of points of observation, and of affording direct means of comparison with the partial curvature of the arcs obtained by geodetico-astronomical observations. Biot, in 1824, carried the line of pendulum measurements from Formentera (38° 39′ 56″) where he had already made observations conjointly with Arago and Chaix, as far as Unst, the most northerly of the Shetland Islands (60° 45′ 25″), and with Mathieu he extended it to the parallels of Bordeaux, Figeac, and Padua, as far as Fiume.[19] These pendulum results, when compared with those of Sabine, certainly give $\frac{1}{290}$ for the compression of the whole northern quadrant, but when separated into two halves, they yield a still more varying result, giving $\frac{1}{276}$ from the equator to 45°, and $\frac{1}{306}$ from 45° to the pole.[20] It has been shown

[19] Biot and Arago, *Recueil d'Observ. Géodesiques et Astronomiques,* 1821, pp. 526—540, and Biot, *Traité d'Astr. Physique,* t. ii, 1844, pp. 465—473.

[20] *Op. cit.* p. 488. Sabine (*Exper. for determining the variation in the length of the Pendulum vibrating Seconds,* 1825, p. 352) finds $\frac{1}{288.3}$ from all the thirteen stations of his pendulum expedition, notwithstanding their great distances from one another in the northern hemisphere; and from these, increased by all the pendulum stations of the British survey and of the French geodetic measurement from Formentera to Dunkirk, comprising therefore in all a comparison of twenty-five points of observation he again found $\frac{1}{288.9}$. It is still more striking, as was already observed by Admiral Lütke, that far to the west of the Atlantic region in the meridians of Petropawlowski and New Archangel, the pendulum lengths yield a much greater ellipticity, namely $\frac{1}{267}$. As the previously applied theory of the influence of the air surrounding the pendulum

in many instances, and in both hemispheres, that there is an appreciable influence exerted by surrrounding denser rocks, (basalt, greenstone, diorite, and melaphyre, in opposition to specifically lighter secondary and tertiary formations,) in the same manner as volcanic islands[21] influence gravity and augment its intensity. Many of the anomalies which presented themselves in these observations do not, however, admit of being explained by any visible geological characters of the soil.

For the southern hemisphere we possess a small number of admirable, but very widely diffused observations made by Freycinet, Duperrey, Fallows, Lütke, Brisbane and Rümker. These observations have confirmed a fact which had been strikingly demonstrated in the northern hemisphere, namely, that the intensity of gravity is not the same for all places having the same latitude, and that the increase of gravity from the equator towards the poles appears to be subjected to different laws under different meridians. Although the pendulum measurements made by Lacaille at the Cape of Good Hope, and those conducted in the Spanish circumnavigating expedition by Malaspina, may have led to the belief that the southern hemisphere is in general much more compressed than the northern, comparisons made between the Falkland Islands and New Holland on the one hand,

led to an error in the calculation, and had rendered a correction necessary as early as 1786, (when a somewhat obscure one was given by the Chevalier de Buat,) on account of the difference in the loss of weight of solid bodies, when they are either at rest in a fluid, or impelled in a vibratory motion, Bessel with his usual analytical clearness laid down the following axiom in his *Untersuchungen über die Länge des einfachen Secundenpendels*, s. 32, 63, 126—129. "When a body is moving in a fluid (the atmosphere), the latter belongs with it to the moved system, and the moving force must be distributed not only over the particles of the solid moved body, but also over all the moved particles of the fluid." On the experiments of Sabine and Baily, which originated in Bessel's practically important pendulum correction (reduction to a vacuum), see John Herschel in the *Memoir of Francis Baily*, 1845, pp. 17—21.

[21] *Cosmos*, vol. i, p. 159. Compare, for the phenomena occurring in islands, Sabine *Pend. Exper.* 1825, p. 237, and Lütke, *Obs. du Pendule invariable, exécutées de* 1826—1829, p. 241. This work contains a remarkable table, p. 239, on the nature of the rocks occurring at 16 pendulum stations, from Melville Island (79° 50′ N. Lat.) to Valparaiso (32° 2′ S. Lat.).

and New York, Dunkirk, and Barcelona on the other, have, however, by their more exact results shown that the contrary is the case, as I have already elsewhere indicated.[22]

From the above data, it follows that the pendulum (although it is by no means an unimportant instrument in geognostic observations, being as it were a sort of plummet cast into the deep and unseen strata of the earth) does not determine the form of our planet with the same exactitude as the measurement of a degree, or the movements of our satellite. The concentric, elliptical, and individually homogeneous strata, which increase in density according to certain functions of distance from the surface towards the centre of the earth, may give rise to local fluctuations in the intensity of gravity at individual points of the earth's surface, which differ according to the character, position, and density of the several points. If the conditions which produce these deviations are much more recent than the consolidation of the

[22] *Cosmos*, vol. i, p. 161. Eduard Schmidt (*Mathem. und Phys. Geographie*, Th. i, s. 394), has separated from a large number of the pendulum observations which were made on board the corvettes Descubierta and Atrevida, under the command of Malaspina, those thirteen stations which belong to the southern hemisphere, from which he obtained a mean compression of $\frac{1}{280.34}$. Mathieu obtained $\frac{1}{284.4}$ from a comparison of Lacaille's observations at the Cape of Good Hope and the Isle of France with Paris, but the iustruments of measurement used at that day did not afford the same certainty as we now obtain by the appliances of Borda and Kater, and the more modern methods of observation. The present would seem a fitting place to notice the beautiful experiments of Foucault, which afford so high a proof of the ingenuity of the inventor, and by which we obtain ocular evidence of the rotation of the earth on its axis by means of the pendulum, whose plane of vibration slowly rotates from east to west. (*Comptes rendus de l'Acad. des Sc., Séance du* 3 *Février*, 1851, t. xxxii, p. 135). Experiments for noticing the deviation towards the east in observations of falling bodies, dropped from church towers or into mines, as suggested by Benzenberg and Reich, require a very great height, whilst Foucault's apparatus makes the effects of the earth's rotation perceptible with a pendulum only six feet long. We must not confound the phenomena which may be explained by rotation (as, for instance, Richer's clock experiments at Cayenne, diurnal aberration, the deviation of projectiles, trade winds, etc.), with those that may at any time be produced by Foucault's apparatus, and of which the members of the *Academia del Cimento* appear to have had some idea, although they did not farther develope it (Antinori, in the *Comptes rendus*, t. xxxii, p. 635).

outer crust, the figure of the surface cannot be assumed to be locally modified by the internal motion of the fused masses. The difference of the results of pendulum measurements is however much too great to be ascribed at the present day to errors of observation. Even where a coincidence in the results, or an obvious regularity has been discovered by the various grouping and combination of the points of observation, the pendulum always gives a greater ellipticity (varying between the limits $\frac{1}{275}$ and $\frac{1}{290}$) than could have been deduced from the measurements of a degree.

If we take the ellipticity which, in accordance with Bessel's last determination, is now generally adopted, namely, $\frac{1}{299 \cdot 152}$, we shall find that the bulging[23] at the

[23] In Grecian antiquity two regions of the earth were designated as being characterised, in accordance with the prevalent opinions of the time, by remarkable protuberances of the surface, namely, the high north of Asia and the land lying under the equator. "The high and naked Scythian plains," says Hippocrates (*de Aëre et Aquis* § xix, p. 72, Littré), "without being crowned by mountains stretch far upward to the meridian of the Bear." A similar opinion had previously been ascribed to Empedocles (Plut. *de Plac. Philos.* ii, 3). Aristotle (*Meteor.* i, 1 a 15, p. 66, Ideler) says that the older meteorologists, according to whose opinions the sun "did not go under the earth, but passed round it," considered that the protuberances of the earth towards the north were the cause of the disappearance of the sun, or of the production of night. And in the compilation of the *Problems* (xxvi, 15, page 941, Bekker), the cold of the north wind was ascribed to the elevation of the soil in this region of the earth, and in all these passages there is no reference to mountains, but merely to a bulging of the earth into elevated plateaux. I have already elsewhere shown (*Asie Centrale,* t. i, p. 58) that Strabo, who alone makes use of the very characteristic word *ὀροπέδια*, says that the difference of climate which arises from geographical position must everywhere be distinguished from that which we ascribe to elevation above the sea, in Armenia (xi, p. 522, Casaub.), in Lycaonia, which is inhabited by wild asses (xii, p. 568), and in Upper India, in the auriferous country of the Derdi (xv, p. 706). "Even in southern parts of the world," says the geographer of Amasia, "every high district, if it be also a plain, is cold" (ii, p. 73). Eratosthenes and Polybius ascribe the very moderate temperature which prevails under the equator not only to the more rapid transit of the sun (Geminus, *Elem. Astron.* c. 13; Cleom. *Cycl. Theor.*, 1, 6), but more especially to the bulging of the earth (See my *Examen Crit. de la Géogr.* t. iii, pp. 150—152). Both maintain, according to the testimony of Strabo (ii, p. 97), "that the district lying immediately below the equator is the highest, on which account much rain falls there, in consequence of the very large accumulation of northern clouds at the period when

equator amounts to about 645,457 feet; about $11\frac{1}{5}$, or more accurately, 11.492 geographical miles. As a comparison has

those winds prevail, which change with the season of the year." Of these two opinions regarding the elevation of the land in Northern Asia (the Scythian Europe of Herodotus) and in the equatorial zone, the former of the two, with the pertinacity characteristic of error, has kept its ground for nearly two thousand years, and has given occasion to the geological myth of an uninterrupted plateau in the Tartar district lying to the north of the Himalayas, whilst the other opinion could only be justified in reference to a portion of Asia, lying beyond the tropical zone, and consequently applies only to the colossal, "elevated or mountain plateau, Meru," which is celebrated in the most ancient and noblest memorials of Indian poetry. (See Wilson's *Dict. Sanscrit and English*, 1832, p. 674, where the word *Meru* is explained to signify an elevated plateau). I have thought it necessary to enter thus circumstantially into this question, in order that I might refute the hypothesis of the intellectual Fréret, who, without indicating any passages from Greek writers, and merely alluding to one which seemed to treat of tropical rain, interprets the opinion advanced regarding bulgings of the soil as having reference to compression or elongation at the poles. In the *Mém. de l'Acad. des Inscriptions*, t. xviii, 1753, p. 112, Fréret expresses himself as follows :– "To explain the rains which prevailed in those equinoctial regions, which the conquests of Alexander first made known, it was supposed that there were currents which drove the clouds from the poles towards the equator, where, in default of mountains to stop their progress, they were arrested by the general elevation of the soil, whose surface at the equator is farther removed from the centre than under the poles. Some physicists have ascribed to the globe the figure of a spheroid, which bulges at the equator and is flattened towards the poles, while on the contrary, in the opinion of those of the ancients who believed that the earth was elongated towards the poles, the polar regions are farther removed than the equatorial zone from the centre of the earth." I can find no evidence in the works of the ancients to justify these assertions. In the third section of the first book of Strabo (page 48, Casaub.), it is expressly stated that, "after Eratosthenes has observed that the whole earth is spherical, although not like a sphere that has been made by a turning-lathe (an expression that is borrowed from Herodotus, iv. 36), and exhibits many deviations from this form, he adduces numerous modifications of shape which have been produced by the action of water and fire, by earthquakes, subterranean currents of wind (elastic vapours?), and other causes of the same kind, which, however, are not given in the order of their occurrence, for the rotundity of the entire earth results from the co-ordination of the whole, such modifications in no degree affecting the general form of our earth, the lesser vanishing in the greater." Subsequently we read, also in Groskurd's admirable translation, "that the earth, together with the sea, is spherical, the two constituting one and the same surface. The projection of the land, which is inconsiderable and may remain unnoticed is very frequently been made from the earliest times of astronomical inquiry between this swelling or convex elevation of the earth's surface and carefully measured mountain masses, I will select as objects of comparison the highest of the known peaks of the Himalayas, namely, that of Kintschindjinga, which was fixed by Colonel Waugh at 28,174 feet, and that portion of the elevated plateau of Thibet which is nearest to the sacred lakes of Rakas-Tal and Manassarova, and which, according to Lieutenant Henry Strachey, is situated at the mean height of 15,347 feet. The bulging of our planet at the equatorial zone is therefore not

lost in such magnitudes, so that in these cases we are unable to determine its spherical form with the same accuracy as in the case of a sphere made by a turning-lathe, or as well as the sculptor, who judges from his conceptions of form, for here we are obliged to determine by physical and less delicate perception." (Strabo, ii, p. 112). "The world is at once a work of nature and of providence,—a work of nature inasmuch as all things tend towards one point, the centre of the whole, round which they group themselves, the less dense element (water) containing the denser (earth)." (Strabo, xvii, p. 809). Wherever we find the figure of the earth described by the Greeks, it is compared (Cleom. *Cycl. Theor.* i, 8, p. 51) with a flat or centrally depressed disc, a cylinder (Anaximander), a cube or pyramid, and lastly we find it generally held to be a sphere notwithstanding the long contest of the Epicureans, who denied the tendency of attraction towards the centre. The idea of compression does not seem to have presented itself to their imagination. The elongated earth of Democritus was only the disc of Thales lengthened in one direction. The drum-like form, *τὸ σχῆμα τυμπανοειδές*, which seems more especially to have emanated from Leucippus (Plut. *de Plac. Philos.* iii, 10; Galen. *Hist. Phil.*, cap. 21; Aristotle, *de Cœlo*, ii, 13 page, 293 Bekker), appears to have been founded upon the idea of a hemisphere with a flat basis, which probably represented the equator, whilst the curvature was regarded as the *οἰκουμένη*. A passage in Pliny, regarding Pearls (xi, 54), elucidates this form, whilst Aristotle merely compares the segments of the sphere with the drum (*Meteorol.* ii, 5, á 10, Ideler, t. i, p. 563), as we also find from the commentary of Olympiodorus (Ideler, t. i, p. 301). I have here purposely avoided referring to two passages which are well known to me in Agathemerus (*de Geographia*, lib. i, cap. 1, p. 2, Hudson) and in Eusebius (*Evangel. Præparat.* t. iv, p. 125, ed. Gaisford, 1843), because they prove with what inaccuracy later writers have often ascribed to the ancients views which were totally foreign to them. According to these versions, "Eudoxus gave for the length and breadth of the earth's disc values which stood in relation to one another as 1 to 2; the same is said in reference to Dicæarchus, the pupil of Aristotle, who, however, advanced his own special proofs of the spherical form of the earth (Marcian, *Capella*, lib. vi, p. 192). Hipparchus regarded the earth as *τραπεζοειδής*, and Thales held it to be a sphere!"

quite three times as great as the elevation of the highest of our mountains above the sea's level, but it is almost five times as great as that of the eastern plateau of Thibet.

We ought here to observe that the results of the earth's compression, which have been obtained by mere measurements of a degree, or by combinations of the former with pendulum measurements, show far less [24] considerable differences in the amount of the equinoctial bulging than we should have been disposed at first sight to conclude from the fractional numbers. The difference of the polar compressions ($\frac{1}{310}$ and $\frac{1}{280}$) amounts to only about 7000 feet in the difference of the major and minor axes, basing the calculation on both extreme numerical limits; and this is not twice the elevation of the small mountains of the Brocken and of Vesuvius; the difference being only about one-tenth

[24] It has often seemed to me as if the amount of the compression of the earth was regarded as somewhat doubtful merely from our wish to attain an unnecessary degree of accuracy. If we take the values of the compression at $\frac{1}{310}$, $\frac{1}{300}$, $\frac{1}{290}$, $\frac{1}{280}$, we find that the difference of both radii is equal to 10,554, 10,905, 11,281, 11,684 toises, or 67,488, 69,554, 73,137, 74,714 feet. The fluctuation of 30 units in the denominator produces only a fluctuation of 1,130 toises or 7,126 feet in the polar radius, an amount which, when compared with the visible inequalities of the earth's surface appears so very inconsiderable, that I am often surprised to find that the experiments coincide within such closely approximating limits. Individual observations scattered over wide surfaces will indeed teach us little more than what we already know, but it would be of considerable importance to connect together all the measurements that have been made over the entire surface of Europe, including in this calculation all astronomically determined points." (Bessel, in a letter addressed to myself, December, 1828.) Even if this plan were carried out, we should then only know the form of that portion of the earth, which may be regarded as a peninsular projection, extending westward, about sixty-six and a half degrees from the great Asiatic Continent. The steppes of Northern Asia, even the middle Kirghis steppe, a considerable portion of which I have myself seen, are often interspersed with hills, and in respect to uninterrupted levels, cannot be compared with the Pampas of Buenos Ayres, or the Llanos of Venezuela. The latter, which are far removed from all mountain chains and consist immediately below the surface of secondary and tertiary strata, having a very uniform and low degree of density, might by differences in the results of pendulum vibrations, yield very decisive conclusions in reference to the local constitution of the deep internal strata of the earth. — Compare my *Views of Nature*, pp. 2—8, 29—32.

of the bulging which would be yielded by a polar compression of $\frac{1}{299}$.

As soon as it had been ascertained by more accurate measurements of a degree, made at very different latitudes, that the earth could not be uniformly dense in its interior, (because the results showed that the compression was very much less than had been assumed by Newton ($\frac{1}{230}$), and much greater than was supposed by Huygens ($\frac{1}{578}$), who considered that all forces of attraction were combined in the centre of the earth,) the connection between the amount of compression and the law of density in the interior of our earth necessarily became a very important object of analytical calculation. Theoretical speculations regarding gravity very early led to the consideration of the attraction of large mountain masses, which rise freely and precipitously into the atmosphere from the dried surface of our planet. Newton, in his *Treatise of the System of the World in a Popular Way*, 1728, endeavoured to determine what amount of deviation from the perpendicular direction the pendulum would experience from a mountain 2,665 feet in height and 5,330 feet in diameter. This consideration very probably gave occasion to the unsatisfactory experiments, which were made by Bouguer on Chimborazo,[25] by Maskelyne and

[25] Bouguer who had been induced by La Condamine to institute experiments on the deviation of the plummet near the mountain of Chimborazo, does not allude in his *Figure de la Terre*, pp. 364—394 to Newton's proposition. Unfortunately the most skilful of the two travellers did not observe on the east and western sides of the colossal mountain, having limited his experiments (December, 1738) to two stations lying on the same side of Chimborazo, first in a southerly direction 61° 30′ West, about 4,572 toises or 29,326 feet from the centre of the mountain, and then to the South 16° West (distance 1,753 toises or 11,210 feet). The first of these stations lay in a district with which I am well acquainted, and probably at the same elevation as the small alpine lake of Yana-cocha, and the other in the pumice-stone plain of the Arenal (La Condamine, *Voyage à l'Equateur*, pp. 68—70). The deviation yielded by the altitudes of the stars, was, contrary to all expectation, only 7.″5 which was ascribed by the observers themselves to the difficulty of making observations so immediately in the vicinity of the limit of perpetual snow, to the want of accuracy in their instruments, and above all to the great cavities which were conjectured to exist within this colossal trachytic mountain. I have already expressed many doubts, based upon geological grounds, as to this assumption of very large cavities, and of the very inconsiderable mass of the tra-

Hutton on Shehallien, near Blair-Athol, in Perthshire; to the comparison of pendulum lengths on a plain lying at an elevation of 6000 feet and at the level of the sea (as for instance Carlini's observations at the Hospice of Mont Cenis, and Biot and Mathieu's at Bordeaux); and lastly to the delicate and thoroughly decisive experiments undertaken in 1837 by Reich and Bailey with the ingeniously constructed torsion-balance which was invented by John Mitchell and subsequently given to Cavendish by Wollaston.[26] The three modes of determining the density of our planet (by vicinity to a mountain mass, elevation of a mountainous plateau, and the balance) have already been so circumstantially detailed in a former part of the *Cosmos* (vol. i, p. 158), that it only remains for us to notice the experiments given in Reich's new treatise, and prosecuted by that indefatigable observer during the interval between the years 1847 and 1850.[27]

chytic dome of Chimborazo. South-south-east of this mountain, near the Indian village of Calpi, lies the volcanic cone of Yana-urcu, which I carefully investigated in concert with Bonpland, and which is certainly of more recent origin then the elevation of the great dome-shaped trachytic mountain, in which neither I nor Boussingault could discover anything analogous to a crater. See the *Ascent of Chimborazo* in my *Kleine Schriften*, Bd. i, s. 138.

[26] Baily, *Exper. with the Torsion Rod for determining the mean density of the earth*, 1843, p. 6; John Herschel, *Memoir of Francis Baily*, 1845, p. 24.

[27] Reich, *Neue Versuche mit der Drehwage*, in the *Abhandl. der mathem. physischen Classe der Kön. Sächsischen Gesellschaft der Wissenschaften zu Leipzig*, 1852, Bd. i, s. 405, 418. The most recent experiments of my respected friend Professor Reich, approximate somewhat more closely to the results given in Baily's admirable work. I have obtained the mean 5.5772 from the whole series of experiments: (a) with the tin ball and the longer thicker copper wire, the result was 5.5712, with a probable error of 0.0113; (b) with the tin ball, and with the shorter thinner copper wire, as well as with the tin ball and the bi-filar iron wire, 5.5832, with a probable error of 0.0149. Taking this error into account, the mean in (a) and (b) is 5.5756. The result obtained by Baily, and which was certainly deduced from a larger number of experiments (5.660), might indeed give us a somewhat higher density, as it obviously rose in proportion to the greater lightness of the balls that were used in the experiments, which were either of glass or ivory. (Reich in Poggend. *Annalen*, Bd. lxxxv, s. 190. Compare also Whitehead Hearn in the *Philos. Transact. for* 1847, pp. 217—229.) The motion of the torsion balance was observed by Baily by means of the reflection of a scale obtained from a mirror, which was attached to the middle of the

The whole may in accordance with the present state of our knowledge be arranged in the following manner :—

Shehallien, according to the mean of the maximum 4.867 and the minimum 4.559, as found by Playfair	4.713
Mont Cenis, observations of Carlini, with the correction of Giulio,	4.950
The torsion-balance, Cavendish (according to Baily's calculation)	5.448
Reich, 1838	5.440
Baily, 1842	5.660
Reich, 1847—1850	5.577

The mean of the two last results gives 5.62 for the density of the earth (taking that of water as 1), and consequently much more than the densest finely granular basalt, which according to the numerous experiments of Leonhard varies from 2.95 to 3.67, and more than that of magnetic iron (4,9 to 5.2), and not much less than that of the native arsenic of Marienberg or Joachimsthal. We have already elsewhere observed (*Cosmos,* vol. i, p. 159) that from the great distribution of secondary and tertiary formations, and of those upheaved strata which constitute the visible continental part of our earth's surface (the plutonic and volcanic upheavals being scattered in the form of islands over a small area of space), the solid portion of the upper part of the earth's crust possesses a density scarcely reaching from 2.4 to 2.6. If we assume with Rigaud that the relation of the solid to the fluid oceanic surface of our globe is as 10 : 27, and if further we consider that the latter has been found by experiments with the sounding lead to extend to a depth of 27,700 feet, the whole density of the upper strata, which underlie the dry and oceanic surfaces, scarcely equals 1.5. The distinguished geometrician Plana has correctly observed that the author of the *Mécanique Céleste* was in error, when he ascribed to the upper stratum of the earth a density equal to that of granite,

balance, a method that had been first suggested by Reich, and was employed by Gauss in his magnetic observations. The use of such a mirror, which is of great importance from the exactness with which the scale may be read off, was proposed by Poggendorff as early as the year 1826 (*Annalen der Physik.* Bd. vii, s. 121).

which, moreover, he estimated somewhat highly at 3, which would give him 10.047 for the density of the centre of the earth.[28] This density would, according to Plana, be 16.27 if we assume that of the upper strata = 1.83, which differs but slightly from the total density of 1.5 or 1.6 of the earth's crust. The vertical pendulum, no less than the horizontal torsion balance, may certainly be designated as a geognostic instrument; but the geology of the inaccessible parts of the interior of our globe is, like the astrognosy of the unilluminated celestial bodies, to be received with considerable cau-

[28] Laplace, *Mécanique Céleste,* éd. de 1846, t. v, p. 57. The mean specific weight of granite cannot be set down at more than 2.7, since the bi-axial white potash-mica, and green uni-axial magnesia-mica range from 2.85 to 3.1, whilst the other constituents of this rock, namely quartz and felspar are 2.56 and 2.65. Even oligoclase is only 2.68. If hornblende rises as high as 3.17, syenite, in which felspar always predominates, never rises above 2.8. As argillaceous schist varies from 2.69 to 2.78, while pure dolomite, lying below limestone, equals only 2.88, chalk 2.72, and gypsum and rocksalt only 2.3, I consider that the density of those continental parts of the crust of our earth, which are appreciable to us should be placed at 2.6 rather than at 2.4. Laplace, on the supposition that the earth's density increases in arithmetical progression from the surface towards the centre, and on the assumption (which is assuredly erroneous) that the density of the upper stratum is equal to 3, has found 4.7647 for the mean density of the whole earth, which deviates very considerably from the results obtained by Reich (5.577) and by Baily (5.660); this deviation being much greater than could be accounted for by the probable error of observation. In a recent discussion on the hypothesis of Laplace, which will soon form a very interesting paper in Schumacher's *Astr. Nachrichten,* Plana has arrived at the result that, by a different method of treating this hypothesis, Reich's mean density of the earth, and the density of the dry and oceanic superficial strata, which I estimated at 1.6, as well as the ellipticity, within the limits that seem probable for the latter value, may be very closely approximated to. "If the compressibility of the substances of which the earth is formed," writes the Turin geometrician, "has given rise to regular strata, nearly elliptical in form, and having a density which increases from the surface towards the centre, we may be allowed to suppose that these strata, in the act of becoming consolidated, have experienced modifications, which, although they are actually very small, are nevertheless large enough to preclude the possibility of our deducing, with all the precision that we could desire, the condition of the solid earth from its prior state of fluidity. This reflection has made me attach the greater weight to the first hypothesis advanced by the author of the *Mécanique Céleste,* and I have consequently determined upon submitting it to a new investigation."

tion. In a portion of my work, which treats of volcanic phenomena, I cannot wholly pass in silence those problems, which have been suggested by other inquirers in reference to the currents pervading the general fluid in the interior of our planet, or the probable or improbable periodically ebbing and flowing movement in individual and imperfectly filled basins, or the existence of portions of space, having a very low specific gravity and underlying the upheaved mountain chains.[29] In a work devoted to cosmical phenomena no question should be overlooked on which actual observations have been instituted, or which may seem to be elucidated by close analogies.

b. *The Existence and Distribution of Heat in the interior of our Globe.*

(Expansion of the Delineation of Nature, *Cosmos*, vol. i, pp. 160—168.)

Considerations regarding the internal heat of our earth, the importance of which has been greatly augmented by the connection which is now generally recognised to exist between it and phenomena of upheavals and of volcanic action, are based partly upon direct, and therefore incontrovertible measurements of temperature in springs, borings, and subterranean mines, and partly upon analytical combinations regarding the gradual cooling of our planet, and the influence which the decrease of heat may have exercised in primeval ages upon the velocity of rotation and upon the direction of the currents of internal heat.[30] The figure of the compressed terrestrial spheroid is further dependent upon the law, according to which density increases in concentric superimposed non-homogeneous strata. The first or experimental, and therefore the more certain portion of the investigation to which we shall limit ourselves in the present place, throws light only upon the accessible crust of the earth, which is of very inconsiderable thickness, whilst the

[29] See Petit *sur la latitude de l'Observatoire de Toulouse, la densité moyenne de la chaine des Pyrénées, et la probabilité qu'il existe un vide sous cette chaine,* in the *Comptes rendus de l'Acad. des Sc.*, t. xxix, 1849, p. 730.

[30] *Cosmos*, vol. i, p. 169.

second or mathematical part, in accordance with the nature of its applications, yields rather negative than positive results. This method of enquiry, which possesses all the charm of ingenious and intellectual combinations of thought,[31] leads to problems, which cannot be wholly overlooked when we touch upon conjectures regarding the origin of volcanic forces, and the reaction of the fused interior upon the solid external crust of our earth. Plato's geognostic myth of the Pyriphlegethon,[32] as the origin of all thermic springs as well as of volcanic igneous currents, emanated from the early and generally felt requirement of discovering some common cause for a great and complicated series of phenomena.

Amid the multiplicity of relations presented by the earth's surface, in respect to insolation (solar action) and its capacity of radiating heat, and amid the great differences in the capacity for conducting heat, which varies in accordance with the composition and density of heterogeneous rocks, it is worthy of notice, that wherever the observations have been conducted with care, and under favourable circumstances, the increase of the temperature with the depth has been found to present for the most part very closely coinciding results, even at very different localities. For very great depths we obtain the most certain results from Artesian wells, especially when they are filled with fluids that have been rendered turbid by the admixture of clay, and are therefore less favourable to the passage of internal currents, and when they do not receive many lateral affluents flowing into them at different elevations through transverse fissures. On account of their depth, we will begin with two of the most remarkable Artesian wells, namely that of Grenelle, near Paris, and that of the New Salt Works at Oeynhausen, near Minden. We will proceed in the following paragraph to give some of the most accurate results which they have yielded.

According to the ingenious measurements of Walferdin,[33]

[31] Hopkins, *Physical Geology*, in the *Report of the British Association for* 1838, p. 92; *Philos. Transact.*, 1839, pt. ii, p. 381, and 1840, pt. i, p. 193; Hennessey (*Terrestrial Physics*) in the *Philos. Transact.*, 1851, pt. ii, pp. 504—525.

[32] *Cosmos*, vol. i, p. 235.

[33] The observations of Walferdin were made in the autumn of 1847, and deviate very slightly from the results obtained with the same appa-

to whom we are indebted for a complete series of very delicate apparatus for determinations of temperature at great depths in the sea and in springs, the surface of the basin of the well at Grenelle lies at an elevation of 36.24 metres or 119 feet above the level of the sea. The upper outlet of the ascending spring is 33.33 metres or 109.3 feet higher. This total elevation of the ascending water (69.57 metres or 228.2 feet) is, when compared with the level of the sea about 196·8 feet lower than the outbreak of the green sandstone strata in the hills near Lusigny, south-east of Paris, to whose infiltrations the rise of the waters in the Artesian wells at Grenelle have been ascribed. The borings extend to a depth of 547 metres or 1794.6 feet below the base of the Grenelle basin, or about 510.76 metres or 1675 feet below the level of the sea; the waters consequently rise to a total height of 580.33 metres or 1904 feet. The temperature of the spring is 81°.95 F.; consequently the increase of heat marks 1° F. for about every 59 feet.

The boring at the New Salt Works at Rehme is situated 231 feet above the level of the sea (above the watermark at Amsterdam). It has penetrated to an absolute depth of 2281 feet below the surface of the earth, measuring from the point where the operations were begun. The salt spring which, when it bursts forth, is impregnated with a large quantity of carbonic acid, lies therefore 2052 feet below the level of the sea, a relative depth which is perhaps the greatest that has ever been reached by man in the interior of the earth. The temperature of the salt spring at the New Salt Works of Oeynhausen is 91°04 F., and as the mean annual temperature of the air at these works is about 49°.3 F., we may assume that there is an increase of temperature of 1° F. for every 54.68 feet. The boring at these Salt Works[34] is therefore 491 feet absolutely deeper than the boring at

ratus, by Arago, in 1840, at a depth of 1657 feet, when the borer had left the chalk and was beginning to penetrate through the gault. See *Cosmos*, vol. i, p. 167, and *Comptes rendus*, t. xi, 1840, p. 707.

[34] According to the manuscript results given by the superintendent of the mines of Oeynhausen. See *Cosmos*, vol. i, pp. 148, 166; and Bischof, *Lehrbuch der Chem. und Phys. Geologie*, Bd. i, Abth. 1, s. 154—163. In regard to absolute depth, the borings at Mondorf, in the Grand Duchy of Luxemburg (2202 feet), approach most nearly to those at the new salt works at Oeynhausen.

Grenelle ; it sinks 377 feet deeper below the surface of the sea, and the temperature of its waters is 9°.18 F. higher. The increase of the heat at Paris, is about 1° F. for 59 feet, and therefore scarcely $\frac{1}{14}$th greater. I have already elsewhere drawn attention to the fact that a similar result was obtained by Auguste de la Rive and Marcet, at Brégny, near Geneva, in investigating a boring which was only 725 feet in depth, although it was situated at an elevation of more than 1600 feet above the Mediterranean Sea.[35]

If to these three springs, which possess an absolute depth varying between 725 feet and 2285 feet, we add another, that of Monkwearmouth, near Newcastle, (the water rising through a coal mine which, according to Phillips is worked at a depth of 1496 feet below the level of the sea,) we shall find this remarkable result, that at four places widely separated from one another an increase of heat of 1° F. varies only between 54 and 58.6 feet ;[36] such a coincidence in the results cannot, however, be always expected to occur when we consider the nature of the means which are employed for determining the internal heat of the earth at definite depths. Although we may assume that the water which is infiltrated in elevated positions through hydrostatic pressure as in connected tubes, may influence the rising of springs at points of great depth, and that the subterranean

[35] *Cosmos*, vol. i, p. 166, and *Mémoires de la Société d'Hist. Naturelle de Genève*, t. vi, 1833, p. 243. The comparison of a number of Artesian wells in the neighbourhood of Lille, with those of Saint Ouen and Geneva would, indeed, lead us to assume, if we were quite certain as to the accuracy of the numerical data, that the different conductive powers of terrestrial and rocky strata exert a more considerable influence than has generally been supposed (Poisson, *Théorie Mathématique de la Chaleur*, p. 421).

[36] In a table of fourteen borings, which were more than one hundred yards in depth, and which were situated in various parts of France, Bravais, in his very instructive encyclopædic memoir in the *Patria*, 1847, p. 145, indicates nine in which an increase of temperature of 1° F. is found to occur for every 50—70 feet of depth, which would give a deviation of about 10 feet in either direction from the mean value given in the text. See also Magnus in Poggen. *Ann.* Bd. xxii, 1831, s. 146. It would appear, on the whole, that the increase of temperature is most rapid in Artesian wells of very inconsiderable depth, although the very deep wells of Monte Massi in Tuscany, and Neuffen on the north-west part of the Swabian Alps, present a remarkable exception to this rule.

waters acquire the temperature of the terrestrial strata with which they are brought in contact, the water that is obtained through borings may, in certain cases, when communicating with vertically descending fissures, obtain some augmentation of heat from an inaccessible depth. An influence of this kind, which is very different from that of the varying conductive power of different rocks, may occur at individual points widely distant from the original boring. It is probable that the waters in the interior of our earth move in some cases within limited spaces, flowing either in streams through fissures (on which account it is not unusual to find that a few only of a large number of contiguous borings prove successful), or else follow a horizontal direction, and thus form extensive basins—a relation which greatly favours the labour of boring, and in some rare cases betrays, by the presence of eels, mussels, or vegetable remains, a connection with the earth's surface. Although from the causes which we have already indicated, the ascending springs are sometimes warmer than the slight depth of the boring would lead us to anticipate, the afflux of colder water which flows laterally through transverse fissures leads to an opposite result.

It has already been observed that points situated on the same vertical line at an inconsiderable depth within the interior of our earth, experience at very different times the maximum and minimum of atmospheric temperature, which is modified by the sun's place, and by the seasons of the year. According to the very accurate observations of Quetelet, daily variations of temperature are not perceptible at depths of $3\frac{4}{5}$ths feet below the surface;[37] and at Brussels, the highest temperature was not indicated until the 10th of December in a thermometer which had been sunk to a depth of more than 25 feet, whilst the lowest temperature was observed on the 15th of June. In like manner, in the admirable experiments made by Professor Forbes, in the neighbourhood of Edinburgh, on the conductive power of different rocks, the maximum of heat was not observed until the 8th of January in the basaltic trap of Calton Hill at a depth of 24 feet below the surface.[38] It would appear

37 Quetelet, in the *Bulletin de l'Acad. de Bruxelles*, 1836, p. 75.

38 Forbes, *Exper. on the temperature of the earth at different depths*

from the observations which were carried on for many years by Arago in the garden of the Paris Observatory, that very small differences of temperature were perceptible 30 feet below the surface. Bravais calculated one degree for about every 50 feet on the high northern latitude of Bossekop, in Finmark (69° 58′ N.L.). The difference between the highest and lowest annual temperature diminishes in proportion with the depth, and according to Fourrier this difference diminishes in a geometrical proportion as the depth increases in an arithmetical ratio.

The stratum of *invariable temperature* depends, in respect to its depth, conjointly upon the latitude of the place, the conductive power of the surrounding strata and the amount of difference of temperature between the hottest and the coldest seasons of the year. In the latitude of Paris (48° 50′) the depth and temperature of the *Caves de l'Observatoire* (86 feet and 53°.30 F.) are usually regarded as affording the amount of depth and temperature of the invariable stratum. Since Cassini and Legentil in 1783 placed a very correct mercurial thermometer in these subterranean caves, which are portions of old stone quarries, the mercury in the tube has risen about 0°.4.[39] Whether the cause of this rising is to be ascribed to an accidental alteration in the thermometrical scale which, however, was adjusted by Arago in 1817 with his usual care, or whether it indicates an actual increase of heat is still undecided. The mean temperature of the air at Paris is 51°.478 F. Bravais is of opinion that the thermometer in the *Caves de l'Observatoire* stands below the limit of invariable temperature, although Cassini believes that he has found a difference of $\frac{25}{100}$ths of a degree (Fahr.) between the winter and summer temperature, the higher tempe-

in the *Trans. of the Royal Soc. of Edinburgh*, vol. xvi, 1849, pt. ii, p. 189.

[39] All numbers referring to the temperature of the *Caves de l'Observatoire* have been taken from the work of Poisson, *Théorie Mathématique de la Chaleur*, pp. 415 and 462. The *Annuaire Météorologique de la France*, edited by Martins and Haeghens, 1849, p. 88, contains corrections by Gay-Lussac for Lavoisier's subterranean thermometer. The mean of three readings, from June till August, was 53°.95 F. for this thermometer, at a time when Gay-Lussac found the temperature to be 53°.32, which was therefore a difference of 0°.63.

rature being found to prevail in the winter.[40] If we now take the mean of many observations of the temperature of the soil between the parallels of Zurich (47° 22′) and Upsala (59° 51′), we obtain an increase of 1° F. for every 40 feet. Differences of latitude cannot produce a difference of more than 12 or 15 feet, which is not marked by any regular alteration from south to north, because the influence which the latitude undoubtedly exerts, is masked within these narrow limits by the influence of the conductive power of the soil, and by errors of observation.

As the terrestrial stratum in which we first cease to observe any alteration of temperature through the whole year lies, according to the theory of the distribution of heat, so much the nearer the surface, as the maxima and minima of the mean annual temperature approximate to one another, a consideration of this subject has led my friend Boussingault to the ingenious and convenient method of determining the mean temperature of a place within the tropical regions (especially between 10 degrees north and south of the equator) by observing a thermometer which has been buried 8 or 12 inches below the surface of the soil in some well protected spot. At different hours and different months of the year, as in the experiments of Captain Hall near the coast of the Choco in Tumaco, those at Salaza in Quito, and those of Boussingault in la Vega de Zupia, Marmato, and Anserma Nuevo in the Cauca valley, the temperature scarcely varied one-tenth of a degree; and almost within the same limits it was identical with the mean temperature of the air at those places in which it had been determined by horary observations. It was, moreover, very remarkable that this identity remained perfectly uniform, whether the thermometric soundings (of less than one foot in depth) were made on the torrid shores of Guayaquil and Payta, on the Pacific, or in an Indian village on the side of the volcano of Purace, which I found from my barometrical measurements to be situated at an elevation of 1356 toises, or 8671 feet above the sea. The mean temperatures differed by fully 25° F. at these different stations.[41]

[40] Cassini, in the *Mém. de l'Acad. des Sciences*, 1786, p. 511.

[41] Boussingault, *sur la profondeur à laquelle on trouve dans la zone torride la couche de température invariable*, in the *Annales de Chimie et*

I believe that special attention is due to two observations which I made on the mountains of Peru and Mexico, in mines which lie at a greater elevation than the summit of the Peak of Teneriffe, and are therefore the highest in which a thermometer has ever been placed. At a height of between 12,000 and 13,000 feet above the level of the sea I found the subterranean air 25° F. warmer than the external atmosphere. Thus, for instance, the little Peruvian town of Micuipampa[42] lies, according to my astronomical and hypsometrical observations, in the latitude 6° 43′ S., and at an elevation of 1857 toises or 11,990 feet, at the base of Cerro de Gualgayoc, celebrated for the richness of its silver mines. The summit of this almost isolated fortress-like and picturesquely situated mountain rises 240 toises or 1504 feet higher than the streets of Micuipampa; the external air at a distance from the mouth of the pit of

de Physique, t. liii, 1833, pp. 225—247. Objections have been advanced by John Caldecott, the astronomer to the Rajah of Travancore, and by Captain Newbold, in India, against the method recommended in this memoir, although it has been employed in South America in many very accurate experiments. Caldecott found at Trevandrum (*Edin. Transact.* vol. xvi, part iii, pp. 379—393), that the temperature of the soil at a depth of three feet and more below the surface, (and therefore deeper than Boussingault's calculation,) was 85° and 86° F., while the mean temperature of the air was 80°.02. Newbold's experiments (*Philos. Transact. for the year* 1845, pt. i, p. 133), which were made at Bellary, lat. 15° 5′, showed an increase of temperature of 4° F. between sunrise and 2 p.m. for one foot of depth, but at Cassargode, lat. 12° 29′, there was only an increase of 1°.30 F., under a cloudy sky. Is it quite certain that the thermometer in this case was sufficiently covered to protect it from the influence of the sun's rays? Compare also Forbes, *Exper. on the Temp. of the Earth at different depths*, in the *Edin. Transact.* vol. xvi, part ii, p. 189. Colonel A. Costa, the admirable historian of New Granada, has made a prolonged series of observations, which fully confirm Boussingault's statement, and which were completed, about a year ago, at Guadua, on the south-western side of the elevated plateau of Bogota, where the mean annual temperature is 43°.94 F. at the depth of one foot, and at a carefully protected spot. Boussingault thus refers to these experiments:—"The observations of Colonel A. Costa, whose extreme precision in everything which is connected with meteorology is well known to you, prove that when *fully sheltered from all disturbing influences*, the temperature within the tropics remains constant at a very small depth below the surface."

[42] In reference to Gualgayoc (or Minas de Chota) and Micuipampa, see Humboldt, *Recueil d'Observ. Astron.* vol. i, p. 324.

the Mina del Purgatorio was 42°.26 F., but in the interior of the mine, which lies more than 2057 toises, or 13,154 feet above the sea, I saw that the thermometer everywhere indicated a temperature of 67°.64 F., there being thus a difference of 25°.38 F. The limestone rock was here perfectly dry, and very few men were working in the mine. In the Mina de Guadalupe, which lies at the same elevation, I found that the temperature of the internal air was 57°.9 F., showing therefore a difference of 15°.64 F. when compared with the external air. The water which flowed out from the very damp mine stood at 52°.34 F. The mean annual temperature of Micuipampa is probably not more than 45°.8 F. In Mexico, in the rich silver mines of Guanaxuato,[43] I found in the Mina de Valenciana the external temperature in the neighbourhood of the Tiro Nuevo (which is 7590 feet above the sea) 70°.16 F., and the air in the deepest mines, for instance in the Planes de San Bernardo, 1630 feet below the opening of the shaft of Tiro Nuevo, fully 80°.6 F., which is about the mean temperature of the littoral region of the Gulf of Mexico. At a point 147 feet higher than the mouth of the Planes de San Bernardo, a spring of water issues from the transverse rock, in which the temperature is 84°.74 F. I determined the latitude of the mountain town of Guanaxuato to be 21° 0′ N., with a mean annual temperature varying between 60°.44 and 61°.26 F. The present is not a fitting place in which to advance conjectures, which it might be difficult to establish in relation to the causes of probably an entirely local rise of the subterranean temperature at mountain elevations, varying from 6000 to more than 12,000 feet.

A remarkable contrast is exhibited in the steppes of Northern Asia, by the conditions of the frozen soil, whose very existence was doubted, notwithstanding the early testimony of Gmelin and Pallas. It is only in recent times that correct views in relation to the distribution and thickness of the stratum of subterranean ice have been established by means of the admirable investigations of Erman, Baer, and Middendorff. In accordance with the descriptions given of Greenland by Cranz, of Spitzbergen by Martens and Phipps,

[43] *Essai Polit. sur le Roy. de la Nouv. Espagne* (2ème ed., t. iii, p. 201).

and of the coasts of the sea of Kara by Sujew, the whole of the most northern part of Siberia was described by too hasty a generalization as entirely devoid of vegetation, always frozen on the surface, and covered with perpetual snow, even in the plains. The extreme limit of vegetation in Northern Asia is not, as was long assumed, in the parallel of 67°, although sea-winds and the neighbourhood of the Bay of Obi make this estimate true for Obdorsk; for in the valley of the great River Lena, high trees grow as far north as the latitude of 71°. Even in the desolate islands of New Siberia, large herds of reindeer and countless lemmings find an adequate nourishment.[44] Middendorff's two Siberian expeditions, which are distinguished by a spirit of keen observation, adventurous daring, and the greatest perseverance in a laborious undertaking, were extended from the year 1843 to 1846 as far north as the Taymir land in 75° 45′ lat., and south-east as far as the Upper Amoor and the Sea of Ochotsk. The former of these perilous undertakings led the learned investigator into a hitherto unvisited region, whose exploration was the more important in consequence of its being situated at equal distances from the eastern and western coasts of the old Continent. In addition to the distribution of organisms in high northern latitudes, as depending mainly upon climatic relations, it was directed by the St. Petersburgh Academy of Sciences that the accurate determination of the temperature of the ground and of the thickness of the subterranean frozen soil should be made the principal objects of the expedition. Observations were made in borings and mines at a depth of from 20 to 60 feet at more than twelve points (near Turuchansk, on the Jenisei, and on the Lena) at relative distances of from 1600 to 2000 geographical miles.

The most important seat of these geothermic observations was however Schergin's shaft at Jakutsk 62° 2′ N. lat.[45]

[44] E. von Baer, in Middendorff's *Reise in Sib.*, Bd. i, s. vii.

[45] The merchant Fedor Schergin, cashier to the Russian-American Trading Company, began, in the year 1828, to dig a well in the courtyard of a house belonging to the company. As he had only found frozen earth and no water at the depth of 90 feet, which he reached in 1830, he determined to give up the attempt, until Admiral Wrangel, who passed through Jakutsk on his way to Sitcha, in Russian America, and who saw how interesting it would be, in a scientific point of view, to penetrate through this subterranean stratum of ice, induced Schergin

Here a subterranean stratum of ice was pierced to a depth of more than 382 feet. The thermometer was sunk at eleven points along the lateral walls of the shaft between the surface and the greatest depth, which was reached in 1837. The observer was obliged to be let down standing in a bucket, with one arm fastened to a rope, while he read off the thermometric scale. The series of observations, whose mean error does not amount to more than 0°.45 F. embrace the interval between April 1844 and June 1846. The decrease of cold was not proportional to the depth at individual points, but nevertheless the following results were obtained for the total increase of the mean temperatures for the different superimposed frozen strata :—

50 feet - - -	17°.13 F.
100 „ - - -	20°.26 „
150 „ - - -	21°.43 „
200 „ - - -	23°.27 „
250 „ - - -	24°.49 „
382 „ - - -	26°.60 „

After a very careful consideration of all these observations, Middendorff determined the general increase of temperature to be 1° F. for every space varying from 44°.5 to 52 feet.[46] This result shows a more rapid increase of heat in

to continue the boring; and, up to 1837, although an opening had been made to a depth of 382 feet below the surface, it had not penetrated beyond the ice.

[46] Middendorff, *Reise in Sib.* Bd. i, s. 125—133. "If we exclude," says Middendorff, "those depths which did not quite reach 100 feet, on the ground that they were influenced by annual deviations of temperature, as was determined by experiments previously made in Siberia, we shall still find certain anomalies in the partial increase of heat. Thus, for instance, between the depths of 150—200 feet the temperature rises at a ratio of 1° F. for only 29.3 feet, while between 250—300 feet the corresponding increase is 96.4 feet. We may, therefore, venture to assert that the results of observations that have hitherto been obtained in Shergin's shaft are by no means sufficient to determine with certainty the amount of the increase of temperature, and that, notwithstanding the great variations which may depend upon the different conductive powers of the terrestrial strata, and the disturbing influence of the air or water which enters from above, an increase of 1° F. occurs for every 44—52 feet. The result of 52 feet is the mean of six partial increases of temperature, measured at intervals of 50 feet between the depths of 100 and 382 feet. On comparing the mean

Schergin's shaft than has been obtained from different borings in Central Europe, whose results approximate closely to one another (see p. 37). The difference fluctuates between $\frac{1}{4}$th and $\frac{1}{8}$th. The mean annual temperature of Jakutsk was determined at 13°.7 F. The oscillation between the summer and winter temperature is so great, according to Newerow's observations, which were continued for fifteen years (from 1829 to 1844), that sometimes for fourteen days consecutively in July and August, the atmospheric temperature rises as high as 77,° or even 84°.6 F., while during 120 consecutive winter days from November to February, the cold falls to between —42°.3 F. and —69° F. In estimating the increase of temperature which was found on boring through the frozen soil, we must take into account the depth below the

annual temperature of Jakutsk 13°.71 F. with that which was found from observation to be the mean temperature of the ice (26°.6) at the greatest depth of the mine (382 feet), I find 29.6 feet for every increase of 1° F. A comparison of the temperature at the deepest part with that at a depth of 100 feet would give 44.4 feet for this increase. From the acute investigations of Middendorff and Peters in reference to the velocity of transmission of changes of atmospheric temperature, including the maxima of cold and heat (Middend. s. 133—157, 168—175), it follows that in the different borings which do not exceed the inconsiderable depth of from 8 to 20 feet, "the temperature rises from March to October, and falls from November to April, because the spring and autumn are the seasons of the year in which the changes of atmospheric temperature are most considerable" (s. 142—145). Even carefully covered mines in Northern Siberia become gradually cooled, in consequence of the walls of the shafts having been for years in contact with the air; this cause, however, has only made the temperature fall about 1° F. in Schergin's shaft, in the course of eighteen years. A remarkable and hitherto unexplained phenomenon, which has also presented itself in the Schergin shaft, is the warmth occasionally observed in the winter, although only at the lowest strata, without any appreciable influence from without (s. 156—178). It seems still more striking to me, that in the borings at Wedensk, on the Pasina, when the atmospheric temperature is — 31° F. it should be 26°.-4 at the inconsiderable depth of 5 or 10 feet! The isogeothermal lines, whose direction was first pointed out by Kupffer, in his admirable investigations (*Cosmos*, vol. i, p. 216) will long continue to present problems that we are unable to solve. The solution of these problems is more especially difficult in those cases in which the complete perforation of the frozen soil is a work of considerable time; we can, however, no longer regard the frozen soil at Jakutsk as a merely local phenomenon, which, in accordance with Slobin's view, is produced by the terrestrial strata deposited from water (Middend. s. 167).

surface at which the ice exhibits the temperature of 32° F., and which is consequently the nearest to the lower limit of the frozen soil; according to Middendorff's results which entirely agree with those that had been obtained much earlier by Erman, this point was found in Schergin's shaft to be 652, or 684 feet below the surface. It would appear, however, from the increase of temperature which was observed in the mines of Mangan, Shilow and Dawydow, which are situated at about three or four miles from Irkutsk, in the chain of hills on the left bank of the Lena, and which are scarcely more than 60 feet in depth, that the normal stratum of perpetual frost seems to be situated at 320 feet below the surface.[47] Is this inequality only apparent in consequence of the uncertainty which attaches to a numerical determination, based on so inconsiderable a depth, and does the increase of temperature obey different laws at different times? Is it certain that if we were to make a horizontal section of several hundred fathoms from the deepest part of Schergin's shaft into the adjoining country, we should find in every direction and at every distance from the mine frozen soil, in which the thermometer would indicate a temperature of 4°.5 below the freezing point?

Schrenk has examined the frozen soil in 67° 30′ N. L. in the country of the Samojedes. In the neighbourhood of Pustojenskoy Gorodok, fire is employed to facilitate the sinking of wells, and in the middle of summer ice was found at only 5 feet below the surface. This stratum could be traced for nearly 70 feet, when the works were suddenly stopped. The inhabitants were able to sledge over the neighbouring lake of Usteje throughout the whole of the summer of 1813.[48] During my Siberian expedition with Ehrenberg and Gustav Rose, we caused a boring to be made

[47] Middendorff, Bd. i, s. 160, 164, 179. In these numerical data and conjectures regarding the thickness of the frozen soil, it is assumed that the temperature increases in arithmetical progression with the depth. Whether a retardation of this increase occurs in greater depths is theoretically uncertain, and hence there is no use in entering upon deceptive calculations regarding the temperature of the centre of the earth in the fused heterogeneous rocky masses which give rise to currents.

[48] Schrenk's *Reise durch die Tundern der Samojeden,* 1848, Th. i, s. 597.

in a piece of turfy ground near Bogoslowsk (59° 44′ N. L.) among the Ural Mountains on the road to the Turjin mines.[49] We found pieces of ice at the depth of 5 feet, which were embedded, breccia-like, in the frozen ground, below which began a stratum of thick ice which we had not penetrated at the depth of 10 feet.

The *geographical extension* of the frozen ground, that is to say, the limits within which ice and frozen earth are found at a certain depth, even in the month of August, and consequently throughout the whole year, in the most northern parts of the Scandinavian peninsula, as far east as the coasts of Asia, depends, according to Middendorff's acute observations (like all geothermal relations) more upon local influences than upon the temperature of the atmosphere. The influence of the latter is on the whole, no doubt, stronger than any other, but the isogeothermal lines are not, as Kupffer has remarked, parallel in their convex and concave curves to climatic isothermal lines, which are determined by the means of the atmospheric temperature. The infiltration of liquid vapours deposited by the air, the rising of thermal springs from a depth, and the varying conductive powers of the soil, appear to be especially active.[50] "On the most northern point of the European continent, in Finmark, between the high latitudes of 70° and 71°, there is as yet no continuous tract of frozen soil. To the eastward, impinging upon the valley of the Obi, 5° south of the North Cape, we find frozen ground at Obdorsk and Beresow. To the east and south-east of this point, the cold of the soil increases, excepting at Tobolsk on the Irtisch, where the temperature of the soil is colder than at Witimsk, in the valley of the Lena, which lies 1° farther north. Turuchansk (65° 54′ N. L.) on the Jenisei, is situated upon an unfrozen soil, although it is close to the limits of the ice. The soil at Amginsk, south-east of Jakutsk, presents as low a temperature as that of Obdorsk, which lies 5° farther north; the same being the case with Oleminsk on the Jenisei. From the Obi to the latter river the curve formed by the limits of the

[49] Gustav Rose, *Reise nach. dem Ural*, Bd. i, s. 428.

[50] Compare my friend, G. von Helmersen's experiments on the relative conductive powers of different kinds of rocks (*Mém. de l'Académie de St. Pétersbourg: Mélanges Physiques et Chimiques*, 1851, p. 32).

frozen soil seems to rise a couple of degrees farther north, after which it intersects, as it turns southward, the Lena valley, almost 8° south of the Jenessei. Farther eastward, this line again rises in a northerly direction."[51] Kupffer, who has visited the mines of Nertshinsk, draws attention to the fact that independently of the continuous northern mass of frozen soil, the phenomenon occurs in an island-like form in the more southern districts, but in general it is entirely independent of the limits of vegetation, or of the growth of timber.

It is a very considerable advance in our knowledge, when we are able gradually to arrive at general and sound cosmical views of the relations of temperature of our earth in the northern portions of the old continent; and to recognise the fact that under different meridians the limits of the frozen soil as well as those of the mean annual temperature, and of the growth of trees, are situated at very different latitudes; whence it is obvious that continuous currents of heat must be generated in the interior of our planet. Franklin found in the north-west part of America that the ground was frozen even in the middle of August at a depth of 16 inches, while Richardson observed upon a more eastern point of the coast in 71° 12′ lat. that the ice-stratum was thawed in July as low as 3 feet beneath the herb-covered surface. Would that scientific travellers would afford us more general information regarding the geothermal relations in this part of the earth and in the southern hemisphere! An insight into the connection of phenomena is the most certain means of leading us to the causes of apparently involved anomalies, and to the comprehension of that which we are apt too hastily to regard as at variance with normal laws.

[51] Middendorff, Bd. i, s. 166. Compare also s. 179. "The curve representing the commencement of the freezing of the soil in Northern Asia exhibits two convexities, inclining southwards, one on the Obi, which is very inconsiderable, and the other on the Lena, which is much more strongly marked. The limit of the frozen soil passes from Berresow on the Obi, towards Turuchansk on the Jenisei, it then runs between Witimsk and Olekminsk, on the right bank of the Lena, and, ascending northwards, turns to the east."

c. *Magnetic Activity of the Earth in its three Manifestations of Force—Intensity, Inclination, and Variation.—Points (called the Magnetic Poles), in which the Inclination is* 90°. —*Curves on which no Inclination is observed* (*Magnetic Equator*). — *The Four different Maxima of Intensity.*— *Curve of weakest Intensity.—Extraordinary Disturbances of the Declination* (*Magnetic Storms*).—*Polar Light.*

(Extension of the Picture of Nature, *Cosmos*, vol. i. pp. 169—197, vol. ii. pp. 717—720, and vol. iv. pp. 394—398.)

The magnetic constitution of our planet can only be deduced from the many and various manifestations of terrestrial force in as far as it presents measureable relations in space and time. These manifestations have the peculiar property of exhibiting perpetual variability of phenomena to a much higher degree even than the temperature, gaseous admixture, and electrical tension of the lower strata of the atmosphere. Such a constant change in the nearly allied magnetic and electrical conditions of matter moreover essentially distinguishes the phenomena of electro-magnetism from those which are influenced by the primitive fundamental force of matter—its molecular attraction and the attraction of masses at definite distances. To establish laws in that which is ever varying, is however the highest object of every investigation of a physical force. Although it has been shown by the labours of Coulomb and Arago that the electro-magnetic process may be excited in the most various substances, it has nevertheless been proved by Faraday's brilliant discovery of diamagnetism, (by the differences of the direction of the axes, whether they incline north and south, or east and west,) that the heterogeneity of matter exerts an influence distinct from the attraction of masses. Oxygen gas, when inclosed in a thin glass tube, will show itself under the action of a magnet to be paramagnetic, inclining north and south like iron; and while nitrogen, hydrogen, and carbonic acid gases remain unaffected, phosphorus, leather, and wood show themselves to be diamagnetic, and arrange themselves equatorially from east to west.

The ancient Greeks and Romans were acquainted with the adhesion of iron to the magnet, attraction and repulsion, and the transmission of the attracting action through brass vessels as well as through rings, which were strung together in a chain-like form, as long as one of the rings was kept in contact with the magnet;[52] and they were likewise acquainted with the non-attraction of wood and of all metals excepting iron. The force of polarity, which the magnet is able to impart to a moveable body susceptible of its influence, was entirely unknown to the Western nations (Phœnicians, Tuscans, Greeks, and Romans). The first notice which we meet with among the nations of Western Europe of the knowledge of this force of polarity, which has exerted so important an influence on the improvement and extension of navigation, and which, from its utilitarian value has led so continuously to the inquiry after one universally diffused, although previously unobserved force of nature, does not date farther back than the 11th and 12th centuries. In the history and enumeration of the principal epochs of a physical contemplation of the universe, it has been found necessary to divide into several sections, and to notice, the sources from which we derive our knowledge of that which we have here summarily arranged under one common point of view.[53]

We find that the application amongst the Chinese of the directive power of the magnet, or the use of the north and south direction of magnetic needles floating on the surface of water, dates to an epoch which is probably more ancient than the Doric migration and the return of the Heraclidæ into the Peloponnesus. It seems, moreover, very striking that the use of the south direction of the needle should have been first applied in Eastern Asia not to navigation but to land travelling. In the anterior part of the magnetic waggon a freely floating needle moved the arm and hand of a small figure, which pointed towards the south. An apparatus of this kind (called *fse-nan*, indicator of the south,) was pre-

[52] The principal passage referring to the magnetic chain of rings occurs in Plato's *Ion.* p. 533, D.E ed. Steph. Mention has been made of this transmission of the attracting action not only by Pliny (xxxiv, 14) and Lucretius (vi, 910), but also by Augustine (*de civitate Dei*, xx, 4) and Philo (*de Mundi opificio*, p. 32 D ed. 1691).

[53] *Cosmos*, vol. i, p. 182; vol. ii, p. 628.

sented during the dynasty of the Tscheu, 1100 years before our era, to the ambassadors of Tonquin and Cochin-China, to guide them over the vast plains, which they would have to cross in their homeward journey. The magnetic waggon was used as late as the 15th century of our era.[54] Several of these waggons were carefully preserved in the imperial palace and were employed in the building of Buddhist monasteries in fixing the points towards which the main sides of the edifice should be directed. The frequent application of magnetic apparatus gradually led the more intelligent of the people to physical considerations regarding the nature of magnetic phenomena. The Chinese eulogist of the magnetic needle, Kuopho (a writer of the age of Constantine the Great), compares, as I have already elsewhere remarked, the attractive force of the magnet with that of rubbed amber. This force, according to him, is "like a breath of wind which mysteriously breathes through these two bodies, and has the property of thoroughly permeating them with the rapidity of an arrow." The symbolical expression of "breath of wind" reminds us of the equally symbolical designation of *soul,* which in Grecian antiquity was applied by Thales, the founder of the Ionian School, to both these attracting substances; *soul* signifying here the inner principle of the moving agent.[55]

[54] Humboldt, *Asie Centrale,* t. i, p. xl—xlii, and *Examen Crit. de l'Hist. de la Géographie,* t. iii, p. 35. Eduard Biot, who has extended and confirmed by his own careful and bibliographical studies, and with the assistance of my learned friend Stanislas Julien, the investigations made by Klaproth in reference to the epoch at which the magnetic needle was first used in China, adduces an old tradition, according to which the magnetic waggon was already in use in the reign of the Emperor Hoang-ti. No allusion to this tradition can, however, be found in any writers prior to the early Christian ages. This celebrated monarch is presumed to have lived 2600 years before our era (that is to say, 1000 years before the expulsion of the Hyksos from Egypt). Ed. Biot *sur la direction de l'aiguille aimantée en Chine* in the *Comptes rendus de l'Acad. des Sciences,* t. xix, 1844, p. 822.

[55] *Cosmos,* vol. i, p. 182. Aristotle (*de Anima,* i, 2) speaks only of the animation of the magnet as of an opinion that originated with Thales. Diogenes Laertius interprets this statement as applying also distinctly to amber, for he says, "Aristotle and Hippias maintain as to the doctrine enounced by Thales." . . . The sophist Hippias of Elis, who flattered himself that he possessed universal knowledge, occupied himself with physical science and with the most ancient traditions of

As the excessive mobility of the floating Chinese needles rendered it difficult to observe and note down the indications which they afforded, another arrangement was adopted in their place as early as the 12th century of our era, in which the needle that was freely suspended in the air was attached to a fine cotton or silken thread exactly in the same manner as Coulomb's suspension which was first used by William Gilbert in Western Europe. By means of this more perfect apparatus,[56] the Chinese as early as the beginning of the 12th century determined the amount of the western variation, which in that portion of Asia seems only to undergo very inconsiderable and slow changes. From its use on land, the compass was finally adapted to maritime purposes, and under the dynasty of Tsin, in the 4th century of our era, Chinese vessels under the guidance of the compass visited Indian ports and the eastern coast of Africa.

Fully 200 years earlier, under the reign of Marcus Aurelius Antoninus, who is called *An-tun* by the writers of the dynasty of Han, Roman legates came by sea by way of Tonquin to China. The application of the magnetic needle to European navigation was however not owing to so transient a source of intercourse, for it was not until its use had become general thoughout the whole of the Indian Ocean, along the shores of Persia and Arabia, that it was introduced into the West in the 12th century, either directly through the influence of the Arabs or through the agency of the Crusaders, who since 1096 had been brought in contact with Egypt and the true Oriental regions. In historical investigations of this nature, we can only determine with certainty

the physiological school. "The attracting breath," which, according to the Chinese physicist, Kuopho, "permeates both the magnet and amber," reminds us, according to Buschmann's investigations into the Mexican language, of the aztec name of the magnet *tlaihioanani tetl*, signifying "the stone which attracts by its breath" (from *ihiotl*, breath, and *ana*, to draw or attract).

[56] The remarks which Klaproth has extracted from the *Penthsaoyan* regarding this singular apparatus are given more fully in the *Mung-khi-pi-than, Comptes rendus,* t. xix, p. 365. We may here ask why, in this latter treatise, as well as in a Chinese book on plants, it is stated that the cypress turns towards the west, and, more generally, that the magnetic needle points towards the south? Does this imply a more luxuriant development of the branches on the side nearest the sun, or in consequence of the direction of the prevalent winds?

those epochs, which must be considered as the latest limits beyond which it would be impossible for us to urge our inquiries. In the politico-satirical poem of Guyot of Provins, the mariner's compass is spoken of (1199) as an instrument that had been long known to the Christian world ; and this is also the case in the description of Palestine which we owe to the Bishop of Ptolemais, Jaques de Vitry, and which was completed between the years 1204 and 1215. Guided by the magnetic needle the Catalans sailed along the northern islands of Scotland as well as along the western shores of tropical Africa, the Basques ventured forth in search of the whale, and the Northmen made their way to the Azores (the Bracir islands of Picigano). The Spanish *Leyes de las Partidas (del sabio Rey Don Alonso el nono)*, belonging to the first half of the 13th century, extolled the magnetic needle as "the true mediatrix (*medianera*) between the magnetic stone (*la piedra*) and the north star." Gilbert also, in his celebrated work *De Magnete Physiologia Nova*, speaks of the mariner's compass as a Chinese invention, although he inconsiderately adds, that Marco Polo "qui apud Chinas artem pyxidis didicit," first brought it to Italy. As, however, Marco Polo began his travels in 1271 and returned in 1295, it is evident from the testimony of Guyot of Provins and Jaques de Vitry, that the compass was at all events used in European seas from 60 to 70 years before Marco Polo set forth on his journeyings. The designations *zohron* and *aphron*, which Vincent of Beauvais applied in his *Mirror of Nature* to the southern and northern ends of the magnetic needle (1254), seem to indicate that it was through Arabian pilots that Europeans became possessed of the Chinese compass. These designations point to the same learned and industrious nation of the Asiatic peninsula whose language too often vainly appeals to us in our celestial maps and globes.

From the remarks which I have already made, there can scarcely be a doubt that the general application of the magnetic needle by Europeans to oceanic navigation as early as the 12th century, and perhaps even earlier in individual cases, originally proceeded from the basin of the Mediterranean. The most essential share in its use seems to have belonged to the Moorish pilots, the Genoese, Venetians, Majorcans, and Catalans. The latter people, under the guidance of their celebrated countryman, the navigator, Don Jaime Ferrer, penetrated, in 1346, to the mouth of the Rio de Ouro (23° 40′ N.L.), on the Western Coast of Africa, and, according to the testimony of Raymundus Lullus (in his nautical work *Fenix de las Maravillas del Orbe*, 1286) the Barcelonians employed atlases, astrolabes, and compasses, long before Jaime Ferrer.

The knowledge of the amount of magnetic variation is of a very early date, and was simultaneously imparted by the Chinese to Indian, Malay, and Arabian seamen, through whose agency it must necessarily have spread along the shores of the Mediterranean. This element of navigation, which is so indispensable to the correction of a ship's reckoning, was then determined less by the rising and setting of the sun than by the polar star, and in both cases the determination was very uncertain; notwithstanding which, we find it marked down upon charts, as for instance upon the very scarce atlas of Andrea Bianco, which was drawn out in the year 1436. Columbus, who had no more claim than Sebastian Cabot, to be regarded as the first discoverer of the variation of the magnetic needle, had the great merit of determining astronomically the position of a line of no variation 2½° east of the Island of Corvo, in the Azores, on the 13th of September, 1492. He found, as he penetrated into the western part of the Atlantic Ocean, that the variation passed gradually from north-east to north-west. This observation led him to the idea, which has so much occupied navigators in later times, of finding the longitude by the position of the curves of variation which he still imagined to be parallel to the meridian. We learn from his ship's log, that when he was uncertain of his position during his second voyage (1496), he actually endeavoured to steer his way by observing the declination. The insight into the possibility of such a method was undoubtedly that uncommunicable secret of longitude, which Sebastian Cabot boasted on his deathbed of having acquired through special divine manifestation.

The idea of a curve of no declination in the Atlantic was associated in the easily excited fancy of Columbus with other somewhat vague views of alterations of climate, of an anomalous configuration of the earth, and of extraordinary motions of the heavenly bodies, in which he found a motive for converting a physical into a political boundary line. Thus the *raya*, on which the *agujas de marear* point directly to the polar star, became the line of demarcation between the kingdoms of Portugal and Castille; and from the importance of determining with astronomical exactness the geographical length of such a boundary in both hemispheres, and over every part of the earth's surface, an arrogant Papal decree, although it failed in effecting this aim, nevertheless exerted a beneficial effect on the extension of astronomico-nautical science and on the improvement of magnetic instruments. (Humboldt, *Examen Crit. de la Géog.*, t. iii, p. 54.) Felipe Guillen, of Seville, in 1525, and probably still earlier, the cosmographer Alonso de Santa Cruz, teacher of mathematics to the young Emperor Charles V., constructed new variation compasses by which solar altitudes could be taken. The latter in 1530, and therefore fully 150 years before Halley, drew up the first general variation chart, although it was certainly based upon very imperfect materials. We may form some idea of the interest that had been excited in reference to terrestrial magnetism in the 16th century, after the death of Columbus, and during the contest regarding the line of demarcation, when we find that Juan Jayme made a voyage in 1585, with Francisco Gali, from the Philippines to Acapulco, for the sole purpose of testing by a long trial in the South Sea a Declinatorium of his own invention.

Amid this generally diffused taste for practical observation, we trace the same tendency to theoretical speculations which always accompanies or even more frequently precedes the former. Many old traditions current amongst Indian and Arabian sailors, speak of rocky islands which bring death and destruction to the hapless mariner, by attracting through their magnetic force all the iron which connects together the planks of the ship, or even by immoveably fixing the entire vessel. The effect of such delusions as these was to give rise to a conception of the concurrence, at the poles, of lines of magnetic variation, represented materially under the image of a high magnetic rock lying near one of the poles. On the remarkable chart of the New Continent, which was added to the Latin edition of 1508 of the Geography of Ptolemy, we find that north of Greenland (Gruentlant), which is represented as belonging to the eastern portion of Asia, the north magnetic pole is depicted as an insular mountain. Its position was gradually marked as being farther south in the *Breve Compendio de la Sphera*, by Martin Cortez, 1545, as well as in the *Geographia di Tolomeo* of Liveo Sanuto, 1588. The attainment of this point, called *el calamitico*, was associated with great expectations, since it was supposed in accordance with a delusion, which was not dissipated till long afterwards, that some *miraculoso stupendo effetto* would be experienced by those who reached it.

Until towards the end of the 16th century, men occupied themselves only with those phenomena of variation which exerted a direct influence on the ship's reckoning and the determination of its place at sea. Instead of the one line of no variation, which had been found by Columbus in 1492, the learned Jesuit Acosta, who had been instructed by Portuguese pilots (1589) expressed the belief in his admirable *Historia Natural de las Indias* that he was able to indicate four such lines. As the ship's reckoning, together with the accurate determination of the direction (or of the angle measured by the corrected compass) also requires the distance the ship had made, the introduction of the log, although this mode of measuring is even at the present day very imperfect, nevertheless marked an important epoch in the history of navigation. I believe that I have proved, although contrary to previously adopted opinions, that the first certain evidence of the use of the log [57] (la cadena de la popa, la corredera) occurs in the journal which was kept by Antonio Pigafetta during the voyage of Magellan, and which refers to the month of January, 1521. Columbus, Juan de la Cosa, Se-

[57] *Cosmos*, vol. ii, pp. 681—634. In the time of King Edward III. of England, when, as Sir Harris Nicolas (*History of the Royal Navy*, 1847, vol. ii, p. 180), has shown, ships were guided by the compass, which was then called the *sailstone dial, sailing needle*, or *adamant*, we find it expressly stated in the accounts of the expenses for equipping the king's ship, "The George," in the year 1345, that sixteen hour-glasses had been bought in Flanders; this statement, however, is by no means a proof of the use of the log. The *ampolletas* (or hour-glasses) of the Spaniards were, as we most plainly find from the statements of Enciso in Cespides, in use long before the introduction of the log, "echando punto por fantasia in la corredera de los perezosos."

bastian Cabot, and Vasco de Gama, were not acquainted with the log and its mode of application, and they estimated the ship's speed merely by the eye, while they found the distance they had made by the running down of the sand in the glasses known as *ampolletas*. For a considerable period the horizontal *declination* from the north pole was the only element of magnetic force that was made use of, but, at length (in 1576), the second element, *inclination*, began to be first measured. Robert Norman was the first who determined the inclination of the magnetic needle in London, which he noted with no slight degree of accuracy by means of an inclinatorium, which he had himself invented. It was not until 200 years afterwards, that attempts were made to measure the third element, the *intensity* of the magnetic terrestrial force.

About the close of the 16th century, William Gilbert, a man who excited the admiration of Galileo, although his merits were wholly unappreciated by Bacon, first laid down comprehensive views of the magnetic force of the earth.[58] He clearly distinguished magnetism from electricity by their several effects, although he looked upon both as emanations of one and the same fundamental force, pervading all matter. Like other men of genius, he had obtained many happy results from feeble analogies, and the clear views which he had taken of terrestrial magnetism (de magno magnete tellure) led him to ascribe the magnetisation of the vertical iron rods on the steeples of old church towers to the effect of this force. He, too, was the first in Europe who showed that iron might be rendered magnetic by being touched with the magnet, although the Chinese had been aware of the fact nearly 500 years before him.[59] Even then, Gilbert gave

[58] *Cosmos,* vol. i, p. 170. *Calamitico* was the name given to these instruments in consequence of the first needles for the compass having been made in the shape of a frog.

[59] See Gilbert, *Physiologia Nova de Magnete,* lib. iii, cap. viii, p. 124. Even Pliny (*Cosmos,* vol. i, p. 170), remarks generally, without, however, referring to the act of touching, that magnetism may be imparted for a long period of time to iron. Gilbert expresses himself as follows in reference to the vulgar opinion of a magnetic mountain :—"vulgaris opinio de montibus magneticis aut rupe aliqua magnetica, de polo phantastico a polo mundi distante" (l. c. p. 42—98). The variation and advance of the magnetic lines were entirely unknown to him, "Varietas uniuscujusque loci constans est" (l. c. 42, 98, 152, 153.

steel the preference over soft iron, because the former has the power of more permanently retaining the force imparted to it, and of thus becoming for a longer time a conductor of magnetism.

In the course of the 17th century, the navigation of the Netherlanders, British, Spaniards and French, which had been so widely extended by more perfect methods of determining the direction and length of the ship's course, increased the knowledge of those lines of no variation which, as I have already remarked, Father Acosta had endeavoured to reduce into a system.[60] Cornelius van Schouten indicated, in 1616, points lying in the midst of the Pacific and south-east of the Marquesas Islands in which the variation was null. Even now there lies in this region a singular, closed system of isogonic lines, in which every group of the internal concentric curves indicates a smaller amount of variation.[61] The emulation which was exhibited in trying to find methods for determining longitudes, not only by means of the variation, but also by the inclination (which when it was observed under a cloudy starless sky, *aëre caliginoso*,[62] was said by Wright to be "worth much gold") led to the multiplication of instruments for magnetic observations, while it tended at the same time to increase the activity of the observers. The Jesuit Cabeus of Ferrara, Ridley, Lieutaud (1668), and Henry Bond (1676), distinguished themselves in this manner. Indeed, the contest between the latter and Beckborrow, together with Acosta's view that there were four lines of no variation which divided the entire surface of the earth, may very probably have had some influence on the theory, advanced in 1683 by Halley, of four magnetic poles or points of convergence.

60 *Historia Natural de las Indias*, lib. i, cap. 17.

61 *Cosmos*, vol. i, p. 175.

62 In the very careful observations of inclination which I made on the Pacific, I demonstrated the conditions under which an acquaintance with the amount of the inclination may be of important practical utility in the determination of the latitude during the prevalence, on the coasts of Peru, of the *Garua*, when both the sun and stars are obscured (*Cosmos*, vol. i, p. 173). The Jesuit, Cabeus, author of the *Philosophia Magnetica* (in qua nova quædam pyxis explicatur, quæ *poli elevationem* ubique demonstrat), drew attention to this fact during the first half of the 17th century.

Halley is identified with an important epoch in the history of terrestrial magnetism. He assumed that there was in each hemisphere a magnetic pole of greater and lesser intensity, consequently four points with 90° inclination of the needle, precisely as we now find among the four points of greatest intensity an analogous inequality in the maximum of intensity for each hemisphere, that is to say, in the rapidity of the oscillations of the needle in the direction of the magnetic meridian. The pole of greatest intensity was situated, according to Halley, in 70° S.L. 120° east of Greenwich, and therefore almost in the meridian of King George's Sound in New Holland (Nuyts Land).[63] Halley's three voyages, which were made in the years 1698, 1699, and 1702, were undertaken with the view of elaborating a theory which must have owed its origin solely to the earlier voyage which he had made seven years before to St. Helena, and to the imperfect observations of variation made by Baffin, Hudson, and Cornelius van Schouten. These were the first expeditions which were equipped by any government for the establishment of a great scientific object—that of observing one of the elements of terrestrial force on which the safety of navigation is especially dependent. As Halley penetrated to 52° south of the equator, he was able to construct the first circumstantial variation chart, which affords to the theoretical labours of the 19th century a point of comparison, although certainly not a very remote one, of the advancing movement of the curves of variation.

Halley's attempt to combine graphically together by lines different points of equal variation was a very happy one,[64] since it has given us a comprehensive and clear insight into the connection of the results already accumulated. My isothermal lines (that is to say lines of equal heat or mean annual summer and winter temperature), which were early

[63] Edmund Halley, in the *Philos. Transact. for* 1683, vol. xii, No. 148, p. 216.

[64] Lines of this kind, which he called *tractus chalyboeliticos,* were marked down upon a chart by Father Christopher Burrus, in Lisbon, and offered by him to the King of Spain for a large sum of money; these lines being drawn for the purpose of showing and determining longitudes at sea. See Kircher's *Magnes,* ed. 2, p. 443. The first variation chart, which was made in 1530, has already been referred to in the text (p. 55).

received with much favour by physicists, have been formed on a similar plan to Halley's isogonic curves. These lines, especially since they have been extended and greatly improved by Dove, are intended to afford a clear view of the distribution of heat on the earth's surface, and of the principal dependence of this distribution on the form of the solid and fluid parts of the earth, and the reciprocal position of continental and oceanic masses. Halley's purely scientific expeditions stand so much the more apart from others, since they were not, like many later expeditions, fitted out at the expense of the Government with the object of making geographical discoveries. In addition to the results which they have yielded in respect to terrestrial magnetism, they were also the means of affording us an important catalogue of southern stars as the fruits of Halley's earlier sojourn in the Island of St. Helena in the years 1677 and 1678. This catalogue was moreover the first that was drawn up after telescopes had been combined, according to Morin's and Gascoigne's methods, with instruments of measurement.[65]

As the 17th century had been distinguished by an advance in a more thorough knowledge of the position of the lines of variation, and by the first theoretical attempt to determine their points of convergence, viz. the magnetic poles, the 18th century was characterised by the discovery of horary periodical alterations of variation. Graham has the incontestable merit of being the first to observe (London, 1722) these hourly variations with accuracy and persistency. Celsius and Hiörter in Upsala,[66] who maintained a correspondence with him, contributed to the extension of our knowledge of this phenomenon. Brugmans, and after him Coulomb, who was endowed with higher mathematical powers, entered profoundly into the nature of ter-

[65] Twenty years after Halley had drawn up his catalogue of southern stars at St. Helena (which, unfortunately, included none under the sixth magnitude) Hevelius boasted, in his *Firmamentum Sobescianum,* that he did not employ any telescope, but observed the heavens through fissures. Halley, who, during his visit to Dantzic in 1679, was present at these observations, praises their exactness somewhat too highly. *Cosmos,* vol. iii, p. 52.

[66] Traces of the diurnal and horary variations of the magnetic force had been observed in London as early as 1634, by Hellibrand, and in Siam, by Father Tachard, in 1682.

restrial magnetism (1784—1788). Their ingenious physical experiments embraced the magnetic attraction of all matter, the local distribution of the force in a magnetic rod of a given form, and the law of its action at a distance. In order to obtain accurate results, the vibrations of a horizontal needle suspended by a thread, as well as deflections by a torsion balance, were in turn employed.

The knowledge of the difference of intensity of terrestrial magnetism at different points of the earth's surface by the measurement of the vibrations of a vertical needle in the magnetic meridian, is due solely to the ingenuity of the Chevalier Borda; not from any series of specially successful experiments, but by a process of reasoning, and by the decided influence which he exerted on those who were equipping themselves for remote expeditions. Borda's long cherished conjectures were first confirmed by means of observations made from the year 1785 to 1787, by Lamanon, the companion of La Perouse. These results remained unknown, unheeded, and unpublished, although they had been communicated as early as the summer of the last-named year to Condorcet, the Secretary of the Académie des Sciences. The first, and therefore certainly an imperfect knowledge of the important law of the variability of intensity in accordance with the magnetic latitude, belongs undoubtedly[67] to the unfortunate but scientifically equipped expedition of La Perouse; but the law itself, as I rejoice to think, was first incorporated in science by the publication of my observations, made from 1798 to 1804, in the south of France, in Spain, the Canary Islands, the interior of tropical America both north and south of the equator, and in the Atlantic and Pacific Oceans. The successful expeditions of Le Gentil, Feuillée, and Lacaille; the first attempt made by Wilke, in 1768, to construct an inclination chart; the memorable circumnavigations of Bougainville, Cook, and Vancouver, have all tended, although by the

[67] *Cosmos*, vol. i, pp. 179—181. The admirable construction of the inclination compass made by Lenoir, according to Borda's plan, the possibility of having long and free oscillations of the needle, the much diminished friction of the pivots and the correct adjustment of instruments provided with scales, have been the means of enabling us accurately to measure the amount of the terrestrial force in different zones.

help of instruments possessing very unequal degrees of exactness, to establish the previously neglected, but very important element of inclination at various intervals of time, and at many different points; the observations being made more at sea and in the immediate vicinity of the ocean than in the interior of continents. Towards the close of the 18th century, the stationary observations of declination which were made by Cassini, Gilpin, and Beaufoy (from 1784 to 1790), with more perfect instruments, showed definitely that there is a periodical influence at different hours of the day, no less than at different seasons of the year,—a discovery which imparted a new stimulus to magnetic investigations.

In the 19th century, half of which has now expired, this increased activity has assumed a special character differing from any that has preceded it. We refer to the almost simultaneous advance that has been made in all branches of the theory of terrestrial magnetism, comprising the numerical determination of the intensity, inclination and variation of the force; in physical discoveries in respect to the excitation and the amount of the distribution of magnetism; and in the first and brilliant suggestions of a theory of terrestrial magnetism, which has been based by its founder, Friedrich Gauss, upon strictly mathematical combinations. The means which have led to these results are improvements in the instruments and methods employed; scientific maritime expeditions, which in number and magnitude have exceeded those of any other century, and which have been carefully equipped at the expense of their respective Governments, and favoured by the happy choice both of the commanders and of the observers who have accompanied them; and various expeditions by land, which having penetrated far into the interior of continents, have been able to elucidate the phenomena of terrestrial magnetism, and to establish a large number of fixed stations, situated in both hemispheres in corresponding north and south latitudes, and often in almost opposite longitudes. These observatories, which are both magnetic and meteorological, form as it were a network over the earth's surface. By means of the ingenious combination of the observations which have been published at the national expense in Russia and England, important and unexpected results have been obtained. The establishment of a law regulating the manifestation of force which is a proximate, although not the ultimate, end of all investigations, has been satisfactorily effected in many individual phases of the phenomenon. All that has been discovered by means of physical experiments concerning the relations which terrestrial magnetism bears to excited electricity, to radiating heat and to light, and all that we may assume in reference to the only lately generalised phenomena of diamagnetism, and to that specific property of atmospheric oxygen—polarity—opens at all events the cheering prospect, that we are drawing nearer to the actual nature of the magnetic force.

In order to justify the praise which we have generally expressed in reference to the magnetic labours of the first half of our century, I will here, in accordance with the nature and form of the present work, briefly enumerate the principal sources of our information, arranging them in some cases chronologically, and in others in groups.[68]

1803—1806. Krusenstern's voyage round the world (1812); the magnetic and astronomical portion was by Horner (Bd. iii, s. 317).

1804. Investigation of the law of the increase in the intensity of terrestrial magnetic force from the magnetic equator northward and southward, based upon observations made from 1799 to 1804. (Humboldt, *Voyage aux Régions Équinoxiales du Nouveau Continent*, t. iii, pp. 615—623; Lametherie, *Journal de Physique*, t. lxix, 1804, p. 433; the first sketch of a chart showing the intensities of the force, *Cosmos*, vol. i, p. 179). Later observations have shown that the minimum of the intensity does not correspond to the magnetic equator, and that the increase of the intensity in both hemispheres does not extend to the magnetic pole.

1805—1806. Gay-Lussac and Humboldt, Observations of Intensity in the south of France, Italy, Switzerland, and Germany. *Mémoires de la Société d'Arcueil*, t. i, pp. 1—22. Compare the observations of Quetelet, 1830 and 1839, with a

[68] The dates with which the following table begins (as, for instance, from 1803—1806) indicate the epoch of the observation, while the figures which are marked in brackets, and appended to the titles of the works, indicate the date of their publication, which was frequently much later.

"Carte de l'intensité magnétique horizontale entre Paris et Naples," in the *Mém. de l'Acad. de Bruxelles,* t. xiv; the observations of Forbes in Germany, Flanders, and Italy in 1832 and 1837 (*Transact. of the Royal Soc. of Edinburgh,* vol. xv, p. 27); the extremely accurate observations of Rudberg in France, Germany, and Sweden, 1832; the observations of Dr. Bache (Director of the Coasts' Survey of the United States), 1837 and 1840, at 21 stations both in reference to inclination and intensity.

1806—1807. A long series of observations at Berlin on the horary variations of declination and the recurrence of magnetic storms (perturbations) by Humboldt and Oltmanns, mainly at the periods of the solstices and equinoxes for 5 and 6, or even sometimes 9 days, and as many nights consecutively, by means of Prony's magnetic telescope which allowed arcs of 7 or 8 seconds to be distinguished.

1812. Morichini, of Rome, maintained that non-magnetic steel-needles become magnetic by contact with the violet rays of light. Regarding the long contention excited by this assertion and the ingenious experiments of Mrs. Somerville, together with the wholly negative results of Riess and Moser, see Sir David Brewster, *Treatise on Magnetism,* 1837, p. 48.

1815—1818.
1823—1826. } The two circumnavigation voyages of Otto von Kotzebue, the first in the Ruric, the second, five years later, in the Predprijatie.

1817—1848. The series of great scientific maritime expeditions equipped by the French Government, and which yielded such rich results to our knowledge of terrestrial magnetism; beginning with Freycinet's voyage in the corvette Uranie 1817—1820, and followed by Duperrey in the frigate La Coquille 1822—1825, Bougainville in the frigate Thetis 1824—1826, Dumont d'Urville in the Astrolabe 1826—1829, and to the south pole in the Zélée 1837—1840, Jules De Blosseville to India 1828 (Herbert *Asiat. Researches,* vol. xviii, p. 4, Humboldt, *Asie Cent.* t. iii, p. 468), and to Iceland 1833, (Lottin, *Voy. de la Recherche* 1836, pp. 376—409), du Petit Thouars with Tessan in the Venus 1837—1839, le Vaillant in the Bonite 1836—1837, the voyage of the "Commission scientifique du Nord" (Lottin, Bravais, Martins, Siljeström) to Scandinavia, Lapland, the Faroe Islands, and Spitzbergen in the corvette la Recherche 1835—1840, Bérard to the Gulf of Mexico and North America 1838, to the Cape of Good Hope and St. Helena 1842 and 1846 (Sabine in the *Phil. Transact. for* 1849, pt. ii, p. 175), and Francis de Castlenau, *Voy. dans les parties centrales de l'Amérique du Sud* 1847—1850.

1818—1851. The series of important and adventurous expeditions in the Arctic Polar Seas through the instrumentality of the British Government first suggested by the praiseworthy zeal of John Barrow; Edward Sabine's magnetic and astronomical observations in Sir John Ross's voyage to Davis Straits, Baffin's Bay, and Lancaster Sound in 1818, as well as in Parry's voyage in the Hecla and Griper through Barrow Straits to Melville Island 1819—1820; Franklin, Richardson, and Back 1819—1822, and again from 1825—1827, Back alone from 1833—1835, when almost the only food that the expedition could obtain for weeks together was a lichen, *Gyrophora pustulata*, the "Tripe de Roche" of the Canadian hunters, which has been chemically analyzed by John Stenhouse in the *Phil. Transact. for* 1849, pt. ii, p. 393; Parry's second expedition with Lyon in the Fury and Hecla 1821—1823; Parry's third voyage with James Ross 1824—1825; Parry's fourth voyage when he attempted with Lieutenants Foster and Crozier to penetrate northward from Spitsbergen on the ice in 1827, when they reached the latitude 82° 45′; John Ross, together with his accomplished nephew James Ross, in a second voyage undertaken at the expense of Felix Booth, and which was rendered the more perilous on account of protracted detention in the ice, namely from 1829 to 1833; Dease and Simpson of the Hudson's Bay Company 1838—1839; and more recently, in search of Sir John Franklin, the expeditions of Captains Ommanney, Austin, Penny, Sir John Ross, and Phillips 1850 and 1851. The expedition of Captain Penny reached the northern latitude of 77° 6′ Victoria Channel into which Wellington Channel opens.

1819—1821. Bellinghausen's voyage into the Antarctic Ocean.

1819. The appearance of the great work of Hansteen *On the Magnetism of the Earth*, which, however, was completed as early as 1813. This work has exercised an undoubted influence on the encouragement and better direction of geomagnetic studies, and it was followed by the author's general charts of the curves of equal inclination and intensity for a considerable part of the earth's surface.

1819. The observations of Admirals Roussin and Givry on the Brazilian coasts between the mouths of the rivers Marañon and La Plata.

1819—1820. Oersted made the great discovery of the fact that a conductor that is being traversed by a closed electric current, exerts a definite action upon the direction of the magnetic needle according to their relative positions, and as long as the current continues uninterrupted. The earliest extension of this discovery (together with that of the exhibition of metals from the alkalies and that of the two kinds of polarization of light—probably the most brilliant discovery of the century—)[69] was due to Arago's observation, that a wire, through which an electrical current is passing, even when made of copper or platinum, attracts and holds fast iron filings like a magnet, and that needles introduced into the interior of a galvanic helix become alternately charged by the opposite magnetic poles in accordance with the reversed direction of the coils (*Ann. de Chim. et de Phys.*, t. xv, p. 93). The discovery of these phenomena, which were exhibited under the most varied modifications, was followed by Ampere's ingenious theoretical combinations regarding the alternating electro-magnetic actions of the molecules of ponderable bodies. These combinations were confirmed by a series of new and highly ingenious instruments, and led to a knowledge of the laws of many hitherto apparently contradictory phenomena of magnetism.

1820—1824. Ferdinand von Wrangel's and Anjou's expedition to the north coasts of Siberia and to the Frozen Ocean. (Important phenomena of polar light, see th. ii, s. 259.)

1820. Scoresby's Account of the Arctic Regions; experiments of magnetic intensity, vol. ii, p. 537—554.

1821. Seebeck's discovery of thermo-magnetism and

[69] Malus's (1808) and Arago's (1811) ordinary and chromatic polarization of Light. See *Cosmos*, vol. ii, p. 715.

thermo-electricity. The contact of two unequally warmed metals (especially bismuth and copper) or differences of temperature in the individual parts of a homogeneous metallic ring, were recognised as sources of the production of magneto-electric currents.

1821—1823. Weddell's voyage into the Antarctic Ocean as far as lat. 74° 15′.

1822—1823. Sabine's two important expeditions for the accurate determination of the magnetic intensity and the length of the pendulum in different latitudes (from the east coasts of Africa to the equator, Brazil, Havannah, Greenland as far as lat. 74° 23′, Norway and Spitzbergen in lat. 79° 50′). The results of these very comprehensive operations were first published in 1824 under the title of *Account of Experiments to determine the Figure of the Earth*, pp. 460—509.

1824. Erikson's Magnetic Observations along the shores of the Baltic.

1825. Arago discovers *Magnetism of Rotation.* The first suggestion that led to this unexpected discovery was afforded by his observation on the side of the hill in Greenwich Park of the decrease in the duration of the oscillations of an inclination needle by the action of neighbouring non-magnetic substances. In Arago's rotation experiments, the oscillations of the needle were affected by water, ice, glass, charcoal, and mercury.[70]

1825—1827. Magnetic Observations by Boussingault in different parts of South America (Marmato, Quito).

1826—1827. Observations of Intensity by Keilhau at 20 stations (in Finmark, Spitzbergen, and Bear Island), by Keilhau and Boeck in Southern Germany and Italy (Schum. *Astr. Nachr.* No. 146).

1826—1829. Admiral Lütke's voyage round the world; the magnetic part was most carefully prepared in 1834 by Lenz (see *Partie Nautique du Voyage*, 1836).

1826—1830. Captain Philip Parker King's Observations in the southern portions of the eastern and western coasts of South America (Brazil, Monte Video, the Straits of Magellan, Chili, and Valparaiso).

1827—1839. Quetelet, *Etat du Magnétisme Terrestre*

[70] *Cosmos*, vol. i, p. 172.

(*Bruxelles*) *pendant douze années.* Very accurate observations.

1827. Sabine, On the determination of the relative intensity of the magnetic terrestrial force in Paris and London. An analogous comparison between Paris and Christiana was made by Hansteen in 1825—1828 (*Meeting of the British Association at Liverpool* 1837, pp. 19—23). The many results of intensity, which had been obtained by French, English, and Scandinavian travellers, now first admitted of being brought into numerical connection with oscillating needles, which had been compared together at the three above-named cities. These numbers which could therefore now be established as relative values were found to be for Paris 1.348, as determined by myself, for London 1.372 by Sabine, and for Christiana 1.423 by Hansteen. They all refer to the intensity of the magnetic force at one point of the magnetic equator (the curve of no inclination) which intersects the Peruvian Cordilleras between Micuipampa and Caxamarca, in south latitude 7° 2′ and western longitude 78° 48′, where the intensity was assumed by myself as = 1.000. This assumed standard (Humboldt, *Recueil d'Observ. Astr.* vol. ii, p. 382—385, and *Voyage aux Régions Equin.*, t. iii, p. 622) formed the basis, for forty years, of the reductions given in all tables of intensity (Gay-Lussac in the *Mém. de la Société d'Arcueil*, t. i. 1807, p. 21; Hansteen, *On the Magnetism of the Earth*, 1819, p. 71; Sabine, in the *Rep. of the British Association at Liverpool*, pp. 43—58). It has, however, in recent times been justly objected to on account of its want of general applicability, because the line of no inclination[71] does not connect together

[71] "Before the practice was adopted of determining *absolute values*, the most generally used scale (and which still continues to be very frequently referred to), was founded on the time of vibration, observed by Mr. de Humboldt, about the commencement of the present century, at a station in the Andes of South America, where the direction of the dipping needle was horizontal, a condition which was for some time erroneously supposed to be an indication of the minimum of magnetic force at the earth's surface. From a comparison of the times of vibration of Mr. de Humboldt's needle in South America and in Paris, the ratio of the magnetic force at Paris to what was supposed to be its minimum was inferred (1.348), and from the results so obtained, combined with a similar comparison made by myself between Paris and London, in 1827, with several magnets, the ratio of the force in London to that of Mr.

the points of feeblest intensity (Sabine, in the *Phil. Transact. for* 1846, pt. iii, p. 254, and in the *Manual of Scient. Inquiry for the use of the British Navy*, 1849, p. 17).

1828—1829. The voyage of Hansteen and Due: Magnetic observations in European Russia and in Eastern Siberia as far as Irkutsk.

1828—1830. Adolf Erman's voyage of circumnavigation, with his journey through Northern Asia, and his passage across both oceans, in the Russian frigate Krotkoi. The identity of the instruments employed, the uniformity of the methods and the exactness of the astronomical determinations of position will impart a permanent scientific reputation to this expedition, which was equipped at the expense of a private individual, and conducted by a thoroughly well-informed and skilful observer. See the *general declination Chart*, based upon Erman's observations in *the Report of the Committee relat. to the Arctic Expedition*, 1840, pl. 3.

1828—1829. Humboldt's continuation of the observations begun in 1800 and 1807, at the time of the solstices and equinoxes regarding horary declination and the epochs of extraordinary perturbations, carried on in a magnetic pavilion specially erected for the purpose at Berlin, and provided with one of Gambey's compasses. Corresponding measurements were made at St. Petersburgh, Nikolajew, and in the mines of Freiberg, by Professor Reich, 227 feet below the surface of the soil. Dove and Riess continued these observations in reference to the variation and intensity of the horizontal magnetic force till November 1830 (Poggend. *Annalen*. Bd. xv, s. 318—336; Bd. xix, s. 375—391, with 16 tab.; Bd. xx, s. 545—555).

1829—1834. The botanist David Douglas, who met his death in Owhyhee, by falling into a trap in which a wild bull had previously been caught, made an admirable series of

de Humboldt's original station in South America has been inferred to be 1.372 to 1.000. This is the origin of the number 1.372, which has been generally employed by British observers. By *absolute* measurements we are not only enabled to compare numerically with one another the results of experiments made in the most distant parts of the globe, with apparatus not previously compared, but we also furnish the means of comparing hereafter the intensity which exists at the present epoch, with that which may be found at future periods." Sabine, in the *Manual for the use of the British Navy*, 1849, p. 17.

observations on declination and intensity along the north-west coast of America, and upon the Sandwich Islands as far as the margin of the crater of Kiraueah (Sabine, *Rep. of the Meeting of the British Association at Liverpool*, pp. 27—32).

1829. Kupffer, *Voyage au Mont Elbrouz dans le Caucase*, pp. 68—115.

1829. Humboldt's magnetic observations on terrestrial magnetism with the simultaneous astronomical determinations of position in an expedition in Northern Asia undertaken by command of the Emperor Nicholas, between the longitudes 11° 3′ and 80° 12′ east of Paris, near the Lake Dzaisan as well as between the latitudes of 45° 43′ (the island of Birutschicassa in the Caspian Sea) to 58° 52′ in the northern parts of the Ural district near Werchoturie (*Asie Centrale*, t. iii, pp. 440—478).

1829. The Imperial Academy of Sciences at St. Petersburgh, acceded to Humboldt's suggestion for the establishment of magnetic and meteorological stations in the different climatic zones of European and Asiatic Russia, as well as for the erection of a physical central observatory in the capital of the empire under the efficient scientific direction of Professor Kupffer. (See *Cosmos*, vol. i, p. 184. Kupffer *Rapport adressé à l'Acad. de St. Pétersbourg relatif à l'Observatoire physique central, fondé auprès du Corps des Mines*, in Schum. *Astr. Nachr.* No. 726; and in his *Annales Magnétiques*, p. xi.) Through the continued patronage, which the Finance Minister, Count Cancrin, has awarded to every great scientific undertaking, a portion of the simultaneously corresponding observations[72] between the White Sea and

[72] The first idea of the utility of a systematic and simultaneously conducted series of magnetic observations is due to Celsius, and, without referring to the discovery and measurement of the influence of polar light on magnetic variation, which was, in fact, due to his assistant, Olav Hiörter (March, 1741), we may mention that he was the means of inducing Graham, in the summer of 1741, to join him in his investigations for discovering whether certain extraordinary perturbations, which had from time to time exerted a horary influence on the course of the magnetic needle at Upsala had also been observed at the same time by him in London. A simultaneity in the perturbations afforded a proof, he said, that the cause of these disturbances is extended over considerable portions of the earth's surface, and is not dependent upon accidental local actions (Celsius, in *Svenska Veten-*

the Crimea, and between the Gulf of Finland and the shores of the Pacific in Russian America, were begun as early as 1832. A permanent magnetic station was established in the old monastery at Pekin, which, from time to time since the reign of Peter the Great, has been inhabited by monks of the Greek Church. The learned astronomer, Fuss, who took the principal part in the measurements for the determination of the difference of level between the Caspian and the Black Sea was chosen to arrange the first magnetic establishments in China. At a subsequent period Kupffer in his voyage of circumnavigation compared together all the instruments that had been employed in the magnetic and meteorological stations as far east as Nertschinsk in 119° 36′ longitude, and with the fundamental standards. The magnetic observations of Fedorow, in Siberia, which are no doubt highly valuable, are still unpublished.

1830—1845. Colonel Graham of the topographical engineers of the United States, made observations on the magnetic intensity at the southern boundary of Canada (*Phil. Transact. for* 1846, pt. iii, p. 242).

1830. Fuss, Magnetic, Astronomical, and Hypsometrical Observations on the journey from the Lake of Baikal, through Ergi-Oude, Durma, and the Gobi, which lies at an elevation of only 2525 feet, to Pekin, in order to establish the magnetic and meteorological observatory in that city, where Kovanko continued for 10 years to prosecute his observations (*Rep. of the Seventh Meeting of the Brit. Assoc.* 1837, pp. 497—499; and Humboldt, *Asie Centrale*, t. i, p. 8; t. ii, p. 141; t. iii, pp. 468, 477).

1831—1836. Captain Fitzroy in his voyage round the world in the Beagle, as well as in the survey of the coasts of the most southern portions of America, with a Gam-

skaps Academiens Handlingar för 1740, p. 44; Hiörter, *op. cit.* 1747, p. 27). As Arago had recognised that the magnetic perturbations owing to polar light are diffused over districts, in which the phenomena of light which accompany magnetic storms have not been seen, he devised a plan, by which he was enabled to carry on simultaneous horary observations (in 1823) with our common friend Kupffer, at Kasan, which lies almost 47° east of Paris. Similar simultaneous observations of declination were begun in 1828 by myself, in conjunction with Arago and Reich, at Berlin, Paris, and Freiberg (see Poggend. *Annalen*, Bd. xix, s. 337).

bey's inclinatorium and oscillation needles supplied by Hansteen.

1831. Dunlop, Director of the Observatory of Paramatta, Observations on a voyage to Australia (*Phil. Transact. for* 1840, pt. i, pp. 133—140).

1831. Faraday's induction-currents, whose theory has been extended by Nobili and Antinori. The great discovery of the development of light by magnets.

1833 and 1839 are the two important epochs of the first enunciation of the theoretical views of Gauss : (1) Intensitas vis magneticæ terrestris ad mensuram absolutam revocata, 1833 ; (p. 3 : "elementum tertium, intensitas, usque ad tempora recentiora penitus neglectum mansit") ; (2) the immortal work on "the general theory of terrestrial magnetism" (see Results of the observations of the Magnetic Association in the year 1838, edited by Gauss and Weber, 1839, pp. 1—57).

1833. Observations of Barlow on the attraction of the ship's iron, and the means of determining its deflecting action on the compass. Investigation of electro-magnetic currents in Terrellas. Isogonic atlases. Compare Barlow's *Essay on Magnetic Attraction*, 1833, p. 89, with Poisson, *sur les déviations de la boussole produite par le fer des vaisseaux* in the *Mém de l'Institut*, t. xvi, pp. 481—555 ; Airy, in the *Phil. Transact. for* 1839, pt. i, p. 167 ; and for 1843, pt. ii, p. 146 ; Sir James Ross, in the *Phil. Transact. for* 1849, pt. ii, pp. 177—195).

1833. Moser's methods of ascertaining the position and force of the variable magnetic pole (Poggend., *Annalen*, Bd. xxviii, s. 49—296).

1833. Christie on the Arctic observations of Captain Back. *Phil. Transact. for* 1836, pt. ii. p. 377 (Compare also his earlier and important treatise in the *Phil. Transact. for* 1825, pt. i. p. 23.)

1834. Parrot's expedition to Ararat (*Magnetismus*, bd. ii, s. 53—64).

1836. Major Estcourt, in the expedition of Colonel Chesney on the Euphrates. A portion of the observations on intensity were lost with the steamer Tigris, which is the more to be regretted since we are entirely deficient in accurate observations of this portion of the interior of

Western Asia, and of the regions lying south of the Caspian Sea.

1836. Letter from M. A. de Humboldt to H.R.H. Duke of Sussex, President of the Royal Society of London, on the proper means of improving our knowledge of terrestrial magnetism by the establishment of magnetic stations and corresponding observations (April 1836). On the happy results of this appeal, and its influence on the great Antarctic expedition of Sir James Ross, see *Cosmos*, vol. i, p. 136, and Sir James Ross's *Voyage to the Southern and Antarctic Regions* 1847, vol. i, pt. xii.

1837. Sabine, *On the Variations of the Magnetic Intensity of the Earth in the Report of the Seventh Meeting of the British Association at Liverpool*, pp. 1—85. The most complete work of the kind.

1837—1838. Erection of a magnetic observatory at Dublin, by Professor Humphrey Lloyd. On the observations made there from 1840 to 1846 (see *Transact. of the Royal Irish Academy*, vol. xxii. pt. i, pp. 74—96).

1837. Sir David Brewster, *A Treatise on Magnetism*, pp. 185—263.

1837—1842. Sir Edward Belcher's voyage to Singapore, the Chinese Seas, and the western coasts of America (*Phil. Transact. for* 1843, pt. ii, pp. 113, 140—142). These observations of inclination, when compared with my own, which were made at an earlier date, show a very unequal advance of the curves. Thus, for instance, in 1803, I found the inclinations at Acapulco, Guayaquil, and Callao de Lima to be + 38° 48′, + 10° 42,′ and — 9° 54′; while Sir Edward Belcher found + 37° 57′, + 9° 1′, and — 9° 54′. Can the frequent earthquakes upon the Peruvian coasts exert a local influence upon the phenomena, which depend upon magnetic force of the earth ?

1838—1842. Charles Wilkes's *Narrative of the United States' Exploring Expedition*, vol. i, p. xxi.

1838. Lieutenant James Sullivan's Voyage from Falmouth to the Falkland Islands (*Phil. Transact. for* 1840, pt. i, pp. 129, 140—143).

1838 and 1839. The establishment of magnetic stations under the admirable superintendence of General Sabine in both hemispheres at the expense of the British Government.

The instruments were dispatched in 1839, and the observations were begun at Toronto and in Van Diemen's Land in 1840, and at the Cape in 1841 (See Sir John Herschel in the *Quarterly Review,* vol. lxvi, 1840, p. 297, and Becquerel, *Traité d'Electricité et de Magnétisme,* t. vi, p. 173). By the careful and thorough elaboration of these valuable observations, which embrace all the elements or variations of the magnetic activity of the earth, General Sabine as superintendent of the Colonial observatories, discovered hitherto unrecognized laws, and disclosed new views in relation to the science of magnetism. The results of his investigations were collected by himself in a long series of separate memoirs (Contributions to terrestrial magnetism) in the *Philosophical Transactions of the Royal Society of London,* and in separate works, which constitute the basis of this portion of the *Cosmos.* We will here indicate only a few of the most important (1) *Observations on days of unusual magnetic disturbances (storms) in the years* 1840 *and* 1841, pp. 1—107, and as a continuation of this treatise, *magnetic storms from* 1843—1845 in the *Phil. Transact. for* 1851, pt. i, pp. 123—139; (2) *Observations made at the Magnetical Observatory at Toronto* 1840, 1841, and 1842 (43° 39′ N. Lat, and 81° 41′ W. Long.) vol. i, pp. xiv—xxviii; (3) *The very variable direction of magnetic declination in one-half of the year at Longwood House, St. Helena* (15° 55′ S. Lat., 8° 3′ W. Long.), *Philosophical Transactions for* 1847, pt. i, p. 54; (4) *Observ. made at the Magn. and Meteor. Observatory at the Cape of Good Hope* 1841—1846; (5) *Observ. made at the Magn. and Meteor. Observatory at Hobarton* (42° 52′ S. Lat., 145° 7′ E. Long.) *in Van Diemen's Land and the Antarctic expedition,* vol. i and ii, (1841—1848); *on the separation of the eastern and western disturbances,* see vol. ii, pp. ix—xxxvi; (6) *Magnetic phenomena within the Antarctic polar circle in Kerguelen's and Van Diemen's Land* (*Phil. Transact. for* 1843, pt. ii, pp. 145—231); (7) *On the isoclinal and isodynamic lines in the Atlantic Ocean, their condition in* 1837 (*Phil. Transact. for* 1840, pt. i, pp. 129—155); (8) Basis of a chart of the Atlantic Ocean which exhibits the lines of magnetic variation between 60° N. Lat. and 60° S. Lat. for the year 1840 (*Phil. Transact. for* 1849, pt. ii, pp. 173—233); (9) *Methods of determining the absolute values, secular change, and annual variation of the magnetic force* (*Phil. Transact. for*

1850, pt. i, pp. 201—219); Coincidence of the epochs of the greatest vicinity of the sun with the greatest intensity of the force in both hemispheres, and of the increase of inclination, p. 216; (10) *On the amount of magnetic intensity in the most northern parts of the New Continent and upon the point of greatest magnetic force found by Captain Lefroy in* 52° 19′ Lat. (*Phil. Transact. for* 1846, pt, iii, pp. 237—336); (11) *The periodic alterations of the three elements of terrestrial magnetism, variation, inclination, and intensity at Toronto and Hobarton,* and *on the connection of the decennial period of magnetic alterations with the decennial period of the frequency of solar spots, discovered by Schwabe at Dessau* (*Phil. Transact. for* 1852, pt. i, pp. 121—124). The observations of variation for 1846 and 1851 are to be considered as a continuation of those indicated in No. 1. as belonging to the years 1840—1845.

1839. Representation of magnetic isoclinal and isodynamic lines from observations of Humphrey Lloyd, John Phillips, Robert Were Fox, James Ross, and Edward Sabine. As early as 1833 it was determined at the meeting of the British Association in Cambridge, that the magnetic inclination and intensity should be determined at several parts of the empire, and in the summer of 1834 this suggestion was fully carried out by Professor Lloyd and General Sabine, and the operations of 1835 and 1836 were then extended to Wales and Scotland (*Report of the Meeting of the Brit. Assoc. held at Newcastle,* 1838, pp. 49—196), with an isoclinal and isodynamic chart of the British islands, the intensity at London being taken as = 1.

1838—1843. The great exploring voyage of Sir James Ross to the South Pole, which is alike remarkable for the additions which it afforded to our knowledge by proving the existence of hitherto doubtful polar regions, as well as for the new light which it has diffused over the magnetic condition of large portions of the earth's surface. It embraces all the three elements of terrestrial magnetism numerically determined for almost two-thirds of the area of all the high latitudes of the southern hemisphere.

1839—1851. Kreil's observations, which were continued for 12 years, at the Imperial Observatory at Prague, in reference to the variation of all the elements of terrestrial magnetism, and of the conjectured soli-lunar influence.

1840. Horary magnetic observations with one of Gambey's declination compasses during a ten years' residence in Chili, by Claudio Gay (see his *Historia fisica y politica de Chile*, 1847).

1840—1851. Lamont, Director of the Observatory at Munich. The results of his magnetic observations, compared with those of Göttingen, which date back as far as 1835. Investigation of the important law of a decennial period in the alterations of declination (see Lamont in Poggend. *Ann. der Phys.*, 1851, Bd. 84, s. 572—582, and Relshuber, 1852, Bd. 85, s. 179—184). The already indicated conjectural connection between the periodical increase and decrease in the annual mean for the daily variation of declination in the magnetic needle, and the periodical frequency of the solar spots was first made known by General Sabine in the *Phil. Transact. for* 1852, and four or five months later, without any knowledge of the previous observations, the same result was enunciated by Rudolf Wolf, the learned Director of the Observatory at Berne.[73] Lamont's manual of terrestrial magnetism, 1848, contains a notice of the newest methods of observation as well as of the development of these methods.

1840—1845. Bache, Director of the Coasts' Survey of the United States, *Observ. made at the Magn. and Meteorol. Observatory at Girard's College, Philadelphia* (published in 1847).

1840—1842. Lieutenant Gilliss U. S. *Magnetical and Meteorological Observations made at Washington*, published 1847, pp. 2—319 ; *Magnetic Storms*, p. 336.

1841—1843. Sir Robert Schomburgk's observations of

[73] The treatise of Rudolf Wolf, referred to in the text, contains special daily observation of the sun's spots (from January 1st to June 30th, 1852) and a table of Lamont's periodical variations of declination with Schwabe's results on the frequency of solar spots (1835—1850). These results were laid before the meeting of the Physical Society of Berne, on the 31st of July, 1852, whilst the more comprehensive treatise of Sabine (*Phil. Transact.* 1852, pp. 116—121) had been presented to the Royal Society of London in the beginning of March, and read in the beginning of May, 1852. From the most recent investigations of the observations of solar spots, Wolf finds that between the years 1600 and 1852 the mean period was 11.11 years.

declination in the woody district of Guiana, between the mountain Roraima and the village Pirara between the parallels of 4° 57′, and 3° 39′ (*Phil. Transact. for* 1849, pt. ii, p. 217).

1841—1845. *Magn. and Meteorol. Observations made at Madras.*

1843—1844. Magnetic observations in Sir Thomas Brisbane's observatory at Makerstoun, Roxburghshire, 55° 34′ North lat. (see *Transact. of the Royal Society of Edin.* vol. xvii, pt. ii, p. 188, and vol. xviii, p. 46).

1843—1849. Kreil, *On the influence of the Alps upon the manifestations of the Magnetic Force* (see Schum. *Astr. Nachr.* No. 602).

1844—1845. Expedition of the Pagoda into high antarctic latitudes as far as 64° and 67°, and from 4° to 117° E. long., embracing all the three elements of terrestrial magnetism, under the command of Lieutenant Moore, who had already served in the Terror in the polar expedition, and of Lieutenant Clerk, of the Royal Artillery, and formerly Director of the Magnetic Observatory at the Cape.—A worthy completion of the labours of Sir James Ross at the South Pole.

1845. *Proceedings of the Magn. and Meteorol. Conference held at Cambridge.*

1845. *Observations made at the Magn. and Meteorol. Observatory at Bombay* under the superintendence of Arthur Bedford Orlebar. This observatory was erected in 1841, on the little island of Colaba.

1845—1850. Six volumes of the *results of the Magn. and Meteorol. Observations* made at the Royal Observatory at Greenwich. The magnetic house was erected in 1838.

1845. Simonoff, Professor at Kazan, *Recherches sur l'action magnétique de la Terre.*

1846—1849. Captain Elliot, Madras Engineers, *Magnetic Survey of the Eastern Archipelago.* Sixteen stations, at each of which observations were continued for several months in Borneo, Celebes, Sumatra, the Nicobars, and Keeling Islands, compared with Madras, between 16° N. lat. and 12° S. lat. and 78° and 123° E. long. (*Phil. Transact. for* 1851, pt. i, pp. 287—331, and also pp. i—clvii.) Charts of equal inclination and declination, which also expressed the horizontal and total force, were appended to these observations, which also give the position of the magnetic equator and of the line of no variation, and belong to the most distinguished and comprehensive that had been drawn up in modern times.

1845—1850. Faraday's brilliant physical discoveries: (1) In relation to the axial, or equatorial (diamagnetic[74]) direction assumed by freely oscillating bodies under external magnetic influences (*Phil. Transact. for* 1846, § 2420, and *Phil. Transact. for* 1851, pt. i, §§ 2718—2796); (2) Regarding the relation of electro-magnetism to a ray of polarized light, and the rotation of the latter by means of the altered molecular condition of the bodies through which the ray of polarized light and the magnetic current have both been transmitted (*Phil. Transact. for* 1846, pt. i, § 2195 and §§ 2215 — 2221; (3) Regarding the remarkable property which oxygen (the only gas which is paramagnetic) exerts on the elements of terrestrial magnetism, namely that like soft iron, although in a much weaker degree, it assumes conditions of polarity through the diffused action of the body of the earth, which represents a permanently present magnet[75] (*Phil. Transact. for* 1851, pt. i, §§ 2297—2967).

[74] See *Cosmos*, vol. iv, p. 396. Diamagnetic repulsion and an equatorial, that is to say, an east and west position in respect to a powerful magnet, are exhibited by bismuth, antimony, silver, phosphorus, rock salt, ivory, wood, apple-shavings, and leather. Oxygen gas, either pure or when mixed with other gases, or when condensed in the interstices of charcoal, is paramagnetic. See in reference to crystallised bodies the ingenious observations made by Plucker concerning the position of certain axes (Poggend. *Annal.* Bd. lxxiii, s. 178, and *Phil. Transact. for* 1851, §§ 2836—2842). The repulsion by bismuth was first recognised by Brugmans, in 1778, next by Le Bailiff, in 1827, and finally, more thoroughly tested by Seebeck, in 1828. Faraday himself (§§ 2429—2431), Reich, and Wilhelm Weber, who, from the year 1836, has shown himself so incessantly active in his endeavours to promote the progress of terrestrial magnetism, have all endeavoured to exhibit the connection of diamagnetic phenomena with those of induction (Poggend. *Annalen*, Bd. lxxiii, s. 241—253). Weber has, moreover, tried to prove that diamagnetism derives its source from Ampere's molecular currents. (Wilh. Weber, *Abhandlungen über electro-dynamische Maassbestimmungen*, 1852, s. 545—570.)

[75] In order to excite this polarity, the magnetic fluids in every particle of oxygen must be separated, to a certain extent, by the *actio in distans* of the earth in a definite direction, and with a definite force. Every particle of oxygen thus represents a small magnet, and all these small magnets react upon one another as well as upon the earth, and

1849. Emory, Magn. observations made at the Isthmus of Panama.

1849. Professor William Thomson, of Glasgow, *A Mathematical Theory of Magnetism* in the *Phil. Transact for* 1851, pt. i. pp. 243—285 (On the problem of the distribution of magnetic force, compare §§ 42 and 56 with Poisson in the *Mém de l'Institut.*, 1811, pt. i, p. 1; pt. ii, p. 163).

1850. Airy, On the present state and prospects of the science of Terrestrial Magnetism—the fragment of what promises to be a most admirable treatise.

1852. Kreil, Influence of the Moon on Magnetic Declination at Prague in the years 1839—1849. On the earlier labours of this accurate observer, between 1836 and 1838, see *Osservazioni sull' intensità e sulla direzione della forza magnetica instituite negli anni* 1836—1838 *all' I. R. Osservatorio di Milano,* p. 171; and also his *Magnetical and Meteorological Observations at Prague,* vol. i, p. 59.

1852. Faraday, On Lines of Magnetic Force, and their definite character.

1852. Sabine's new proof deduced from observations at Toronto, Hobarton, St. Helena, and the Cape of Good Hope (from 1841 to 1851), that everywhere between the hours of seven and eight in the morning the magnetic declination exhibits an annual period; in which the northern solstice presents the greatest eastern elongation, and the southern

finally, in connection with the latter, they further act upon a magnetic needle, which may be assumed to be in or beyond the atmosphere. The envelope of oxygen that encircles our terrestrial sphere may be compared to an armature of soft iron upon a natural magnet or a piece of magnetised steel; the magnet may further be assumed to be spherical, like the earth, while the armature is assumed to be a hollow shell, similar to the investment of atmospheric oxygen. The magnetic power which each particle of oxygen may acquire by the constant force of the earth, diminishes with the temperature and the rarefaction of the oxygen gas. When a constant alteration of temperature and an expansion follows the sun around the earth from east to west, it must proportionally alter the results of the magnetic force of the earth, and of the oxygen investment, and this, according to Faraday's opinion, is the origin of one part of the variations in the elements of terrestrial magnetism. Plucker finds that as the force with which the magnet acts upon the oxygen is proportional to the density of this gas, the magnet presents a simple eudiometric means of recognising the presence of free oxygen gas in a gaseous mixture even to the 100th or 200th part.

solstice the greatest western elongation, without the temperature of the atmosphere or of the earth's crust evincing a maximum or minimum at these turning periods. Compare the second volume of the Observations made at Toronto, p. xvii, with the two treatises of Sabine, already referred to on the Influence of the sun's vicinity (*Phil. Transact. for* 1850, pt. i, p. 216), and of the solar spots (*Phil. Transact. for* 1852, p. i, p. 121).

The chronological enumeration of the progress of our knowledge of terrestrial magnetism during half a century, which I have uninterruptedly watched with the keenest interest, exhibits a successful striving towards the attainment of a twofold object. The greater number of these labours have been devoted to the observation of the magnetic activity of our planet in its numerical relations to time and space, while the smaller part belongs to experiments, and to the manifestation of phenomena, which promise to lead us to the knowledge of the character of this activity, and of the internal nature of the magnetic force. Both these methods —the numerical observation of the manifestation of terrestrial magnetism, both in respect to its direction and intensity, —and physical experiments on the magnetic force generally, have tended reciprocally to the advancement of our physical knowledge. Observations alone, independently of every hypothesis regarding the causal connection of phenomena, or regarding the hitherto immeasurable and unattainable reciprocal action of molecules in the interior of substances, have led to important numerical laws. Experimental physicists have succeeded by the display of the most wondrous ingenuity in discovering in solid and gaseous bodies polarising properties, whose presence had never before been suspected, and which stand in special relation to the temperature and pressure of the atmosphere. However important and undoubted these discoveries may be, they cannot in the present condition of our knowledge be regarded as satisfactory grounds of explanation for the laws which have already been recognized in the movements of the magnetic needle. The most certain means of enabling us thoroughly to comprehend the variable numerical relations of space, as well as to extend and complete that mathematical theory of terrestrial magnetism, which was so nobly sketched by Gauss, is to prosecute simultaneous and continuous observations of all the three elements of the magnetic force at numerous well selected points of the earth's surface. I have, however, elsewhere illustrated by example the sanguine hopes which I entertained of the great advantages that may be derived from the combination of experimental and mathematical investigation.[76]

Nothing that occurs upon our planet can be supposed to be independent of cosmical influences. The word planet instinctively leads us to the idea of dependence upon a central body, and of a connection with a group of celestial bodies of very different masses which probably have a similar origin. The influence of the sun's position upon the manifestation of the magnetic force of the earth, was recognised at a very early period. The most distinct intimation of this relation was afforded by the discovery of horary variation, although it had been obscurely perceived by Kepler, who, a century before, had conjectured that all the axes of the planets were magnetically directed towards one portion of the universe. He says expressly, "that the sun may be a magnetic body, and that on that account, the force which impels the planets may be centred in the sun."[77] The attraction of masses and gravitation appeared at that time under the semblance of magnetic attraction. Horrebow,[78] who did not confound gravitation with magnetism, was the first who called the process of light a perpetual northern light, produced in the solar atmosphere by means of magnetic forces. Nearer our

[76] See p. 6.

[77] Kepler, in *Stella Martis*, pp. 32—34 (and compare with it his treatise, *Mysterium Cosmogr.* cap. xx, p. 71).

[78] *Cosmos,* vol. iv, p. 386, where, however, in consequence of an error of the press, in the place of *Basis Astronomiæ* we should read *Clavis Astronomiæ.* The passage (§ 226) in which the luminous process of the sun is characterised as a perpetual northern light does not occur in the first edition of the *Clavis Astr.* by Horrebow (Havn. 1730), but is only found in the second and enlarged new edition of the work in Horrebow's *Operum Mathematico-Physicorum,* t. i, Havn. 1740, p. 317, as it belongs to this appended portion of the *Clavis.* Compare with Horrebow's view the precisely similar views of Sir William and Sir John Herschel (*Cosmos,* vol. iii, pp. 39, 40).

own times (and this difference of opinion is very remarkable) two distinct views were promulgated in reference to the nature of the influence exerted by the sun.

Some physicists, as Canton, Ampère, Christie, Lloyd, and Airey, have assumed that the sun, without being itself magnetic, acts upon terrestrial magnetism merely by producing changes of temperature, whilst others, as Coulomb, believed the sun to be enveloped by a magnetic atmosphere[79] which exerts an action on terrestrial magnetism by distribution. Although Faraday's splendid discovery of the paramagnetic property of oxygen gas has removed the great difficulty of having to assume with Canton that the temperature of the solid crust of the earth and of the sea must be rapidly and considerably elevated from the immediate effect of the sun's transit through the meridian of the place, the perfect co-ordination and an ingenious analysis of all the measurements and observations of General Sabine have yielded this result: that the hitherto observed periodic variations of the magnetic activity of the earth cannot be based upon periodic changes of temperature in those parts of the atmosphere which are accessible to us. Neither the principal epochs of diurnal and annual alterations of declination at the different hours of the day and night, nor the periods of the mean intensity of the terrestrial force[80] coincide with the periods of

[79] *Mémoires de Mathém. et de Phys. présentés à l'Acad. Roy. des Sc.* t. ix, 1780, p. 262.

[80] "So far as these four stations (Toronto, Hobarton, St. Helena, and the Cape), so widely separated from each other and so diversely situated, justify a generalisation, we may arrive at the conclusion that at the hour of 7 to 8 A.M. the magnetic declination is *everywhere* subject to a variation of which the period is a year, and which is everywhere similar in character and amount, consisting of a movement of the north end of the magnet from east to west, between the northern and the southern solstice, and a return from west to east between the southern and the northern solstice, the amplitude being about 5 minutes of arc. The *turning periods of the year* are not, as many might be disposed to anticipate, *those months in which the temperature at the surface of our planet, or of the subsoil, or of the atmosphere* (as far as we possess the means of judging of the temperature of the atmosphere) *attains its maximum and minimum.* Stations so diversely situated would, indeed, present in these respects *thermic conditions* of great variety; whereas uniformity in the epoch of the *turning* periods is a not less conspicuous feature in the annual variation than similarity of character and numerical value. At all the stations the *solstices* are the turning periods of

the maxima and minima of the temperature of the atmosphere, or of the upper crust of the earth. We may remark that the annual alterations were first accurately represented by Sabine from a very large number of observations. The turning points in the most important magnetic phenomena are the solstices and the equinoxes. The epoch at which the intensity of the terrestrial force is the greatest, and that at which the dipping needle most nearly assumes the vertical position in both hemispheres, is identical with the period at which the earth is nearest to the sun,[81] and consequently when its velocity of translation is the greatest. At this period, however, when the earth is nearest to the sun, namely in December, January, and February; as well as in May, June, and July, when it is farthest from the sun, the relations of temperature of the zones on either side of the equator are completely reversed, the turning points of the decreasing and

the annual variation at the hour of which we are treating. The only periods of the year in which the diurnal or horary variation at that hour does actually disappear are at the *equinoxes*, when the sun is passing from the one hemisphere to the other, and when the magnetic direction, in the course of its annual variation from east to west, or vice versâ, coincides with the direction which is the mean declination of all the months and of all the hours. The *annual variation* is obviously connected with, and dependent on, the *earth's* position in its orbit relatively to the sun around which it revolves; as the *diurnal variation* is connected with, and dependent on, the *rotation of the earth* on its axis, by which each meridian successively passes through every angle of inclination to the sun in the round of 24 hours." Sabine, *on the Annual and Diurnal Variations*, in the second volume of *Observations made at the Magn. and Meteorol. Observatory at Toronto*, p. xvii—xx. See also his memoir, *On the Annual Variation of the Magnetic Declination at different periods of the day*, in the *Philos. Transact. for* 1851, pt. ii, p. 635, and the *Introduction* of his *Observ. made at the Observatory at Hobarton*, vol. i, p. xxxiv—xxxvi.

81 Sabine, *On the means adopted for determining the Absolute Values, Secular Change, and Annual Variation of the Terrestrial Magnetic Force*, in the *Phil. Transact. for* 1850, pt. i, p. 216. In his address to the Association at Belfast (*Meeting of the Brit. Assoc. in* 1852), he likewise observes, "that it is a remarkable fact which has been established that the magnetic force is greater in both the northern and southern hemispheres in the months of December, January, and February, when the sun is nearest to the earth, than in those of May, June, and July, when he is most distant from it: whereas, if the effects were due to temperature, the two hemispheres should be oppositely, instead of similarly, affected in each of the two periods referred to."

increasing intensity, declination and inclination cannot therefore be ascribed to the sun in connection with its thermic influence.

The annual means deduced from observations at Munich and Göttingen, have enabled the active director of the Royal Bavarian Observatory, Professor Lamont, to deduce the remarkable law of a period of $10\frac{1}{3}$ years in the alterations of declination.[82] In the period between 1841 and 1850, the mean of the monthly alterations of declination attained very uniformly their minimum in $1843\frac{1}{2}$, and their maximum in $1848\frac{1}{2}$. Without being acquainted with these European results, General Sabine was led to the discovery of a periodically active cause of disturbance from a comparison of the monthly means of the same years, namely from 1843 to 1848, which were deduced from observations made at places which lie almost as far distant from one another as possible (Toronto in Canada, and Hobarton in Van Diemen's Land). This cause of disturbance was found by him to be of a purely cosmical nature, being also manifested in the decennial periodic alterations in the sun's atmosphere.[83] Schwabe, who has observed the spots upon the sun with more constant attention than any other living astronomer, discovered (as I have already elsewhere observed),[84] in a long series of years (from 1826 to 1850), a periodically varying frequency in the occurrence of the solar spots, showing that their maxima fell in the years 1828, 1837, and 1848, and their minima in the years 1833 and 1843. "I have not had the opportunity," he writes, "of investigating a continuous series of older observations, but I willingly subscribe to the opinion that this period may itself be variable." A somewhat analogous kind of variability—*periods within periods*—is undoubtedly observable in the processes of light of other self-luminous suns. I need here only refer to those complicated changes of intensity, which have been shown by Goodricke and Argelander to exist in the light of β Lyræ and Mira Ceti.[85]

[82] Lamont, in Poggend. *Annalen,* Bd. lxxxiv, s. 579.

[83] Sabine, *On periodical laws discoverable in the mean effects of the larger magnetic disturbances,* in the *Phil. Transact. for* 1852, pt. i, p. 121. Vide *supra,* p. 75.

[84] *Cosmos,* vol. iv, p. 398.

[85] *Op. cit.* vol. iii, p. 228.

If, as Sabine has shown, the magnetism of the sun is manifested by an increase in the terrestrial force when the earth is nearest to that luminary, it is the more striking that, according to Kreil's very thorough investigations of the magnetic influence of the moon, the latter should hitherto not have been perceptible, either during the different lunar phases, or at the different distances assumed by the satellite in relation to the earth. The vicinity of the moon does not appear, when compared with the sun, to compensate in this respect for the smallness of its mass. The main result of the investigation, in relation to the magnetic influence of the earth's satellite, which, according to Melloni, exhibits only a trace of calorification [86], is that the magnetic declination in our planet undergoes a regular alteration in the course of a lunar day, during which it exhibits a twofold maximum and a twofold minimum. Kreil very correctly observes, "that if the moon exerts no influence on the temperature on the surface of our earth (which is appreciable by the ordinary means of measuring heat), it obviously cannot in this way effect any alteration in the magnetic force of the earth; but if, notwithstanding, an alteration of this kind is actually experienced, we must necessarily conclude that it is produced by some other means than through the moon's heat." Everything that cannot be considered as the product of a single force must require, as in the case of the moon, that all foreign elements of disturbance should be eliminated, in order that its true nature may be recognized.

Although hitherto the most decisive and considerable variations in the manifestations of terrestrial magnetism do not admit of being satisfactorily explained by the maxima and minima in the variations of temperature, there can be no doubt that the great discovery of the polar property of oxygen in the gaseous envelope of our earth will, by a more profound and comprehensive view of the process of the magnetic activity, speedily afford us a most valuable assistance in elucidating the mode of origin of this process. It would be inconceivable if, amid the harmonious co-operation of all the forces of nature, this property of oxygen and its modification by an increase of temperature, should not par-

[86] Kreil, *Einfluss des Mondes auf die Magnetische Declination*, 1852, s. 27, 29, 46.

ticipate in the production and manifestation of magnetic phenomena.

If, according to Newton's view, it is very probable that the substances which belong to a group of celestial bodies (to one and the same planetary system) are for the most part identical,[87] we may from inductive reasoning conclude that the electro-magnetic activity is not limited to the gravitating matter on our own planet. To adopt a different hypothesis would be to limit cosmical views with arbitrary dogmatism. Coulomb's hypothesis regarding the influence of the magnetic sun on the magnetic earth is not at variance with analogies, based upon the observation of facts.

If we now proceed to the purely objective representation of the magnetic phenomena, which are exhibited by our planet on different parts of its surface, and in its different positions in relation to the central body, we must accurately distinguish, in the numerical results of our measurements, the alterations which are comprised within short or very long periods. All are dependent on one another, and in this dependence they reciprocally intensify, or partially neutralize and disturb each other, as the wave-circles in moving fluids intersect one another. Twelve objects here present themselves most prominently to our consideration.

Two *magnetic poles*, which are unequally distant from the poles of rotation of the earth, and are situated one in each hemisphere; these are points of our terrestrial spheroid at which the magnetic inclination is equal to 90°, and at which therefore the horizontal force vanishes.

The *magnetic equator*, the curve on which the inclination of the needle = 0°.

The *lines of equal declination*, and those on which the declination = 0 (*isogonic lines* and *lines of no variation*).

The lines of equal inclination (*isoclinal lines*).

The four *points* of *greatest intensity* of the magnetic force, two of unequal intensity in each hemisphere.

The *lines of equal terrestrial force* (*isodynamic lines*).

The *undulating line* which connects together on each meridian the points of the weakest intensity of the terrestrial force, and which has sometimes been designated as a *dynamic*

[87] *Cosmos*, vol. i, pp. 122, 123; also vol. iv, p. 568.

equator.[88] This undulating line does not coincide either with the geographical or the magnetic equator.

The limitation of the zone where the intensity is generally very weak, and in which the horary alterations of the magnetic needle participate, in accordance with the different seasons of the year, in producing the alternating phenomena observed in both hemispheres[89].

In this enumeration I have restricted the use of the word *pole* to the two points of the earth's surface, at which the horizontal force disappears, because, as I have already remarked, these points, which are the true magnetic poles, but which by no means coincide with the maxima of intensity, have frequently been confounded in recent times with the four terrestrial points of greatest intensity.[90] Gauss has also shown that it would be inappropriate to attempt to distinguish the chord which connects the two points, at which the dip of the needle = 90°, by the designation of magnetic axis of the earth[91]. The intimate connection which prevails between the objects here enumerated fortunately renders it possible to concentrate, under three points of view, the complicated phenomena of terrestrial magnetism in accordance with the three manifestations of one active force—Intensity, Inclination, and Declination.

Intensity.

The knowledge of the most important element of terrestrial magnetism, the direct measurement of the intensity of

[88] See Mrs. Somerville's short but lucid description of terrestrial magnetism, based upon Sabine's works (*Physical Geography*, vol. ii, p. 102). Sir James Ross, who intersected the curve of lowest intensity in his great Antarctic expedition, December, 1839, in 19° S. lat. and 29° 13′ W. long., and who has the great merit of having first determined its position in the southern hemisphere, calls it "the equator of less intensity." See his *Voyage to the Southern and Antarctic Regions*, vol. i, p. 22.

[89] "Stations of an *intermediate* character, situated between the northern and southern magnetic hemispheres, partaking, although in opposite seasons, of those contrary features which separately prevail (in the two hemispheres) throughout the year." Sabine, in the *Phil. Transact. for* 1847, pt. i, pp. 53—57.

[90] The pole of intensity is not the pole of verticity. *Phil. Transact. for* 1846, pt. iii, p. 255.

[91] Gauss, *Allgem. Theorie des Erdmagnetismus*, § 31.

the terrestrial force, followed somewhat tardily the knowledge of the relations of the direction of this force in horizontal and vertical planes (declination and inclination). Oscillations, from the duration of which the intensity is deduced, were first made an object of experiment towards the close of the 18th century, and yielded matter for an earnest and continuous investigation during the first half of the 19th century. Graham, in 1723, measured the oscillations of his dipping-needle with the view of ascertaining whether they were constant,[92] and in order to find the ratio which the force directing them bore to gravity. The first attempt to determine the intensity of magnetism at widely different points of the earth's surface, by counting the number of oscillations in equal times, was made by Mallet in 1769. He found, with a very imperfect apparatus, that the number of the oscillations at St. Petersburg (59° 56′ N. lat.), and at Ponoi (67° 4′), were precisely equal[93], and hence arose the erroneous opinion which was even transmitted to Cavendish, that the intensity of the terrestrial force was the same under all latitudes. Borda, as he has himself often told me, was prevented, on theoretical grounds, from falling into this error, and the same had previously been the case with Le Monnier; but the imperfection of the dipping-needle, the friction which existed between it and the pivot, prevented Borda (in his expedition to the Canary Islands in 1776), from discovering any difference in the magnetic force between Paris, Toulon, Santa Cruz de Teneriffe, and Goree in Senegambia, over a space of 35° of latitude. (*Voyage de La Perouse*, t. i, p. 162.) This difference was, for the first time, detected with improved instruments in the disastrous expedition of La Perouse in the years 1785 and 1787 by Lamanon, who communicated it from Macao to the Secretary of the French Academy. This communication, as I have already stated, (see p. 61), remained unheeded, and like many others lay buried in the archives of the Academy.

The first published observations of intensity, which more-

[92] *Phil. Transact.* vol. xxxiii, *for* 1724—1725, p. 332 ("to try if the dip and vibrations were constant and regular").

[93] *Novi Comment. Acad. Scient. Petropol*, t. xiv, pro anno 1769, pars 2, p. 33. See also Le Monnier *Lois du Magnetisme comparées aux observations*, 1776, p. 50.

over were instituted at the suggestion of Borda, are those which I made during my voyage to the tropical regions of the New Continent between the years 1798 and 1804. The results obtained at an earlier date (from 1791 to 1794), regarding the magnetic force, by my friend de Rossel, in the Indian Ocean, were not printed till four years after my return from Mexico. In the year 1829 I enjoyed the advantage of being able to prosecute my observations of the magnetic intensity and inclination over a space of fully 188° of longitude from the Pacific eastwards as far as the Chinese Dzungarei, two-thirds of this portion of the earth's surface being in the interior of continents. The differences in the latitudes amounted to 72° (namely, from 60° N. to 12° S. Lat.).

When we carefully follow the direction of the closed isodynamic lines (curves of equal intensity), and pass from the external and weaker to the interior and gradually stronger curves, we shall find in considering the distribution of the magnetic force in each hemisphere, that there are two points, or foci, of the maxima of intensity, a stronger and a weaker one, lying at very unequal distances both from the poles of rotation and the magnetic poles of the earth. Of these four terrestrial points the stronger, or American, is situated in the northern hemisphere[94] in 52° 19′ N. lat. and in 92° W. long., whilst the weaker, which is often called the Siberian, is situated in 70° N. lat. and in 120° E. long. or perhaps a few degrees less to the eastward. In the journey from Parschinsk to Jakutsk, Erman found, in 1829, that the curve of greatest intensity (1.742) was situated at Beresowski Ostrow in 117° 51′ E. long. and 59° 44′ N. lat. (Erman *Magnet. Beob.* s. 172—540 ; Sabine, in the *Phil. Transact. for* 1850, pt. i, p. 218). Of these determinations, that of the American focus is the more certain, especially in respect to latitude, while in respect "to longitude it is probably somewhat too far west." The oval which incloses the stronger northern focus lies, consequently, in the meridian of the western end of Lake Superior, between the southern extremity of Hud-

[94] In those cases in which individual treatises of General Sabine have not been specially referred to in these notes, the passages have been taken from manuscript communications, which have been kindly placed at my disposal by this learned physicist.

son's Bay and that of the Canadian lake of Winipeg. We owe this determination to the important land expedition, undertaken in the year 1843, by Captain Lefroy, of the Royal Artillery, and formerly director of the Magnetic Observatory at St. Helena. "The mean of the lemniscates which connect the stronger and the weaker focus appears to be situated north-east of Behring's Straits, and somewhat nearer to the Asiatic than to the American focus."

When I crossed the magnetic equator, the line on which the inclination = 0, between Micuipampa and Caxamarca, in the Peruvian chain of the Andes, in the southern hemisphere, in 7° 2′ lat. and 78° 48′ W. long. and when I observed that the intensity increased to the north and south of this remarkable point, I was led from an erroneous generalization of my own observations, and in the absence of all points of comparison (which were not made till long afterwards), to the opinion that the magnetic force of the earth increases uninterruptedly from the magnetic equator towards both magnetic poles, and that it was probable that the maximum of the terrestrial force was situated at these points, that is to say, where the inclination = 90°. When we first strike upon the trace of a great physical law, we generally find that the earliest opinions adopted require subsequent revision. Sabine,[95] by his own observations, which were made from 1818 to 1822 in very different zones of latitude, and by the able arrangement and comparison of the numerous oscillation-experiments with the vertical and horizontal needles, which of late years have gradually become more general, has shown that the intensity and inclination are very variously modified; that the minimum of the terrestrial force at many points lies far from the magnetic equator; and that in the most northern parts of Canada and in the Arctic regions around Hudson's Bay from 52° 20′ lat. to the magnetic pole in 70° lat. and from about 92° to 93° W. long. the intensity, instead of increasing, diminishes. In the Canadian focus of greatest intensity, in the northern hemisphere, found by Lefroy, the dip of the needle in 1845 was only 73° 7′ and

[95] *Fifth Report of the British Association*, p. 72; *Seventh Report*, pp. 64—68. *Contributions to Terrestrial Magnetism* No. vii in the *Phil. Transact. for* 1846, pt. iii, p. 254.

in both hemispheres we find the maxima of the terrestrial force coinciding with a comparatively small dip.[96]

However admirable and abundant are the observations of intensity which we owe to the expeditions of Sir James Ross, Moore, and Clerk, in the Antarctic polar seas, there is still much doubt in reference to the position of the stronger and weaker focus in the southern hemisphere. The first of these navigators has frequently crossed the isodynamic curves of greatest intensity, and from a careful consideration of his observations, Sabine has been led to refer one of the foci to 64° S. lat. and 137° 30′ E. long. Ross himself, in the account of his great voyage,[97] conjectures that the focus lies in the neighbourhood of the Terre d'Adélie, discovered by D'Urville, and therefore in about 67° S. lat. and 140° E. long. He thought that he had approached the other focus in 60° S. lat. and 125 W. long.; but he was disposed to place it somewhat further south, not far from the magnetic pole, and therefore in a more easterly meridian.[98]

Having thus established the position of the four maxima of intensity, we have next to consider the relation of the forces. These data can be obtained from a much earlier

[96] Sabine, in the *Seventh Report of the Brit. Assoc.* p. 77.

[97] Sir James Ross, *Voyage in the Southern and Antarctic Regions*, vol. i, p. 322. This great navigator, in sailing between Kerguelen's Land and Van Diemen's Land, twice crossed the curve of greatest intensity, first in 46° 44′ S. lat. 128° 28′ E. long. where the intensity increased to 2.034, and again diminished, further east, near Hobarton, to 1.824 (*Voy.* vol. i, pp. 103—104); then again, a year later, from January the 1st to April the 3rd, 1841, during which time, it would appear from the log of the Erebus that they had gone from 77° 47′ S. lat. 175° 41′ E. long. to 51° 16′ S. lat. 136° 50′ E. long., where the intensities were found to be uninterruptedly more than 2.00, and even as much as 2.07 (*Phil. Transact. for* 1843, pt. ii, pp. 211—215). Sabine's result for the one focus of the southern hemisphere (64° S. lat. 137° 30′ E. long.) which I have already given in the text, was deduced from observations made by Sir James Ross between the 19th and 27th of March, 1841 (while crossing the southern isodynamic ellipse of 2.00, about midway between the extremities of its principal axis), between the southern latitudes 58° and 64° 26′, and the eastern longitudes of 128° 40′ and 148° 20′ (*Contrib. to Terr. Magn.* in the *Phil. Transact. for* 1846, pt. iii, p. 252).

[98] Ross, *Voyage*, vol. ii, p. 224. In accordance with the instructions drawn up for the expedition, the two sonthern foci of the maximum of intensity were conjectured to be in 47° S. lat. 140° E. long. and in 60° S. lat. 235 E. long. (vol. i, p. xxxvi).

source, to which I have already frequently referred, that is to say, by a comparison with the intensity which I found at a point of the magnetic equator in the Peruvian chain of the Andes, which it intersects in 7° 2′ lat. and 78° 48′ W. long. or, according to the earliest suggestions of Poisson and Gauss, by absolute measurement.[99] If we assume the intensity at the above indicated point of the magnetic equator = 1.000, in the relative scale, we find from the comparison made between the intensity of Paris and that of London in the year 1827 (see page 67), that the intensities of these two cities are 1.348 and 1.372. If we express these numbers in accordance with the absolute scale they will stand as about = 10.20 and 10.38, and the intensity, which was assumed to be 1.000 for Peru, would, according to Sabine, be 7.57 in the absolute scale, and therefore even greater than the intensity at St. Helena, which, in the same absolute scale = 6.4. All these numbers must be subjected to a revision on account of the different years in which the comparisons were made. They can only be regarded as provisional, whether they are reckoned in the relative (or arbitrary) scale or in the absolute scale, which is to be preferred to the former, but even in their present imperfect degree of accuracy they throw considerable light on the distribution of the magnetic force—a subject which, till within the last half century, was shrouded in the greatest obscurity. They afford what is cosmically of very great importance, historical points of departure for those alterations in the force, which will be manifested in future years, probably through the dependence of the earth upon the magnetic force of the sun, by which it is influenced.

In the northern hemisphere the stronger or Canadian focus in 52° 19′ N. lat. and 92° W. long. has been most satisfactorily determined by Lefroy. This intensity is expressed in the relative scale by 1.878, the intensity of London being 1.372, while in the absolute scale it would be expressed by 14.21.[100] Even in New York, lat. 40° 42′, Sabine found the

[99] *Phil. Transact. for* 1850, pt. i, p. 201; *Admiralty Manual,* 1849, p. 16; Erman, *Magnet. Beob.* s. 437—454.

[100] On the map of isodynamic lines for North America which occurs in Sabine's *Contributions to Terrestrial Magnetism,* No. vii, we find, by mistake, the value 14.88 instead of 14.21, although the latter, which is the true number, is given at page 252 of the text of this memoir.

magnetic force not much less (1.803). For the weaker northern or Siberian focus, 70° lat., 120° E. long., it was found by Erman to be 1.74 in the relative scale, and by Hansteen, 1.76, that is to say, about 13.3 in the absolute scale. The Antarctic expedition of Sir James Ross has shown us that the difference of the two foci in the southern hemisphere is probably less than in the northern, but that each of the two southern foci exceeds both the northern in intensity. The intensity in the stronger southern focus, 64° lat., 137° 30′ E. long., is at least 2.06 in the relative or arbitrary scale,[1] while in the absolute scale it is 15.60 ; in the weaker southern focus, 60° lat., 129° 40′ W. long., we find also, according to Sir James Ross, that it is 1.96 in the arbitrary scale and 14.90 in the absolute scale. The greater or lesser distance of the two foci from one another in the same hemisphere has been recognised as an important element of their individual intensity, and of the entire distribution of the magnetic force. "Even although the foci of the southern hemisphere exhibit a strikingly greater intensity (namely 15.60 and 14.90 in the absolute scale), than the foci of the northern hemisphere (which are respectively 14.21 and 13.30), the total magnetic force of the one hemisphere cannot be esteemed as greater than that of the other."

"The result is, however, totally different when we separate the terrestrial sphere into an eastern and western part, in accordance with the meridians of 100° and 280° E. long. reckoning from west to east in such a manner that the eastern or more continental sphere shall enclose South America, the Atlantic Ocean, Europe, Africa, and Asia, almost as far as Baikal, whilst the western, which is the more oceanic and insular, includes almost the whole of North

[1] I follow the value given in Sabine's *Contributions*, No. vii, p. 252, namely 15.60. We find from the Magnetic Journal of the Erebus (*Phil. Transact. for* 1843, pt. ii, pp. 169—172), that several individual observations, taken on the ice on the 8th of February, 1841, in 77° 47′ S. lat. and 172° 42′ W. long. yielded 2.124. The value of the intensity 15.60 in the absolute scale would lead us to assume provisionally that the intensity at Hobarton was 13.51 (*Magn. and Meteorol. Observ. made at Hobarton*, vol. i, p. 75). This value has, however, lately been slightly augmented (to 13.56) (vol. ii, xlvi). In the *Admiralty Manual*, p. 17, I find the southern focus of greatest intensity changed to 15.8.

America, the broad expanse of the Pacific, New Holland, and a portion of Eastern Asia." These meridians lie the one about 4° west of Singapore, the other 13° west of Cape Horn, in the meridian of Guayaquil. All four foci of the maximum of the magnetic force, and even the two magnetic poles fall within the western hemisphere.[3]

Adolph Erman's important observation of least intensity in the Atlantic Ocean, east of the Brazilian province of Espiritu Santo (20 S. lat., 35 02′ W. long.), has been already mentioned in our Delineation of Nature.[4] He found in the relative scale 0.7062 (in the absolute scale 5.35). This region of weakest intensity was also twice crossed by Sir James Ross in his Antarctic expedition[5] between 19° and 21° S. lat., as well as by Lieutenant Sulivan and Dunlop in their voyage to the Falkland Islands.[6] In his isodynamic chart of the entire Atlantic Ocean, Sabine has drawn the curve of least intensity, which Ross calls *the equator of less intensity*, from coast to coast. It intersects the West African shore of Benguela, near the Portuguese colony of Mossamedes, (15° S. lat.); its summits are situated in the middle of the ocean in 18° W. long., and it rises again on the Brazilian coast as high as 20° S. lat. Whether there may not be another zone of tolerably low intensity (0·97), lying north of the equator (10° to 12° lat.), and about 20° east of the Philippines is a question that must be left for future investigations to elucidate.

I do not think that the ratio which I formerly gave of the weakest to the strongest terrestrial force requires much modification in consequence of later investigations. This ratio falls between 1 : 2½ and 1 : 3, being some-

[3] See the interesting *Map of the World, divided into hemispheres by a plane coinciding with the meridians of* 100 *and* 280 *E. of Greenwich, exhibiting the unequal distribution of the magnetic intensity in the two hemispheres*, plate v, in the *Proceedings of the Brit. Assoc. at Liverpool*, 1837, pp. 72—74. Erman found that the intensity of the terrestrial force was almost constantly below 0.76, and consequently very small in the southern zone between latitudes 24° 25′ and 13° 18′, and between the western longitudes of 34° 50′ and 32° 44′.

[4] *Cosmos*, vol. i, p. 181.

[5] *Voyage in the Southern Seas*, vol. i, pp. 22, 27 ; vide supra, p. 96.

[6] See the Journal of Sulivan and Dunlop, in the *Phil. Transact. for* 1840, pt. i, p. 143. They found as the minimum only 0.800.

what nearer to the latter number, and the difference of the data[7] arises from the circumstance that in some cases the minima alone, and in others the minima and maxima together, have been altered somewhat arbitrarily. Sabine[8] has the great merit of having first drawn attention to the importance of the dynamic equator, or curve of least intensity. "This curve connects the points of each geographical meridian at which the terrestrial intensity is the smallest. It describes numerous undulations in passing round the earth, on both sides of which the force increases with the higher latitudes of each hemisphere. It in this manner indicates the limits between the two magnetic hemispheres more definitely than the magnetic equator, on which the direction of the magnetic force is vertical to the direction of gravity. In respect to the theory of magnetism, that which refers directly to the force itself is of even greater importance than that which merely refers to the direction of the needle, its horizontal or vertical position. The curves of the dynamic equator are numerous, in consequence of their depending upon forces, which produce four points (foci) of the greatest terrestrial force, which are unsymmetrical and of unequal intensity. We are more especially struck in these inflections with the great convexity in the Atlantic Ocean towards the South Pole, between the coasts of Brazil and the Cape of Good Hope."

Does the intensity of the magnetic force perceptibly decrease at such heights as are accessible to us, or does it perceptibly increase in the interior of the earth? The problem which is suggested by these questions is extremely

[7] We obtain 1:2.44 on comparing in the absolute scale St. Helena, which is 6.4, with the focus of greatest intensity at the south pole, which is 15.60, and 1:2.47 by a comparison of St. Helena with the higher southern maximum of 15.8, as given in the *Admiralty Manual*, p. 17, and 1:2.91 by a comparison in the relative scale of Erman's observation in the Atlantic Ocean (0.706), with the southern focus (2.06); indeed, even 1:2.95, when we compare together in the absolute scale the lowest value given by this distinguished traveller (5.35), with the highest value for the southern focus (15.8). The mean resulting ratio would be 1:2.69. Compare for the intensity of St. Helena (6.4 in the absolute, or 0.845 in the arbitrary scale), the earliest observations of Fitzroy (0.836), *Phil. Transact. for* 1847, pt. i, p. 52, and *Proceedings of the Meeting at Liverpool*, p. 56.

[8] See *Contrib. to Terrestr. Magnetism*, No. vii, p. 256.

complicated in the case of observations which are made either in or upon the earth, since a comparison of the effect of considerable heights on mountain journeys is rendered difficult, because the upper and lower stations are seldom sufficiently near one another, owing to the great mass of the mountain, and since further, the nature of the rock and the penetration of veins of minerals, which are not accessible to our observation, together with imperfectly understood horary and accidental alterations in the intensity, modify the results, where the observations are not perfectly simultaneous. In this manner we often ascribe to the height or depth alone, conditions which by no means belong to either. The numerous mines of considerable depth which I have visited in Europe, Peru, Mexico, and Siberia, have never afforded localities which inspired me with any confidence.[9] Then, moreover, care should be taken in giving the depths, not to neglect the perpendicular differences above or below the level of the sea, which constitutes the mean surface of the earth. The borings at the mines of Joachimsthal in Bohemia are upwards of 2000 feet in absolute depth, and yet they only reach to a stratum of rock which lies between 200 and 300 feet *above* the level of the sea.[10] Very different and more favourable conditions are afforded by balloon ascents. Gay-Lussac rose to an elevation of 23,020 feet above Paris; consequently, therefore, the greatest relative depth that has been reached by borings in Europe, scarcely amounts to $\frac{1}{11}$th of this height. My own mountain observations between the years 1799 and 1806, led me to believe that the terrestrial force gradually decreases with the elevation, although, in consequence of the causes of disturbance already indicated, several results are at variance with this conjectural decrease. I have collected in a note individual data, taken from 125 measurements of intensity made in the Andes, in the Swiss Alps, Italy, and Germany.[11] These observations extended from the level of

[9] We may ask what kind of error can have led in the coal mines of Flenu to the result that in the interior of the earth, at the depth of 87 feet, the horizontal intensity had increased 0.001? *Journal de l'Institut,* 1845, Avril, p. 146. In an English mine, which is 950 feet below the level of the sea, Henwood did not find any increase in the intensity (Brewster, *Treatise on Magn.* p. 275).

[10] *Cosmos,* vol. i, p. 150.

[11] A diminution of the intensity with the height is shown in my

the sea to an elevation of 15,944 feet, and therefore to the very limits of perpetual snow, but the greatest heights did not afford me the most reliable results. The most satisfactory were obtained on the steep declivity of the Silla de Caracas (8638 feet), which inclines towards the neighbouring coasts of La Guayra; the Santuario de Nostra Señora de Guadalupe,

observations from the comparisons of the Silla de Caracas (8638 feet above the sea, intensity 1.188), with the harbour of Guayra (height 0 feet, intensity 1.262), and the town of Caracas (height 2648 feet, intensity 1.209); from a comparison of the town of Santa Fé de Bogota (elevation 8735 feet, intensity 1.147), with the chapel of Neustra Senora da Guadalupe (elevation 10,794 feet, intensity 1.127), which seems to hang over the town like a swallow's nest, perched upon a steep ledge of rock; from a comparison of the volcano of Purace (elevation 14,548 feet, intensity 1.077), with the mountain village of Purace (elevation 8671 feet, intensity 1.087), and with the neighbouring town of Popayan (elevation 5825 feet, intensity 1.117); from a comparison of the town of Quito (elevation 9541 feet, intensity 1.067), with the village of San Antonio de Lulumbamba (elevation 8131 feet, intensity 1.087) lying in a neighbouring rocky fissure directly under the geographical equator. The oscillation experiments, which I made at the highest point at which I ever instituted observations of the kind, namely, at an elevation of 15,944 feet on the declivity of the long since extinct volcano of Antisana, opposite the Chussulongo, were quite at variance with this result. It was necessary to make this observation in a large cavern, and the great increase in the intensity was no doubt the consequence of a magnetic local attraction of the trachytic rock, as has been shown by the experiments which I made with Gay-Lussac within, and on the margin of, the crater of Vesuvius. I found the intensity in the Cave of Antisana increased to 1.188, while in the neighbouring lower plateau it was scarcely 1.068. The intensity at the Hospice of St. Gotthard (1.313) was greater than that at Airolo (1.309), but less than that at Altorf (1.322). Airolo, on the other hand, exceeded the intensity of the Ursern Lake (1.307). In the same manner Gay-Lussac and myself found that the intensity was 1.344 at the Hospice of Mont Cenis, whilst at the foot of the same mountain, at Lans le Bourg, it was 1.323, and at Turin 1.336. The greatest contradictions were necessarily presented by the burning volcano of Vesuvius, as we have already remarked. Whilst in 1805 the terrestrial force at Naples was 1.274, and at Portici 1.288, it rose in the Monastery of St. Salvador to 1.302, whilst it fell in the crater of Vesuvius lower than anywhere else throughout the whole district, namely, to 1.193. The iron contained in the lava, the vicinity of magnetic poles, and the heat of the soil, which probably has the effect of diminishing this force, combined to produce the most opposite local disturbances. See my *Voyage aux Régions Equinoxiales*, t. iii, pp. 619—626, and *Mém. de la Société d'Arcueil*, t. i, 1807, pp. 17—19.

which rises immediately over the town of Bogota, upon the declivity of a steep wall of limestone rock, with a difference of elevation amounting to upwards of 2000 feet; and the volcano of Purace, which rises 8740 feet above the Plaza Mayor of the town of Popayan. Kupffer in the Caucasus,[12] Forbes in many parts of Europe, Laugier and Mauvais on the Canigou, Bravais and Martins on the Faulhorn, and during their very adventurous sojourn in the immediate vicinity of the summit of Mont Blanc, have certainly observed that the intensity of the magnetic force diminished with the height, and this decrease appeared from Bravais's general consideration of the subject to be more rapid in the Pyrenees than in the chain of the Alps.[13]

Quetelet's entirely opposite results, obtained in an excursion from Geneva to the Col de Balme and the Great St. Bernard, make it doubly desirable for the final and decisive settlement of so important a question, that observations should be made at some distance from the surface of the earth; and these observations can only be carried on by means of balloon ascents, such as were employed in 1804, by Gay-Lussac, first in association with Biot, on the 24th of August, and subsequently alone on the 16th of September. Oscillations measured at elevations of 19,000 feet, can however only afford us certain information regarding the transmission of the terrestrial force in the free atmosphere, when

[12] Kupffer's observations do not refer to the summit of the Elbruz, but to the difference of height (4796 feet) between two stations, viz. the bridge of Malya, and the mountain declivity of Kharbis, which unfortunately differ considerably in longitude and latitude. Regarding the doubts which Necker and Forbes have advanced in relation to this result see *Transact. of the Royal Soc. of Edin.* vol. xiv, 1840, pp. 23—25.

[13] Compare Laugier and Mauvais, in the *Comptes rendus*, t. xvi, 1843, p. 1175; and Bravais, *Observ. de l'Intensité du Magnetisme Terrestre en France, en Suisse, et en Savoie,* in the *Annales de Chemie et de Phys.* 3ème Série, t. xviii. 1846, p. 214; Kreil, *Einfluss der Alpen auf die Intensität,* in the *Denkschriften der Wiener Akad. der Wiss. Mathem. Naturwiss. Cl.* Bd. i, 1850, s. 265, 279, 290. It is very remarkable that so accurate an observer as Quetelet should have found, in a tour which he made in the year 1830, that the horizontal intensity increased with the height, in ascending from Geneva (where it was 1.080), to the Col de Balne (where it was 1.091), and to the Hospice of St. Bernard where it was as high as 1.096). See Sir David Brewster, *Treatise on Magn.* p. 275.

care is taken to obtain corrections for temperature in the needles that are employed both before and after the ascent. The neglect of such a correction has led to the erroneous result deducible from Gay-Lussac's experiments, that the magnetic force remains the same to an elevation of more than 22,000 feet,[14] whilst conversely the experiment showed a decrease in the force on account of the shortening of the oscillating needle in the upper cold region.[15] Faraday's brilliant discovery of the paramagnetic force of oxygen must not be disregarded in the discussion of this subject. This great physicist shows that in the upper strata of the atmosphere, the decrease in the intensity cannot be sought merely in the original source of the force, namely the solid earth, but that it may equally arise from the excessively rarefied condition of the air, since the quantity of oxygen in a cubic foot of atmospheric air must differ in the upper and lower strata. It seems to me, however, that we are not justified in assuming more than this—that the decrease of the paramagnetic property of the oxygenous parts of the atmosphere which diminish with the elevation and with the rarefaction of the air, must be regarded as a co-operating modifying cause. Alterations of temperature and density through the ascending currents of air may further alter the amount of this influence.[16] Such disturbances assume a variable and specially local character, and they operate in the atmosphere in the same manner as different kinds of rocks upon the surface of the earth. With every advance which we may rejoice in having made in our knowledge of the gaseous envelope of our planet and of its physical properties, we at the same time learn to know new causes of disturbance in the alternating mutual action of forces, which should teach us how cautiously we ought to draw our conclusions.

The intensity of the terrestrial force, when measured at definite points of the surface of our planet, has, like all the phenomena of terrestrial magnetism, its horary as well as its secular variations. The horary variations were distinctly

[14] *Annales de Chimie*, t. lii, 1805, pp. 86—87.

[15] Arago, in the *Annuaire du Bureau des Longitudes pour* 1836, p. 287; Forbes, in the *Edin. Transact.* vol. xiv, 1840, p. 22.

[16] Faraday, *Exper. Researches in Electricity*, 1851, pp. 53, 77, §§ 2881, 2961.

recognized by Parry during his third voyage, and also, conjointly with him, by Lieutenant Foster (1825) at Port Bowen. The increase of intensity from morning till evening in the mean latitudes has been made an object of the most careful investigation by Christie,[17] Arago, Hansteen, Gauss, and Kupffer. As horizontal oscillations, notwithstanding the great improvements which have been made in the present day in the dipping-needle, are preferable to oscillations of the latter kind, it is not possible to ascertain the horary variation of the total intensity without a very accurate knowledge of the horary variation of the dip. The establishment of magnetic stations, in the northern and the southern hemisphere, has afforded the great advantage of yielding the most abundant, and, incomparatively, the most accurate results. It will be sufficient here to instance two points of the earth's surface, which are both situated without the tropics, and almost in equal latitudes on either side of the equator—namely, Toronto, in Canada, 43° 39′ N. lat., and Hobarton, in Van Diemen's Land, in 42° 53′ S. lat., with a difference of longitude of about 15 hours. The simultaneous horary magnetic observations belong at the one station to the winter months, while at the other they fall within the period of the summer months. While measurements are made at the one place during the day, they are being simultaneously carried on at the other station for the most part during the night. The variation at Toronto is 1° 33′ West; at Hobarton it is 9° 57′ East; the inclination and the intensity are similar to one another; the former is, at Toronto, about 75° 15′ to the north, and at Hobarton about 70° 34′ to the south, whilst the total intensity is 13·90 in the absolute scale at Toronto, and 13·56 at Hobarton. It would appear from Sabine's investigation, that these well-chosen stations exhibit[19] four turning points for the intensity in Canada, and only two such points for Van Diemen's Land. At Toronto, the variation in intensity reaches its principal maximum at 6 P.M., and its principal minimum at 2 A.M.; a weaker

[17] Christie, in the *Phil. Transact. for* 1825, p. 49.

[18] Sabine, *On Periodical Laws of the Larger Magnetic Disturbances,* in the *Phil. Transact. for* 1851, pt. i, p. 126, and on the *Annual Variation of the Magn. Declin.* in the *Phil. Transact. for* 1851, pt. ii, p. 636.

[19] *Observ. made at the Magn. and Meteorol. Observatory at Toronto,* vol. i (1840—1842), p. lxii.

secondary maximum at 8 A.M., and a weaker secondary minimum at 10 A.M. The intensity at Hobarton, on the contrary, exhibits a simple progression from a maximum between 5 and 6 P.M. to a minimum between 8 and 9 A.M.; although the inclination there, no less than at Toronto, exhibits four turning points[20]. By a comparison of the variations of inclination, with those of the horizontal force, it has been established that, in Canada, during the winter months, when the sun is in the southern signs of the zodiac, the total terrestrial force has a greater intensity than in the summer months, whilst in Van Diemen's Land the intensity is greater than the mean annual value—that is to say, the total terrestrial force—from October to February, which constitutes the summer of the southern hemisphere, while it is less from April to August. According to Sabine,[21] this intensity of the terrestrial magnetic force is not dependent on differences of temperature, but on the lesser distance of the magnetic solar body from the earth. At Hobarton, the intensity during the summer is 13.574 in the absolute scale, whilst during the winter it is 13.543. The secular variation of intensity has hitherto been deduced from only a small number of observations. At Toronto, it appears to have suffered some decrease between 1845 and 1849, and the comparison of my own observations with those of Rudberg, in the years 1806 and 1832, give a similar result for Berlin.[22]

[20] Sabine, in *Magn. and Meteor. Observations at Hobarton,* vol. i, p. lxviii. "There is also a correspondence in the range and turning hours of the diurnal variation of the total force at Hobarton and at Toronto, although the progression is a *double one* at Toronto and a single one at Hobarton." The time of the maximum of intensity falls at Hobarton between 8 and 9 A.M.; whilst the secondary or lesser minimum falls at Toronto about 10 A.M., and consequently the increase and diminution of the intensity fall within the same hours in accordance with the time of the place, and not at opposite hours, as is the case with respect to the inclination and the declination. See, regarding the causes of this phenomenon, p. lxix (compare also Faraday, *Atmospheric Magnetism,* § § 3027—3034).

[21] *Phil. Transact. for* 1850, pt. i, pp. 215—217; *Magnet. Observ. at Hobarton,* vol. ii, 1852, p. xlvi. See also p. 22 of the present volume. At the Cape of Good Hope the intensity presents less difference at opposite periods of the year than the inclination (*Magnet. Observ. made at the Cape of Good Hope,* vol. i, 1851, p. lv).

[22] See the magnetic part of my work on *Asie Centrale,* t. iii, p. 442.

Inclination.

The knowledge of the *isoclinal* curves, or *lines of equal inclination*, as well as the more rapid or slower increase of the inclination by which they are determined, (reckoning from the magnetic equator where the inclination = 0 to the northern and southern magnetic pole where the horizontal force vanishes,) has acquired additional importance in modern times, since the element of the total magnetic force cannot be deduced from the horizontal intensity, which requires to be measured with excessive accuracy, unless we are previously well acquainted with the inclination. The knowledge of the geographical position of both magnetic poles is due to the observations and scientific energy of the adventurous navigator, Sir James Ross. His observations of the northern magnetic pole were made during the second expedition of his uncle, Sir John Ross (1829—1833),[23] and of the southern during the Antarctic expedition under his own command (1839—1843). The northern magnetic pole in 70° 5′ lat., 96° 43′ W. long., is 5° of latitude farther from the ordinary pole of the earth than the southern magnetic pole, 75° 35′ lat., 154° 10′ E. long., whilst it is also situated farther west from Greenwich than the northern magnetic pole. The latter belongs to the great island of Boothia Felix, which is situated very near the American continent, and is a portion of the district which Captain Parry had previously named North Somerset. It is not far distant from the western coast of Boothia Felix, near the promontory of Adelaide, which extends into King William's Sound and Victoria Strait.[24] The southern magnetic pole has not been directly reached in the same manner as the northern pole. On the 17th of February, 1841, the Erebus penetrated as far as 76° 12′ S. lat., and 164° E. long. As the inclination was here only 88° 40′, it was assumed that the southern magnetic pole was about 160 nautical miles distant.[25] Many accurate observations of declination, deter-

[23] Sir John Barrow, *Arctic Voyages of Discovery*, 1846, pp. 521—529.

[24] The strongest inclination which has as yet been observed in the Siberian continent, is 82° 16′, which was found by Middendorf, on the river Taimyr, in 74° 17′ N. lat, and 95° 40′ E. long. (Middend. *Siber. Reise*, th. i, s. 194).

[25] Sir James Ross, *Voyage to the Antarctic Regions*, vol. i, p. 246. "I

mining the intersection of the magnetic meridian, render it very probable that the south magnetic pole is situated in the interior of the great antarctic region of South Victoria Land, west of the Prince Albert mountains, which approach the south pole, and are connected with the active volcano of Erebus, which is 12,400 feet in height.

The position and change of form of the magnetic equator, that is to say, the line on which the dip is null, were very fully considered in the Picture of Nature, *Cosmos*, vol i., p. 176. The earliest determination of the African node (the intersection of the geographical and magnetic equators) was made by Sabine[26] at the beginning of his pendulum expedition in 1822. Subsequently, in 1840, the same learned observer noted down the results obtained by Duperrey, Allen, Dunlop, and Sulivan, and constructed a chart of the magnetic equator[27] from the west coast of Africa at Biafra, (4° N. lat. 9° 30′ E. long.) through the Atlantic Ocean and Brazil (16° S. lat., between Porto Seguro and Rio Grande,) to the point where, upon the Cordilleras, in the neighbourhood of the Pacific, I saw the northern inclination assume a southern direction. The African node, as the point of intersection of both equators, was situated, in 1837, in 3° E. long., while, in 1825, it had been in 6°57′E. long. The secular motion of the node, turning from the basaltic island of St. Thomas, which rises to an elevation of more than 7000 feet, was therefore somewhat less than half a degree westward in the course of a year; after which the line of no inclination turned towards the north on the African coast, whilst on the Brazilian coast it is inclined southward. The convexity of the magnetic equatorial curve is persistently turned towards the south pole, while in the Atlantic Ocean it passes at a distance of about 16° from the geographical equator. For the interior of South America, the *terra incognita* of Matto

had so long cherished the ambitious hope," says this navigator, "to plant the flag of my country on *both* the magnetic poles of our globe; but the obstacles which presented themselves being of so insurmountable a character was some degree of consolation as it left us no grounds for self-reproach" (p. 247).

[26] Sabine, *Pendul. Exper.* 1825, p. 476.

[27] Sabine, in the *Phil. Transact. for* 1840, pt. i, pp. 136, 139, 146. I follow for the progression of the African node the map which is appended to this treatise.

Grosso between the large rivers of Xingu, Madera, and Ucayle, we have no observations of the dip until we reach the chain of the Andes, where, 68 geographical miles east of the shores of the Pacific, between Montan, Micuipampa, and Caxamarca, I determined astronomically the position of the magnetic equator, which rises towards the north-west (7° 2′ S. lat., and 78° 46′ W. long.) [28].

The most complete series of observations which we possess in reference to the position of the magnetic equator was made by my old friend, Duperrey, during the years 1823—1825. He crossed the equator six times during his voyages of circumnavigation, and he was enabled to determine this line by his own observations over a space of 220°.[29] According to Duperrey's chart of the magnetic equator, the two nodes are situated in long. 5° 50′ E. in the Atlantic Ocean, and in long. 177° 20′ E. in the Pacific, between the meri-

[28] I here give, in accordance with my usual practice, the elements of this not wholly unimportant determination : Micuipampa, a Peruvian mountain town at the foot of Cerro de Guelgayoc, celebrated for its rich silver mines, 6° 44′ 25″ S. lat., 78° 33′ 3″ W. long., elevation above the Pacific 11,872 feet, magnetic inclination 0°.42 north (according to the centesimal division of the circle); Caxamarca, a town situated on a plateau at an elevation of 9362 feet, 7° 8′ 38″ S. lat., 5h 23′ 42″ long., inclination 0.15 south; Montan, a farm-house (or *hacienda*), surrounded by Llama flocks, situated in the midst of mountains, 6° 33′ 9″ S. lat., 5h 26′ 51″ W. long., elevation 8571 feet, inclination 0.70 north; Tomependa, on the mouth of the Chinchipe, on the river Amazon, in the province of Jaen de Bracamoros, 5° 31′ 28″ S. lat., 78° 37′ 30″ W. long., elevation 1324 feet, inclination 3°.55 north; Truxillo, a Peruvian town on the Pacific, 8° 5′ 40″ S. lat., 79° 3′ 37″ W. long., inclination 2°.15 south. Humboldt, *Recueil d'Observ. Astron.* (Nivellement Barométrique et Geodésique) vol. i, p. 316, No. 242, 244—254. For the basis of astronomical determinations, obtained by altitudes of the stars and by the chronometer, see the same work, vol. ii, pp. 379—391. The result of my observations of inclination in 1802, in 7° 2′ S. lat., and 78° 48′ W. long., accords pretty closely by a singular coincidence, and notwithstanding the secular alteration, with the conjecture of Le Monnier, which was based upon theoretical calculation. He says, "the magnetic equator must be in 7° 45′ north of Lima, or at most in 6° 30′ S. lat., in 1776" (*Lois du Magnétisme comparées aux Observations*, pt. ii, p. 59).

[29] Saigey, *Mém sur l'Equateur Magnétique d'après les Observ. du Capitaine Duperrey*, in the *Annales Maritimes et Coloniales*, Dec. 1833, t. iv, p. 5. Here it is observed that the magnetic equator is not a curve of equal intensity, but that the intensity varies in different parts of this equator from 1 to 0.867.

dians of the Fejee and Gilbert Islands. While the magnetic equator leaves the western coasts of the South American continent, probably between Punta de la Aguja and Payta, it is constantly drawing nearer in the west to the geographical equator, so that it is only at a distance of 2° from it in the meridian of the group of the Mèndana Islands.[30] About 10° farther west, in the meridian which passes through the western part of the Paumotu Islands (Low Archipelago) lying in 153° 50′ E. long., Captain Wilkes found that the distance from the geographical equator in 1840 was still fully 2°.[31] The intersection of the nodes in the Pacific is not as much as 180° from that of the Atlantic nodes, that is to say, it does not occur in 174° 10′ W. long., but in the meridian of the Fejee Islands, situated in about 177° 20′ E. long. If, therefore, we pass from the west coast of Africa, through South America westward, we shall find in this direction that the distance of the nodes from one another is about 8½° too great, which is a proof that the curve of which we are here speaking is not one of the great circles.

According to the admirable and comprehensive determinations which were made by Captain Elliot from 1846 to 1849, between the meridians of Batavia and Ceylon, and which coincide in a remarkable manner with those of Jules de Blosseville (see page 64), it would appear that the magnetic equator passes through the northern point of Borneo, and almost due west into the northern point of Ceylon, in 9° 45′ N. lat. The curve of minimum total intensity runs almost parallel to this part of the magnetic equator,[32] which enters the western part of the continent of Africa, south of the Cape of Gardafui. This important re-entering point of the curve has been determined with great accuracy by Rochet d'Héricourt on his second Abyssinian expedition, from 1842 to 1845, and by the interesting dis-

[30] This position of the magnetic equator was confirmed by Erman for the year 1830. On his return from Kamtscatka to Europe, he found the inclination almost null at 1° 30′ S. lat., 132° 37′ W. long.; in 1° 52′ S. lat., 135° 10′ W. long.; in 1° 54′ lat., in 133° 45′ W. long.; in 2° 1′ S. lat., 139° 8′ W. long. (Erman, *Magnet Beob.* 1841, s. 536).

[31] Wilkes, *United States Exploring Expedition,* vol. iv, p. 263.

[32] Elliot, in the *Phil. Transact. for* 1851, pt. i, pp. 287—331.

cussion to which his magnetic observations gave rise.[33] This point lies south of Gaubade, between Angolola and Angobar, the capital of the kingdom of Schoa, in 10° 7′ N. lat., and in 41° 13′ E. long. The course of the magnetic equator in the interior of Africa, from Angobar to the Gulf of Biafra, is as thoroughly unexplored as that in the interior of South America, east of the chain of the Andes, and south of the geographical equator. Both these continental districts are nearly of equal extent, measured from east to west, each extending over a space of about 80° of longitude, so that we are still entirely ignorant of the magnetic condition of nearly one quarter of the earth's circumference. My own observations of inclination and intensity for the whole of the interior of South America, from Cumana to the Rio Negro, as well as from Cartagena de Indias to Quito, refer only to the tropical zone north of the geographical equator, while those which I made in the southern hemisphere, from Quito as far as Lima, were limited to the district lying near the western coast.

The translation of the African node towards the west from 1825 to 1837, which we have already indicated, has been confirmed on the eastern coasts of Africa by a comparison of the inclination-observations made by Panton, in the year 1776, with those of Rochet d'Héricourt. The latter observer found the magnetic equator much nearer the Straits of Bab-el-Mandeb, namely, 1° south of the island of Socotora, in 8° 40′ N. lat. There was, therefore, an alteration of 1° 27′ lat. for 49 years, whilst the corresponding alteration in the longitude was determined by Arago and Duperrey to have been 10° from east to west. The direction of the secular variation of the nodes of the magnetic equator on the eastern coasts of Africa, towards the Indian Ocean, was precisely similar to that on the western coast. The quantity of the motion must, however, be ascertained from much more accurate results than we at present possess.

The periodicity of the alterations of the magnetic inclination, whose existence had been noticed at a much earlier period, has only been established with certainty and thorough completeness within the last twelve years, since the erection of British magnetic stations in both hemispheres.

33 Duperrey, in the *Comptes rendus,* t. xxii, 1846, pp. 804—806.

Arago, to whom the theory of magnetism is so largely indebted, had indeed recognised, in the autumn of 1827, "that the dip was greater at 9 A.M. than at 6 P.M., whilst the intensity of the magnetic force, when measured by the oscillations of a horizontal needle, attained its minimum in the first, and its maximum in the second period."[34] In the

[34] In a letter from Arago to myself, dated Mayence, 13th of December, 1827, he writes as follows:—"I have definitely proved during the late Auroræ boreales, which have been seen at Paris, that this phenomenon is always accompanied by a variation in the position of the horizontal and dipping needles, as well as in intensity. The changes of inclination have amounted to 7′ or 8′. To effect this change, after allowing for every change of intensity, the horizontal needle must oscillate more or less rapidly, according to the time at which the observation is made, but in correcting the results by calculating the immediate effects of the inclination, there still remained a sensible variation of intensity. On repeating by a new method the diurnal observation of inclination, on which I was engaged during your late visit to Paris, I found a regular variation, not for the means but for *each day,* which was greater in the morning at nine than in the evening at six. You are aware that the intensity, *measured with the horizontal needle,* is on the contrary at its *minimum* at the first period, while it attains its *maximum* between six and seven in the evening. The total variation being very small, one might suppose that it was merely due to a change of inclination; and, indeed, the greatest portion of the *apparent variation of intensity* depends upon the diurnal alteration of the horizontal component, but, when every correction has been made, there still remains a small quantity as an indication of a *real variation of intensity.*" In another letter, which Arago wrote to me from Paris on the 20th of March, 1829, shortly before my Siberian expedition, he expressed himself as follows:—"I am not surprised that you should have found it difficult to recognise the diurnal change of inclination, of which I have already spoken to you, in the winter months, for it is only during the warmer portions of the year that this variation is sufficiently sensible to be observed with a lens. I would still insist upon the fact, that changes of inclination are not sufficient to explain the change of intensity, deduced from the observation of a horizontal needle. An augmentation of temperature, all other circumstances remaining the same, retards the oscillations of the needles. In the evening, the temperature of my horizontal needle is always *higher* than in the morning; hence the needle *must on that account* make fewer oscillations in a given time in the evening than in the morning; in fact it oscillates more frequently than we can account for by the change of inclination, and hence there must be a *real augmentation* of intensity from morning till evening in the terrestrial magnetic force." Later and more numerous observations at Greenwich, Berlin, St. Petersburg, Toronto, and Hobarton, have confirmed Arago's assertion (in 1827) that the horizontal intensity

British magnetic stations this opposition and the periodicity of the horary variation in the dip have been firmly established by several thousand regularly prosecuted observations, which have all been submitted to a careful discussion since 1840. The present would seem the most fitting place to notice the facts that have been obtained as materials on which to base a general theory of terrestrial magnetism. It must, however, first be observed, that if we consider the periodical variations which are recognised in the three elements of terrestrial magnetism, we must, with Sabine, distinguish in the turning hours at which the maxima or minima occur, two greater, and therefore more important, extremes, and other slight variations, which seem to be intercalated amongst the others, as it were, and which are for the most part of an irregular character. The recurring movements of the horizontal and dipping needles, as well as the variation in the intensity of the total force, consequently present principal and secondary maxima or minima, and generally some of either type, which therefore constitutes a double progression with four turning hours (the ordinary case), and a simple progression with two turning hours, that is to say, with a single maximum and a single minimum. Thus, for instance, in Van Diemen's Land, the intensity or total force exhibits a simple progression, combined with a

was greater in the evening than towards morning. At Greenwich the principal maximum of the horizontal force was about 6 P.M., the principal minimum about 10 A.M. or at noon; at Schulzendorf, near Berlin, the maximum falls at 8 P.M., the minimum at 9 A.M.; at St. Petersburg the max. falls at 8 P.M., the min. at 11h. 20m. A.M.; at Toronto the max. falls at 4 P.M., the min. at 11 A.M. The time is always reckoned according to the true time of the respective places (Airy, *Magn. Observ. at Greenwich for* 1845, p. 13; *for* 1846, p. 102; *for* 1847, p. 241; Riess and Moser, in Poggend. *Annalen.* Bd. xix, 1830, s. 175; Kupffer, *Compte rendu Annuel de l'Observatoire Centrale Magn. de St. Pétersb.* 1852, p. 28; and Sabine, *Magn. Observ. at Toronto,* vol. i, 1840—1842, p. xlii). The turning hours at the Cape of Good Hope and at St. Helena, where the horizontal force is the weakest in the evening, seem to be singularly at variance, and almost the very opposite of one another (Sabine, *Magn. Obs. at the Cape of Good Hope,* p. xl, *at St. Helena,* p. 40). Such, however, is not the case further eastward, in other parts of the great southern hemisphere. "The principal feature in the diurnal change of the *horizontal* force at Hobarton is the decrease of force in the forenoon and its subsequent increase in the afternoon" (Sabine, *Magn. Obs. at Hobarton,* vol. i, p. liv. vol. ii, p. xliii).

double progression of the inclination, while at one part of the northern hemisphere, which corresponds exactly with the position of Hobarton, namely, Toronto, in Canada, both the elements of intensity and inclination exhibit a double progression.[35] At the Cape of Good Hope there is only one maximum and one minimum of inclination. The horary periodical variations of the magnetic dip are as follows :—

I. *Northern Hemisphere.*

Greenwich : Maxim. 9 A.M.; minim. 3 P.M. (Airy, *Observ. in* 1845, p. 21 ; *in* 1846, p. 113 ; *in* 1847, p. 247). Inclin. in the last named year about 9 A.M. on an average 68° 59′ 3″, but at 3 P.M. it was 68° 58′ 6″. In the monthly variation, the maximum falls between April and June and the minimum between October and December.

Paris : Maxim. 9 A.M. ; minim. 6 P.M. This simple progression from Paris and Greenwich is repeated at the Cape of Good Hope.

St. Petersburg : Maxim. 8 A.M.; minim. 10 P.M. Variation of the inclination the same as at Paris, Greenwich, and Pekin ; less in the cold months, and the maxima more closely dependent on time than the minima.

Toronto : Principal maxim. 10 A.M. ; principal minim. 4 P.M. ; secondary maxim. 10 P.M.; secondary minim. 6 A.M. (Sabine, *Tor.* 1840—1842, vol. i, p. lxi.)

II. *Southern Hemisphere.*

Hobarton, Van Diemen's Land : principal minim. 6 A.M.; principal maxim. 11. 30. A.M. ; secondary minim. 5 P.M. ; secondary maxim. 10 P.M. (Sabine, *Hob.*, vol. i, p. lxvii.) The inclination is greater in the summer when the sun is in the southern zodiacal signs, 70° 36′.74 ; it is smaller in winter when the sun is in the northern signs, 70° 34′.66. The annual mean taken from the observations of six years gives 70° 36′.01. (Sabine, *Hob.*, vol. ii, p. xliv.) Moreover the intensity at Hobarton is greater from October to February than from April to August, p. xlvi.

Cape of Good Hope : Simple progression, the minim. being 0 h. 34 m. P.M. ; maxim. 8 h. 34 m. P.M., with an exceedingly

[35] Sabine, *Hobarton*, vol. i, pp. lxvii, lxix.

small intermediate variation between 7 and 9 A.M. (Sabine, *Cape Obs.* 1841—1850, p. liii.)

The phenomena of the turning hours of the maximum of the inclinations expressed in the time of the place, fall with remarkable regularity between 8 and 10 A.M. for places in the northern hemisphere, such as Toronto, Paris, Greenwich, and St. Petersburg, whilst in like manner the minima of the turning hours all fall in the afternoon or evening, although not within equally narrow limits (at 4, 6, and 10 P.M.). It is so much the more remarkable, that in the course of very accurate observations made at Greenwich during five years there was one year, 1845, in which the epochs of the maxima and minima were reversed. The annual mean of the inclinations was for 9 A.M. : 68° 56′.8, and for 3 P.M.: 68° 58′.1.

When we compare together the stations of Toronto and Hobarton, which exhibit a corresponding geographical position on either side of the equator, we find that there is at Hobarton a great difference in the turning hours of the principal minimum of inclination (at 4 o'clock in the afternoon and 6 o'clock in the morning), although such is not the case in the turning hours of the principal maximum (10 and 11. 30 A M.). The period of the principal minimum (6 A.M.) at Hobarton coincides with that of the secondary minimum at Toronto. The principal and secondary maxima occur at both places at the same hours, between 10 and 11. 30 A.M. and 10 P.M. The four turning hours of the inclination occur almost precisely the same at Toronto as at Hobarton, only in a reversed order (4 or 5 P.M., 10 P.M., 6 A.M., and 10 or 11. 30 A.M.) This complicated effect of the internal terrestrial force is very remarkable. If, on the other hand, we compare Hobarton and Toronto in respect to the order in which the turning hours of the alterations of intensity and inclination occur, we shall find that at the former place in the southern hemisphere the minimum of the intensity follows only 2 hours after the principal minimum of the inclination, whilst the delay in the maximum amounts to 6 hours, while in the northern hemisphere, at Toronto, the minimum of intensity precedes the principal maximum of inclination by 8 hours, whilst the maximum of intensity differs only by 2 hours from the minimum of inclination.[36]

[36] Total intensity at Hobarton, max. 5h. 30m. P.M., min. 8h. 30m, A.M.;

The periodicity of inclination at the Cape of Good Hope does not coincide with that at Hobarton, which lies in the same hemisphere, nor with any one point of the northern hemisphere. The minimum of inclination is indeed reached at an hour at which the needle at Hobarton has very nearly reached the maximum.

For the determination of the secular variation of the inclination, it is necessary to have a series of observations that have not only been conducted with extreme accuracy, but which have likewise extended over long intervals of time. Thus for instance, we cannot go with certainty as far back as the time of Cook's voyages, for although in his third expedition the poles were always reversed, we frequently observe differences of 40′ to 55′ in the observations of this great navigator and of Bayley on the Pacific Ocean, a discrepancy which may very probably be referred to the imperfect construction of the magnetic needle at that time, and to the obstacles which then prevented its free motion. For London we scarcely like to go further back than Sabine's observation of August 1821, which compared with the admirable determination made by himself, Sir James Ross and Fox in May 1838, yielded an annual decrease of 2′.73, whilst Lloyd with equally accurate instruments, but in a shorter interval of time, obtained at Dublin, the very accordant result of 2′.38.[37] At Paris, where the annual diminution of inclination is likewise on the decrease, this diminution is greater than in London. The very ingenious methods suggested by Coulomb for determining the dip, had indeed led their inventor to incorrect results. The first observation which was made with one of Le Noir's perfect instruments at the Paris Observatory, belongs to the year 1798. At that time I found, after often repeating the experiments conjointly with the Chevalier Borda 69° 51′; in the year 1810, in conjunction with Arago, I found 68° 50′.2, and in the year 1826, with Mathieu, 67° 56′.7. In the year 1841, Arago found 67° 9′, and in the year 1851, Laugier and Mauvais

at Toronto, principal max. 6 P.M., principal min. 2 A.M., secondary max. 8 A.M., secondary min. 10 A.M. See Sabine, *Toronto*, vol. i, pp. lxi, lxii, and *Hobarton*, vol i, p. lxviii.

[37] Sabine, *Report on the Isoclinal and Isodynamic Lines in the British Islands*, 1839, pp. 61—63.

found 66° 35′: all these observers adopting similar methods and using similar instruments. This entire period which extends over more than half a century (from 1798 to 1851) gives a mean annual diminution of the inclination at Paris of 3′.69. The intermediate periods stood as follows :—

From 1798—1810 at	.. ..	5′.08
1810—1826	.. ..	3 .37
1826—1841	.. ..	3 .13
1841—1851	.. ..	3 .40

The decrease between 1810 and 1826 has been strikingly, though gradually retarded; for an observation which Gay-Lussac made with extreme care (69° 12′) after his return in 1806 from Berlin, whither he had accompanied me after our Italian expedition, gave an annual diminution of 4′.87 since 1798. The nearer the node of the magnetic equator approaches to the meridian of Paris in its secular progression from east to west, the slower seems to be the decrease, ranging in half a century from about 5′.08 to 3′.40. Shortly before my Siberian expedition in April 1829, I laid before the Academy of Berlin, a memoir, in which I had compared together the different points observed by myself, and which I believe I may venture to say, had all been obtained with equal care.[38] Sabine more than 25 years after me measured the inclination and intensity of the magnetic force at the Havanah, which in respect to these equinoctial regions, affords a very considerable interval of time, while he also determined the variation of two important elements. Hansteen, in 1831, gave the result of his investigations of the annual variation of the dip in both hemispheres,[39] in a very admirable work which is of a more comprehensive nature than my own.

[38] Humboldt, in Poggend. *Annalen,* Bd. xv, s. 319—336, Bd. xix, s. 357—391, and in the *Voyage aux Régions Equinox.* t. iii, pp. 616—625.

[39] Hansteen, *Ueber jährliche Veränderung der Inclination,* in Poggend. *Ann.* Bd. xxi, s. 403—429. Compare also, on the influence of the progression of the nodes of the magnetic equator, Sir David Brewster, *Treatise on Magnetism,* p. 247. As the great number of observations made at different stations have opened an almost inexhaustible field of inquiry in this department of special investigation, we are constantly meeting with new complications in our search for the laws by which these forces are controlled. Thus, for instance, in the course of a series

Although Sir Edward Belcher's observations for the year 1838, when compared with those I made in 1803 (see p. 73), along the Western Coast of America, between Lima, Guayaquil, and Acapulco, indicate considerable alterations in the inclination (and the longer the intermediate period the greater is the value of the results), the secular variation of the dip at other points of the Pacific has been found to be strikingly slow. At Otaheite, Bayley found in 1773, 29° 43′ and Fitzroy in 1835, 30° 14′, whilst Captain Belcher in 1840, again found 30° 17′, and hence the mean annual variation scarcely amounted, in the course of 67 years, to 0′.51.[40] A very careful observer, Sawelieff, found in Northern Asia, 22 years after my visit to those regions, in a journey which he made from Casan to the shores of the Caspian Sea, that the inclination to the north and south of the parallel of 50° had varied very irregularly.[41]

	Humboldt. 1829.		Sawelieff. 1851.
Casan ..	68° 26′.7	.. ..	68° 30′.8
Saratow..	64 40.9	.. ..	64 48.7
Sarepta ..	62 15.9	.. ..	62 39.6
Astrachan	59 58.3	.. ..	60 27.9

For the Cape of Good Hope we now possess an extended series of observations, which if we do not go further back than from Sir James Ross and du Petit Thouars (1840) to Vancouver (1791), may be regarded as of a very satisfactory nature in respect to the variation of the inclination for nearly half a century.[42]

of successive years we see that the dip passes in one of the turning hours —that of the maximum from a decrease to an absolute increase, whilst in the turning hour of the minimum, the progressive annual decrease continued the same. Thus, at Greenwich, the magnetic inclination in the maximum hour (9 A.M.) decreased in the years 1844 and 1845, while it increased at the same hour from 1845 to 1846, and continued in the turning hour of the minimum (3 P.M.) to decrease from 1844 to 1846 (Airy, *Magn. Observ. at Greenwich*, 1846, p. 113).

40 *Phil. Transact. for* 1841, pt. i, p. 35.

41 Compare Sawelieff, in the *Bulletin Physico-Mathématique de l'Acad. Imp. de St. Pétersb.* t. x, No. 219, with Humboldt, *Asie Centr.* t. iii, p. 440.

42 Sabine, *Magn. Observ. at the Cape of Good Hope*, vol. i, p. lxv. If we may trust to the observations made by Lacaille for the year 1751,

The solution of the question whether the elevation of the soil does in itself exert a perceptible influence on magnetic dip and intensity,[43] was made the subject of very careful investigation during my mountain journeys in the chain of the Andes, in the Ural, and Altai. I have already observed, in the section on Magnetic Intensity, how very few localities were able to afford any certainty as to this question, because the distance between the points to be compared together must be so small as to leave no ground for suspecting that the difference found in the inclination may be a consequence of the elevation of the soil, instead of the result of the curvature of the isodynamic and isoclinal lines, or of some great peculiarity in the composition of the rocks. I will limit myself to the four results which I thought at the time they were obtained, showed more decisively than could be done by observations of intensity, the influence exerted by elevation in diminishing the dip of the needle.

The *Silla de Caracas*, which rises almost vertically above La Guayra, and 8638 feet above the level of the sea, south of the coast but in its immediate vicinity and north of the town of Caracas, yielded the inclination of 41°.90; La Guayra, elevation 10 feet, inclination 42°.20; the town of Caracas, height above the shores of the Rio Guayre, 2648 feet, inclination 42°.95. (Humboldt, *Voy. aux Rég. Equinox.*, t. i, p. 612.)

Santa Fé de Bogota: elevation 8735 feet, inclination 27°.15; the chapel of Nuestra Señora de Guadalupe, built upon the projecting edge of a rock, elevation 10,794 feet, inclination 26°.80.

Popayan: elevation 5825 feet, inclination 23°.25; mountainous village of Purace on the declivity of the volcano, elevation 8671 feet, inclination 21°.80; summit of the volcano of Purace, elevation 14,548 feet, inclination 20°.30.

Quito: elevation 9541, inclination 14°.85; San Antonio de Lulumbamba, where the geographical equator intersects

who, indeed, always reversed the poles, but who made his observations with a needle which did not move freely, it follows that there has been an increase in the inclination at the Cape of Good Hope of 3°.08 in 89 years!

[43] Arago, in the *Annuaire du Bureau des Long. pour* 1825, pp. 285—288.

the torrid valley, elevation of the bottom of the valley 8153 feet, inclination 16°.02. (All the above-named inclinations have been expressed in decimal parts of a degree.)

It might perhaps be deemed unnecessary, considering the extent of the relative distances and the influence of the neighbouring kinds of rock,[44] for me to enter fully into the details of the following observations: the Hospice of St. Gotthard, 7087 feet, inclination 66° 12′; compared with Airolo, elevation 3727 feet, inclination 66° 54′, and Altorf, inclination 66° 55′; or to notice the apparently contradictory data yielded by Lans le Bourg, inclination 66° 9′, the Hospice of Mont Cenis, 6676 feet, inclination 66° 22′, and Turin 754 feet, inclination 66° 3′; or by Naples, Portici and the margin of the crater of Vesuvius; or by the summit of the Great Milischauer (Phonolith) inclination 67° 53′.5, Teplitz inclination 67° 19′.5, and Prague inclination 66°47′.6.[44] Simultaneously with the series of admirable comparative observations published with the fullest details of the horizontal intensity, which were made in 1844 by Bravais, in conjunction with Martins and Lepileur, and compared at 35 stations, including the summits of Mont Blanc (15,783 feet), of the Great St. Bernard (8364 feet), and of the Faulhorn (8712 feet), the above-named physicists made a series of inclination experiments on the grand plateau of Mont Blanc (12,893 feet), and at Chamouni (3421 feet). Although the comparison of these results showed that the elevation of the soil exerted an influence in *diminishing* the magnetic inclination, observations made at the Faulhorn and at Brienz (1870 feet in elevation) showed the opposite result of the inclination increasing with the height. The different investigations on horizontal intensity and inclination failed to yield any satisfactory solution of the problem. (Bravais, *Sur l'Intensité du Magnétisme Terrestre en France, en Suisse, et en Savoie*, in the *Annales de Chimie et de Physique*, 3ème série, t. xviii, 1846, p. 225.) In a manuscript report by Borda of his expedition

[44] I would again repeat that all the European observations of inclination which have been given in this page have been reckoned according to the division of the circle into 360 parts, and it is only in those observations of inclination which I made myself before the month of June, 1804, in the New Continent, that the centesimal division of the arc has been adhered to (*Voy. aux Régions Equinox.*, t. iii, pp. 615—623).

to the Canary Islands, in the year 1776, which is preserved at Paris in the *Dépôt de la Marine*, and which I have been enabled to consult through the obliging courtesy of Admiral Rosily, I have discovered that Borda was the first who made an attempt to investigate the influence of a great elevation on the inclination. He found that the inclination was 1° 15′ greater at the summit of the Peak of Teneriffe than in the harbour of Santa Cruz, owing undoubtedly to the local attractions of the lava, as I have often observed on Vesuvius and different American volcanoes. (Humboldt, *Voy. aux Régions Equinox.*, t. i, pp. 116, 277, 288.)

In order to try whether the deep interior portions of the body of the earth influence magnetic inclination in the same manner as elevations above the surface, I instituted an experiment during my stay at Freiberg, in July 1828, with all the care that I could bestow upon it, and with a constant inversion of the poles; when I found after very careful investigation that the neighbouring rock, which was composed of gneiss, exerted no action on the magnetic needle. The depth below the surface was 854 feet, and the difference between the inclination of the subterranean parts of the mine and those points which lay immediately above it, and even with the surface, was only 2′.06; but considering the care with which my experiments were made, I am inclined to think from the results given for each needle, as recorded in the accompanying note,[45] that the inclination is greater in

[45] In the Churprinz mine at Freiberg, in the mountains of Saxony, the subterranean point was 133½ fathoms deep, and was observed with Freiesleben and Reich at 2½ P.M. (temperature of the mine being 60°.08 F.). The dipping needle A showed 67° 37′.4, the needle B 67° 32′.7, the mean of both needles in the mine was 67° 35′.05. In the open air, at a point of the surface which lies immediately above the point of subterranean observation, the needle A stood at 11 A.M. at 67° 33′.87 and the needle B at 67° 32′.12. The mean of both needles in the upper station was 67° 32′.99, the temperature of the air being 60°.44 F., and the difference between the upper and lower result 2′.06. The needle A, which, as the stronger of the two, inspired me with most confidence, gave even 3′.53, whilst the influence of the depth remained almost inappreciable when the needle B only was used (Humboldt, in Poggend. *Annal.* Bd. xv, s. 326). I have already described in detail, and elucidated by examples, in *Asie Centr.* t. iii, pp. 465—467, the uniform method which I have always employed in reading the azimuth circle in order to find the magnetic meridian by corresponding

the Churprinz mine than on the surface of the mountain. It would be very desirable if opportunities were to present themselves in cases, where there is evidence that the rock has not exerted any local influence on the magnet, for carefully repeating my experiments in mines, in which, like those of Valenciana near Guanaxuato in Mexico, the vertical depth is 1686 feet ; or in English coal mines nearly 1900 feet deep, or in the now closed shaft at Kuttenberg in Bohemia, 3778 feet in depth.[46]

After a violent earthquake at Cumana on the 4th of November, 1799, I found that the inclination was diminished 0°.90, or nearly a whole degree. The circumstances under which I obtained this result, and which I have elsewhere fully described,[47] afford no sufficient ground for the suspicion of an error in the observation. Shortly after my arrival at Cumana I found that the inclination was 43°.53. A few days before the earthquake, I was induced to begin a long series of carefully conducted observations in the harbour of Cumana, in consequence of having accidentally noticed a statement in an otherwise valuable Spanish work, Mendoza's *Tratado de Navegacion*, t. ii, p. 72, according to which it was erroneously asserted that the hourly and monthly alterations of inclination were greater than those of variation. I found between the 1st and 2nd of November that the inclination exhibited very steadily the mean value of 43°.65. The instrument remained untouched and properly levelled on the same spot, and on the 7th of November, and therefore three days after the great earthquake and when the instrument had again been adjusted, it yielded 42°.75. The intensity of the force, measured by vertical oscillations was not changed. I expected that the inclination would perhaps gradually return to its former position, but it remained stationary. In September, 1800, in an expedition of

inclinations, or by the perpendicular position of the needle ; as also to find the inclination itself on the vertical circle by reversing the bearings of the needle and by taking the readings at both points, before and after the poles had been reversed. The position of the two needles has, in each case, been read off 16 times, in order to obtain a mean result. Where so small an amount has to be determined, it is necessary to enter fully into the individual details of the observation.

[46] *Cosmos*, vol. i, p. 148.

[47] Humboldt, *Voy. aux Régions Equinox.* t. i, pp. 515—517.

more than 2000 geographical miles on the waters and along the shores of the Orinoco and the Rio Negro, the same instrument, which was one of Borda's, which I had constantly carried with me, yielded 42°.80, showing, therefore, the same dip as before my journey. As mechanical disturbances and electrical shocks excite polarity in soft iron by altering its molecular condition, we might suspect a connection between the influences of the direction of magnetic currents and the direction of earthquakes; but carefully as I observed this phenomenon, of whose objective reality I did not entertain a doubt in 1799, I have never on any other occasion, in the many earthquakes which I experienced in the course of three years at a subsequent period in South America, noticed any sudden change of the inclination, which I could ascribe to these terrestrial convulsions, however different were the directions, in which the undulations of the strata were propagated. A very accurate and experienced observer, Erman, likewise found that after an earthquake at Lake Baikal, on the 8th of March, 1828, there was no disturbance in the declination [48] and its periodic changes.

Declination.

We have already referred to the historical facts of the earliest recognition of those phenomena, which depend upon the third element of terrestrial magnetism, namely, *declination.* The Chinese, as early as the 12th century of our era, were not only well acquainted with the fact of the variation of a horizontal magnetic needle (suspended by a cotton thread) from the geographical meridian, but they also knew how to determine the amount of this variation. The intercourse which the Chinese carried on with the Malays and Indians, and the latter with Arab and Moorish pilots, led to the extensive use of the mariner's compass amongst the Genoese, Majorcans and Catalans, in the basin of the Mediterranean, on the west coast of Africa, and in high northern latitudes; while the maps, which were published as early as 1436, even give the variation for different parts of the sea. [49] The geographical position of a

48 Erman, *Reise um die Erde,* Bd. ii, s. 180.

49 See page 52; Petrus Peregrine informs a friend that he found the variation in Italy was 5° east in 1269.

line of no variation, on which the needle turns to the true north,—the pole of the axis of the earth—was determined by Columbus on the 13th of September, 1492, and it did not escape his notice that the knowledge of the magnetic declination might serve in the determination of geographical longitudes. I have elsewhere shewn, from the Admiral's log, that when he was uncertain of the ship's reckoning, he endeavoured, on his second voyage, April, 1496, to ascertain his position by observations of declination.[50] The horary changes of variation which were simply recognized as certain facts by Hellibrand and Father Tachard, at Louvo, in Siam, were circumstantially and almost conclusively observed by Graham in 1722. Celsius was the first who made use of these observations to institute simultaneous measurements at two widely remote points.[51]

Passing to the consideration of the phenomena observed in the variation of the magnetic needle, we must first notice its alterations in respect to the different hours of the night and day, the different seasons of the year and the mean annual values; next, in respect to the influence which the extraordinary, although periodically recurring disturbances, and the magnetic position, north or south of the equator, exert on these alterations, and finally in respect to the different lines passing through the terrestrial points at which the variation is equal, or even null. These linear relations are certainly most important in respect to the direct

[50] Humboldt, *Examen. Crit. de l'Hist. de la Géogr.* t. iii, pp. 29, 36, 38, 44—51. Although Herrera (*Dec.* i, p. 23) says that Columbus had remarked that the magnetic variation was not the same by day and by night, it does not justify us in ascribing to this great discoverer a knowledge of the horary variation. The actual Journal of the admiral, which has been published by Navarreté, informs us that from the 17th to the 30th of September, 1492, Columbus had reduced everything to a so-called "unequal movement" of the polar star and the pointers (*Guardas*), *Examen Crit.* t. iii, pp. 56—59.

[51] See pages 60, 70. The first printed observations for London are those by Graham, in the *Phil. Transact. for* 1724 *and* 1725, vol. xxxiii, pp. 96—107 (*An Account of Observations made of the Horizontal Needle at London*, 1722—1723, by Mr. George Graham). The change of the variation depends "neither upon heat nor cold, dry or moist air. The variation is greatest between 12 and 4 in the afternoon, and the least at 6 or 7 in the evening." These, however, are not the true turning hours.

practical application of their results to the ship's reckoning, and to navigation generally; but all the cosmical phenomena of magnetism, amongst which we must place those extraordinary and most mysterious disturbances which often act simultaneously at very remote distances (magnetic storms), are so intimately connected with one another, that no single one of them can be neglected in our attempt gradually to complete the mathematical theory of terrestrial magnetism.

In the middle latitudes, throughout the whole northern magnetic hemisphere, (the terrestrial spheroid being assumed to be divided through the magnetic equator) the north end of the magnetic needle,—that is to say, the end which points towards the north pole,—is most closely in the direction of that pole about 8h. 15m. A.M. The needle moves from east to west, from this hour till about 1h. 45m. P.M., at which time it attains its most westerly position. This motion westward is general, and occurs at all places in the northern hemisphere, whether they have a western variation, as the whole of Europe, Pekin, Nertschinsk and Toronto, or an eastern variation, like Kasan, Sitka in Russian America, Washington, Marmato (New Grenada), and Payta on the Peruvian coast.[52] From this most westerly point, at 1h. 45m. P.M., the magnetic needle continues to retrograde

[52] Proofs of this are afforded by numerous observations of George Fuss and Kowanko, at the observatory in the Greek convent at Pekin, by Anikin at Nertschinsk, by Buchanan Riddell at Toronto in Canada; (all these being places of western variation); by Kupffer and Simonoff at Kasan; by Wrangel, notwithstanding the many disturbances from the Aurora borealis at Sitka, on the north-west coast of America; by Gilliss at Washington; by Boussingault at Marmato, in South America; and by Duperrey at Payta, on the Peruvian shores of the Pacific; (all these being places with an eastern variation). I would here observe that the mean declination was 2° 15′ 42″ west at Pekin (Dec., 1831) (Poggend. *Annalen*, Bd. xxxiv, s. 54); 4° 7′ 44″ west at Nertschinsk (Sept., 1832) (Poggend. *Op. Cit.* s. 61); 1° 33′ west at Toronto (November, 1847) (see *Observ. at the Magnetical and Meteorological Observatory at Toronto*, vol. i, p. xi, and Sabine, in the *Phil. Transact. for* 1851, pt. ii, p. 636), 2° 21′ east at Kasan (August, 1828), (Kupffer, Simonoff, and Erman, *Reise um die Erde*, Bd. ii, s. 532); 28° 16′ east at Sitka (November, 1829) (Erman, *Op. Cit.* s. 546); 6° 33′ east at Marmato (August, 1828), (Humboldt, in Poggend. *Annalen*, Bd. xv, s. 331); 8° 56′ east at Payta (August, 1823), (Duperrey, in the *Connaissance des Temps pour* 1828, p. 252). At Tiflis the declination was westerly from 7 A.M. till 2 P.M. (Parrot, *Reise zum Ararat*, 1834, Th. ii, s. 58).

towards the east throughout the whole of the afternoon and a portion of the night till midnight, or 1 A.M., while it often makes a short pause about 6 P.M. In the night there is again a slight movement towards the west, until the minimum or eastern position is reached at 8h. 15m. A.M. This nocturnal period which was formerly entirely overlooked, since a gradual and uninterrupted retrogression towards the east between 1h. 45m. P.M. and 8h. 15m. A.M. was assumed, had already been carefully studied by me at Rome, when I was engaged with Gay-Lussac in observing the horary changes of variation with one of Prony's magnetic telescopes. As the needle is generally unsteady as long as the sun is below the horizon, the small nocturnal motion westward is more seldom and less distinctly manifested. At those occasions when this motion was clearly discernible, I never saw it accompanied by any restlessness of the needle. The needle, during this small western period, passes quietly from point to point of the dial, exactly in the same manner as in the reliable diurnal period, between 8h. 15m. A.M. and 1h. 45m. P.M., and very differently from the manner in which it moves during the occurrence of the phenomenon which I have named a magnetic storm. It is very remarkable that when the needle changes its continuous western motion into an eastern movement, or conversely, it does not continue unchanged for any length of time, but it turns round almost suddenly, more especially by day, at the above-named periods, 8h. 15m. A.M. and 1h. 45m. P.M. The slight motion westward does not commonly occur until after midnight and towards the early morning. On the other hand, it has been observed at Berlin, and during the subterranean observations at Freiberg, as well as at Greenwich, Makerstoun in Scotland, Washington and Toronto, soon after 10 or 11 P.M.

The four movements of the needle, which I recognised in 1805,[53] have been represented in the admirable collection of observations made at Greenwich in the years 1845, 1846, and

[53] See extracts from a letter, which I addressed to Karsten, from Rome, June the 22nd, 1805, "On four motions of the magnetic needle, constituting, as it were, four periods of magnetic ebbing and flowing, analogous to the barometrical periods." This communication was printed in Hansteen's *Magnetismus der Erde*, 1819, s. 459. On the long disregarded nocturnal alterations of variation, see Faraday, *On the Night Episode*, §. 3012—3024.

1847, as the results of many thousand horary observations in the following four turning points,[54] namely, the first minimum at 8 A.M.; the first maximum at 2 P.M.; the second

[54] Airy, *Magnetic and Meteorological Observations made at Greenwich* (*Results*, 1845, p. 6, 1846, p. 94, 1847, p. 236). The close correspondence between the earliest results of the nocturnal and diurnal turning hours, and those which were obtained four years later, in the admirable observatories at Greenwich and at Toronto in Canada, is clearly shown by the investigation made by my old friend, Enke, the distinguished director of the observatory at Berlin, between the corresponding observations of Berlin and Breslau. He wrote as follows on the 11th of October, 1836 :—"In reference to the nocturnal maximum, or the inflection of the curve of horary variation, I do not think that there can be a doubt, as, indeed, Dove has also shown from the Freiberg observations for 1830 (Poggend. *Ann.* Bd. xix, s. 373). Graphical representations are preferable to numerical tables for affording a correct insight into this phenomenon. In the former, great irregularities at once attract the attention, and enable the observer to draw a line of average; while in the latter the eye is frequently deceived, and individual and striking irregularities are mistaken for a true maximum or minimum. The periods seem to fall regularly at the following turning hours :—

The greatest eastern declination falls at	8 A.M.	1 max.	E.
„ „ western „ „	1 P.M.	1 min.	E.
The secondary or lesser eastern max.	10 P.M.	11 max.	E.
„ „ „ western min.	4 A.M.	11 min.	E.

The secondary or lesser minimum (the nocturnal elongation westward) falls, more correctly speaking, between 3 and 5 A.M., sometimes nearer the one hour, and sometimes nearer the other." I need scarcely observe that the periods which Enke and I designate as the eastern *minima* (the principal and the secondary minimum at 4 A.M.) are named *western maxima* in the registers of the English and American stations, which were established in 1840, and consequently our *eastern maxima* (8 A.M. and 10 P.M.) would, in accordance with the same form of expression, be converted into *western minima*. In order, therefore, to give a representation of the horary motion of the needle in its general character and analogy in the northern hemisphere, I will employ the terms adopted by Sabine, beginning with the period of the *greatest western elongation*, reckoned according to the mean time of the place :—

	Freiberg. 1829.	Breslau. 1836.	Greenwich. 1846-47.
Maximum	1 P.M.	1 P.M.	2 P.M.
Minimum	1 A.M.	10 P.M.	12 P.M.
Maximum	4 A.M.	4 A.M.	4 A.M.
Minimum	8 A.M.	8 A.M.	8 A.M.

minimum at 12 P.M. or 2 A.M.; and the second maximum at 2 A.M. or 4 A.M. I must here content myself with merely giving the mean conditions, drawing attention to the fact,

	Makerstoun. 1842-43.	Toronto. 1845-47.	Washington. 1840-42.
Maximum	0h. 40m.	1 P.M.	2 P.M.
Minimum	10 P.M.	10 P.M.	10 P.M.
Maximum	2h. 15m. A.M.	2 A.M.	2 A.M.
Minimum	7h. 15m. A.M.	8 A.M.	8 A.M.

The different seasons exhibited some striking differences at Greenwich. In the year 1847 there was only one maximum (2 P.M.) and one minimum (12 night) during the winter; in the summer there was a double progression, but the secondary minimum occurred at 2 A.M. instead of 4 A.M. (p. 236). The greatest western elongation (principal maximum) remained stationary at 2 P.M. in winter as well as in summer, but the smaller or secondary minimum fell, in 1846, as usual (p. 94), at about 8 A.M. in the summer, and in winter about 12 at night. The mean winter western elongation continued without intermission throughout the whole year between midnight and 2 P.M. (see also for 1845, p. 5). We owe the erection of the observatory at Makerstoun, Roxburghshire, in Scotland, to the generous scientific zeal of Sir Thomas Brisbane (see John Allan Broun, *Obs. in Magnetism and Meteorology made at Makerstoun in* 1843, pp. 221—227). On the horary diurnal and nocturnal observations of St. Petersburg, see Kupffer, *Compte-rendu Météor. et Mag. à Mr. de Brock en* 1851, p. 17. Sabine, in his admirable and ingeniously combined graphic representation of the curve of horary declination at Toronto (*Phil. Transact. for* 1851, pt. ii, plate 27), shows that there is a singular period of rest (from 9 to 11 P.M.) occurring before the small *nocturnal* western motion, which begins about 11 P.M., and continues till about 3 A.M. "We find," he observes, "alternate progression and retrogression at Toronto twice in the 24 hours. In 2 of the 8 quarters (1841 and 1842) the inferior degree of regularity during the night occasions the occurrence of *a triple max. and min.;* in the remaining quarters the turning hours are the same as those of the mean of the 2 years." (*Obs. made at the Magn. and Meteor. Observatory at Toronto, in Canada*, vol. i, pp. xiv, xxiv, 183—191, and 228; and *Unusual Magn. Disturbances*, pt. i, p. vi.) For the very complete observations made at Washington, see Gilliss, *Magn. and Meteor. Observations made at Washington*, p. 325 (*General Law*). Compare with these Bache, *Observ. at the Magn. and Meteor. Observatory at the Girard College, Philadelphia, made in the years* 1840 *to* 1845 (3 volumes, containing 3212 quarto pages) vol. i, p. 709, vol. ii, p. 1285, vol. iii, pp. 2167, 2702. Notwithstanding the vicinity of these two places (Philadelphia lying only 1° 4′ north, and 0° 7′ 33″ east of Washington), I find a difference in the lesser periods of the western secondary maximum and secondary minimum. The former falls about 1h. 30m. and the latter about 2h. 15m. earlier at Philadelphia.

that the morning principal minimum of 8h. is not changed in our northern zone by the earlier or later time of sunrise. At the two solstitial periods, and the three equinoxes, at which, conjointly with Oltmanns, I watched the horary variations for 5 to 6 consecutive days and nights, I found that the eastern turning point remained fixed between 7h. 45m. A.M. and 8h. 15m. A.M. both in summer and in winter, and was only very slightly anticipated by the earlier period at which the sun rose.[55]

In the high northern latitudes near the Arctic circle, and between the latter and the pole of the earth's rotation, the regularity of the horary declination has not yet been very clearly recognised, although there has been no deficiency in the number of very carefully conducted observations regarding this point. The local action of the rocks and the frequency of the disturbing action of the polar light, either in the immediate vicinity or at a distance, made Lottin hesitate in drawing definite conclusions in reference to these turning hours, from his own great and careful labours, which were carried on during the French scientific expedition of Lilloise in 1836, or from the earlier results, that had been obtained with much care and accuracy by Löwenörn, in 1786. It would appear that at Reikjavik, in Iceland, 64° 8′ lat., as well as at Godthaab, on the coast of Greenland, according to observations made by the missionary, Genge, the minimum of the western variation fell almost as in the

[55] Examples of the slightly earlier occurrence of the turning hours are given by Lieutenant Gilliss, in his *Magn. Observ. of Washington*, p. 328. At Makerstoun, in Scotland (55° 35′ N. lat.), variations are observed in the secondary minimum, which occurs about 9 A.M. in the first three and the last four months of the year, and about 7 A.M. in the remaining five months (from April till August); the reverse being the case at Berlin and Greenwich (Allan Broun, *Observ. made at Makerstoun*, p. 225). The idea of heat exerting an influence on the regular changes of the horary variation, whose minimum falls in the morning near the time of the minimum of the temperature, as the maximum very nearly coincides with maximum heat, is most distinctly contradicted by the nocturnal motions of the needle, constituting the secondary min. and secondary max. "There are 2 maxima and 2 minima of variation in the 24 hours, but only one minimum and one maximum of temperature" (Relshuber, in Poggend. *Annalen der Physik und Chemie*, Bd. 85, 1852, s. 416). On the normal motion of the magnetic needle in Northern Germany, see Dove, Poggend. *Annalen*, Bd. xix, s. 364—374.

middle latitudes at about 9 or 10 A.M., whilst the maximum did not appear to occur before 9 or 10 P.M.[56] Farther to the north, at Hammerfest, in Finmark, 70° 40′ lat., Sabine found that the motion of the needle was tolerably regular, as in the south of Norway and Germany,[57] the western minimum being at 9 A.M. and the western maximum at 1h. 30m. P.M.; he found it, however, different at Spitzbergen, in 79° 50′ lat., where the above-named turning hours fell at 6 and at 7h. 30m. A.M. In reference to the Arctic polar archipelago, we possess an admirable series of observations, made during Captain Parry's third voyage, in 1825, by Lieutenants Foster and James Ross, at Port Bowen, on the eastern coast of Prince Regent's Inlet, 73° 14′ N. lat., which were extended over a period of 5 months. Although the needle passed twice in the course of 24 hours through that meridian, which was regarded as the mean magnetic meridian of the place, and although no Aurora borealis was visible for fully 2 months (during the whole of April and May), the periods of the principal elongations varied from 4 to 6 hours, and from January to May, the means of the maxima and minima of the western variation differed by only 1h.! The quantity of the declination rose in individual days from 1° 30′ to 6° or 7°, whilst at the turning periods it hardly reaches as many minutes.[58] Not only within the Arctic circle, but also in the equatorial regions, as, for instance, at Bombay, 18° 56′ lat., a great complication is observable in the horary periods of magnetic variation. These periods may be grouped into two principal classes, which present great differences between April and October on the one hand, and between October and December on the other, and these are again divided into two sub-periods, which are very far from being accurately determined.[59]

[56] *Voy. en Islande et en Groënland, exécuté en* 1835 *et* 1836, *sur la Corv. la Recherche; Physique* (1838), pp. 214—225, 358—367.

[57] Sabine, *Account of the Pendulum Experiments*, 1825, p. 500.

[58] See Barlow's "Report of the Observations at Port Bowen," in the *Edinb. New Philos. Journal*, vol. ii, 1827, p. 347.

[59] Professor Orlebar, of Oxford, former superintendent of the Magnetic Observatory of the Island of Colaba, erected at the expense of the East India Company, has endeavoured to elucidate the complicated laws of the changes of declination in the sub-periods (*Observations made at the Magn. and Meteor. Observatory at Bombay in*

Europeans could not have learnt, from their own experience, the direction of the magnetic needle in the southern hemisphere before the second half of the 15th century, when they may have obtained an imperfect knowledge of it from the adventurous expeditions of Diego Cam with Martin Behaim, and Bartholomew Diaz, and Vasco de Gama. The Chinese, who, as early as the 3rd century of our era, as well as the inhabitants of Corea and the Japanese Islands, had guided their course by the compass at sea, no less than by land, are said, according to the testimony of their earliest writers, to have ascribed great importance to the south direction of the magnetic needle, and this was probably mainly dependent on the circumstance, that their navigation was entirely directed to the south and south-west. During these southern voyages, it had not escaped their notice that the magnetic needle, according to whose direction they steered their course, did not point accurately to the south pole. We even know, from one of their determinations, the amount[60] of the variation towards the south-east, which prevailed during the 12th century. The application and farther diffusion of such nautical aids favoured the very ancient intercourse of the Chinese and Indians with Java, and to a still greater extent the voyages of the Malay races and their colonisation of the island of Madagascar.[61]

1845, *Results*, pp. 2—7. It is singular to find that the position of the needle during the first period from April to October (western min. 7h. 30m. A.M., max. 0h. 30m. P.M.; min. 5h. 30m., max. 7 P.M.) coincides so closely with that of Central Europe. The month of October is a transition period, as the amount of diurnal variation scarcely amounts to 2 minutes in November and December. Notwithstanding that this station is situated 8° from the magnetic equator, there is no obvious regularity in the turning hours. Everywhere in nature, where various causes of disturbances act upon a phenomenon of motion at recurring periods (whose duration, however, is still unknown to us), the law by which these disturbances are brought about often remains for a long time unexplained in consequence of the perturbing causes either reciprocally neutralising or intensifying one another.

[60] See my *Examen Crit. de l'Hist. de la Géogr.* t. iii, pp. 34—37. The most ancient notice of the variation given by Keutsungchy, a writer belonging to the beginning of the twelfth century, was east $\frac{2}{5}$ south. Klaproth's *Lettre sur l'invention de la Boussole*, p. 68.

[61] On the ancient intercourse of the Chinese with Java, according to statements of Fahian in the Fo-kue-si, see Wilhelm von Humboldt, *Ueber die Kawi Sprache*, Bd. i, s. 16.

Although, judging from the present very northern position of the magnetic equator, it is probable that the town of Louvo in Siam was very near the extremity of the northern magnetic hemisphere, when the missionary father, Guy Tachard, first observed the horary alterations of the magnetic variation at that place in the year 1682, it must be remembered, that accurate observations of the horary declination in the southern magnetic hemisphere were not made for fully a century later. John Macdonald watched the course of the needle during the years 1794 and 1795 in Fort Marlborough, on the south-western coast of Sumatra, as well as at St. Helena.[62] The results which were then obtained drew the attention of physicists to the great decrease in the quantity of the daily alterations of variation in the lower latitudes. The elongation scarcely amounted to 3 or 4 minutes. A more comprehensive and a deeper insight into this phenomenon was obtained through the scientific expeditions of Freycinet and Duperrey, but the erection of magnetic stations at three important points of the southern magnetic hemisphere, at Hobarton in Van Diemen's Land, at St. Helena, and at the Cape of Good Hope (where for the last 10 years horary observations have been carried on for the registration of the alterations of the three elements of terrestrial magnetism in accordance with one uniform method), afforded us the first general and systematic results. In the middle latitudes of the southern magnetic hemisphere

[62] *Phil. Transact. for* 1795, pp. 340—349, *for* 1798, p. 397. The result which Macdonald himself draws from his observations at Fort Marlborough (situated above the town of Bencoolen, in Sumatra, 3° 47′ S. lat.), and according to which the eastern elongation was on the increase from 7 A.M. to 5 P.M., does not appear to me to be entirely justified. No regular observation was made between noon and 3, 4, or 5 P.M., and it seems probable, from some scattered observations made at different times from the normal hours, that the turning hours between the eastern and western elongation fall as early as 2 P.M., precisely the same as at Hobarton. We are in possession of declination-observations made by Macdonald during 23 months (from June, 1794, to June, 1796), and from these I perceive that the eastern variation increases at all times of the year between 7h. 30m. A.M. till noon, the needle moving steadily from west to east during that period. There is here no trace of the type of the northern hemisphere (Toronto), which was observable at Singapore, from May till September; and yet Fort Marlborough lies in almost the same meridian, although to the south of the geographical equator, and only 5° 4′ distant from Singapore.

the needle moves in a totally opposite direction from that which it follows in the northern, for while in the south the needle that is pointed southward turns from east to west between morning and noon, the northern point of the needle exhibits a direction from west to east.

Sabine, to whom we are indebted for an elaborate revision of all these variations, has arranged the horary observations that were carried on for five years at Hobarton (42° 53′ S. lat., variation 9° 57′ east,) and Toronto (43° 39′ N. lat., variation 1° 33′ west), so that we can draw a distinction between the periods from October to February, and from April to August, since the intermediate months of March and September present, as it were, phenomena of transition. At Hobarton the extremity of the needle which points northwards exhibits two eastern and two western maxima of elongation,[63] so that in the period of the year from October to February it moves eastward from 8 or 9 o'clock A.M. till 2 P.M., and then from 2 till 11 P.M., somewhat to the west, from 11 P.M. to 3 A.M. it again turns eastward, and from 3 to 8 A.M. it goes back to the west. In the period between April and August, the eastern turning hours are later, occurring at 3 P.M. and 4 A.M., whilst the western turning hours fall earlier, namely at 10 A.M. and at 11 P.M. In the northern magnetic hemisphere the motion of the needle westward from 8 A.M. till 1 P.M. is greater in the summer than in the winter, whilst in the southern magnetic hemisphere, where the motion has an opposite direction between the above-named turning hours, the quantity of the elongation is greater when the sun is in the southern than when it is in the northern signs.

The question which I discussed seven years ago in the Picture of Nature,[64] whether there may not be a region of the earth, probably between the geographical and magnetic equators, in which there is no horary variation (before the return of the northern extremity of the needle to an opposite direction of variation in the same hours), is one which

[63] Sabine, *Magn. Observ. made at Hobarton*, vol. i (1841 and 1842), pp. xxxv; 2, 148; vol. ii (1843—1845), pp. iii—xxxv, 172—344. See also Sabine, *Obs. made at St. Helena*, and in *Phil. Transact. for* 1847, pt. i, p. 55, pl. iv, and *Phil. Transact. for* 1851, pt. ii, p. 36, pl. xxvii.

[64] *Cosmos*, vol. i, p. 176.

it would seem from recent experiments, and more especially since Sabine's ingenious discussions of the observations made at Singapore (1° 17′ N. lat.), at St. Helena (15° 56′ S. lat.), and at the Cape of Good Hope (33° 56′ S. lat.), must be answered in the negative. No point has hitherto been discovered, at which the needle does not exhibit a horary motion, and since the erection of magnetic stations, the important and very unexpected fact has been evolved, that there are places in the southern magnetic hemisphere, at which the horary variations of the dipping needle alternately participate in the phenomena (types) of both hemispheres. The island of St. Helena lies very near the line of weakest magnetic intensity, in a region where this line divaricates very widely from the geographical equator and from the line of no inclination. At St. Helena, the movement of the end of the needle which points to the north is entirely opposite in the months from May to September from the direction which it follows in the analogous hours from October to February. It has been found after five years' horary observations, that during the winter of the southern hemisphere, in the above-named periods of the year, while the sun is in the northern signs, the northern point of the needle has the greatest eastern variation at 7 A.M., from which hour, as in the middle latitudes of Europe and North America, it moves westward till 10 A.M. and remains very nearly stationary until 2 P.M. At other parts of the year, on the other hand, namely from October till February, (which constitutes the summer of the southern hemisphere and when the sun is in the southern signs and therefore nearest to the earth) the greatest western elongation of the needle falls about 8 A.M., showing a movement from west to east until noon, precisely in accordance with the type of Hobarton (42° 53 S. lat.), and of other districts of the middle parts of the southern hemisphere. At the time of the equinoxes, or soon afterwards, as for instance in March and April, as well as in September and October, the course of the needle fluctuates on individual days, showing periods of transition from one type to another, from that of the northern to that of the southern hemisphere.[65]

[65] Sabine, *Observations made at the Magn. and Meteor. Observatory at St. Helena in* 1840—1845, vol. i, p. 30, and in the *Phil. Transact. for*

Singapore lies a little to the north of the geographical equator, between the latter and the magnetic equator, which, according to Elliot, coincides almost exactly with the curve of lowest intensity. According to the observations which were made at Singapore every two hours during the years 1841 and 1842, Sabine again finds the St. Helena types in the motion of the needle from May to August and from November to February; the same occurs at the Cape of Good Hope, which is 34° distant from the geographical and still more remote from the magnetic equator, and where the inclination is 53° south and the sun never reaches the zenith.[66] We possess the published horary observations made

1847, pt. i, pp. 51—56, pl. iii. The regularity of this opposition in the two divisions of the year, the first occurring between May and September (type of the middle latitudes in the northern hemisphere), and the next between October and February (type of the middle latitudes in the southern hemisphere), is graphically and strikingly manifested when we separately compare the form and inflections of the curve of horary variation in the portions of the day intervening between 2 P.M. and 10 A.M., between 10 A.M. and 4 P.M., and between 4 P.M. and 2 A.M. Every curve above the line which indicates the mean declination has an almost similar one corresponding to it below it (vol. i, pl. iv, the curves AA and BB). This opposition is perceptible even in the nocturnal periods, and it is still more remarkable, that while the type of St. Helena and of the Cape of Good Hope is found to be that belonging to the northern hemisphere, the same earlier occurrence of the turning hours which is observed in Canada (Toronto) is noticed in the same months at these two southern points. Sabine, *Observ. at Hobarton*, vol. i, p. xxxvi.

[66] *Phil. Transact. for* 1847, pt. i, pp. 52, 57, and Sabine, *Observations made at the Magn. and Meteor. Observatory at the Cape of Good Hope*, 1841—1846, vol. i, p. xii—xxiii, pl. iii. See also Faraday's ingenious views regarding the causes of those phenomena, which depend upon the alternations of the seasons, in his *Experiments on Atmospheric Magnetism*, § 3027—3068, and on the analogies with St. Petersburg, § 3017. It would appear that the singular type of magnetic declination, varying with the seasons, which prevails at the Cape of Good Hope, St. Helena, and Singapore, has been noticed on the southern shores of the Red Sea by the careful observer, d'Abbadie (Airy, *On the Present State of the Science of Terrestrial Magnetism*, 1850, p. 2). "It results from the present position of the four points of maximum of intensity at the surface of the earth," observes Sabine, "that the important curve of the relatively, but not absolutely, weakest intensity in the Southern Atlantic Ocean should incline away from the vicinity of St. Helena, in the direction of the southern extremity of Africa. The astronomico-geographical position of this southern extremity, where the sun remains throughout the whole year north of the zenith, affords a

at the Cape for six years, from May to September, according to which, almost precisely as at St. Helena, the needle moves westward till 11 h. 30 m. A.M. from its extreme eastern position (7h. 30m. A.M.), while from October to March it moves eastward from 8h. 30m. A.M. to 1h. 30m. and 2 P.M. The discovery of this well-attested, but still unexplained and obscure phenomenon, has more especially proved the importance of observations continued uninterruptedly from hour to hour for many years. Disturbances which, as we shall soon have occasion to show, have the power of diverting the needle either to the eastward or westward for a length of time, would render the isolated observations of travellers uncertain.

By means of extended navigation and the application of the compass to geodetic surveys, it was very early noticed that at certain times the magnetic needle exhibited an extraordinary disturbance in its direction, which was frequently connected with a vibratory, trembling and fluctuating motion. It became customary to ascribe this phenomenon to some special condition of the needle itself, and this was characteristically designated by French sailors *l'affolement de l'aiguille*, and it was recommended that *une aiguille affolée* should be again more strongly magnetised. Halley was certainly the first who inferred that polar light was a magnetic phenomenon—a statement [67] which he made on the occasion

principal ground of objection against de la Rive's thermal explanation (*Annales de Chimie et de Physique*, t. xxv, 1849, p. 310) of the phenomenon of St. Helena here referred to, which, although it seems at first sight apparently abnormal, is nevertheless entirely in accordance with established law, and is found to occur at other points." See Sabine, in the *Proceedings of the Royal Society*, 1849, p. 821.

[67] Halley, *Account of the late surprising appearance of Lights in the Air*, in the *Phil. Transact.* vol. xxix, 1714—1716, No. 347, pp. 422—428. Halley's explanation of the Aurora borealis is unfortunately connected with the fantastic hypothesis which had been enounced by him twenty-five years earlier, in the *Phil. Transact. for* 1693, vol. xvii, No. 195, p. 563, according to which there was a luminous fluid in the hollow terrestrial sphere lying between the outer shell which we inhabit and the inner denser nucleus, which is also inhabited by human beings. These are his words:—"In order to make that inner globe capable of being inhabited, there might not improbably be contained some luminous medium between the balls, so as to make a perpetual day below." Since the outer shell of the earth's crust is far less thick in the region of the poles of rotation (owing to the compression produced at those

of his being invited by the Royal Society of London to explain the great meteor of the 6th of March, 1716, which was seen in every part of England. He says, "that the meteor is analogous with the phenomenon, which Gassendi first designated in 1621 by the name of *Aurora borealis.*" Although in his voyages for the determination of the line of variation, he advanced as far south as 52°, yet we learn from his own confession, that he had never seen a northern, or southern polar light before the year 1716, although the latter, as I can testify, is visible in the middle of the tropical zone of Peru. Halley, therefore, does not appear from his own observation to have been aware of the restlessness of the needle, or of the extraordinary disturbances and fluctuations which it exhibits at the periods of visible, or invisible northern or southern polar lights. Olav Hiörter and Celsius at Upsala were the first who, in the year 1741, and therefore before Halley's death, confirmed by a long series of measurements and determinations the connection, which he had merely conjectured to exist between the appearance of the Aurora borealis and a disturbance in the normal course of the needle. This meritorious investigation led them to enter into an arrangement for carrying on systematic observations simultaneously with Graham in London, while the extraordinary disturbances of variation, observed on the appearance of the Aurora, were made subjects of special investigation by Wargentin, Canton, and Wilke.

The observations which I had the opportunity of making, conjointly with Gay-Lussac, in 1805, on the Monte Pincio at Rome, and more especially the investigations suggested by these observations, and which I prosecuted conjointly with Oltmanns during the equinoctial and solstitial periods of

parts) than at the equator, the inner luminous fluid (that is, the magnetic fluid), seeks at certain periods, more especially at the times of the equinoxes, to find itself a passage in the less thick polar regions through the fissures of rocks. The emanation of this fluid is, according to Halley, the phenomenon of the northern light. When iron filings are strewn over a spheroidal magnet (a *terella*), they serve to show the direction of the luminous coloured rays of the Aurora. "As each one sees his own rainbow, so also the *Corona* appears to every observer to be at a different point" (p. 424). Regarding the geognostic dreams of an intellectual investigator, who displayed such profound knowledge in all his magnetic and astronomical labours, see *Cosmos,* vol. i, p. 163.

the years 1806 and 1807, in a large isolated garden at Berlin, by means of one of Prony's magnetic telescopes, and of a distant tablet-signal, which admitted of being well illuminated by lamp-light, showed me that this element of terrestrial activity (which acts powerfully at certain epochs, and not merely locally, and which has been comprehended under the general name of extraordinary disturbances), is worthy, on account of its complicated nature, of being made the subject of continuous observation. The arrangement of the signal and the cross wires in the telescope, which was suspended in one instance to a silken thread and in another to a metallic wire, and attached to a bar magnet, enclosed in a large glass case, enabled the observer to read off to 8″ in the arc. As this method of observation allowed of the room in which the telescope and the attached bar-magnet stood, being left unilluminated by night, all suspicion of the action of currents of air was removed, and those disturbances avoided, which otherwise are apt to arise from the illumination of the scale in variation compasses, provided with microscopes, however perfect they may otherwise be. In accordance with the opinion then expressed by me that "a continuous uninterrupted hourly and half-hourly observation (*Observatio Perpetua*) of several days and nights was greatly to be preferred to isolated observations extending over many months," we continued our investigations for 5, 7, and even 11 days and nights consecutively,[68] during the equinoctial and solstitial periods—the importance of such observations at these times being admitted by all recent observers. We soon perceived that, in order to study the peculiar physical character of these anomalous disturbances, it was not sufficient to determine the amount of the alteration of the variation, but that the numerical degree of disturbance of the needle must be appended to each observation by obtaining the measured elongation of the oscillations. In the ordinary horary course of the needle, it was found to be so quiet that in 1500 re-

[68] When greatly fatigued by observing for many consecutive nights, Professor Oltmanns and myself were occasionally relieved by very trustworthy observers, as, for instance, by Mämpel, the geographer Friesen, the skilful mechanician Nathan Mendelssohn, and our great geognosist, Leopold von Buch. It has always afforded me pleasure to record the names of those who have kindly assisted me in my labours.

sults, deduced from 6000 observations, made from the middle of May, 1806, to the end of June, 1807, the oscillation generally fluctuated only from one-half of a graduated interval to the other half, amounting therefore only to 1′ 12″; in individual cases, and often when the weather was very stormy and much rain was falling, the needle appeared to be either perfectly stationary, or to vary only 0.2 or 0.3 of a graduated interval, that is to say, about 24″ or 28″. But on the occurrence of a magnetic storm, whose final and strongest manifestation is the Aurora borealis, the oscillations were either in some cases only 14′ and in others 38′ in the arc, each one being completed in from $1\frac{1}{2}$ to 3 seconds of time. Frequently, on account of the magnitude and inequality of the oscillations, which far exceeded the scale parts of the tablet in the direction of one or both of its sides, it was not possible to make any observation.[69] This, for instance, was the

[69] The month of September, 1806, was singularly rich in *great magnetic disturbances.* By way of illustration, I will give the following extracts from my journal:—

$\frac{21}{22}$	Sept.	1806,	from	4h. 36m.	A.M.	till	5h. 43m.	A.M.
$\frac{22}{23}$	”	”	”	4h. 40m.	”	”	7h. 2m.	”
$\frac{23}{24}$	”	”	”	3h. 33m.	”	”	6h. 27m.	”
$\frac{24}{25}$	”	”	”	3h. 4m.	”	”	6h. 2m.	”
$\frac{25}{26}$	”	”	”	2h. 22m.	”	”	4h. 30m.	”
$\frac{26}{27}$	”	”	”	2h. 12m.	”	”	4h. 3m.	”
$\frac{27}{28}$	”	”	”	1h. 55m.	”	”	5h. 27m.	”
$\frac{28}{29}$	”	”	”	0h. 3m.	”	”	1h. 22m.	”

The disturbance last referred to was very small, and was succeeded by the greatest quiet, which continued throughout the whole night, and until the following noon.

$\frac{29}{30}$ Sept. 1806, from 10h. 20m. P.M. till 11h. 32m. P.M.

This was a small disturbance, which was succeeded by great calm until 5h. 6m. A.M. $\frac{30}{1}$ $\frac{\text{Sept.}}{\text{Oct.}}$, 1806, about 2h. 46m. A.M. a great but short magnetic storm, followed by perfect calm. Another equally great magnetic disturbance about 4h. 30m. A.M.

The great storm of $\frac{25}{26}$ September had been preceded by a still greater disturbance from 7h. 8m. till 9h. 11m. P.M. In the following winter months there was only a very small number of storms, and these could not be compared with the disturbances during the autumnal equinox. I apply the term *great storm* to a condition in which the needle makes oscillations of from 20 to 38 minutes, or passes beyond all the scale parts of the segment, or when it is impossible to make any observation. In small storms, the needle makes irregular oscillations of from 5 to 8 minutes.

case for long and uninterrupted periods during the night of the 24th September, 1806, lasting on the first occasion from 2 h. 0 m. to 3 h. 32 m. A.M., and next from 3h. 57m. to 5h. 4m. A.M.

In general, during unusual or larger magnetic disturbances (magnetic storms), the mean of the arc of the oscillations exhibited an increase either westward or eastward, although with irregular rapidity, but in a few cases, extraordinary fluctuations were also observed, even when the variation was not irregularly increased or decreased, and when the mean of the oscillations did not exceed the limits appertaining to the normal position of the needle at the given time. We saw, after a relatively long rest, sudden motions of very unequal intensity, describing arcs of from 6′ to 15′, either alternating with one another or abnormally intermixed, after which the needle would become suddenly stationary. At night, this mixture of total quiescence and violent perturbation without any progression to either side was very striking.[70] One special modification of the motion,

[70] Arago, during the ten years in which he continued to make careful observations at Paris (till 1829), never noticed any oscillations without *a change in the variation.* He wrote to me as follows, in the course of that year :—"I have communicated to the Academy the results of our simultaneons observations. I am surprised to notice the oscillations which the dipping needle occasionally exhibited at Berlin during the observations of 1806, 1807, and of 1828—1829, even when the mean declination was not changed. Here (at Paris) we never experience anything of the kind. The only time at which the needle exhibits violent oscillations is on the occurrence of an Aurora borealis, and when its absolute direction has been considerably disturbed; and even then, the disturbances of direction are *most frequently* unaccompanied by any oscillatory movement." The condition here described is, however, entirely opposite to the phenomena which were observed at Toronto (43° 91′ N. lat.) during the years 1840 and 1841; and which correspond accurately with those manifested at Berlin. The observers at Toronto have paid so much attention to the nature of the motion that they indicate whether the vibrations and shocks are "strong" or "slight," and characterise the disturbances in accordance with definite and uniform subdivisions of the scale, following a fixed and uniform nomenclature. Sabine, *Days of Unusual Magn. Disturbances,* vol. i, pt. i, p. 46. Six groups of successive days (146 in all) are given from the two above-named years in Canada, which were marked by very strong shocks, without any perceptible change in the horary declination. Such groups (see *op. cit.* pp. 47, 54, 74, 88, 95, 101), are designated as *"Times of Observations at Toronto, at which the magnetometers were dis-*

which I must not pass without notice, consisted in the very rare occurrence of a vertical motion, a kind of tilting motion, an alteration of the inclination of the northern point of the needle, which was continued for a period of from 15 to 20 minutes, accompanied by either a very moderate degree of horizontal vibration or by the entire absence of this movement. In the careful enumeration of all the secondary conditions which are recorded in the registers of the English observatories, I have only met with three references to "constant vertical motion, the needle oscillating vertically,"[71] and these three instances occurred in Van Diemen's Land.

The periods of the occurrence of the greater magnetic storms fell, according to the mean of my observations in Berlin, about 3 hours after midnight, and generally ceased about 5 A.M. We observed lesser disturbances during the daytime, as, for instance, between 5 and 7 P.M., and frequently on the same days of September, during which violent storms occurred after midnight, when, owing to the magnitude and rapidity of the oscillations, it was impossible to read them off or to estimate the means of their elongation. I soon became so convinced of the occurrence of magnetic storms in groups during several nights consecutively, that I acquainted the Academy at Berlin with the peculiar nature of these extraordinary disturbances, and even invited my friends to visit me at predetermined hours, at which I hoped they might have an opportunity of witnessing this phenomenon, and in general I was not deceived in my anticipa-

turbed, but the mean readings were not materially changed." The changes of variation were also nearly always accompanied by strong vibrations at Toronto during the frequent Auroræ boreales; in some cases these vibrations were so strong as entirely to prevent the observations from being read off. We learn, therefore, from these phenomena, whose further investigation we cannot too strongly recommend, that although momentary changes of declination which disturb the needle may often be followed by great and definite changes of variation (Younghusband, *Unusual Disturbances*, pt. ii, p. x), the size of the arc of vibration in no respect agrees with the amount of the alteration in the declination; that in very inconsiderable changes of variation the vibrations may be very strong, while the progressive motion of the needle towards a western or eastern declination may be rapid and considerable, independently of any vibration; and further, that these processes of magnetic activity assume a *special and different character at different places.*

[71] *Unusual Disturb.* vol. i, pt. i, pp. 69, 101.

tions.[72] Kupffer, during his travels in the Caucasus in 1829, and at a later period, Kreil, in the course of the valuable observations which he made at Prague, were both enabled to confirm the recurrence of magnetic storms at the same hours.[73]

The observations which I was enabled to make during the year 1806, at the equinoctial and solstitial periods, in reference to the extraordinary disturbances in the variation, have become one of the most important acquisitions to the theory of terrestrial magnetism, since the erection of magnetic stations in the different British colonies (from 1838 to 1840), through the accumulation of a rich harvest of materials, which have been most skilfully elaborated by General Sabine. In the results of both hemispheres this talented observer has separated magnetic disturbances, according to diurnal and nocturnal hours, according to different seasons of the year, and according to their deviations eastward or westward. At Toronto and Hobarton the disturbances were twice as frequent and strong by night as by day,[74] and the same was the case in the oldest observations at Berlin; exactly the reverse of what was found in from 2600 to 3000 disturbances at the Cape of Good Hope, and more especially at the island of St. Helena, according to the elaborate investigation of Cap-

[72] This was at the end of September, 1806. This fact, which was published in Poggendorff's *Annalen der Physik*, Bd. xv (April, 1829), s. 330, was noticed in the following terms:—"The older horary observations which I made conjointly with Oltmanns, had the advantage that at that period (1806 and 1807), none of a similar kind had been prosecuted either in France or in England. They gave the *nocturnal* maxima and minima; they also showed how remarkable *magnetic storms* could be recognised, which it is often impossible to record, owing to the intensity of the vibrations, and which occur for many nights consecutively at the same time, although no influence of meteorological relations has hitherto been recognised as the inducing cause of the phenomena." The earliest record of a certain periodicity of extraordinary disturbances was not, therefore, noticed for the first time in the year 1839. *Report of the Fifteenth Meeting of the British Association at Cambridge*, 1845, pt. ii, p. 12.

[73] Kupffer, *Voyage au Mont Elbruz dans le Caucase*, 1829, p. 108. "Irregular deviations often recur at the same hour and for several days consecutively."

[74] Sabine, *Unusual Disturb.* vol. i, pt. i, p. xxi, and Younghusband, *On Periodical Laws in the Larger Magnetic Disturbances*, in the *Phil. Transact. for* 1853, pt. i, p. 173.

tain Younghusband. At Toronto the principal disturbances generally occurred in the period from midnight to 5 A.M.; it was only occasionally that they were observed as early as from 10 P.M. to midnight, and consequently they predominated by night at Toronto, as well as at Hobarton. After having made a very careful and ingenious investigation of the 3940 disturbances at Toronto, and the 3470 disturbances at Hobarton, which were included in the cycle of 6 years (from 1843 to 1848), of which the disturbed variations constituted the ninth and tenth parts, Sabine was enabled to draw the conclusion[75] that "the disturbances belong to a special kind of periodically recurring variations, which follow recognisable laws, depend upon the position of the sun in the ecliptic and upon the daily rotation of the earth round its axis, and, further, ought no longer to be designated as irregular motions, since we may distinguish in them, in addition to a special local type, processes which affect the whole earth." In those years in which the disturbances were more frequent at Toronto, they occurred in almost equal numbers in the southern hemisphere at Hobarton. At the first-named of these places these disturbances were, on the whole, doubly as frequent in the summer, namely from April to September, as in the winter months, from October to March. The greatest number fell in the month of September, in the same manner as at the autumn equinox in my Berlin observations of 1806.[76] They are more rare in the winter months in all places; at

[75] Sabine, in the *Phil. Transact. for* 1851, pt. i, pp. 125—127. "The *diurnal variation* observed is in fact constituted by two variations *superposed* upon each other, having different laws, and bearing different proportions to each other in different parts of the globe. At tropical stations the influence of what have been hitherto called the *irregular* disturbances (*magnetic storms*), is comparatively feeble; but it is otherwise at stations situated as are Toronto (Canada) and Hobarton (Van Diemen's Island), where their influence is both really and proportionally greater, and amounts to a clearly recognisable part of the whole diurnal variation." We find here, in the complicated effect of simultaneous but different causes of motion, the same condition which has been so admirably demonstrated by Poisson in his theory of waves (*Annales de Chimie et de Physique*, t. vii, 1817, p. 293). "Waves of different kinds may cross each other in the water as in the air, where the smaller movements are *superposed* upon each other." See Lamont's conjectures regarding the compound effect of a *polar* and an *equatorial wave*, in Poggend. *Annalen*, Bd. lxxxiv, s. 583.

[76] See p. 134.

Toronto they occur less frequently from November till February, and at Hobarton from May till August. At St. Helena and at the Cape of Good Hope the periods, at which the sun crosses the equator, are characterised, according to Younghusband, by a very decided frequency in the disturbances.

The most important point, and one which was also first noticed by Sabine in reference to this phenomenon, is the regularity with which, in both hemispheres, the disturbances occasion an augmentation in the eastern or western variation. At Toronto, where the declination is slightly westward (1° 33′), the progression eastward in the summer, that is, from June till September, preponderated over the progression westward during the winter (from December till April), the ratio being 411 : 290. In like manner, in Van Diemen's Land, taking into account the local seasons of the year, the winter months (from May till August) are characterised by a strikingly diminished frequency of magnetic storms.[77] The co-ordination of the observations obtained in the course of 6 years at the two opposite stations, Toronto and Hobarton, led Sabine to the remarkable result that, from 1843 to 1848, there was in both hemispheres not only an increase in the number of the disturbances, but also (even when, in order to determine the normal annual mean of the daily variation, 3469 storms were excluded from the calculation,) that the amount of total variation from this mean gradually progressed during the above-named five years from 7′.65 to 10′.58. This increase was simultaneously perceptible, not only in the amplitude of the declination, but also in the inclination and in the total terrestrial force. This result acquired additional importance from the confirmation and generalisation afforded to it by Lamont's complete treatise (September, 1851) "regarding a decennial period, which is perceptible in the daily motion of the magnetic needle." According to the observations made at Göttingen, Munich, and Kremsmünster,[78] the mean amplitude of the daily declination attained its

[77] Sabine, in the *Phil. Transact. for* 1852, pt. ii, p. 110 (Younghusband, *op. cit.* p. 169).

[78] According to Lamont and Relshuber, the magnetic period is 10 years 4 months, so that the amount of the mean of the diurnal motion of the needle increases regularly for 5 years, and decreases for

minimum between 1843 and 1844, and its maximum from 1848 to 1849. After the declination has thus increased for 5 years it again diminishes for a period of equal length, as is proved by a series of exact horary observations, which go back as far as to a maximum in 1786½.[79] In order to discover a general cause for such a periodicity in all three elements of telluric magnetism, we are disposed to refer it to cosmical influences. Such a connection is indeed appreciable, according to Sabine's conjecture, in the alterations which take place in the photosphere, that is to say, in the luminous gaseous envelopes of the dark body of the sun.[80] According to the investigations which were made throughout a long series of years by Schwabe, the period of the greatest and smallest frequency of the solar spots entirely coincides with that which has been discovered in magnetic variations. Sabine first drew attention to this coincidence in a memoir which he laid before the Royal Society of London, in March, 1852. "There can be no doubt," says Schwabe, in the remarks with which he has enriched the astronomical portion of the present work, "that, at least from the year 1826 to 1850, there has been a recurring period of about 10 years in the appearance of the sun's spots, whose maxima fell in the years 1828, 1837, and 1848, and the minima in the years 1833 and 1843."[81] The important influence exerted by the sun's body, as a mass, upon terrestrial magnetism is confirmed by Sabine in the ingenious observation, that the period at which the intensity of the magnetic force is greatest, and the direction of the needle most near to the vertical line, falls, in both hemispheres, between the months of October and

the same length of time; on which account the winter motion (the *amplitude* of declination) is always twice as small as the summer motion (see Lamont, *Jahresbericht der Sternwarte zu München für* 1852, s. 54—60). The Director of the Observatory at Berne, Rudolph Wolf, finds by a much more comprehensive series of operations, that the period of magnetic declination which coincides with the frequency of the solar spots, must be estimated at 11.1 years.

[79] See page 75.

[80] Sabine, in the *Phil. Transact. for* 1852, pt. i, pp. 103, 121. See the observations made in July, 1852, by Rudolph Wolf, above referred to in page 76 of the present volume; also the very similar conjectures of Gautier, which were published very nearly at the same time in the *Bibliothêque Universelle de Genève*, t. xx, p. 189.

[81] *Cosmos,* vol. iv, p. 397—400.

February; that is to say, precisely at the time when the earth is nearest to the sun, and moves in its orbit with the greatest velocity.[82]

I have already treated in the Picture of Nature[83] of the simultaneity of many magnetic storms, which are transmitted for thousands of miles and indeed almost round the entire circumference of the earth, as on the 25th of September, 1841, when they were simultaneously manifested in Canada, Bohemia, the Cape of Good Hope, Van Diemen's Land, and Macao; and I have also given examples of those cases, in which the perturbations were of a more local kind, passing from Sicily to Upsala, but not from Upsala farther north in the direction of Alten and Lapland. In the simultaneous observations of declination which were instituted by Arago and myself in 1829 at Berlin, Paris, Freiberg, St. Petersburg, Casan, and Nikolajew, with the same Gambey's instruments, individual perturbations of a marked character were not transmitted from Berlin as far as Paris, and not on any one occasion to the mine at Freiberg, where Reich was making a series of subterranean observations on the magnet. Great variations and disturbances of the needle simultaneously with the occurrence of the Aurora borealis at Toronto certainly occasioned magnetic storms in Kerguelen's Land, but not at Hobarton. When we consider the capacity for penetrating through all intervening bodies, which distinguishes the magnetic force, as well as the force of gravity inherent in all matter, it is certainly very difficult to form a clear conception of the obstacles which may prevent its transmission through the interior of the earth. These obstacles are analogous to those which we observe in sound-waves, or in the waves of commotion in earthquakes, in which certain

82 Sabine, in the *Phil. Transact. for* 1850, pt. i, p. 216. Faraday, *Exper. Researches on Electricity,* 1851, pp. 56, 73, 76, § 2891, 2949, 2958.

83 *Cosmos,* vol. i, p. 185; Poggend. *Annalen,* Bd. xv, s. 334, 335; Sabine, *Unusual Disturb.* vol. i, pt. i, pp. xiv—xviii; where tables are given of the simultaneous storms at Toronto, Prague, and Van Diemen's Land. On those days in which the magnetic storms were the most marked in Canada (as, for instance, on the 22nd of March, the 10th of May, the 6th of August, and the 25th of September, 1841), the same phenomena were observed in the southern hemisphere in Australia. See also Edward Belcher, in the *Phil. Transact. for* 1843, p. 133.

spots which are situated near one another never experience the shocks simultaneously.[84] Is it possible that certain magnetic intersecting lines may by their intervention oppose all further transmission?

We have here described the regular and the apparently irregular motions presented by horizontally suspended needles. If by an examination of the normal recurring motion of the needle we have been enabled from the mean numbers of the extremes of the horary variations to ascertain the direction of the magnetic meridian, in which the needle has vibrated equally to either side, from one solstice to another, the comparison of the angles which the magnetic meridian describes at different parallels with the geographical meridian has led in the first place to the knowledge of lines of variation of strikingly heterogeneous value (Andrea Bianco, in 1436, and Alonzo de Santa Cruz, cosmographer to the Emperor Charles V., even attempted to lay down these lines upon charts); and more recently to the successful generalization of *isogonic curves, lines of equal variation*, which British seamen have long been in the habit of gratefully designating by the historical name of *Halley's lines*. Among the variously curved and differently arranged closed systems of isogonic lines, which are sometimes almost parallel, and more rarely re-enter themselves so as to form oval closed systems, the greatest attention in a physical point of view is due to those lines, on which the variation is null, and on both sides of which variations of opposite denominations prevail, which increase unequally with the distance.[85] I have already elsewhere shown how the first discovery made by Columbus on the 13th of September, 1492, of a line of no variation in the Atlantic Ocean, gave an impetus to the study of terrestrial magnetism, which, however, continued for two centuries and a half to be directed solely to the discovery of better methods for obtaining the ship's reckoning.

However much the higher scientific education of mariners in recent times and the improvement of instruments and methods of observation have extended our knowledge of

[84] *Cosmos*, vol. i, p. 208.

[85] *Op. cit.* vol. i, pp. 187—189; vol. ii, pp. 657—659 and pp. 52—60 of the present volume.

individual portions of lines of no variation in Northern Asia, in the Indian Archipelago and the Atlantic Ocean, we have still to regret, that in this department of our knowledge, where the necessity of cosmical elucidation is strongly felt, the progress has been tardy and the results deficient in generalization. I am not ignorant that a large number of observations of accidental crossings of lines of no variation have been noted down in the logs of various ships, but we are deficient in a comparison and co-ordination of the materials, which cannot acquire any importance in reference to this object or in respect to the position of the magnetic equator, until individual ships shall be despatched to different seas for the sole purpose of uninterruptedly following these lines throughout their course. Without a simultaneity in the observations, we can have no history of terrestrial magnetism. I here merely reiterate a regret which I have often previously expressed.[86]

[86] At very different periods, once in 1809, in my *Recueil d'Observ. Astron.* vol. i, p. 368, and again, in 1839, when, in a letter addressed to the Earl of Minto, then First Lord of the Admiralty, a few days before the departure of Sir James Ross on his Antarctic expedition, I endeavoured more fully to develope the importance of the proposition advanced in the text (see *Report of the Committee of Physics and Meteor. of the Royal Soc. relative to the Antarctic Exped.* 1840, pp. 88—91). "In order to follow the indications of the magnetic equator or those of the lines of no variation, the ship's course must be made to cross the lines 0 at very small distances, the bearings being changed each time that observations of inclination or of declination show that the ship has deviated from these points. I am well aware that, in accordance with the comprehensive views of the true basis for a *general theory of terrestrial magnetism,* which we owe to Gauss, a thorough knowledge of the *horizontal intensity,* and the choice of the points at which the three elements of declination, inclination, and total intensity have all been simultaneously measured, suffice for finding the value of $\frac{V}{R}$ (Gauss, § 4 and 27), and that these are the essential points for future investigations; but the sum total of *the small local attractions,* the requirements of steering ships, the ordinary corrections of the compass, and the safety of navigation continue to impart special importance to the knowledge of the position, and to the movements of the periodic translation of *lines of no variation.* I here plead the cause of these various requirements, which are intimately connected with the interests of physical geography." Many years must still pass before seamen can be enabled to guide the ship's course by charts of variation, constructed in accordance with the theory of terrestrial magnetism (Sabine, in the *Phil. Transact. for* 1849, pt. ii, p. 204), and the wholly objective view directed to actual observa-

According to the facts which we already generally know concerning the position of lines of no variation, it would appear that instead of the four meridian systems which were believed at the end of the 16th century to extend from pole to pole,[87] there are probably three very differently formed systems of this kind, if by this name we designate those groups in which the line of variation does not stand in any direct connection with any other line of the same kind, or cannot, in accordance with the present state of our knowledge, be regarded as the continuation of any other line. Of these three systems which we will separately describe, the middle, or Atlantic, is limited to a single line of no variation, inclining from SS.E. to NN.W. between the parallels of 65° south and 67° north latitude. The second system, which lies fully 150° farther east, occupying the whole of Asia and Australia, is the most extended, and most complicated of all, if we merely take into account the points at which the line of no variation intersects the geographical equator. This system rises and falls in a remarkable manner, exhibiting one curvature directed southward and another

tion, which I would here advocate, would, if it led to periodically-repeated determinations, and consequently to expeditions prosecuted simultaneously by land and sea, in accordance with some preconcerted plan, give the double advantage of, in the first place, yielding a direct practical application and affording us a correct knowledge of the annual progressive movement of these lines; and secondly, of supplying many new data for the further development of the theory enounced by Gauss (Gauss, § 25). It would, moreover, greatly facilitate the accurate determination of the *progression of the two lines of no inclination and no varition,* if *landmarks* could be established at those points, where the lines enter or leave continents at stated intervals, as, for instance, in the years 1850, 1875, 1900. . . . . In expeditions of this kind, which would be similar to those undertaken by Halley, many isoclinal and isogonic systems would necessarily be intersected before the lines of no declination and no inclination could be reached, and by this means the horizontal and total intensities might be measured along the coasts, so that several objects would thus be simultaneously attained. The views which I have here expressed are, I am happy to find, supported by a very great authority in nautical questions, viz. Sir James Ross. (See his *Voyage in the Southern and Antarctic Regions,* vol. i, p. 105.)

87 Acosta, *Historia de las Indias,* 1590, lib. i, cap. 17. I have already considered the question whether the opinion of Dutch navigators regarding the existence of four lines of no variation may not, through the differences between Bond and Beckborrow, have had some influence on Halley's theory of four magnetic poles (*Cosmos,* vol. ii, p. 658)

northward; indeed it is so strongly curved at its north-eastern extremity that the line of no variation forms an ellipse, surrounding those lines which rapidly increase in variation from without inwards. The most westerly and the most easterly portions of this Asiatic curve of no variation, incline like the Atlantic line from south to north, and in the space between the Caspian Sea and Lapland even from SS.E. to NN.W. The third system, that of the Pacific, which has been least investigated, is the smallest of all, and lying entirely to the south of the geographical equator forms almost a closed oval of concentric lines, whose variation is opposite to that which we observe in the north-eastern part of the Asiatic system, and decreases from without inwards. If we base our opinion upon the magnetic declination observed on the coast, we find that the African continent[88] only presents lines which exhibit a western variation of from 6° to 29°; for according to Purchas, the Atlantic line of no variation left the southern point of Africa (the Cape of Good Hope) in the year 1605, inclining further from east to west. The possibility, that we may discover in some part of Central Africa an oval group of concentric lines of variation, decreasing to 0°, and which is similar to that of the Pacific, can neither be asserted or denied on any sure grounds.

The Atlantic portion of the American curve of no variation was accurately determined in both hemispheres for the year 1840, by the admirable investigations of General Sabine who employed 1480 observations, and duly took into account the secular changes. It passes in the meridian of 70° S. lat., and about 19° W. long.,[89] in a NN.W. direction, to about

[88] In the interior of Africa, the isogonic line of 22° 15′ W. is especially deserving of careful cosmical investigation, as being the intermediate line between very different systems, and as proceeding (according to the theoretical views of Gauss), from the Eastern Indian Ocean, straight across Africa on to Newfoundland. The very comprehensive plan of the African expedition, conducted by Richardson, Barth, and Overweg, under the orders of the British Government, may probably lead to the solution of such magnetic problems.

[89] Sir James Ross intersected the curve of no variation in 61° 30′ S. lat. and 27° 10′ W. long. (*Voyage to the Southern Seas,* vol. ii, p. 357). Captain Crozier found the variation in March, 1843, 1° 38′ in 70° 43′ S. lat. and 21° 28′ W. long., and he was therefore very near the line of no variation. See Sabine, *On the Magn. Declination in the Atlantic Ocean for* 1840, in the *Phil. Transact. for* 1849, pt. ii, p. 233.

3° east of Cook's Sandwich Land, and to about 9° 30′ east of South Georgia; it then approaches the Brazilian coast, which it enters at Cape Frio 2° east of Rio Janeiro and traverses the southern part of the New Continent no farther than 0° 36′ S. lat., where it again leaves it somewhat to the east of Gran Para, near Cape Tigioca on the Rio do Para, one of the secondary outlets of the Amazon, crossing the geographical equator in 47° 44′ W. long., then skirting along the coast of Guiana at a distance of eighty-eight geographical miles as far as 5° N. lat., and afterwards following the arc of the small Antilles as far as the parallel of 18°, and finally touching the shore of North Carolina near Cape Lookout, south-east of Cape Hattaras in 34° 50′ N. lat., 74° 8′ W. long. In the interior of North America, the curve follows a north-western direction as far as 41° 30′ N. lat., 77° 38′ W. long., towards Pittsburgh, Meadville, and Lake Erie. We may conjecture that it has advanced very nearly half a degree farther west since 1840.

The Australo-Asiatic curve of no variation (if according to Erman we consider the part which rises suddenly from Kasan to Archangel and Russian Lapland as identical with the part in the sea of Molucca and Japan) can scarcely be followed as far as 62° in the southern hemisphere. This starting point lies farther west from Van Diemen's Land than had hitherto been conjectured, and the three points, at which Sir James Ross crossed the curve of no variation on his Antarctic voyage of discovery in 1840 and 1841,[90] are all situated in the parallels of 62°, 54°. 30, and 46°, between 133° and 135° 40′ E. long.; and therefore mostly in a meridian-like direction running from south to north. In its further course, the curve crosses Western Australia from the southern coast of Nuyts' Land about 10° W. of Adelaide to the northern coast near Vansittart river and Mount Cockburn, from whence it enters the sea of the Indian Archipelago in a region of the world, in which the inclination, declination, total intensity, and the maximum and minimum of the horizontal force were investigated by Captain Elliot from 1846 to 1848, with more care than has been done in any other portion of the globe. Here the line passes south of Flores and through

[90] Sir James Ross, *Op. cit.* vol. i, pp. 104, 310, 317.

the interior of the small Sandal-wood Island,[91] in a direct east and west direction from about 120° 30′ to 93° 30′ E. long., as had been accurately demonstrated sixteen years before by Barlow. From the last named meridian it ascends towards the north-west in 9° 30′ S. lat., judging by the position in which Elliot followed the curve of 1° east variation to Madras. We are not able here to decide definitely whether, crossing the equator in about the meridian of Ceylon, it enters the continent of Asia between the Gulf of Cambay and Guzurat, or further west in the Bay of Muscat,[92] and whether, therefore, it is identical[93] with the curve of no variation, which appears to advance southward from the basin of the Caspian Sea; or whether, as Erman maintains, it may not curve to the eastward, and rising between Borneo and Malacca, reach the Sea of Japan,[94] and penetrate into Eastern

[91] Elliot, in the *Phil. Transact. for* 1851, pt. i, p. 331, pl. xiii. The long and narrow small island from which we obtain the sandalwood (*tschendana*, Malay and Java, *tschandana*, Sanscrit, *fsandel*, Arab).

[92] According to Barlow, and the chart of *Lines of Magnetic Declinations computed according to the theory of Mr. Gauss*, in the *Report of the Committee for the Antarctic Expedition*, 1840. According to Barlow the line of no variation proceeding from Australia enters the Asiatic Continent at the Bay of Cambay, but turns immediately to the north-east, across Thibet and China, near Thaiwan (Formosa), from whence it enters the Sea of Japan. According to Gauss, the Australian line ascends merely through Persia, past Nishnei-Nowgorod to Lapland. This great geometrician regards the Japan and Philippine line of no variation, as well as the closed oval group in Eastern Asia, as entirely independent of the line belonging to Australia, the Indian Ocean, Western Asia, and Lapland.

[93] I have already elsewhere spoken of this identity, which is based upon my own declination-observations in the Caspian Sea, at Uralsk on the Jaik, and in the Steppe of Elton Lake (*Asie Centrale*, t. iii, pp. 458—461).

[94] Adolf Erman's *Map of the Magnetic Declination*, 1827—1830. Elliot's chart shows, however, most distinctly that the Australian curve of no variation does not intersect Java, but runs parallel with, and at a distance of 1° 30′ latitude from the southern coast. Since, according to Erman, although not according to Gauss, the Australian line of no variation between Malacca and Borneo enters the Continent through the Japanese Sea, proceeding to the closed oval group of Eastern Asia, on the northern coast of the Sea of Ochotsk (59° 30′ N. lat.), and again descends through Malacca, the ascending line can only be 11° distant from the descending curve; and according to this graphical representation, the Western Asiatic line of no variation (from the Caspian Sea to Russian Lapland) would be the shortest and most direct prolongation of the part descending from north to south.

Asia through the Gulf of Ochotsk. It is much to be lamented, that notwithstanding the frequent voyages made to and from India, Australia, the Philippines, and the north-east coasts of Asia, a vast accumulation of materials should remain buried and unheeded in various ships' logs, which might otherwise lead to general views, by which we might be enabled to connect Southern Asia with the more thoroughly explored parts of Northern Asia and thus to solve questions which were started as early as 1840. In order, therefore, not to blend together known facts with uncertain hypotheses, I will limit myself to the consideration of the Siberian portion of the Asiatic continent, as far as it has been explored in a southerly direction to the parallel of 45° by Erman, Hansteen, Due, Kupffer, Fuss, and myself. In no other part of the earth has so extended a range of magnetic lines been accessible to us in continental regions; and the importance which European and Asiatic Russia presents in this respect was ingeniously conjectured even before the time of Leibnitz.[95]

[95] I drew attention as early as 1843 to the fact, which I had ascertained from documents preserved in the Archives of Moscow and Hanover (*Asie Centrale,* t. iii, pp. 469—476), that Leibnitz, who constructed the first plan of a French expedition to Egypt, was also the first who endeavoured to profit by the relations which the Czar, Peter the Great, had established with Germany in 1712, by using his influence to secure the prosecution of observations for "determining the position of the lines of variation and inclination, and for insuring that these observations should be repeated at certain definite epochs" in different parts of the Russian empire, whose superficies exceed those of the portions of the moon visible to us. In a letter addressed to the Czar, discovered by Pertz, Leibnitz describes a small hand-globe, or *terrella,* which is still preserved at Hanover, and on which he had represented the curve at which the variation is null (his *linea magnetica primaria*). Leibnitz maintains that there is only *one line of no variation,* which divides the terrestrial sphere into two almost equal parts, and has four *puncta flexus contrarii,* or sinuosities, where the curves are changed from convex to concave. From the Cape de Verd it passes in lat. 36° towards the eastern shores of North America, after which it directs its course through the South Pacific to Eastern Asia and New Holland. This line is a closed one, and passing near both poles, it approaches closer to the southern than the northern pole; at the latter, the declination must be 25° west, and at the former only 5°. The motion of this important curve must have been directed towards the north pole at the beginning of the 18th century. The variation must have ranged between 0° and 15° *east* over a great portion of the Atlantic Ocean, the whole of the

In order to follow the usual direction of Siberian expeditions from west to east, and starting from Europe, we will begin with the northern part of the Caspian Sea. Here, in the small island of Birutschikassa, in Astracan, on Lake Elton, in the Kirghis steppe, and at Uralsk, on the Jaik, between 45° 43′ and 51° 12′ N. lat., and 46° 37′ and 51° 24′ E. long., the variation fluctuates from 0° 10′ east to 0° 37′ west.[96] Farther northward, this line of no variation inclines somewhat more towards the north-west, passing near Nishnei-Nowgorod.[97] In the year 1828 it passed between Osablikowo and Doskino in the parallel of 56° N. lat. and 43° E. long. It becomes elongated in the direction of Russian Lapland between Archangel and Kola, or more accurately according to Hansteen (1830) between Umba and Ponoi.[98] It is not until we have passed over nearly two-thirds of the greatest breadth of Northern Asia, advancing eastward to the latitudes of from 50° and 60° (a district in which at present the variation is entirely easterly), that we reach the line of no variation, which in the north-eastern part of the Lake of Baikal, rises to a point west of Wiluisk, which reaches the latitude of 68°, in the meridian of Jakutsk 129° 50′ E. long., forming at this point the outer shell of the eastern group of oval concentric lines of variation, to which we have frequently referred, again sinking in the direction of Ochotsk in 143° 10′ E. long., intersecting the arc of the Kurile Islands, and penetrating into the southern part of the Japanese Sea. All the curves of from 5° to 15° eastern variation which occupy the space between the lines of no variation in Western and Eastern Asia, have their concavities turned northward. The maximum of their curvature falls, according to Erman, in 80° E. long., and almost in one meridian between Omsk

Pacific, Japan, a part of China, and New Holland. "As the Czar's private physician, Donelli, is dead, it would be advisable to supply his place by some one else, who will be disposed to administer very little medicine, but who may be able to give sound scientific advice regarding determinations of magnetic declination and inclination." . . . . These hitherto unnoticed letters of Leibnitz certainly do not express any special theoretical views.

[96] See my Magnetic Observations, in *Asie Centrale*, t. iii, p. 460.

[97] Erman, *Astron. und Magnet. Beobachtungen* (*Reise um die Erde*, Abth. ii, Bd. 2, s. 532.

[98] Hansteen, in Poggend. *Ann.* Bd. xxi, s. 371.

and Tomsk, and are therefore not very different from the meridian of the southern extremity of the peninsula of Hindostan. The axis major of the closed oval group extends 28° of latitude as far as Corea.

A similar configuration, although on a still larger scale, is exhibited in the Pacific. The closed curves here form an oval between 20° N. lat. and 42° S. lat. The axis major lies in 130° W. long. That which most especially distinguishes this singular group (the greater portion of which belongs to the southern hemisphere and exclusively to the sea) from the continent of Eastern Asia is, as has been already observed, the relative succession in the value of the curves of variation. In the former, the eastern variation diminishes, whilst in the latter the western variation increases the farther we penetrate into the interior of the oval. The variation in the interior of this closed group in the southern hemisphere amounts, however, as far as we know, only to from 8° to 5°. Is it likely that there is a ring of southern variation within the oval, or that we should again meet with western variation farther to the interior of this closed line of no variation ?

Curves of no variation, like all magnetic lines, have their own history, which, however, does not as yet unfortunately date further back than two centuries. Scattered notices may indeed be met with, as early even as in the 14th and 15th centuries, and here again Hansteen has the great merit of having collected and carefully compared together all the various data. It would appear, that the northern magnetic pole is moving from west to east, and the southern magnetic pole from east to west; accurate observations show us, however, that the different parts of the isogonic curves are progressing very irregularly, and that where they were parallel they are losing their parallelism; and lastly that the domain of the declination of one denomination, that is to say, east or west declination, is enlarging and contracting in very different directions in contiguous parts of the earth. The lines of no variation in Western Asia and in the Atlantic are advancing from east to west; the former line having crossed Tobolsk in 1716, while in 1761, in Chappe's time, it crossed Jekatherinenburg and subsequently Kasan, and in 1829 it was found to have passed between Osablikowo and

Doskino, not far from Nishneinowgorod, and consequently had advanced 24° 45′ westward in the course of 113 years. Is the line of the Azores, which Christopher Columbus determined on the 13th of September, 1492, the same, which, according to the observations of Davis and Keeling, in 1607, passed through the Cape of Good Hope?[99] and is it identical with the one which we designate as the Western Atlantic, and which passes from the mouth of the river Amazon to the sea-coast of North Carolina? if it be, we are led to ask what has become of the line of no variation which passed in 1600 through Konigsberg, in 1620 (?) through Copenhagen, from 1657 to 1662 through London, and which did not, according to Picard, reach Paris, notwithstanding its more eastern longitude, until 1666, passing through Lisbon somewhat before 1668?[100] Those points of the earth at which no secular progression has been observed for long periods of time are especially worthy of our notice. Sir John Herschel has already drawn attention to a corresponding long period of cessation in Jamaica,[1] while Euler[2] and Barlow[3] refer to a similar condition in Southern Australia.

Polar Light.

We have now treated fully of the three elements of terrestrial magnetism in the three principal types of its manifestation, namely, Intensity, Inclination and Declination, in reference to the movements which depend upon geographical relations of place, and diurnal and annual periods. The extraordinary disturbances which were first observed in the dip, are as Halley conjectured, and as Dufay and Hiörter recognised, in part forerunners, and in part accompaniments of the

99 Sabine, *Magn. and Meteor. Observ. at the Cape of Good Hope,* vol. i, p. lx.

100 In judging of the approximate epochs of the crossing of the line of no variation, and in endeavouring to decide upon the claim of priority in this respect, we must bear in mind how readily an error of 1° may have been made with the instruments and methods then in use.

1 *Cosmos,* vol. i, p. 174.

2 Euler, in the *Mém. de l'Acad. de Berlin,* 1757, p. 176.

3 Barlow, in the *Phil. Transact. for* 1833, pt. ii, p. 671. Great uncertainty prevails regarding the older magnetic observations of St. Petersburg during the first half of the 18th century. The variation seems to have been always 3° 15′ or 3° 30′ from 1726 to 1772! Hansteen, *Magnetismus der Erde,* s. 7, p. 143.

magnetic polar light. I have already fully treated, in the Picture of Nature, of the peculiarities of this luminous process, which is often so remarkable for the brilliant display of colours with which it is accompanied; and more recent observations have in general accorded with the views which I formerly expressed. "The Aurora borealis has not been described merely as an external cause of a disturbance in the equilibrium of the distribution of terrestrial magnetism, but rather as an increased manifestation of telluric activity; amounting even to a luminous phenomenon, exhibited on the one hand, by the restless oscillation of the needle, and on the other, by the polar luminosity of the heavens." The polar light appears in accordance with this view to be a kind of silent discharge or shock as the termination of a magnetic storm, very much in the same manner as in the electric shock, the disturbed equilibrium of the electricity is renewed by a development of light by lightning, accompanied by pealing thunder. The reiteration of a definite hypothesis in the case of a complicated and mysterious phenomenon has at all events the advantage of giving rise with a view to its refutation to more persistent and careful observations of the individual processes.[4]

Dwelling only on the purely objective description of these processes, which are mainly based upon the materials yielded by the beautiful and unique series of observations, which were continued without intermission for eight months (1838, 1839), —during the sojourn of the distinguished physicists, Lottin, Bravais and Siljeström—in the most northern parts of Scandinavia,[5] we will first direct our attention to the so-called *black segment* of the Aurora, which rises gradually on the horizon like a dark wall of clouds.[6] The blackness is not, as Argel-

[4] *Cosmos*, vol. i, pp. 187—199, and Dove, in Poggend. *Annalen*, Bd. xix, s. 388.

[5] The able narrative of Lottin, Bravais, Lilliehöök, and Siljeström, who observed the phenomena of the northern light from the 19th of September, 1838, till the 8th of April, 1839, at Bossekop (69° 58′ N. lat.) in Finmark and at Jupvig (70° 6′ N. lat.) was published in the fourth section of *Voyages en Scandinavie, en Laponie, au Spitzberg et aux Feroës, sur la Corvette, la Recherche* (*Aurores boréales*). To these observations are appended important results obtained by the English superintendent of the copper mines at Kalfiord (69° 56′ N. lat.), pp. 401—435.

[6] See the work above referred to (pp. 437—444) for a description of the *Segment obscure de l'Aurore boréale.*

ander observes, a mere result of contrast, since it is occasionally visible before it is bounded by the brightly illuminated arch. It must be a process effected within some part of the atmosphere, for nothing has hitherto shown that the obscuration is owing to any material blending. The smallest stars are visible through the telescope in this black segment, as well as in the coloured illuminated portions of the fully developed Aurora. In northern latitudes, the black segment is seen far less frequently than in more southern regions. It has even been found entirely absent in these last named latitudes in the months of February and March, when the Aurora was frequent in bright clear weather; and Keilhau did not once observe it during the whole of a winter, which he spent at Talwig in Lapland. Argelander has shown by accurate determination of the altitudes of stars, that no part of the polar light exerts any influence on these altitudes. Beyond the segment, there appear, although rarely, *black rays*, which Hansteen and I have often watched[7] during their ascent; blended with these, appear round *black patches*, or *spots*, enclosed by luminous spaces. The latter phenomena have been made a special subject of investigation by Siljeström.[8] The central portion of the corona of the Aurora (which owing to the effect of linear perspective corresponds at its highest point with the magnetic inclination of the place), is also usually of a very deep black colour. Bravais regards this blackness and the black rays as the effect of optical illusions of contrast. Several luminous arches are frequently simultaneously present; in some rare cases as many as seven or nine are seen

[7] Schweigger's *Jahrbuch der Chemie und Physik*, 1826, Bd. xvi, s. 198, and Bd. xviii, s. 364. The dark segment and the incontestible rising of black rays or bands, in which the luminous process is annihilated (by interference?) reminds us of Quet's *Recherches sur l'Electrochimie dans le vide*, and of Ruhmkorff's delicate experiments, in which in a vacuum the *positive* metallic balls glowed with red light, while the *negative* balls showed a violet light, and the strongly luminous parallel strata of rays were regularly separated from one another by perfectly dark strata. "The light which is diffused between the terminal knobs of the two electric conductors divides into numerous parallel bands, which are separated by alternate obscure and perfectly distinct strata." *Comptes rendus de l'Acad. des Sc.* t. xxxv, 1852, p. 949.

[8] *Voyages en Scandinavie* (*Aurores bor.*), p. 558. On the Corona and bands of the northern light, see the admirable investigations of Bravais, pp. 502—514.

advancing towards the zenith, parallel to one another; while in other cases they are altogether absent. The bundles of rays and columns of light assume the most varied forms, appearing either in the shape of curves, wreathed festoons and hooks, or resembling waving pennants or sails.[9]

In the higher latitudes, "the prevailing colour of the polar light is usually white, while it presents a milky hue when the Aurora is of faint intensity. When the colours brighten, they assume a yellow tinge; the middle of the broad ray becomes golden yellow, while both the edges are marked by separate bands of red and green. When the radiation extends in narrow bands, the red is seen above the green. When the Aurora moves sideways from left to right, or from right to left, the red appears invariably in the direction towards which the ray is advancing, and the green remains behind it." It is only in very rare cases that either one of the complementary colours, green or red, has been seen alone. Blue is never seen, while dark red, such as is presented by the reflection of a great fire, is so rarely observed in the north that Siljeström noticed it only on one occasion.[10] The luminous intensity of the Aurora never even in Finmark quite equals that of the full moon.

The probable connection which, according to my views, exists between the polar light and the formation of very small and delicate fleecy clouds (whose parallel and equivalent rows follow the direction of the magnetic meridian), has met with many advocates in recent times. It still remains a doubtful question, however,[11] whether, as the northern travellers, Thienemann and Admiral Wrangel believe, these parallel fleecy clouds are the substratum of the polar light, or whether

[9] *Op. cit.* pp. 35, 37, 45, 67, 481 ("*Draperie ondulante, flamme d'un navire de guerre déployée horizontalement et agitée par le vent, crochets, fragments d'arcs et de guirlandes*)." M. Bevalet, the distinguished artist to the expedition, has given an interesting collection of the many varied forms assumed by this phenomenon.

[10] See *Voy. en Scandinavie* (*Aur. boréal.*), pp. 523—528, 557.

[11] *Cosmos*, vol i, p. 194 ; see also, Franklin, *Narrative of a Journey to the Shores of the Polar Sea in* 1819—1822, p. 597; and Kämtz, *Lehrbuch der Meteorologie*, Bd. iii (1836), s. 488—490. The earliest conjectures advanced in relation to the connection between the northern light and the formation of clouds are probably those of Frobesius. (See *Auroræ borealis spectacula*, Helmst, 1739, p. 139).

they are not rather, as has been conjectured by Franklin, Richardson, and myself, the effect of a meteorological process generated by and accompanying the magnetic storm. The regular coincidence in respect to direction between the very fine cirrous clouds (polar bands) and the magnetic declination, together with the turning of the points of convergence, were made the subjects of my most careful observation on the Mexican plateau in 1803, and in Northern Asia in 1829. When the last named phenomenon is complete, the two apparent points of convergence do not remain stationary, the one in the north-east and the other in the south-west (in the direction of the line which connects together the highest points of the arch of the polar light which is luminous at night), but move by degrees towards the east and west.[12] A precisely similar turning, or translation of the line, which in the true Aurora connects the highest points of the luminous arch, whilst its bases (the points of support by which it rests on the horizon) change in the azimuth and move from east-west towards north-south, has been several times observed with much accuracy in Finmark.[13] These clouds ar-

[12] I will give a single example from my M.S. journal of my Siberian journey :—"I spent the whole of the night of the 5—6th of August (1829), separated from my travelling companions, in the open air, at the Cossack outpost of Krasnajazarki, the most *eastern* station on the Irtisch, on the boundary of the Chinese Dzungarei, and hence a place whose astronomical determination was of considerable importance. The night was extremely clear. In the eastern sky polar bands of cirrous clouds were suddenly formed before midnight (which I have recorded as '*de petits moutons également espacés, distribués en bandes parallèles et polaires*)'. Greatest altitude 35°. The northern point of convergence is moving slowly toward the east. They disappear without reaching the zenith; and a few minutes afterwards, precisely similar cirrous bands are formed in the north-east; which move during a part of the night, and almost till sunrise, regularly northward 70° E. An unusually large number of falling stars and coloured rings round the moon throughout the night. No trace of a true Aurora. Some rain falling from speckled feathery masses of clouds. At noon on the 6th of August the sky was clear, polar bands were again formed, passing from N.N.E. to S.S.W., where they remained immoveable, without altering the azimuth, as I had so often seen in Quito and Mexico." (The magnetic variation in the Altai is easterly.)

[13] Bravais, who, contrary to my own experience, almost invariably observed that the masses of cirrous clouds at Bossekop were directed, like the Aurora borealis, at right angles to the magnetic meridian (*Voyages en Scandinavie, Phénomène de translation dans les pieds de*

ranged in the form of polar bands correspond, according to the above developed views, in respect to position, with the luminous columns or bundles of rays which ascend in the true Aurora towards the zenith from the arch, which is generally inclined in an east and west direction; and they cannot, therefore, be confounded with those arches of which one was distinctly seen by Parry in bright day-light after the occurrence of a northern light. This phenomenon occurred in England on the 3rd of September, 1827, when columns of light were seen shooting up from the luminous arch even by day.[14]

It has frequently been asserted that a continuous evolution of light prevails in the sky immediately around the northern magnetic pole. Bravais, who continued to prosecute his observations uninterruptedly for 200 nights, during which he accurately described 152 Auroræ, certainly asserts that nights, in which no northern lights are seen, are altogether exceptional, but he has sometimes found even when the atmosphere was perfectly clear, and the view of the horizon was wholly uninterrupted, that not a trace of polar light could be observed throughout the whole night, or else that the magnetic storm did not begin to be apparent until a very late hour. The greatest absolute number of northern lights appears to occur towards the close of the month of September; and as March, when compared with February and April, seems to exhibit a relatively frequent occurrence of the phenomenon, we are here led, as in the case of other magnetic phenomena, to conjecture some connection with the period

l'arc des Aurores boréales, pp. 534—537), describes with his accustomed exactitude the turnings or rotations of the true arch of the Aurora borealis, pp. 27, 92, 122, 487. Sir James Ross has likewise observed in the southern hemisphere similar progressive alterations of the arch of the Aurora (a progression in the southern lights from W.N.W.—E.S.E. to N.N.E.—S.S.W.) *Voyage in the Southern and Antarctic Regions,* vol. i, p. 311. An absence of all colour seems to be a frequent characteristic of southern lights, vol. i, p. 266, vol. ii, p. 209. Regarding the absence of the northern light in some nights in Lapland, see Bravais, *Op. cit.* p. 545.

[14] *Cosmos,* vol. i, p. 191. The arch of the Aurora seen in bright day-light reminds us by the intensity of its light of the nuclei and tails of the comets of 1843 and 1847, which were recognised in the immediate vicinity of the sun in North America, Parma, and London. *Op. cit.* vol. i, p. 85, vol. iii. p. 543.

of the equinoxes. To the northern lights which have been seen in Peru, and to the southern lights which have been visible in Scotland, we may add a coloured Aurora, which was observed for more than two hours continuously by Lafond in the Candide, on the 14th of January, 1831, *south* of New Holland, in latitude 45°.[15]

The accompaniment of sound in the Aurora has been as definitely denied by the French physicists and Siljeström at Bossekop[16] as by Thienemann, Parry, Franklin, Richardson, Wrangel, and Anjou. Bravais estimated the altitude of the phenomenon to be fully 51307 toises (or 52 geographical miles), whilst an otherwise very careful observer, Farquharson, considers that it scarcely amounts to 4000 feet. The data on which all these determinations are based are very uncertain, and are rendered less trustworthy by optical illusions, as well as by erroneous conjectures regarding the positive identity of the luminous arch seen simultaneously at two remote points. There is, however, no doubt whatever of the influence of the northern light on declination, inclination, horizontal and total intensity, and consequently on all the elements of terrestrial magnetism, although this influence is exerted very unequally in the different phases of this great phenomenon, and on the different elements of the force. The most complete investigations of the subject were those made in Lapland by the able physicists Siljeström and Bravais[17] (in 1838—1839), and the Canadian observations at Toronto (1840—1841), which have been most ably discussed by Sabine.[18] In the preconcerted simultaneous observations which were made by us at Berlin (in the Mendelssohn-Bartholdy Garden), at Freiberg below the surface of the earth, at St. Petersburgh, Kasan and Nikolajew, we found that the magnetic variation was affected at all these places by the Aurora borealis, which was visible at Alford in Aberdeenshire (57° 15′ N. lat.) on the night of the 19-20th of December, 1829. At some of these stations, at which

[15] *Comptes rendus de l'Acad. des Sciences*, t. iv, 1837, p. 589.

[16] *Voyages en Scandinavie, en Laponie, etc.*, (*Aurores boréales,*) p. 559; and Martin's *Trad. de la Météorologie de Kaemtz*, p. 460. In reference to the conjectured elevation of the northern light, see Bravais, *Op. cit.* pp. 549, 559.

[17] *Op. cit.* p. 462.

[18] Sabine, *Unusual Magnet. Disturbances*, pt. i, pp. xviii, xxii, 3, 54.

the other elements of terrestrial magnetism could be noted, the magnetic intensity and inclination were affected no less than the variation.[19]

During the beautiful Aurora, which Professor Forbes observed at Edinburgh on the 21st of March, 1833, the inclination was strikingly small in the mines at Freiberg, while the variation was so much disturbed that the angles could scarcely be read off. The decrease in the total intensity of the magnetic force which has been observed to coincide with the increasing energy of the luminosity of the northern light is a phenomenon which is worthy of special attention. The measurements which I made in conjunction with Oltmanns at Berlin during a brilliant Aurora on the 20th of December, 1806,[20] and which are printed in Hansteen's "Untersuchungen über den Magnetismus der Erde," were con-

[19] Dove, in Poggend. *Ann.* Bd. xx, s. 333—341. The unequal influence which an Aurora exerts on the dipping needle at points of the earth's surface, which lie in very different meridians, may in many cases lead to the local determination of the active cause, since the manifestation of the luminous magnetic storm does not by any means always originate in the magnetic pole itself; while, moreover, as Argelander maintained and as Bravais has confirmed, the summit of the luminous arch is in some cases as much as 11° from the magnetic meridian.

[20] "On the 20th of December, 1806, the heavens were of an azure blue, with not a trace of clouds. Towards 10 P.M. a reddish-yellow luminous arch appeared in the N.N.W., through which I could distinguish stars of the 7th magnitude in the night telescope. I found the azimuth of this point by means of α Lyræ, which was almost directly under the highest point of the arch. It was somewhat further west than the vertical plane of the magnetic variation. The Aurora, which was directed N.N.W., caused the north pole of the needle to be deflected, for, instead of progressing westward like the azimuth of the arch, the needle moved back towards the east. The changes in the magnetic declination, which generally amount to from 2′ 27″ to 3′ in the nights of this month, increased progressively and without any great oscillation to 26′ 28″ during the northern light. The variation was the smallest about 9h. 12m. when the Aurora was the most intense. We found that the horizontal force amounted to 1′ 37″.73 for 21 vibrations during the continuance of the Aurora, while at 9h. 50m. A.M., and consequently long after the disappearance of the Aurora, which had entirely vanished by 2h. 10m. A.M. it was 1′ 37″.17 for the same number of vibrations. The temperature of the room, in which the vibrations of the small needle were measured, was in the first case 37°.76 F. and in the second 37°.04 F. The intensity was therefore slightly diminished during the continuance of the northern light. The moon presented no coloured rings." From my magnetic journal, see Hansteen, s. 459.

firmed by Sabine and the French physicists in Lapland in 1838.[21]

While in this careful development of the present condition of our positive knowledge of the phenomena of terrestrial magnetism, I have necessarily limited myself to a mere objective representation of that which did not even admit of being elucidated by merely theoretical views, based only upon induction and analogy; I have likewise purposely abstained in the present work from entering into any of those geognostic hypotheses, in which the direction of extensive mountain chains and of stratified mountain masses is considered in relation to its dependence upon the direction of magnetic lines, more especially the isoclinal and isodynamic systems. I am far from denying the influence of all cosmical primary forces—dynamic and chemical forces—as well as of magnetic and electrical currents on the formation of crystalline rocks and the filling up of veins;[22] but owing to the progressive movement of all magnetic lines and their consequent change of form, their present position can teach us nothing in reference to the direction in primeval ages of mountain chains, which have been upheaved at very different epochs, or to the consolidation of the earth's crust, from which heat was being radiated during the process of its hardening.

Of a different order, not referring generally to terrestrial magnetism, but merely to very partial local relations, are those geognostic phenomena, which have been designated by the name of the magnetism[23] of mountain masses. These phenomena engaged much of my attention before my American expedition, at a time when I was occupied in examining the magnetic serpentine rock of the Haidberg mountain in Franconia in 1796, and then gave occasion in

[21] Sabine, *On Days of Unusual Magn. Disturbances*, pt. i, p. xviii. "M. Bravais concludes from the observations made in Lapland that the horizontal intensity diminishes when the phenomenon of the Aurora borealis is at its maximum" (Martins, p. 461).

[22] Delesse, Sur l'association des minéraux dans les roches qui ont un pouvoir magnétique élevé, in the *Comptes rendus de l'Acad. des Sc.* t. xxxi, 1850, p. 806; and *Annales des Mines*, 4ème Série, t. xv (1849), p. 130.

[23] Reich, *Ueber Gebirgs- und Gesteins-Magnetismus*, in Poggend. *Ann.* Bd. lxvii, s. 35.

Germany to a considerable amount of literary dissension, which, however, was of a very harmless nature. They present a number of problems, which are by no means incapable of solution, but which have been much neglected in recent times, and only very imperfectly investigated both as regards observation and experiment. The force of this magnetism of rocks may be tested for the determination of the increase of magnetic intensity by means of pendulum experiments and by the deflection of the needle in broken off fragments of hornblende and chloritic schists, serpentine, syenite, dolerite, basalt, melaphyre and trachyte. We may in this manner decide by a comparison of the specific gravity, by the rinsing of finely pulverised masses, and by the application of the microscope, whether the intensity of the polarity may not depend in various ways upon the relative position, rather than upon the quantity, of the granules of magnetic iron and protoxide of iron, intermixed in the mass. More important, however, in a cosmical point of view is the question which I long since suggested in reference to the Haidberg mountain; whether there exist entire mountain ranges, in which opposite polarities are found to occur on opposite declivities of the mass.[24] An accurate astronomical determi-

[24] This question was made the subject of lively discussion when, in the year 1796, at the time that I fulfilled the duties of superintendent of the mining operations in the Fichtelgebirge, in Franconia, I discovered the remarkable magnetic serpentine mountain (the Haidberg) near Gefress, which had the property at some points of causing the needle to be deflected at a distance of even 23 feet (*Intelligenz-Blatt der Allgem. Jenaer Litteratur-Zeitung, Dec.* 1796, No. 169, s. 1447, and *März,* 1797, No. 38, s. 323 — 326; Gren's *Neues Journal der Physik,* Bd. iv, 1797, s. 136; *Annales de Chimie,* t. xxii, p. 47). I had thought that the magnetic axes of the mountain were diametrically opposed to the terrestrial poles; but according to the investigations of Bischoff and Goldfuss, in 1816 (*Beschreibung des Fichtelgebirges,* Bd. i, s. 176), it would appear that they discovered magnetic poles, which penetrated through the Haidberg and presented opposite poles on the opposite declivities of the mountain, while the directions of the axes were not the same as I had given them. The Haidberg consists of dull green serpentine, which partially merges into chloritic and hornblende schists. At the village of Voysaco, in the chain of the Andes of Pasto, we saw the needle deflected by fragments of porphyritic clay, while on the ascent to Chimborazo, groups of columnar masses of trachyte disturbed the motion of the needle at a distance of three feet. It struck me as a very remarkable fact that I should have found in the black and red

nation of the position of such magnetic axes of a mountain would be of the greatest interest, if it could be ascertained

obsidians of Quinche, north of Quito, as well as in the gray obsidian of the Cerro de la Navajas of Mexico, large fragments with distinct poles. The large collective magnetic mountains in the Ural chain, as Blagodat, near Kuschwa, Wyssokaja Gora, at Nishne Tagilsk, and Katschkanar, near Nishne Turinsk, have all broken forth from augitic or rather uralitic porphyry. In the great magnetic mountain of Blagodat, which I investigated with Gustav Rose, in our Siberian expedition, in 1829, the *combined effect* of the polarity of the individual parts did not indeed appear to have produced any determined and recognisable magnetic axes. In close vicinity to one another lie irregularly mixed opposite poles. A similar observation had previously been made by Erman (*Reise um die Erde*, Bd. i, s. 362). On the degree of intensity of the polar force in serpentine, basaltic, and trachytic rock, compared with the quantity of magnetic iron and protoxide of iron, intermixed with these rocks, as well as on the influence of the contact of the air in developing polarity, which had already been maintained by Gmelin and Gibbs, see the numerous and very admirable experiments of Zaddach, in his *Beobachtungen über die Magnetische Polarität des Basaltes und der Trachytischen Gesteine*, 1851, s. 56, 65—78, 95. A comparison of many basaltic quarries, made with a view of ascertaining the polarity of individual columns which have stood isolated for a long period, and an examination of the sides of these columns which have been recently brought in contact with the outer air in consequence of the removal from individual masses of a certain depth of earth, have led Dr. Zaddach to hazard the conjecture (see s. 74, 80) that the polar property, which always appears to be manifested with the greatest intensity in rocks to which the air has been freely admitted, and which are intersected by open fissures, " diffuses itself from without inwards, and generally from above downwards." Gmelin expresses himself as follows in respect to the great magnetic mountain, Ulu-utasse-Tau, in the country of the Baschkiri, near the Jaik :—" The sides which are exposed to the open air exhibit the most intense magnetic force, while those which lie under ground are much weaker" (*Reise durch Siberien*, 1740—1743, Bd. iv, s. 345). My distinguished teacher, Werner, in describing the magnetic iron of Sweden, in his lectures, also spoke of " the influence which contact with the atmosphere might have, although not by means of an increased oxidation, in rendering the polar and attracting force more intense." It is asserted by Colonel Gibbs, in reference to the magnetic iron mines at Succassuny, in New Jersey, that "the ore raised from the bottom of the mine has no magnetism at first, but acquires it after it has been some time exposed to the influence of the atmosphere" (*On the connexion of Magnetism and Light*, in Silliman's *American Journal of Science*, vol. i, 1819, p. 89). Such an assertion as this ought assuredly to stimulate observers to make careful and exact investigations! When I drew attention in the text (see page 160), to the fact that it was not only the quantity of the small particles of iron which were intermixed in the stone, but also their relative distribution (their position) which acted as the reafter considerable periods of time, that the three variable elements of the total force of terrestrial magnetism caused either an alteration in the direction of the axes, or that such small systems of magnetic forces were at least *apparently* independent of these influences.

II.

Reaction of the interior of the Earth upon its surface; manifesting itself:—a. *Merely dynamically, by tremulous undulations* (*earthquakes*);—b. *By the high temperature of mineral springs, and by the difference of the intermixed salts and gases* (*Thermal springs*); c. *By the outbreak of elastic fluids, sometimes accompanied by phenomena of spontaneous ignition* (*gas and mud volcanoes, burning naphtha springs, Salses*); d. *By the grand and mighty actions of true volcanoes, which* (*when they have a permanent connexion with the atmosphere by fissures and craters*) *throw up fused earth from the depths of the interior, partly only in the form of red-hot cinders, but partly submitted to varying processes of crystalline rock formation, poured out in long, narrow streams.*

In order to maintain, in accordance with the fundamental plan of this work, the co-ordination of *telluric* phenomena

sultant upon the intensity of the polar force, I considered the small particles to be so many small magnets. See the new views regarding this subject in a treatise by Melloni, read by that distinguished physicist before the Royal Academy at Naples, in the month of January, 1853 (*Esperienze intorno al Magnetismo delle Rocche*, Mem. i, *Sulla Polarità*). The popular notion which has been so long current, more especially on the shores of the Mediterranean, that if a magnetic rod be rubbed with an onion, or brought in contact with the emanations of the plant, the directive force will be diminished, while a compass thus treated would mislead the steersman, is mentioned in *Procli Diadochi Paraphrasis Ptolem.* libri iv, *de Siderum affectionibus*, 1635, p. 20 (Delambre, *Hist. de l'Astronomie Ancienne*, t. ii, p. 545). It is difficult to conceive what could have given occasion to so singular a popular error.

—the co-operation of a single system of impelling forces—in the descriptive representation, we must here remind the reader, how, starting from the general properties of *matter*, and the three principal directions of its activity (*attraction, vibrations producing light and heat, and electro-magnetic processes*), we have in the first section taken into consideration the *size, form, and density* of our planet, its *internal diffusion of heat and of magnetism*, in their effects of intensity, dip, and variation, changing in accordance with definite laws. The *directions of the activity of matter* just mentioned are nearly allied[1] manifestations of one and the same primitive force. They occur in a condition of the greatest independence of all differences of matter, in *gravitation and molecular attraction.* We have at the same time represented our planet in its *cosmical* relation to the central body of its system; because the internal *primitive heat,* which is probably produced by the condensation of a rotating nebular ring, is modified by the action of the sun (*Insolation*). With the same view, the periodical action of the solar spots (that is to say, the frequency or rarity of the apertures in the solar envelopes) upon terrestrial magnetism, has been referred to, in accordance with the most recent hypotheses.

The second section of this volume is devoted to the entirety of those telluric phenomena which are to be ascribed to the constantly active *reaction of the interior of the earth upon its surface.*[2] To this entirety I give the general name of *Vulcanism* or *Vulcanicity*; and I regard it as advantageous to avoid the separation of that which is causally connected and differs only in the strength of the manifestation of force and the complication of physical processes. By taking this general view, small and apparently unimportant phenomena acquire a greater significance. The unscientific observer who comes for the first time upon the basin of a thermal spring and sees gases capable of extinguishing light rising in it, or who wanders amongst rows of changeable cones of mud volcanoes, scarcely exceeding himself in height, never dreams that in the calm space occupied by the latter, eruptions of fire to the height of many thousand feet have often taken place; and that one

[1] *Cosmos,* vol. iii, p. 39.
[2] *Cosmos,* vol. i, p. 197—199.

and the same internal force produces colossal craters of elevation, nay even the mighty, desolating, lava-pouring volcanoes of Etna and the Peak of Teyde, and the cinder-erupting Cotopaxi and Tunguragua.

Amongst the multifarious, *mutually intensifying*, phenomena of the reaction of the interior of the earth upon its external crust, I first of all separate those, the essential character of which is purely *dynamical*, namely, that of movement or tremulous undulations in the solid strata of the earth ; a volcanic activity which is not *necessarily* accompanied by any chemical changes of matter, or by the expulsion or production of anything of a material nature. In the other phenomena of the reaction of the interior upon the exterior of the earth :—in *gas and mud volcanoes, burning springs and salses,* and in the large *burning mountains* to which the name of *volcano* was first, and for a long time exclusively, applied, the production of something of a material nature (gaseous or solid), and processes of decomposition and gas-evolution, such as the formation of rocks from particles arranged in a crystalline form, are never wanting. When most fully generalized, these are the distinctive characters of the *volcanic vital activity* of our planet. In so far as this activity is to be ascribed in great measure to the high temperature of the innermost strata of the earth, it becomes probable that all cosmical bodies which have become conglomerated with an enormous evolution of heat, and passed from a state of vapour to a solid condition, must present analogous phenomena. The little that we know of the form of the moon's surface, appears to indicate this.[3]—*Upheaval* and plastic activity in the production of crystalline rock from a fused mass, are conceivable even in a sphere which is regarded as destitute of both air and water.

The genetic connexion of the classes of volcanic phenomena here referred to is indicated by the numerous traces of the *simultaneousness* of the simpler and weaker with stronger and more complex effects, and the accompanying transitions of the one into the other. The arrangement of the materials in the representation selected by me is justified by such a consideration. The increased *magnetic* activity of our planet, the seat of which, however, is not to be sought

[3] *Cosmos,* vol. iii, p. 44; iv, pp. 426, 491, 495—498.

in the fused mass of the interior (even though, according to Lenz and Riess, iron, in the fused state, may be capable of *conducting* an electrical or galvanic current), produces evolution of light in the magnetic poles of the earth, or at least usually in their vicinity. We concluded the first section of the volume on telluric phenomena with the *luminosity of the earth.* This phenomenon of a luminous vibration of the ether by *magnetic forces* is immediately followed by that class of *volcanic* agencies, which, in their essential nature, act purely dynamically, exactly like the magnetic force:—causing movement and vibrations in the solid ground, but neither producing nor changing anything of a material nature. Secondary and unessential phenomena (the ascent of flames during the earthquake, and eruptions of water and evolutions of gas[4] following it) remind one of the action of thermal springs and salses. Eruptions of flame, visible at a distance of many miles, and masses of rock, torn from their deep seats and hurled about,[5] are presented by the *salses,* which thus, as it were, prepare us for the magnificent phenomena of the true *volcanoes;* which again, between their distant epochs of eruption, like the salses, only exhale aqueous vapour and gases from their fissures. So remarkable and instructive are the analogies which are presented in various stages by the gradations of vulcanism.

a. *Earthquakes.*

(Amplification of the Picture of Nature.
Cosmos, vol. i. pp. 199—213).

Since the appearance in the first volume of this work (1845) of the general representation of the phenomena of earthquakes, the obscurity, in which the seat and causes of these phenomena are involved, has but little diminished; but the excellent works[6] of Mallet (1846) and Hopkins (1847) have thrown some light upon the nature of concussions, the connection of apparently distinct effects and the separa-

[4] *Cosmos,* vol. i, p. 214.

[5] *Cosmos,* vol. i, p. 222. Compare Bertrand-Geslin, "*Sur les roches lancées par le Volcan de boue du Monte Zibio près du bourg de Sassuolo,*" in Humboldt, *Voyage aux Régions Equinoxiales du Nouveau Continent* (*Relation Historique*), t. iii, p. 566.

[6] Robert Mallet, in the *Transactions of the Royal Irish Academy,* vol. xxi (1848), pp. 51—113, and *First Report on the Facts of Earthquake Phenomena,* in the *Report of the Meeting of the British Association,*

tion of chemical and physical processes, which may accompany it or occur simultaneously with it. Here, as elsewhere, a mathematical mode of treatment, such as that adopted by Poisson, may have a beneficial effect. The analogies between the oscillations of solid bodies and the sound-waves in the ordinary atmosphere to which Thomas Young[7] had already called attention, are peculiarly adapted to lead to simpler and more satisfactory views, in theoretical considerations upon the dynamics of earthquakes.

Displacement, commotion, elevation, and formation of fissures indicate the essential character of the phenomenon. We have to distinguish the efficient force, which, as the *impulse*, gives rise to the vibration; and the nature, propagation, increase or diminution of the commotion. In the Picture of Nature I have described what is especially manifested to the senses; what I had myself the opportunity of observing for so many years on the sea, on the sea-bottom of the plains (*Llanos*), and at elevations of eight to fifteen thousand feet; on the margin of the craters of active volcanos, and in regions of granite and mica schist, twelve hundred geographical miles from any eruptions of fire; in districts where at certain periods the inhabitants take no more notice of the number of earthquakes, than we in Europe of that of the showers of rain, and where Bonpland and I were compelled to dismount, from the restiveness of our mules, because the earth shook in a forest for 15 to 18 minutes *without intermission.* By such long custom, as Boussingault subsequently experienced even in a still higher degree, one becomes fitted for quiet and careful observation, and also for collecting varying evidence with critical care on the spot, nay, even for examining under what conditions the mighty changes of the surface of the earth, the fresh traces of which one recognises, have taken place. Although five years had already elapsed

1850, pp. 1—89; also *Manual of Scientific Inquiry for the Use of the British Navy*, 1849, pp. 196—223. William Hopkins, *On the Geological Theories of Elevation and Earthquakes*, in the *Report of the British Association for* 1847, pp. 33—92. The rigorous criticism to which Mr. Mallet has subjected my previous work in his very valuable memoirs (*Irish Transactions*, pp. 99—101, and *Meeting of the British Association at Edinburgh*, p. 209), has been repeatedly made use of by me.

[7] Thomas Young, *Lectures on Natural Philosophy*, 1807, vol. i, 717.

since the terrible earthquake of Riobamba, which, on the 4th of February, 1797, destroyed upwards of 30,000 people in a few minutes,[8] we nevertheless saw the formerly advancing cone of the Moya[9] which rose out of the earth, and witnessed the employment of this combustible substance for cooking in the huts of the Indians. I might describe the results of alterations of the ground from this catastrophe, which, although on a larger scale, were exactly analogous to those presented by the famous earthquake of Calabria (February 1783), and were long considered to have been represented in an incorrect and exaggerated manner, because they could not be explained in accordance with hastily formed theories.

By carefully separating, as we have already indicated, the investigation of that which gives the impulse to the vibration, from that of the nature and propagation of the waves of commotion, we distinguish two classes of problems of very unequal accessibility. The former, in the present state of our knowledge, can lead to no generally satisfactory results, as is the case with so many problems in which we wish to ascend to *primary* causes. Nevertheless, whilst we are endeavouring to discover laws in that which is submitted to actual observation, it is of great cosmical interest that we should bear constantly in mind the various genetic explanations which have hitherto been put forward as probable. As with all vulcanicity, the greater part of these refer, under various modifications, to the high temperature and chemical nature of the fused interior of the earth; one of the most recent explanations of earthquakes in trachytic regions, is the result of geognostic suppositions regarding the want of cohesion in rocky masses *raised by volcanic action.* The following summary furnishes a more exact but very brief indication of the variety of views as to the nature of the first *impulse* to the commotion :—

The nucleus of the earth is supposed to be in a state of igneous fluidity, as the consequence of every planetary process of formation from a gaseous material, by evolution

[8] I follow the statistical account communicated to me by the Corregidor of Tacunga in 1802. It rose to a loss of 30,000—34,000 people, but some twenty years later the number of those killed immediately was reduced by about one-third.

[9] *Cosmos,* vol. i, p. 209, Bohn's edition.

of heat during the transition from fluidity to solidity. The external strata were first cooled by radiation, and were the first to become consolidated. The commotion is occasioned by an unequal ascent of elastic vapours formed (at the limit between the fluid and solid parts) either from the fused terrestrial mass alone, or from the penetration of sea-water into higher strata of rock, nearer to the surface of the earth, the sudden opening of fissures, and by the sudden ascent of vapours produced in the hotter and consequently more elastic depths. The attraction of the moon and sun[10] on the fluid, fused surface of the nucleus

[10] Hopkins has expressed doubts as to the action upon the fused "subjacent fluid confined into internal *lakes*," at the *Meeting of the British Association for* 1847 (p. 57), as Mallet has also done with regard to "the subterraneous lava tidal wave, moving the solid crust above it," at the *British Association Meeting* for 1850 (p. 20). Poisson also, with whom I have often spoken regarding the hypothesis of the subterranean ebb and flow, caused by the sun and moon, considers the impulse, which he does not deny, to be inconsiderable, "as in the open sea the effect scarcely amounts to 14 inches." Ampère, on the other hand, says :—" Those who admit the fluidity of the internal nucleus of the earth, do not appear to have sufficiently considered the action which would be exercised by the moon upon this enormous liquid mass; an action from which would result tides analogous to those of our seas, but far more terrible, both from their extent and from the density of the liquid. It is difficult to conceive how the envelope of the earth should be able to resist the incessant action of a sort of hydraulic ram(?) of 1400 leagues in length" (Ampère, *Théorie de la Terre,* in *Revue des deux Mondes,* July, 1833, p. 148). If the interior of the earth be fluid, which in general cannot be doubted, as, notwithstanding the enormous pressure, the particles are still displaceable, then the same conditions are fulfilled in the interior of the earth that give rise on the surface to the ocean tides; and the tide-producing force will constantly become weaker in approaching the centre, as the difference of the distances of every two opposite points, considered in their relation to the attracting bodies, constantly becomes less in receding from the surface, and the force depends exclusively upon the difference of the distances. If the solid crust of the earth opposes a resistance to this effort, the interior of the earth will only exert a pressure against its crust at these points; as my astronomical friend, Dr. Brunnow, expresses himself, no more tide will be produced than if the ocean had an indestructible covering of ice. The thickness of the solid unfused crust of the earth is calculated from the fusing points of the different kinds of rock, and the law of the increase of heat from the surface into the depths of the earth. I have already (*Cosmos,* vol. i, p. 26), justified the assumption that, at somewhat more than twenty geographical

of the earth, may also be regarded as the subsidiary action of a non-telluric cause, by which an increased pressure must be produced, either immediately against a solid, superimposed rocky arch; or indirectly, when the solid mass is separated, in subterranean basins, from the fused, fluid mass by elastic vapours.

The nucleus of our planet is supposed to consist of unoxidised masses, the metalloids of the alkalies and earths. Volcanic activity is excited in the nucleus by the access of water and air. Volcanoes certainly pour forth a great quantity of aqueous vapour into the atmosphere; but the assumption of the penetration of water into the volcanic focus is attended with much difficulty, considering the opposing pressure[11] of the external column of water and

miles ($21\frac{6}{10}$, 25 English) below the surface, a heat capable of melting granite prevails. Nearly the same number (45,000 metres=24 geographical miles) was named by Elie de Beaumont (*Geologie*, edited by Vogt, 1846, vol. i, p. 32), as the thickness of the solid crust of the earth. Moreover, according to the ingenious experiments of Bischof on the fusion of various minerals, of which the importance to the progress of geology is so great, the thickness of the unfused strata of the earth is between 122,590 and 136,448 feet, or on the average $21\frac{1}{3}$ geographical ($24\frac{1}{2}$ English) miles; see Bischof, *Wärmelehre des Innern unsers Erdkörpers*, pp. 286 and 271. This renders it the more remarkable to me to find that, with the assumption of a definite limit between the solid and fused parts, and not of a gradual transition, Hopkins, from the fundamental principles of his speculative geology, establishes the result that "the thickness of the solid shell cannot be less than about one-fourth or one-fifth(?) of the radius of its external surface" (*Meeting of British Association*, 1847, p. 51). Cordier's earliest supposition was only 56 geographical (72 English) miles, without correction, which is dependent upon the increased pressure of the strata at great depths, and the hypsometrical form of the surface. The thickness of the solid part of the crust of the earth is probably very unequal.

11 Gay Lussac, *Reflexions sur les Volcans*, in the *Annales de Chimie et de Physique*, tome xxii, 1823, pp. 418 and 426. The author, who, in company with Leopold von Buch and myself, observed the great eruption of lava from Vesuvius in September, 1805, has the merit of having submitted the chemical hypotheses to a strict criticism. He seeks for the cause of volcanic phenomena in a "very energetic and still unsatisfied affinity between the substances, which a fortuitous contact permits them to obey;" in general he favours the hypothesis of Davy and Ampère, which is now given up, "supposing that the radicals of silica, alumina, lime, and iron are combined with chlorine in the interior of the earth," and the penetration of sea water does not appear to him to be improbable under certain conditions (pp. 419, 420, 423, and 426).

of the internal lava; and the deficiency, or, at all events, very rare occurrence of burning hydrogen gas during the eruption, (which the formation of hydrochloric acid,[12] ammonia, and sulphuretted hydrogen, certainly does not sufficiently replace) has led the celebrated originator of this hypothesis to abandon it of his own accord.[13]

According to a third view, that of the highly endowed South American traveller, Boussingault, a deficiency of coherence in the trachytic and doleritic masses which form the elevated volcanoes of the chain of the Andes, is regarded as a primary cause of many earthquakes of very great extent. The colossal cones and dome-like summits of the Cordilleras, according to this view, have by no means been elevated in a soft and semifluid state, but have been thrown up and piled on one another when perfectly hardened, in the form of enormous, sharp-edged fragments. In an elevation and piling of this description, large interstices and cavities have necessarily been produced; so that by sudden sinking, and by the fall of solid masses which are too weakly supported, shocks are produced.[14]

Upon the difficulty of a theory founded upon the penetration of water, see Hopkins, *Brit. Assoc. Rep.* 1847, p. 38.

[12] According to the beautiful analyses made by Boussingault, on the margins of five craters (Tolima, Purace, Pasto, Tuqueras, and Cumbal), hydrochloric acid is entirely wanting in the vapours poured forth by the South American volcanoes, but not in those of Italy (*Annales de Chimie*, tome lii, 1833, pp. 7 and 23).

[13] *Cosmos*, vol. i, p. 234, Bohn's edition. Whilst Davy, in the most distinct manner, gave up the opinion that volcanic eruptions are a consequence of the contact of the metalloid bases with water and air, he still asserted that the presence of oxidizable metalloids in the interior of the earth might be a *co-operating* cause in volcanic processes already commenced.

[14] Boussingault says:—"I attribute most of the earthquakes in the Cordillera of the Andes to falls produced in the interior of these mountains by the subsidence which takes place, and which is a consequence of their elevation. The mass which constitutes these gigantic ridges has not been raised in a soft state; the elevation did not take place until after the solidification of the rocks. I assume, therefore, that the elevated masses ot the Andes are composed of fragments heaped upon each other. The consolidation of the fragments could not be so stable from the beginning as that there should be no settlements after the elevation, or that there should be no interior movements in the fragmentary masses" (Boussingault, *Sur les Tremblemens de Terre des Andes,* in

The *effects of the impulse*, the *waves of commotion*, may be reduced to simple mechanical theories with more distinctness than is furnished by the consideration of the *nature* of the first impulse, which indeed may be regarded as heterogeneous. As already observed, this part of our knowledge has advanced essentially in very recent times. The earth-waves have been represented in their progress and their propagation through rocks of different density and elasticity;[15] the causes of the rapidity of propagation, and its diminution by the *refraction*, *reflection*, and *interference*[16] of the oscillations have been

Annales de Chimie et de Physique, tome lviii, 1835, pp. 84—86). In the description of his memorable ascent of Chimborazo (*Ascension au Chimborazo le* 16 *Déc.* 1831, *loc. cit.* p. 176), he says again:—"Like Cotopaxi, Antisana, Tunguragua, and the volcanoes in general which project from the plateaux of the Andes, the mass of Chimborazo is formed by the accumulation of trachytic *débris*, heaped together without any order. These fragments, often of enormous volume, have been elevated in the solid state by elastic fluids which have broken out through the points of least resistance; their angles are always sharp." The cause of earthquakes here indicated is the same as that which Hopkins calls "a shock produced by the falling of the roof of a subterranean cavity," in his "Analytical Theory of Volcanic Phenomena" (*Brit. Assoc. Report*, 1847, p. 82).

[15] Mallet, *Dynamics of Earthquakes*, pp. 74, 80, and 82; Hopkins, *Brit. Assoc. Report*, 1847, pp. 74—82. All that we know of the waves of commotion and oscillations in solid bodies shows the untenability of the older theories as to the facilitation of the propagation of the movement by a series of cavities. Cavities can only act a *secondary* part in the earthquake, as spaces for the accumulation of vapours and condensed gases. "The earth, so many centuries old," says Gay Lussac very beautifully (*Ann. de Chimie et de Phys.* tome xxii, 1823, p. 428), "still preserves an internal force, which raises mountains (in the oxidized crust), overturns cities and agitates the entire mass. Most mountains, in issuing from the bosom of the earth, must have left vast cavities, which have remained empty, at least unless they have been filled with water (and gaseous fluids). It is certainly incorrect for Deluc and many geologists to make use of these empty spaces, which they imagine produced into long galleries, for the propagation of earthquakes to a distance. These phenomena, so grand and terrible, are very powerful sonorous waves, excited in the solid mass of the earth by some commotion, which propagates itself therein with the same velocity as sound. The movement of a carriage over the pavement shakes the vastest edifices, and communicates itself through considerable masses, as in the deep quarries below the city of Paris."

[16] Upon phenomena of interference in the earth-waves, analogous to those of the waves of sound, see *Cosmos*, vol. i, p. 211, Bohn's edition, and Humboldt, *Kleinere Schriften*, Bd. i. p. 379.

mathematically investigated. Attempts have been made to reduce to a rectilinear[17] standard the apparently circling (*rotatory*) shocks of which the obelisks before the monastery of San Bruno, in the small town of Stephano del Bosco (Calabria, 1783), furnished such a well-known example. Air, water, and earth-waves follow the same laws which are recognized by the theory of motion, at all events in space; but the earth-waves are accompanied, in their destructive action, by phenomena which remain more obscure in their nature and belong to the class of physical processes. As such we have to mention,—discharges of elastic vapours, and of gases; or, as in the small, moving Moya-cones of Pelileo, grit-like mixtures of pyroxene crystals, carbon, and infusorial animalcules with silicious shields. These wandering cones have overthrown a great number of Indian huts.[18]

In the general Delineation of Nature many facts are narrated concerning the great catastrophe of Riobamba (4th of February, 1797), which were collected on the spot from the lips of the survivors, with the most earnest endeavours after historic truth. Some of them are analogous to the occurrences in the great earthquake of Calabria in the year 1783; others are new, and especially characterized by the mine-like manifestation of force *from below upwards*. The earthquake itself was neither accompanied nor announced by any subterranean noise. A prodigious explosion, still indicated by the simple name of *el gran ruido*, was not perceived until 18 or 20 minutes afterwards, and only under the two cities of Quito and Ibarra, far removed from Tacunga, Hambato, and the principal scene of the destruction. There is no other event in the troubled destinies of the human race, by which in a few minutes, and in sparingly peopled mountain lands, so many thousands at once may be overtaken by death, as by the production and passage of a few earth-waves, accompanied by phenomena of cleavage!

[17] Mallet on vorticose shocks and cases of twisting, in *Brit. Assoc. Report*, 1850, pp. 33 and 49, and in the *Admiralty Manual*, 1849, p. 213 (see *Cosmos*, vol. i, p. 199, Bohn's edition).

[18] The Moya-cones were seen by Boussingault nineteen years after I saw them. "Muddy eruptions, consequences of the earthquake, like the eruptions of the *Moya* of Pelileo, which have buried entire villages" (*Ann. de Chim. et de Phys.* t. lviii, p. 81).

In the earthquake of Riobamba, of which the celebrated Valencian botanist, Don José Cavanilles, gave the earliest account, the following phenomena are deserving of special attention :—fissures which alternately opened and closed again, so that men saved themselves by extending both arms in order to prevent their sinking; the disappearance of entire caravans of riders or loaded mules (*recuas*), some of which disappeared through transverse fissures suddenly opening in their path, whilst others, flying back, escaped the danger; such violent oscillations (non-simultaneous elevation and depression) of neighbouring portions of the ground, that people standing upon the choir of a church at a height of more than 12 feet, got upon the pavement of the street without falling; the sinking of massive houses,[19] in which the inhabitants could open inner doors, and for two whole days, before they were released by excavations, passed uninjured from room to room, procured lights, fed upon supplies accidentally discovered, and disputed with each other regarding the probability of their rescue; and the disappearance of such great masses of stones and building materials. Old Riobamba contained churches and monasteries amongst houses of several stories; and yet, when I took the plan of the destroyed city, I only found in the ruins heaps of stone of 8 to 10 feet in height. In the south-western part of Old Riobamba (the former *Barrio de Sigchuguaicu*) a mine-like explosion, the effect of a force from below upwards, was distinctly perceptible. On the *Cerro de la Culca*, a hill of some hundred feet in height, which rises above the *Cerro de Cumbicarca* situated to the north of it, there lies stony rubbish mixed with human bones. *Translatory movements*, in a horizontal direction, by which avenues of trees become displaced, without being uprooted, or fragments of cultivated ground of very different kinds mutually displace each other, have occurred repeatedly in Quito, as well as

[19] Upon the displacement of buildings and plantations during the earthquake of Calabria, see Lyell's *Principles of Geology*, vol. i, pp. 484—491. Upon escapes in fissures during the great earthquake of Riobamba, see my *Rélation Historique*, tome ii, p. 642. As a remarkable example of the closing of a fissure it must be mentioned that, according to Scacchi's report, during the celebrated earthquake (in the summer of 1851), in the Neapolitan province of Basilicata, a hen was found caught by both feet in the street pavement in Barile, near Melfi.

in Calabria. A still more remarkable and complicated phenomenon is the discovery of utensils belonging to one house in the ruins of another at a great distance; a circumstance which has given rise to law-suits. Is it, as the natives believe, a sinking followed by an eruption? or, notwithstanding the distance, a mere projection? As, in nature, everything is repeated when similar conditions again occur, we must, by not concealing even what is still imperfectly observed, call the attention of future observers to special phenomena.

According to my observations it must not be forgotten that besides the commotion of solid parts as earth-waves, very different forces, as for instance physical forces, emanations of gas and vapour, also assist in most cases in the *production of fissures.* When in the undulatory movement the extreme *limit of the elasticity* of matter set in motion (according to the difference of the rocks or the looser strata) is exceeded and separation takes place, tense elastic fluid may break out through the fissures, bringing substances of various kinds from the interior to the surface and giving rise again by their eruption to translatory movements. Amongst these phenomena, which only *accompany* the primitive commotion (the earthquake) are the elevation of the undoubtedly wandering cone of the Moya, and probably also the transportation of objects upon the surface of the earth.[20] When large clefts are formed, and these only close again at their upper parts, the production of permanent subterranean cavities may not only become the cause of new earthquakes, as, according to Boussingault's supposition, imperfectly supported masses become detached in course of time and fall, producing commotions, but we may also imagine it possible that the *circles of commotion* are enlarged thereby, and that in the new earthquake, the clefts opened in the previous one enable elastic fluids to act in places to which they could not otherwise have obtained access. It is therefore an accompanying pheno-

[20] *Cosmos*, vol. i, p. 201, Bohn's edition. Hopkins has very correctly shown theoretically that the fissures produced by earthquakes are very instructive as regards the formation of veins and the phenomenon of dislocation, the more recent vein displacing the older formations. But long before Phillips (in his "Theorie der Gänge," 1791), Werner showed the comparative ages of the displacing penetrating vein and of the disrupted penetrated rock (see *Brit. Assoc. Report,* 1847, p. 62).

menon, and not the strength of the wave commotion which has once passed through the solid parts of the earth, that gives rise to the gradual and very important, but too little considered *enlargement of the circle of commotion.*[21]

Volcanic activities, of which the earthquake is one of the lower grades, almost always include at the same time, movement and the physical production of matter. In the Delineation of Nature we have already repeatedly indicated that water and hot vapours, carbonic acid gas and other *mofettes*, black smoke (as was the case for several days in the rock of Alvidras during the earthquake of Lisbon on the 1st November, 1755), flames of fire, sand, mud and moyas mixed with charcoal, rise from fissures at a distance from all volcanoes. The acute geognosist, Abich, has proved the connexion which exists in the Persian Ghilan between the thermal springs of Sarcin (5051 feet), on the road from Ardebil to Tabriz, and the earthquakes which frequently visit the elevated districts in every second year. In October, 1848, an undulatory movement of the earth, which lasted for a whole hour, compelled the inhabitants of Ardebil to abandon the town; and the temperature of the springs, which is between 44° and 46° C. (= 111° — 115° F.) rose immediately to a most painful scalding heat, and continued so for a whole month.[22] As Abich says, nowhere perhaps upon the face of the earth is "the intimate connexion of fissure-producing earthquakes, with the phenomena of mud-volcanoes, of salses, of combustible gases penetrating through the perforated soil, and of

[21] Upon the simultaneous commotion of the tertiary limestone of Cumana and Maniquarez since the great earthquake of Cumana on the 14th December, 1796, see Humboldt's *Rélation Historique*, tome i, p. 314; *Cosmos*, vol. i, p. 208, Bohn's edition; and Mallet, *Brit. Assoc. Report*, 1850, p. 28.

[22] Abich, on Daghestan, Schagdagh, and Ghilan, in Poggend. *Annalen*, Bd. lxxvi, 1849, p. 157. The salt spring in a well near Sassendorf, in Westphalia (in the district of Amsberg), also increased about 1½ per cent. in amount of saline matter, in consequence of the widely extended earthquake of the 29th July, 1846, the centre of commotion of which is placed at St. Goar, on the Rhine; this was probably because other fissures of supply had opened (Nöggerath, *Das Erdbeben im Rheingebiete vom* 29 *Juli*, 1846, p. 14). According to Charpentier's observation, the temperature of the sulphureous spring of Lavey (above St. Maurice, on the bank of the Rhone), rose from 87°.8 to 97°.3 F. during the Swiss earthquake of the 25th August, 1851.

petroleum springs, more distinctly expressed or more clearly recognizable, than in the south-eastern extremity of the Caucasus, between Schemacha, Baku, and Sallian. It is the part of the great Aralo-Caspian basin, in which the earth is most frequently shaken."[23] I was myself struck with the remarkable fact that in Northern Asia the circle of commotion, the centre of which appears to be in the vicinity of Lake Baikal, extends westwards only to the eastern borders of the Russian Altai, as far as the silver mines of Riddersk, the trachytic rock of Kruglaia Sopka and the hot springs of Rachmanowka and Arachan, but not to the Ural chain. Further, towards the south, on the other side of the parallel of 45° N., in the chain of the Thianschan (Mountains of Heaven) there appears a *zone of volcanic activity* directed from east to west, with every kind of manifestation. It extends not only from the fire district (Ho-tscheu) in Turfan, through the small chain of Asferah to Baku, and thence over Ararat into Asia Minor; but it is believed that it may be traced, oscillating between the parallels of 38° and 40° N., through the volcanic basin of the Mediterranean as far as Lisbon and the Azores. I have elsewhere[24] treated in detail

[23] At Schemacha (elevation 2393 feet), one of the numerous meteorological stations founded by Prince Woronzow, in the Caucasus, under Abich's directions, 18 earthquakes were recorded by the observer in the journal in 1848 alone.

[24] See *Asie Centrale,* tome i, pp. 324—329, and tome ii, pp. 108—120; and especially my *Carte des Montagnes et Volcans de l'Asie,* compared with the geognostic maps of the Caucasus, and of the plateau of Armenia by Abich, and the map of Asia Minor (Argaeus) by Peter Tschichatschef, 1853 (Rose, *Reise nach dem Ural, Altai, und Kaspischem Meere,* Bd. ii, pp. 576 and 597). In *Asie Centrale* we find:—"From Tourfan, situated upon the southern slope of the Thianchan, to the Archipelago of the Azores, there are 120 degrees of longitude. This is probably the longest and most regular *band of volcanic reactions,* oscillating slightly between 38° and 40° of latitude, which exists upon the face of the earth; it greatly surpasses in extent the volcanic band of the Cordillera of the Andes in South America. I insist the more upon this singular line of ridges, of elevations, of fissures, and of propagations of commotions, which comprises a third of the circumference of a parallel of latitude, because some small accidents of surface, the unequal elevation and the breadth of the ridges, or linear elevations, as well as the interruption caused by the sea-basins (Aralo-Caspian, Mediterranean, and Atlantic basins), tend to mark the great features of the geological constitution of the globe. (This bold sketch of a regularly prolonged line of commotion by no means excludes other

of this important subject of volcanic geography. In Greece, also, which has suffered from earthquakes more than any other part of Europe (Curtius, *Peloponnesos*, i, s. 42—46), it appears that an immense number of thermal springs, some still flowing, others already lost, have broken out with earth-shocks. A similar thermic connexion is indicated in the remarkable book of Johannes Lydus upon earthquakes (*De Ostentis*, cap. liv, p. 189, Hase). The great natural phenomenon of the destruction of Helice and Bura in Achaia (373 B.C. ; *Cosmos*, vol. iv, p. 543) gave rise in an especial manner to hypotheses regarding the causal connexion of volcanic activity. With Aristotle originated the curious theory of the force of the winds collecting in the cavities of the depths of the earth (*Meteor.* ii, p. 368). By the part which they have taken in the early destruction of the monuments of the most flourishing period of the arts, the unhappy frequency of earthquakes in Greece and Southern Italy has exercised the most pernicious influence upon all the studies which have been directed to the evolution of the Greek and Roman civilisation at various epochs. Egyptian monuments also, for example that of a colossal Memnon (27 years B.C.), have suffered from earthquakes, which, as Letronne has proved, have been by no means so rare as was supposed in the valley of the Nile (*Les Statues Vocales de Memnon*, 1833, pp. 23—27, 255).

The physical changes here referred to, as induced by earthquakes by the production of fissures, render it the more re-

lines in the direction of which the movements may also be propagated.)" As the city of Khotan and the district south of the Thianschan has been the most ancient and celebrated seat of Buddhism, the Buddhistic literature was occupied very early and earnestly with the causes of earthquakes (see *Foe-koue-ki, ou Rélation des Royaumes Bouddiques*, translated by M. Abel Rémusat, p. 217). By the followers of Sâkhyamuni eight of these causes are adduced, amongst which a revolving wheel of steel, hung with reliques ('sarîra, signifying *body* in Sanscrit), plays a principal part,—a mechanical explanation of a dynamic phenomenon, scarcely more absurd than many of our geological and magnetic myths, which have but recently become antiquated! According to a statement of Klaproth's, priests, and especially begging monks (*Bhikchous*) have the power of causing the earth to tremble and of setting the subterranean wheel in motion. The travels of Fahian, the author of the *Foe-koue-ki*, date about the commencement of the fifth century.

markable that so many warm mineral springs retain their composition and temperature unchanged for centuries, and therefore must flow from fissures which appear to have undergone no alteration either vertically or laterally. The establishment of communications with higher strata would have produced a diminution, and that with lower ones an increase of heat.

When the great eruption of the volcano of Conseguina (in Nicaragua) took place on the 23rd of January, 1835, the subterranean noise[25] (*los ruidos subterraneos*) was heard at the same time on the island of Jamaica and on the plateau of Bogotá, 8740 feet above the sea, at a greater distance than from Algiers to London. I have also elsewhere observed, that in the eruptions of the volcano on the island of Saint Vincent, on the 30th of April, 1812, at 2 o'clock in the morning, a noise like the report of cannons was heard without any sensible concussion of the earth over a space of 160,000 geographical square miles.[26] It is very remarkable that when earthquakes are combined with noises, which is by no means constantly the case, the strength of the latter does not at all increase in proportion to that of the former. The most singular and mysterious phenomenon of subterranean sound is undoubtedly that of the *bramidos de Guanaxuato* which lasted from the 9th of January to the middle of February, 1784, regarding which I was the first to collect trustworthy details from the lips of living witnesses, and from official records (*Cosmos*, vol. i, p. 205).

The rapidity of the propagation of the earthquake upon the surface of the earth must from its nature be modified in many ways by the variable densities of the solid rocky strata (granite and gneiss, basalt and trachytic porphyry, jurassic limestone and gypsum), as well as by that of the alluvial soil, through which the wave of commotion passes. It

[25] Acosta, *Viajes cientificos á los Andes ecuatoriales*, 1849, p. 56.

[26] *Cosmos*, vol. i, pp. 204—206; Humboldt, *Rélation Historique*, t. iv, chap. 14, pp. 31—38. Some sagacious theoretical observations by Mallet upon sonorous waves in the earth and sonorous waves in the air occur in the *Brit. Assoc. Report*, 1850, pp. 41—46, and in the *Admiralty Manual*, 1849, pp. 201 and 217. The animals which in tropical countries are disquieted by the slightest commotions of the earth sooner than man are, according to my experience, fowls, pigs, dogs, asses, and crocodiles (Caymans); the latter suddenly quit the bottom of the rivers.

would, however, be desirable to ascertain once for all with certainty what are the extreme limits between which the velocities vary. It is probable that the more violent commotions by no means always possess the greatest velocity. The measurements, moreover, do not always relate to the same direction which the waves of commotion have followed. Exact mathematical determinations are much wanted, and it is only at a very recent period that a result has been obtained with great exactitude and care from the Rhenish earthquake of the 29th of July, 1846, by Julius Schmidt, assistant at the Observatory of Bonn. In the earthquake just mentioned the velocity of propagation was 14,956 geographical miles in a minute, that is 1466 feet in the second. This velocity certainly exceeds that of the waves of sound in the air; but if the propagation of sound in water is at the rate of 5016 feet, as stated by Colladon and Sturm, and in cast iron tubes 11393 feet, according to Biot, the result found for the earthquake appears very weak. For the earthquake of Lisbon on the 1st of November, 1755, Schmidt (working from less accurate data) found the velocity between the coasts of Portugal and Holstein to be more than five times as great as that observed on the Rhine, on the 29th of July, 1846. Thus, for Lisbon and Glückstadt (a distance of 1348 English miles) the velocity obtained was 89.26 miles in a minute or 7953 feet in a second; which, however, is still 3438 feet less than in cast iron.[27]

[27] Julius Schmidt, in Nöggerath, *Ueber das Erdbeben vom 29 Juli*, 1846, s. 28—37. With the velocity stated in the text, the earthquake of Lisbon would have passed round the equatorial circumference of the earth in about 45 hours. Michell (*Phil. Transact.* vol. i, pt. ii, p. 572) found for the same earthquake of the 1st November, 1755, a velocity of only 50 English miles in a minute, that is, instead of 7956, only 4444 feet in a second. The inexactitude of the older observations and difference in the direction of propagation may conduce to this result. Upon the connexion of Neptune with earthquakes, at which I have glanced in the text (p. 181), a passage of Proclus in the commentary to Plato's Cratylus, throws a remarkable light. "The middle one of the three deities, Poseidon, is the cause of movement in all things, even in the *immovable*. As the originator of movement he is called 'Εννοσίγαιος; to him, of those who shared the empire of Saturn, fell the middle lot, the easily moved sea" (Creuzer, *Symbolik und Mythologie*, Th. iii, 1842, s. 260). As the Atlantis of Solon and the Lyctonia, which, according to my idea, was nearly allied to it, are geological myths, both the lands destroyed by earthquakes are re-

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Concussions of the earth and sudden eruptions of fire from volcanoes which have been long in repose, whether these merely emit cinders, or, like intermittent springs, pour forth fused, fluid earths in streams of lava, have certainly a single, common causal connexion in the high temperature of the interior of our planet ; but one of these phenomena is usually manifested quite independently of the other. Thus, in the chain of the Andes in its linear extension, violent earthquakes shake districts in which unextinguished, often indeed active, volcanoes exist, without the latter being perceptibly excited. During the great catastrophe of Riobamba, the volcanoes of Tungurahua and Cotopaxi, the former in the immediate vicinity, and the latter rather further off, remained perfectly quiet. On the other hand, volcanoes have presented violent and long-continued eruptions, without any earthquake being perceived in their vicinity, either previously or simultaneously. In fact, the most destructive earthquakes recorded in history, and which have passed through many thousand square miles, if we may judge from what is observable at the surface, stand in no connexion with the activity of volcanoes. These have lately been called *Plutonic*, in opposition to the true *Volcanic* earthquakes, which are usually limited to smaller districts. In respect of the more general views of vulcanicity, this nomenclature is, however, inadmissible. By far the greater part of the earthquakes upon our planet must be called Plutonic.

That which is capable of exciting earth-shocks, is everywhere under our feet ; and the consideration that nearly ¾ths of the earth's surface are covered by the sea (with the exception of some scattered islands) and without any permanent communication between the interior and the atmosphere, that is to say, without active volcanoes, contradicts the erroneous, but widely disseminated belief that all earthquakes are to be ascribed to the eruption of some distant volcano. Earthquakes on continents are certainly propa-

garded as standing under the dominion of Neptune, and set in opposition to the Saturnian continents. According to Herodotus (lib. ii, c. 43 et 50), Neptune was a Libyan deity, and unknown in Egypt. Upon these circumstances—the disappearance of the Libyan lake Tritonis by earthquake—and the idea of the great rarity of earthquakes in the valley of the Nile, see my *Examen Critique de la Géographie*, t. i, pp. 171 and 179.

gated along the sea-bottom from the shores, and give rise to the terrible sea-waves, of which such memorable examples were furnished by the earthquakes of Lisbon, Callao de Lima, and Chili. When, on the contrary, the earthquakes start from the sea bottom itself, from the realm of Poseidon, the earth-shaker (*σεισίχθων, κινησίχθων*), and are not accompanied by upheaval of islands (as in the ephemeral existence of the island of Sabrina or Julia), an unusual rolling and swelling of the waves may still be observed at points where the navigator would feel no shock. The inhabitants of the desert Peruvian coasts have often called my attention to a phenomenon of this kind. Even in the harbour of Callao, and near the opposite island of San Lorenzo, I have seen wave upon wave suddenly rising up in the course of a few hours to more than 10 or 15 feet, in perfectly still nights, and in this otherwise so thoroughly peaceful part of the South Sea. That such a phenomenon might have been the consequence of a storm which had raged far off upon the open sea, was by no means to be supposed in these latitudes.

To commence from those commotions which are limited to the smallest space, and evidently owe their origin to the activity of a volcano, I may mention in the first place how when sitting at night in the crater of Vesuvius at the foot of a small cone of eruption with my chronometer in my hand, (this was after the great earthquake of Naples on the 26th of July, 1805, and the eruption of lava which took place seventeen days subsequently), I felt a concussion of the soil of the crater very regularly every 20 or 25 seconds, immediately *before* each eruption of red hot cinders. The cinders, thrown up to a height of 50—60 feet fell back partly into the orifice of eruption, whilst a part of them covered the walls of the cone. The regularity of such a phenomenon renders its observation free from danger. The constantly repeated small earthquake was quite imperceptible beyond the crater,—even in the *Atrio del Cavallo* and in the Hermitage *del Salvatore.* The periodicity of the concussion shows that it was dependent upon a determinate *degree of tension* which the vapours must attain, to enable them to break through the fused mass in the interior of the cone of cinders. In the case just described no concussions were felt on the declivity of the ashy cone of Vesuvius, and in an exactly analogous but far grander phenomenon, on the ash-cone of the volcano of Sangai, which rises to a height of 17,006 feet to the south-east of the city of Quito, no trembling of the earth[28] was felt by a very distinguished observer, M. Wisse, when (in December, 1849,) he approached within a thousand feet of the summit and crater, although no less than 267 explosions (eruptions of cinders) were counted in an hour.

A *second*, and infinitely more important kind of earthquake, is the very frequent one which usually accompanies or precedes great eruptions of volcanoes,—whether the volcanoes, like ours in Europe, pour forth streams of lava ; or like Cotopaxi, Pichincha, and Tunguragua of the Andes only throw out calcined masses, ashes and vapours. For earthquakes of this kind the volcanoes are especially to be regarded as safety valves, as indicated even by Strabo's expression concerning the fissure pouring out lava near Lelante in Eubœa. The earthquakes cease, when the great eruption has taken place.

Most widely[29] distributed, however, are the ravages of the waves of commotion which pass sometimes through completely non-trachytic, non-volcanic countries and sometimes through

[28] The explosions of the Sangai, or *Volcan de Macas*, took place on an average every 13″.4, see Wisse, *Comptes rendus de l'Acad. des Sciences*, tome xxxvi, 1853, p. 720. As an example of commotions confined within the narrowest limits, I might also have cited the report of Count Larderel upon the lagoons in Tuscany. The vapours containing boron or boracic acid give notice of their existence and of their approaching eruption at fissures by shaking the surrounding rocks (Larderel, *Sur les établissements industriels de la production d'acide boracique en Toscane*, 1852, p. 15).

[29] I am glad that I am able to cite an important authority in confirmation of the views that I have endeavoured to develope in the text. "In the Andes the oscillation of the soil, due to a volcanic eruption, is, so to speak, local, whilst an earthquake, which, at all events in appearance, is not connected with any volcanic eruption, is propagated to incredible distances. In this case it has been remarked that the shocks followed in preference the direction of the chains of mountains, and were principally felt in Alpine districts. The frequency of the movements in the soil of the Andes, and the little coincidence observed between these movements and volcanic eruptions, must necessarily lead us to suppose that *in most cases* they are occasioned by a cause *independent of volcanoes*" (Boussingault, *Annales de Chimie et de Physique*, t. lviii, 1835, p. 83).

trachytic, volcanic regions, without exerting any influence upon the neighbouring volcanoes. This is a *third* group of phenomena, and is that which most convincingly indicates the existence of a general cause, lying in the thermic nature of the interior of our planet. To this third group also belongs the phenomenon, sometimes, though rarely, met with in non-volcanic lands, but little disturbed by earthquakes, of a trembling of the soil, within the most narrow limits, continued uninterruptedly for months together, so as to give rise to apprehensions of an elevation and formation of an active volcano. This was the case in the Piedmontese valleys of Pelis and Clusson, as well as in the vicinity of Pignerol in April and May, 1805, and also in the spring of 1829 in Murcia, between Orihuela and the sea-shore, upon a space of scarcely sixteen square miles. When the cultivated surface of Jorullo upon the western declivity of the plateau of Mechoacan in the interior of Mexico was shaken uninterruptedly for 90 days, the volcano rose with many thousand cones of 5—7 feet in height (*los hornitos*) surrounding it, and poured forth a short but vast stream of lava. In Piedmont and Spain, on the contrary, the concussions of the earth gradually ceased, without the production of any other phenomenon.

I have considered it expedient to enumerate the perfectly distinct kinds of manifestation of the same volcanic activity (the reaction of the interior of the earth upon its surface) in order to guide the observer, and bring together materials which may lead to fruitful results with regard to the causal connexion of the phenomena. Sometimes the volcanic activity embraces at one time or within short periods so large a portion of the earth, that the commotions of the soil excited may be ascribed simultaneously to many causes related to each other. The years 1796 and 1811 present particularly memorable examples[30] of such a grouping of the phenomena.

[30] The great phenomena of 1796 and 1797, and 1811 and 1812, occurred in the following order :—

27th of September, 1796. Eruption of the volcano of the island of Guadaloupe, in the Leeward Islands, after a repose of many years

November, 1796. The volcano on the plateau of Pasto, between the small rivers Guaytara and Juanambu, became ignited and began to smoke permanently;

b. *Thermal Springs.*

(Amplification of the Representation of Nature. *Cosmos*, vol. i, pp. 216—221).

As a consequence of the vital activity of the interior of our planet, evidenced in irregularly repeated and often fearfully destructive phenomena, we have described the

14th of December, 1796. Earthquake and destruction of the city of Cumana;

4th of February, 1797. Earthquake and destruction of Riobamba. On the same morning the columns of smoke of the volcano of Pasto, at a distance of at least 200 geographical miles from Riobamba, disappeared suddenly, and never reappeared; no commotion was felt in its vicinity.

30th of January, 1811. First appearance of the island of Sabrina, in the group of the Azores, near the island of St. Michael. The elevation preceded the eruption of fire, as in the case of the little Kameni (Santorin) and that of the volcano of Jorullo. After an eruption of cinders, lasting for six days, the island rose to a height of 320 feet above the surface of the sea. It was the third appearance and disappearance of the island nearly at the same point, at intervals of 91 and 92 years.

May, 1811. More than 200 shocks of earthquake on the island of St. Vincent up to April, 1812.

December, 1811. Innumerable shocks in the river-valleys of the Ohio, Mississippi, and Arkansas up to 1813. Between New Madrid, Little Prairie, and La Saline, to the north of Cincinnati, the earthquakes occurred almost every hour for months together.

December, 1811. A single shock in Caraccas.

26th of March, 1812. Earthquake and destruction of the town of Caraccas. The circle of commotion extended over Santa Marta, the town of Honda, and the elevated plateau of Bogotá, to a distance of 540 miles from Caraccas. The motion continued until the middle of the year 1813.

30th of April, 1812. Eruption of the volcano of St. Vincent; and on the same day, about 2 o'clock in the morning, a fearful subterranean noise, like the roar of artillery, was heard at the same time and with equal distinctness on the shores of Caraccas, in the Llanos of Calabazo and of the Rio Apure, without being accompanied by any concussion of the earth (see *ante*, p. 178). The subterranean noise was also heard upon the Island of St. Vincent, but, and this is very remarkable, it was stronger at some distance upon the sea.

earthquake. In this, there prevails a volcanic power, which in its essential nature only *acts dynamically*, producing movement and commotion, but when it is favoured at particular points by the fulfilment of subsidiary conditions, it is capable of bringing to the surface *material products*, although not of generating them like true volcanoes. Just as water, vapours, petroleum, mixtures of gases, or pasty masses (mud and *moya*) are thrown out, through fissures suddenly opened in earthquakes sometimes of short duration, so do liquid and aerial fluids flow *permanently* from the bosom of the earth through the universally diffused network of communicating fissures. The brief and impetuous eruptive phenomena are here placed beside the great peaceful *spring-system* of the crust of the earth, which beneficently refreshes and supports organic life. For thousands of years it returns to organized nature the moisture which has been drawn from the atmosphere by falling rain. Analogous phenomena are mutually illustrative in the eternal economy of nature; and wherever an attempt is made at the generalisation of ideas, the intimate concatenation of that which is recognized as allied must not remain unnoticed.

The widely disseminated classification of springs, into *cold and hot*, which appears so natural in ordinary conversation, has but a very indefinite foundation when reduced to numerical data of temperature. If the temperature of springs be compared with the internal heat of man (found, with thermo-electrical apparatus, to be 98°—98°.6 F. according to Brechet and Becquerel), the degree of the thermometer at which a fluid is called cold, warm, or hot, when in contact with parts of the human body, is very different according to individual sensations. No absolute degree of temperature can be established, above which a spring should be designated warm. The proposition to call a spring cold in any climatic zone, when its average annual temperature does not exceed the average annual temperature of the air in the same zone, at least presents a scientific exactitude, by affording a comparison of definite numbers. It has the advantage of leading to considerations upon the different *origin* of springs, as the ascertained agreement of their temperature with the annual temperature of the air is recognized directly in unchangeable springs; and in changeable ones, as has been shown by Wahlenberg and Erman the elder, in the averages of the summer and winter months. But in accordance with the criterion here indicated, a spring in one zone must be denominated warm, which hardly attains the seventh or eighth part of temperature of one which in another zone, near the equator, will be called cold. I may mention the differences between the average temperature of St. Petersburg (38°.12 F.) and of the shores of the Orinoco. The purest spring water which I drank in the vicinity of the cataracts of Atures[31] and Maypures (81°.14 F.) or in the forest of Atabapo, had a temperature of more than 79° F.; even the temperature of the great rivers in tropical South America, corresponds with the high degrees of heat of such cold[32] springs.

31 Humboldt, *Voyage aux Régions Equinoxiales*, t. ii, p. 376.

32 For the sake of comparing the temperature of springs where they break forth directly from the earth, with that of large rivers flowing through open channels, I here bring together the following average numbers from my journals:—

Rio Apure, lat. 7¾°; temperature, 81°.

Orinoco, between 4° and 8° of latitude; 81°.5—85°.3.

Springs in the forest, near the cataract of Maypures, breaking forth from the granite, 82°.

Cassiquiare, the branch of the Upper Orinoco, which forms the union with the Amazon; only 75°.7.

Rio Negro, above San Carlos (scarcely 1° 53′ to the north of the equator); only 74°.8.

Rio Atabapo, 79°.2 (lat. 3° 50′).

Orinoco, near the entrance of the Atabapo, 82°.

Rio Grande de la Magdalena (lat. 5° 12′ to 9° 56′), 79° 9′.

Amazon, 5° 31′ south latitude, opposite to the Pongo of Rentema (Provincia Jaen de Bracamoros), scarcely 1300 feet above the South Sea, only 72°.5.

The great mass of water of the Orinoco consequently approaches the average temperature of the air of the vicinity. During great inundations of the Savannahs, the yellowish brown waters, which smell of sulphuretted hydrogen, acquire a temperature of 92°.8; this I found to be the temperature in the *Lagartero*, to the east of Guayaquil, which swarmed with crocodiles. The soil there becomes heated, as in shallow rivers, by the warmth produced in it by the sun's rays falling upon it. With regard to the multifarious causes of the low temperature of the water of the Rio Negro, which is of a *coffee-brown* colour by reflected light, and of the *white* waters of the Cassiquiare (a constantly clouded sky, the quantity of rain, the evaporation from the dense forests, and

The breaking out of springs, effected by multifarious causes of pressure and by the communication of fissures containing water, is such a universal phenomenon of the surface of the earth, that waters flow forth at some points from the most elevated mountain strata, and at others from the bottom of the sea. In the first quarter of this century numerous results were collected by Leopold von Buch, Wahlenberg and myself, with regard to the temperature of springs and the diffusion of heat in the interior of the earth in both hemispheres, from 12° S. lat. to 71° N.[33] The springs which have an unchangeable temperature were carefully separated from those which vary with the seasons; and Leopold von Buch ascertained the powerful influence of the distribution of rain in the course of the year, that is to say, the influence of the proportion between the relative abundance of winter and summer rain upon the temperature of the variable springs, which, as regards number, are the most widely distributed. More recently[34] some very ingenious

the want of hot sandy tracts upon the banks), see my river voyage, in the *Rélation Historique*, t. ii, pp. 463 and 509. In the Rio Guancabamba or Chamaya, which falls into the Amazon, near the Pongo de Rentema, I found the temperature of the water to be only 67°.6, as its waters come with prodigious swiftness from the elevated lake Simicocha on the Cordillera. On my voyage of 52 days up the river Magdalena, from Mahates to Honda, I perceived most distinctly, from numerous observations, that a rise in the level of the water was indicated for hours previously by a diminution of the temperature of the river. The refrigeration of the stream occurred before the cold mountain waters from the Paramos near the source came down. Heat and water move, so to speak, in opposite directions and with very unequal velocities. When the water near Badillas rose suddenly, the temperature fell long before from 80°.6 to 74°.3. As, during the night, when one is established upon a low sandy islet, or upon the bank, with bag and baggage, a rapid rise of the river may be dangerous, the discovery of a prognostic of the approaching rise (the *avenida*) is of some importance.

[33] Leopold von Buch, *Physicalische Beschreibung der canarischen Inseln*, s. 8: Poggend. *Annalen*, Bd. xii, s. 403; *Bibliothèque Britannique, Sciences et Arts*, t. xix, 1802, p. 263; Wahlenberg, *De Veget. et Clim. in Helvetia Septentrionali Observatis*, pp. lxxviii and lxxxiv; Wahlenberg, *Flora Carpathica*, p. xciv, and in Gilbert's *Annalen*, Bd. xli, s. 115; Humboldt, in the *Mém. de la Soc. d'Arcueil*, t. iii (1817) p. 599.

[34] De Gasparin, in the *Bibliothèque Univ. Sciences et Arts*, t. xxxviii, 1828, pp. 54, 113 and 264; *Mém. de la Soc. Centrale d'Agriculture*,

comparative observations by De Gasparin, Schouw and Thurmann have thrown considerable light, in a geographical and hypsometrical point of view, in accordance with latitude and elevation upon this influence. Wahlenberg asserted that in very high latitudes the average temperature of variable springs is rather higher than that of the atmosphere; he sought the cause of this, not in the dryness of a very cold atmosphere and in the less abundant winter rain caused thereby, but in the snowy covering diminishing the radiation of heat from the soil. In those parts of the plain of Northern Asia, in which a perpetual icy stratum, or at least a frozen alluvial soil mixed with fragments of ice is found at a depth of a few feet,[35] the temperature of springs can only be employed with great caution for the investigation of Kupffer's important theory of the isogeothermal lines. A two-fold radiation of heat is then produced in the upper stratum of the earth: one upwards towards the atmosphere, and another downwards towards the icy stratum. A long series of valuable observations made by my friend and companion, Gustav Rose, during our Siberian expedition in the heat of summer (often in springs still surrounded by ice) between the Irtysch, the Obi, and the Caspian Sea, revealed a great complication of local disturbances. Those which present themselves from perfectly different causes in the tropical zone, in places where

1826, p. 178; Schouw, *Tableau du Climat et de la Végétation de l'Italie* vol. i, 1839, pp. 133—195; Thurmann, *Sur la température des sources de la chaîne du Jura, comparée à celle des sources de la plaine Suisse, des Alpes et des Vosges,* in the *Annuaire Météorologique de la France,* 1850, pp. 258—268. As regards the frequency of the summer and autumn rains, De Gasparin divides Europe into two strongly contrasted regions. Valuable materials are contained in Kämtz, *Lehrbuch der Meteorologie,* Bd. i, s. 448—506. According to Dove (Poggend. *Annalen,* Bd. xxxv, s. 376) in Italy, "at places to the north of which a chain of mountains is situated, the maxima of the curves of monthly quantities of rain fall in March and September; and where the mountains lie to the south, in April and October." The totality of the proportions of rain in the temperate zones may be comprehended under the following general point of view:—"The period of winter rain in the borders of the tropics constantly divides, the further we depart from these, into two maxima united by slighter falls, and these again unite into a summer-maximum in Germany; where, therefore, a temporary want of rain ceases altogether." See the section "Geothermik" in the excellent *Lehrbuch der Geognosie,* by Naumann, Bd. i, (1850), s. 41—73.

[35] See above, p. 45.

mountain springs burst forth upon vast elevated plateaux, eight or ten thousand feet above the sea (Micuipampa, Quito, Bogota), or in narrow, isolated mountain-peaks many thousand feet higher, not only include a far greater part of the surface of the earth, but also lead to the consideration of analogous thermic conditions in the mountainous countries of the temperate zones.

In this important subject it is above all things necessary to separate the cycle of actual observations from the theoretical conclusions which are founded upon them. What we seek, expressed in the most general way, is of a triple nature: —the distribution of heat in the crust of the earth which is accessible to us, in the aqueous covering (the ocean) and in the atmosphere. In the two envelopes of the body of the earth, the liquid and gaseous, an opposite alteration of temperature (diminution and increase in the superposed strata) prevails in a vertical direction. In the solid parts of the body of the earth the temperature increases with the depth; the alteration is in the same direction, although in a very different proportion, as in the aerial ocean, the shallows and rocks of which are formed by the elevated plateaux and multiform mountain peaks. We are most exactly acquainted by direct experiments, with the distribution of heat in the atmosphere,—geographically by local determination in latitude and longitude, and in accordance with hypsometric relations in proportion to the vertical elevation above the surface of the sea,—but in both cases almost exclusively in close contact with the solid and fluid parts of the surface of our planet. Scientific and systematically arranged investigations by aerostatic voyages in the free aerial ocean, beyond the near action of the earth, are still very rare, and therefore but little adapted to furnish the numerical data of average conditions which are so necessary. Upon the decrease of heat in the depths of the ocean observations are not wanting; but currents, which bring in water of different latitudes, depths, and densities, prevent the attainment of general results, almost to a greater extent than currents in the atmosphere. We have here touched preliminarily upon the thermic conditions of the envelopes of our planet, which will be treated of in detail hereafter, in order to consider the influence of the vertical distribution of heat in the solid crust of the earth, and the system of the geo-isothermic lines, not in too isolated a condition, but as a part of the all-penetrating motion of heat, a truly cosmical activity.

Instructive as are, in many respects, observations upon the unequal diminution of temperature of springs which do not vary with the seasons as the height of their point of emergence increases,—still the local law of such a diminishing temperature of springs cannot be regarded, as is often done, as a universal geothermic law. If we were certain that waters flowed unmixed in a horizontal stratum of great extent, we might certainly suppose that they have gradually acquired the temperature of the solid ground, but in the great network of fissures of elevated masses, this case can rarely occur. Colder and more elevated waters mix with the lower ones. Our mining operations, inconsiderable as may be the depth to which they attain, are very instructive in this respect; but we should only obtain a direct knowledge of the isogeothermal lines, if thermometers were buried, according to Boussingault's method,[36] to a depth below that affected by the influences of the changes of temperature of the neighbouring atmosphere, and at very different elevations above the sea. From the forty-fifth degree of latitude to the parts of the tropical regions in the vicinity of the equator, the depth at which the stratum of invariable temperature commences, diminishes from 60 to 1½ or 2 feet. Burying the geothermometer at a small depth in order to obtain a knowledge of the average temperature of the earth, is therefore readily practicable only between the tropics or in the subtropical zone. The excellent expedient of Artesian wells which have indicated an increase of heat of 1° F. for every 54 to 58 feet in absolute depths of from 745 to 2345 feet has hitherto only been afforded to the physicist in districts not much more than 1600 feet above the level of the sea[37] I have visited silver-mines in the chain of the Andes, 6°45′ south of the equator at an elevation of nearly 13,200 feet and found the temperature of the water penetrating through the fissures of the limestone to be 52°.3 F.[38] The waters which were heated in the baths of the Inca

[36] See *Cosmos*, vol. i, p. 218, and vol. v, p. 40, Bohn's edition.
[37] See above, p. 37.
[38] Mina de Guadalupe, one of the Minas de Chota, *l.c. sup.* p. 41.

Tupac Yupanqui, upon the ridge of the Andes (*Paso del Assuay*), probably come from springs of the *Ladera de Cadlud*, where I have traced their course, near which the old Peruvian causeway also ran, barometrically to an elevation of 15,526 feet (almost that of Mont Blanc).[39] These are the highest points at which I could observe spring water in South America. In Europe the brothers Schlagintweit have found gallery-water in the gold mine in the Eastern Alps at a height of 9442 feet, and found that the temperature of small springs near the opening of the gallery of only 33°.4 F.,[40] at a distance from any snow or glacier ice. The highest limits of springs are very different according to geographical latitude, the elevation of the snow line and the relation of the highest peaks to the mountain ridges and plateaux.

If the radius of our planet were to be increased by the height of the Himalaya at the Kintschindjunga, and therefore uniformly over the whole surface by 28,175 feet (4.34 English miles), with this small increase of only $\frac{1}{800}$th of the radius, the heat in the surface cooled by radiation, would be (according to Fourier's analytical theory), almost the same as it now is in the upper crust of the earth. But if individual parts of the surface raise themselves in mountain chains and narrow peaks, like rocks upon the bottom of the aerial ocean, a diminution of heat takes place in the interior of the elevated strata, and this is modified by contact with strata of air of different temperature, by the capacity for heat and conductive power of heterogeneous kinds of rocks, by the sun's action on the forest-clad summits and declivities, by the greater and less radiation of the mountains in accordance with their form (relief), their massiveness) or their conical and pyramidal narrowness. The special elevations of the region of clouds, the snow and ice-coverings at various elevations of the snow line, and the frequency of the cool currents of air coming down the steep declivities, at particular times of the day, alter the effect of the terrestrial radiation. In proportion as the towering cones of the summits become cooled, a weak current

39 Humboldt, *Views of Nature*, p. 393.

40 Mine on the Great Fleuss in the Moll Valley of the Tauern, see Hermann and Adolph Schlagintweit, *Untersuchungen über die physikalische Geographie der Alpen*, 1850, s. 242—273.

of heat tending towards, but never reaching an equilibrium, sets in from below upwards. The recognition of so many factors acting upon the vertical distribution of heat, leads to well-founded presumptions regarding the connexion of complicated local phenomena, but not to direct numerical determinations. In the mountain springs (and the higher ones, being important to the chamois-hunter, are carefully sought) there so often remains the doubt that they are mixed with waters, which by sinking down introduce the colder temperature of higher strata, or by ascending introduce the warmer temperature of lower strata. From 19 springs, observed by Wahlenberg, Kämtz draws the conclusion that in the Alps we must rise from 960 to 1023 feet in order to see the temperature of the springs sink 1° C. (1°.8 F.). A greater number of observations selected with more care by Hermann and Adolph Schlagintweit in the eastern Carinthian Alps and in the western Swiss Alps on the Monte Rosa, give only 767 feet. According to the great work[41] of these excellent observers, "the decrease of the temperature of springs is certainly somewhat more gradual than that of the average annual temperature of the air, which in the Alps amounts to about 320 feet for 1° F. The springs there are in general warmer than the average temperature of the air at the same level; and the difference between the temperature of the air and springs increases with the elevation. The temperature of the soil is not the same at equal elevations in the entire range of the Alps, as the isothermal surfaces which unite the points of the same average temperature of springs, rise higher above the level of the sea, *independently of the influence of latitude*, in proportion to the average convexity of the surrounding soil; perfectly in accordance with the laws of the distribution of heat in a solid body of varying thickness, with which the relief (the mass-elevation) of the Alps may be compared."

In the chain of the Andes, and indeed in those volcanic parts of it which present the greatest elevations, the burying of thermometers may in particular cases lead to deceptive results by the influence of local circumstances. From the opinion formerly held by me, that black rocky ridges, visible at a great distance, which penetrate the snowy

[41] *Monte Rosa*, 1853, chap. vi, s. 212—225.

region, are not always indebted for their entire freedom from snow to the steepness of their sides, but to other causes, I buried the bulb of a thermometer only three inches deep in the sand which filled the fissure in a ridge on the Chimborazo at an elevation of 18,290 feet, and therefore 3570 feet above the summit of Mont Blanc. The thermometer permanently showed 10°.5 F. above the freezing point, whilst the air was only 4°.5 F. above that point. The result of this observation is of some importance; for even 2558 feet lower, at the lower limit of perpetual snow of the volcano of Quito, according to numerous observations collected by Boussingault and myself, the average temperature of the atmosphere is not higher than 34°.9 F. The ground temperature of 42°.5 must therefore be ascribed to the subterranean heat of the doleritic mountain: I do not say of the entire mass, but to the currents of air ascending in it from the depths. At the foot of Chimborazo, at an elevation of 9486 feet towards the hamlet of Calpi, there is, moreover, a small crater of eruption, Yana-Urcu, which, as indeed is shown by its black, slag-like rock (augitic-porphyry), appears to have been active in the middle of the fifteenth century.[42]

The aridity of the plain from which Chimborazo rises, and the subterranean brook, which is heard rushing under the volcanic hill (Yana-Urcu) just mentioned, have led Boussingault and myself[43] at very different times to the idea that the water which the enormous masses of snow produce daily by melting at their lower limit, sinks into the depths through the fissures and chambers of the elevated volcano. These waters perpetually produce a refrigeration in the strata through which they run down. Without them the whole of the doleritic and trachytic mountains would acquire, even at times when no near eruption is foretold, a still higher temperature in their interior, from the volcanic source, perpetually in action, although perhaps not lying at the same depth in all latitudes. Thus, in the varying struggle of the causes of heat and cold, we have to assume a constant tide of heat upwards and downwards in those places where conical solid parts ascend into the atmosphere.

[42] Humboldt, *Kleinere Schriften*, Bd. i, pp. 139 and 147.
[43] Humboldt, *Op. cit.*, s. 140 and 203.

As regards the area which they occupy, however, mountains and elevated peaks form a very small phenomenon in the relief formation of continents; and moreover nearly two-thirds of the entire surface of the earth is sea-bottom (according to the present state of geographical discovery in the polar regions of both hemispheres, we may assume the proportion of sea and land to be in the ratio of 8 : 3). This is directly in contact with aqueous strata, which, being slightly salt, and depositing themselves in accordance with the maximum of their density (at 38°.9), possess an icy coldness. Exact observations by Lenz and du Petit-Thouars have shown that within the tropics, where the temperature of the surface of the ocean is 78°.8 to 80°.6, water of the temperature of 36°.5 could be drawn up from a depth of seven or eight hundred fathoms, —phenomena which prove the existence of under currents from the polar regions. The consequences of this constant, suboceanic refrigeration of by far the greater part of the crust of the earth deserve a degree of attention which they have not hitherto received. Rocks and islands of small size, which project, like cones, from the sea-bottom above the surface of the water, and narrow isthmuses, such as Panama and Darien washed by great oceans, must present a distribution of heat in their rocky strata, different from that of parts of equal circumference and mass in the interior of continents. In a very elevated mountainous island, the submarine part is in contact with a fluid which has an increasing temperature from below upwards. But as the strata pass into the atmosphere, unmoistened by the sea, they come in contact, under the influence of insolation and free radiation of dark heat, with a gaseous fluid in which the temperature diminishes with the elevation. Similar thermic conditions of opposed decrease and increase of temperature in a vertical direction are repeated between two large inland seas, the Caspian and Aral Sea, in the narrow Ust-Urt, which separates them from each other. In order, however, to clear up such complicated phenomena, the only means to be employed are such as borings of great depth, which lead directly to the knowledge of the internal heat of the earth, and not merely observations of springs, or of the temperature of the air in caves, which give just as uncertain results as the air in the galleries and chambers of mines.

When a low plain is compared with a mountain chain or plateau, rising boldly to a height of many thousand feet, the law of the increase and diminution of temperature does not depend simply upon the relative vertical elevation of two points on the earth's surface (in the plain and on the summit of the mountain). If we should calculate from the supposition of a definite proportion in the change of temperature in a certain number of feet from the plain upwards to the summit, or from the summit downwards to the stratum in the interior of the mountain mass which lies at the same level as the surface of the plain, we should in the one case find the summit too cold, and in the other the stratum in the interior of the mountain far too hot. The distribution of heat in a gradually sloping mountain (an undulation of the surface of the earth) is dependent, as has already been remarked, upon form, mass, and conductibility; upon insolation, and radiation of heat towards the clear or cloudy strata of the atmosphere; and upon the contact and play of the ascending and descending currents of air. According to such assumptions, mountain springs must be very abundant, even at very moderate elevations of four or five thousand feet, where the temperature would exceed the average temperature of the locality by 72 or 90 degrees; and how would it be at the foot of mountains under the tropics, which at an elevation of 14,900 feet are still free from perpetual snow; and often exhibit no volcanic rock, but only gneiss and mica schist![44] The great mathematician, Fourier, who had been much interested in the fact of the volcano of Jorullo having been upheaved, in a plain, where for many thousands of square miles around no unusual terrestrial heat was to be detected, occupied himself at my request in the very year before his death with theoretical investigations upon the question, how in the elevation of mountains and alterations in the surface of the earth, the isothermal surfaces are brought into equilibrium with the new form of the soil. The lateral radiation from strata which lie in the same level, but are differently covered,

[44] I differ here from the opinion of one of my best friends, a physicist who has done excellent service as regards the distribution of telluric heat. See "upon the cause of the hot springs of Leuck and Warmbrum," Bischof, *Lehrbuch der chemischen und physikalischen Geologie*, Bd. i, s. 127—133.

plays in this case a more important part than the direction (inclination) of the cleavage planes of the rock, in cases where stratification is observable.

I have already elsewhere mentioned[45] how the hot springs in the environs of ancient Carthage, probably the thermal springs of Pertusa (*aquæ calidæ* of Hammâm-el-Enf) led Bishop Patricius, the martyr, to the correct view of the cause of the higher or lower temperature of the bubbling waters. When the Proconsul Julius tried to confuse the accused Bishop by the mocking question, "*Quo auctore fervens hæc aqua tantum ebulliat?*" Patricius set forth his theory of the central heat, "which causes the fiery eruptions of Etna and Vesuvius, and communicates more and more heat to the springs, in proportion as they have a deeper origin." With the learned Bishop, Plato's Pyriphlegethon was the hell of sinners; and as though he desired at the

[45] With regard to this passage, discovered by Dureau de la Malle, see *Cosmos*, vol. i, pp, 220, 221. "Est autem," says Saint Patricius, "et supra firmamentum cæli, et *subter* terram ignis atque aqua; et quæ supra terram est aqua, coacta in unum, appellationem marium: quæ vero infra, abyssorum suscepit; ex quibus ad generis humani usus in terram velut siphones quidam emittuntur et scaturiunt. Ex iisdem quoque et thermæ exsistunt: quarum quæ ab igne absunt longius, provida boni Dei erga nos mente, *frigidiores;* quæ vero *propius* admodum, *ferventes* fluunt. In quibusdam etiam locis et tepidæ aquæ reperiuntur, pro ut majore ab igne intervallo sunt disjunctæ." So run the words in the collection:—*Acta Primorum Martyrum, opera et studio Theodorici Ruinart*, ed. 2, Amstelædami, 1713 fol. p. 555. According to another report (A. S. Mazochii, *in vetus marmoreum sanctæ Neapolitanæ Ecclesiæ Kalendarium commentarius*, vol. ii, Neap. 1744, 4to, p. 385), Saint Patricius developed nearly the same theory of telluric heat before the proconsul Julius, but at the conclusion of his speech the *cold hell* is more distinctly indicated:—"Nam quæ longius ab igne subterraneo absunt, Dei optimi providentia frigidiores erumpunt. At quæ propiores igni sunt, ab eo fervefactæ, intolerabili calore præditæ promuntur foras. Sunt et alicubi tepidæ, quippe non parum sed longiuscule ab eo igne remotæ. Atque ille infernus ignis impiarum est animarum carnificina; non secus ac subterraneus frigidissimus gurges, in glaciei glebas concretus, qui Tartarus nuncupatur." The Arabic name, *Hammâm-el-Enf*, signifies *nose-baths*, and is, as Temple has already remarked, derived from the form of a neighbouring promontory, and not from a favourable action exerted by this thermal water upon diseases of the nose. The Arabic name has been variously altered by reporters:—Hammam l'Enf or Lif, Emmamelif (Peyssonel), la Mamelif (Desfontaines). See Gumprecht, *Die Mineralquellen auf dem Festlande von Africa* (1851), s. 140—144.

same time to remind one of the cold hells of the Buddhists, an *aqua gelidissima concrescens in glaciem* is admitted, somewhat unphysically and notwithstanding the depth, for the *nunquam finiendum supplicium impiorum.*

Amongst hot springs, those which, approaching the boiling heat of water, attain a temperature of 194° F., are far more rare than is usually supposed in consequence of inexact observations; least of all do they occur in the vicinity of still active volcanoes. I was so fortunate, during my American travels, as to investigate two of the most important of these springs, both between the tropics. In Mexico, not far from the rich silver mines of Guanaxuato, in 21° N. lat., and at an elevation of about 6500 feet above the surface of the sea, near Chichemequillo,[46] the *Aguas de Comangillas* burst forth from a mountain of basalt and basaltic breccia. In September, 1803, I found their temperature to be 205°.5 F. This mass of basalt has broken in the form of veins through a columnar porphyry, which again rests upon a white syenite rich in quartz. At a greater elevation, but not far from this nearly boiling spring, near *los Joares*, to the north of Santa Rosa de la Sierra, snow falls from December to April even at an elevation of 8,700 feet, and the inhabitants prepare ice the whole year round, by radiation in artificial basins. On the road from Nueva Valencia in the Valles de Aragua, towards the harbour of Portocabello (in about 10¼° of latitude), on the northern slope of the coast chain of Venezuela, I saw the *aguas calientes de las Trincheras* springing from a stratified granite, which does not pass at all into gneiss. I found[47] the springs in February, 1800, at 194°.5 F., whilst the *Baños de Mariara* in the Valles de Aragua, which belong to the gneiss, showed a temperature of 138°.7 F. Twenty-three years later, and again in the month of February, Boussingault and Rivero[48] found in the Mariara exactly 147°.2 F.;

[46] Humboldt, *Essai Politique sur la Nouvelle Espagne*, ed. 2, t. iii (1827), p. 190.

[47] *Relation Historique*, t. ii, p. 98; *Cosmos*, vol. i, p. 219. The hot springs of Carlsbad also originate in the granite (Leop. von Buch, in Poggend. *Annalen*, Bd. xii, s. 230), just like the hot springs of Momay, in Thibet, visited by Joseph Hooker, which break forth near Changokhang, at an elevation of 16,000 feet above the sea, with a temperature of 115° (*Himalayan Journal*, vol. ii, p. 133).

[48] Boussingault, "Considérations sur les eaux thermales des Cordil-

and in the Trincheras de Portocabello, at a small elevation above the Caribbean Sea, in one basin 198° F., in the other 206°.6 F. The temperature of these hot springs had therefore risen unequally in the short interval between these two periods :—in Mariara about 8°.5 F., and in the Trincheras about 12°.1 F. Boussingault has justly called attention to the fact, that it was in the above mentioned interval that the fearful earthquake took place, which overwhelmed the city of Caraccas on the 26th of March, 1812. The commotion at the surface was indeed not so strong in the vicinity of the lake of Tacarigua (Nueva Valencia); but in the interior of the earth, where elastic vapours act upon fissures, may not a movement which propagated itself so far and so powerfully, readily alter the net-work of fissures and open deeper canals of supply? The hot waters of the Trincheras, rising from a granite formation, are nearly pure, as they only contain traces of silicic acid, a little sulphuretted hydrogen and nitrogen; after forming numerous, very picturesque cascades, surrounded by a luxuriant vegetation, they constitute a river, the Rio de Aguas calientes; and this, towards the coast, is full of large crocodiles, to which the warmth, already considerably diminished, is very suitable. In the most northern parts of India (30° 52′ N. lat.), and also from granite, issues the very hot well of Jumnotri which attains a temperature of 194° F., and as it presents this high temperature at an elevation of 10,850 feet almost reaches the boiling point proper to this atmospheric pressure.[49]

Amongst the intermittent hot springs, the Icelandic boiling fountains, and of these especially the Great Geysir and Strokkr, have justly attained the greatest celebrity. According to the admirable recent investigations of Bunsen, Sartorius von Waltershausen and Descloiseaux the temperature of the streams of water in both diminishes in a remarkable manner from below upwards. The Geysir possesses a truncated cone of 25 to 30 feet in height formed by horizontal layers of silicious sinter. In this cone there lies a shallow basin of 52 feet in diameter, in the centre of which

lères," in the *Annales de Chimie et de Physique,* t. lii, 1833, pp. 188—190.

49 Captain Newbold, "On the Temperature of the Wells and Rivers in India and Egypt" (*Phil. Transact. for* 1845, pt. i, p. 127).

the funnel of the boiling spring, one-third of its diameter, and surrounded by perpendicular walls, goes down to a depth of 75 feet. The temperature of the water which constantly fills the basin is 180°. At very regular intervals of one hour and 20 or 30 minutes the thunder below proclaims the commencement of the eruption. The jets of water, of 9 feet in thickness, of which about three large ones follow one another, attain a height of 100 and sometimes 150 feet. The temperature of the water ascending in the funnel has been found to be 260°.6 at a depth of 72 feet a little while before the eruption, during the eruption 255°.5, and immediately after it 251°.6 ; at the surface of the basin it is only 183°—185°. The Strokkr, which is also situated at the base of the Bjarnafell, has a smaller mass of water than the Geysir. The sinter margin of its basin is only a few inches in height and breadth. The eruptions are more frequent than in the Geysir, but do not announce themselves by subterranean thunder. In the Strokkr the temperature during the eruption is 235°—239° at a depth of 42 feet, and almost 212° at the surface. The eruptions of the intermittent boiling springs, and the slight changes in the type of the phenomena are perfectly independent of the eruptions of Hecla, and were by no means disturbed by the latter in the years 1845 and 1846.[50] With his peculiar acuteness in observation and discussion, Bunsen has refuted the earlier hypotheses regarding the periodicity of the Geysir eruptions (subterranean cauldrons, which, as steam-boilers, are filled sometimes with vapours and sometimes with water). According to him the eruptions are caused by a portion of the column of water which

[50] Sartorius von Waltershausen, *Physisch-geographische Skizze von Island, mit besonderer Rücksicht auf vulkanische Erscheinungen*, 1847, s. 128 — 132 ; Bunsen and Descloiseaux, in the *Comptes rendus des Séances de l'Acad. des Sciences*, t. xxiii, 1846, p. 935 ; Bunsen, in the *Annalen der Chemie und Pharmacie*, Bd. lxii, 1847, s. 27—45. Lottin and Robert had already found that the temperature of the jet of water in the Geysir diminishes from below upwards. Amongst the forty silicious bubbling springs, which are situated in the vicinity of the Great Geysir and Strokkr, one bears the name of the Little Geysir. Its jet of water only rises 20 or 30 feet. The term boiling springs (*Kochbrunnen*) is derived from the word Geysir, which is connected with the Icelandic *giosa* (to boil). On the high land of Thibet also, according to the report of Esoma de Körös, there is, near the Alpine lake Mapham a Geysir, which rises to the height of 12 feet.

has acquired a high temperature at a lower point under great pressure of accumulated vapours, being forced upwards, and thus coming under a pressure which does not correspond with its temperature. In this way "the Geysirs are natural collectors of steam power."

Of the hot springs a few approach nearly to absolute purity; others contain solutions of 8—12 parts of solid or gaseous matters. Among the former are the baths of Luxeueil, Pfeffer, and Gastein, the efficacy of which may appear so mysterious on account of their purity.[51] As all springs are fed principally by meteoric water, they contain nitrogen, as Boussingault has proved in the very pure[52] springs flowing from the granite in las Trincheras de Portocabello, and Bunsen[53] in the Cornelius spring at Aix and in the Geysir of Iceland. The organic matter dissolved in many springs also contains nitrogen, and is even sometimes bituminous. Until it was known from the experiments of Gay-Lussac and myself that rain and snow-water contain more oxygen than the atmosphere (the former 10, and the latter at least 8 per cent. more) it appeared very remarkable that a gaseous mixture, rich in oxygen, could be evolved from the springs of Nocera in the Apennines. The analyses made by Gay-Lussac during our stay at this mountain spring showed that it only contained as much oxygen as might have been furnished to it by atmospheric moisture.[54] If we be astonished at the

[51] Trommsdorf finds in the springs of Gastein only 0.303 of solid constituents in 1000 parts; Löwig, 0.291 in Pfeffer; and Longchamp only 0.236 in Luxeuil; on the other hand, 0.478 were found in 1000 parts of common well water in Berne; 5.459 in the Carlsbad bubbling spring; and even 7.454 in Wiesbaden (Studer, *Physikal. Geographie und Geologie*, ed. 2, 1847, cap. i, s. 92).

[52] "The hot springs which gush from the *granite* of the Cordillera of the coast (of Venezuela), are *nearly pure*; they only contain a small quantity of silica in solution, and hydrosulphuric acid gas, mixed with a little *nitrogen*. Their composition is identical with that which would result from the action of water upon sulphuret of silicium" (*Annales de Chimie et de Physique*, t. lii, 1833, p. 189). Upon the great quantity of nitrogen which is contained in the hot spring of Orense (154°.4), see Maria Rubio, *Tratado de las Fuentes Minerales de España*, 1853, p. 331.

[53] Sartorius von Waltershausen, *Skizze von Island*, s. 125.

[54] The distinguished chemist Morechini of Rome, had stated the oxygen contained in the spring of Nocera (situated 2240 feet above the sea) to be 0.40; Gay-Lussac (26 September, 1805) found the exact

silicious deposits as a constructive material of which nature, as it were, artificially composes the apparatus of Geysirs, we must remember that silicic acid is also diffused in many cold springs which contain a very small portion of carbonic acid.

Acid springs and jets of carbonic acid gas, which were long ascribed to deposits of coal and lignite, appear rather to belong entirely to the processes of deep volcanic activity :—an activity which is universally disseminated, and therefore does not exert itself merely in those places where volcanic rocks testify to the existence of ancient local fiery eruptions. In extinguished volcanoes jets of carbonic acid certainly remain longest after the Plutonic catastrophes ; they follow the stage of Solfatara activity ; but nevertheless waters impregnated with carbonic acid, and of the most various temperatures, burst forth from granite, gneiss, and old and new floetz mountains. Acid springs become impregnated with alkaline carbonates, and especially with carbonate of soda, wherever water impregnated with carbonic acid acts upon rocks containing alkaline silicates.[55] In the north of Germany many of the carbonic acid springs and gaseous jets are particularly remarkable for the dislocation of the strata about them and for their eruption in circular valleys (Pyrmont, Driburg) which are usually completely closed. Friedrich Hoffman and Buckland have almost at the same time very characteristically denominated such depressions *valleys of elevation* (*Erhebungs-Thäler*).

In the springs to which the name of sulphurous waters is given, the sulphur by no means constantly occurs combined in the same way. In many, which contain no carbonate of soda, sulphuretted hydrogen is probably dissolved ; in others, for example in the sulphurous waters of Aix (the Kaiser, Cornelius, Rose, and Quirinus springs), no sulphuretted hydrogen is contained, according to the precise experiments of Bunsen and Liebig, in the gases obtained by boiling the

quantity of oxygen to be only 0.299. We had previously found 0.31 of oxygen in meteoric waters (rain). Upon the nitrogen gas contained in the acid springs of Neris and Bourbon l'Archambault, see the works of Anglade and Longchamp (1834), and on carbonic acid exhalations in general, see Bischof's admirable investigations in his *Chemische Geologie*, Bd. i, s. 243—350.

[55] Bunsen, in Poggendorff's *Annalen*, Bd. lxxxiii, s. 257; Bischof, *Geologie*, Bd. i, s. 271.

waters without access of air; indeed the Kaiserquelle alone contains 0.31 per cent. of sulphuretted hydrogen in gas bubbles which rise spontaneously from the springs.[56]

A thermal spring which gives rise to an entire river of water acidified by sulphur, the Vinegar river (*Rio Vinagre*), called Pusambio by the aborigines, is a remarkable phenomenon to which I first called attention. The Rio Vinagre rises at an elevation of about 10,660 feet on the north-western declivity of the volcano of Purace, at the foot of which the city of Popayan is situated. It forms three picturesque cascades,[57] of one of which I have given a representation, falling over a steep trachytic wall probably 320 feet in perpendicular height. From the point where the small river falls into the Cauca, this great river for a distance of 2—3 miles (from 8 to 12 English miles) downwards, as far as the junctions of the Pindamon and Palacé, contains no fish; which must be a great inconvenience to the inhabitants of Popayan, who are strict observers of fasts! According to Boussingault's subsequent analysis, the waters of the Pusambio contain a great quantity of sulphuretted hydrogen and carbonic acid, with some sulphate of soda. Near the source, Boussingault found the temperature to be 163°. The upper part of the Pusambio runs underground. Degenhardt (of Clausthal in the Harz), whose early death has caused a great loss to Geognosy, discovered a hot spring in 1846 in the Paramo de Ruiz, on the declivity of the volcano of the same name, at the sources of the Rio Guali, and at an altitude of 12,150 feet, in the water of which Boussingault found three times as much sulphuric acid as in the Rio Vinagre.

The equability of the temperature and chemical constitu-

[56] Liebig and Bunsen, *Untersuchung der Aachener Schewefelquellen*, in the *Annalen der Chemie und Pharmacie*, Bd. lxxix (1851), s. 101. In the chemical analyses of mineral waters which contain sulphuret of sodium, carbonate of soda and sulphuretted hydrogen are often stated to occur from an excess of carbonic acid being present in those waters.

[57] One of these cascades is represented in my *Vues des Cordillères*, pl. xxx. On the analysis of the water of the Rio Vinagre, see Boussingault, in the *Annales de Chimie et de Physique*, 2e, série, t. lii, 1833, p. 397, and Dumas, 3e série, t. xviii, 1846, p. 503; on the spring in the Paramo de Ruiz, see Joaquin Acosta, *Viajes Cientificos á los Andes Ecuatoriales*, 1849, p. 89.

tion of springs as far as we can ascertain from reliable observations, is far more remarkable than the instability[58] which has been occasionally detected. The hot spring-waters, which, during their long and tortuous course, take up such a variety of constituents from the rocks with which they are in contact, and often carry them to places where they are deficient in the strata through which the springs burst forth, have also an action of a totally different nature. They exert a transforming and at the same time a formative activity, and in this respect they are of great geognostic importance. Senarmont has shown with wonderful acuteness, how extremely probable it is that many vein-crevices (ancient courses of thermal waters) have been filled from below upwards by

[58] The examples of alteration of temperature in the thermal springs of Mariara and las Trincheras lead to the question whether the Styx water, whose source, so difficult of access, is situated in the wild Aroanic Alps of Arcadia, near Nonacris, in the district of Pheneos, has lost its pernicious qualities by alteration in the subterranean fissures of supply? or whether the waters of the Styx have only occasionally been injurious to the wanderer by their icy coldness? Perhaps they are indebted for their evil reputation, which has been transmitted to the present inhabitants of Arcadia, only to the awful wildness and desolation of the neighbourhood, and to the myth of their origin from Tartarus. A young and learned philologist, Theodor Schwab, succeeded a few years ago, with great exertion, in penetrating to the rocky wall from which the spring trickles down, exactly as described by Homer, Hesiod, and Herodotus. He drank some of the water, which was extremely cold, but very pure to the taste, without perceiving any injurious effects (Schwab, *Arkadien, seine Natur und Geschichte,* 1852, s. 15—20). Amongst the ancients it was asserted that the coldness of the water of the Styx burst all vessels except those made of the hoof of an ass. The legends of the Styx are certainly very old, but the report of the poisonous properties of its spring appears to have been widely disseminated only in the time of Aristotle. According to a statement of Antigonus of Carystus (*Hist. Mirab.* § 174), it was contained very circumstantially in a book of Theophrastus, which has been lost to us. The calumnious fable of the poisoning of Alexander by the water of the Styx, which Aristotle communicated to Cassander by Antipater, was contradicted by Plutarch and Arrian, and disseminated by Vitruvius, Justin, and Quintus Curtius, but without mentioning the Stagirite (Stahr, *Aristotelia,* Th. i, 1830, s. 137—140). Pliny (xxx, 53) says, somewhat ambiguously:—"Magna Aristotelis infamia excogitatum." See Ernst Curtius, *Peloponnesus* (1851), Bd. i, s. 194—196, and 212; St. Croix, *Examen Critique des Anciens Historiens d'Alexandre,* p. 496. A representation of the cascade of the Styx, drawn from a distance, is contained in Fiedler's *Reise durch Griechenland,* Th. i, s. 400.

the deposition of the dissolved elements. By changes of pressure and temperature, by internal electro-chemical processes, and the specific attraction of the lateral walls (the rock traversed), sometimes lamellar deposits, and sometimes masses of concretion are produced in fissures and vesicular cavities. In this way druses and porous amygdaloids appear to have been sometimes formed. Where the deposition of the veins has taken place in parallel zones, these zones usually correspond with each other symmetrically in their nature both vertically and laterally. Senarmont has succeeded in preparing a considerable number of minerals artificially, by perfectly analogous synthetical methods.[59]

One of my intimate friends, a highly endowed scientific observer, will, I hope, before long publish a new and important work upon the conditions of temperature of springs, and in it treat with great acumen and universality, by induction from a long series of recent observations, upon the involved phenomenon of disturbances. In the determinations of temperature made by him in Germany (on the Rhine) and in Italy (in the vicinity of Rome, in the Albanian mountains and the Apennines) from the year 1845 to 1853, Eduard Hall-

[59] "Very important metalliferous lodes, perhaps the greater number, appear to have been formed by solution, while the veins filled with concretions of metal seem to be nothing but immense canals more or less obstructed, and formerly traversed by encrusting thermal waters. The formation of a great number of minerals which are met with in these lodes, does not always presuppose conditions or agents very far removed from *existing causes.* The two principal elements of the most widely diffused thermal waters, the alkaline sulphurets and carbonates, have enabled me to reproduce artificially, by very simple synthetic methods, 29 distinct mineral species, nearly all crystallised, belonging to the native metals (native silver, copper, and arsenic), quartz, specular iron, carbonates of iron, nickel, zinc, manganese, sulphate of baryta, pyrites, malachite, copper pyrites, sulphuret of copper, red arsenical and antimonial silver. . . . We approach as closely as possible to the processes of nature, if we succeed in reproducing minerals in their conditions of possible association, by means of the most widely diffused natural chemical agents, and by imitating the phenomena which we still see realised in the foci in which the mineral creation has concentrated the remains of that activity which it formerly displayed with a very different energy" (H. de Senarmont, *Sur la Formation des Minéraux par la Voie Humide,* in the *Annales de Chemie et de Physique,* 3ème série t. xxxii, 1851, p. 234; see also Elie de Beaumont, *Sur les Emanations Volcaniques et Métallifères,* in the *Bulletin de la Société Géologique de France,* 2e série, t. xv. p. 129).

mann distinguishes :—1. *Purely meteorological* springs, the average temperature of which is not increased by the internal heat of the earth; 2. *Meteorologico-geological* springs, which, being independent of the distribution of rain, and warmer than the air, only undergo such alterations of temperature as are communicated to them by the soil through which they flow out; 3. *Abnormally cold* springs, which bring down their coldness from great elevations.[60] The more we have

[60] "In order to ascertain the amount of variation of the average temperature of springs from that of the air, Dr. Eduard Hallmann observed at his former residence, Marienberg, near Boppard, on the Rhine, the temperature of the air, the amount of rain and the temperature of seven springs for five years, from the 1st December, 1845, to the 30th November, 1850; upon these observations he has founded a new elaboration of the relative temperature of springs. In this investigation the springs with a perfectly constant temperature (the purely geological springs) are excluded. On the other hand, all those springs have been made the subject of investigation which undergo an alteration in their temperature according to the seasons.

"The variable springs fall into two natural groups :—

"1. *Purely meteorological* springs: that is to say, those whose average is demonstrably not elevated by the heat of the earth. In these springs the amount of variation of the average from the aerial average is dependent upon the distribution of the annual amount of rain through the 12 months. These springs are on the average colder than the air when the proportion of rain for the four cold months, from December to March, amounts to more than 33⅓ per cent.; they are on the average warmer than the air, when the proportion of rain for the four warm months, from July to October, amounts to more than 33⅓ per cent. The negative or positive difference of the spring-average from the air-average, is larger in proportion to the excess of rain in the above-mentioned cold or warm thirds of the year. Those springs in which the difference of the average from that of the air is in accordance with the law, that is to say, the largest possible by reason of the distribution of rain in the year, are called purely meteorological springs of *undistorted average*; but those in which the amount of difference of the average from the air average is diminished by the disturbing action of the atmospheric heat during the seasons which are free from rain are called purely meteorological springs of *approximate average*. The approximation of the average to the aerial average is caused either by the enclosure, especially by a channel at the lower extremity of which the temperature of the spring was observed, or it is the consequence of a superficial course and the poverty of the feeders of the spring. In each year the amount of difference of the average from the aerial average is similar in all purely meteorological springs, but it is smaller in the approximate than in the undistorted springs, and indeed is smaller in proportion as the disturbing action of the atmospheric heat is greater.

advanced of late years, by the successful employment of chemistry, in the geognostic investigation of the formation

Of the springs of Marienberg 4 belong to the group of purely meteorological springs, of these 4 one is undistorted in its average, the three others are approximated in various degrees. In the first year of observation the portion of rain of the cold third predominated, and all four springs were on the average colder than the air. In the four following years of observation the rain of the warm third predominated, and in these all the four springs had a higher average temperature than the air; and the positive variation of the average of the spring from that of the air was higher, the greater the excess of rain in the warm third of one of the four years.

"The view put forward in the year 1825, by Leopold von Buch, that the amount of variation of the average of springs from that of the air must depend upon the distribution of rain in the seasons of the year has been shown to be perfectly correct by Hallmann, at least for his place of observation, Marienberg, in the Rhenish Grauwacke mountains. The purely meteorological springs of undistorted average alone have any value for scientific climatology; these springs are to be sought for everywhere, and to be distinguished on the one hand from the purely meteorological springs with an approximate average, and on the other from the meteorologico-geological springs.

"2. *Meteorologico-geological springs:* that is to say, those of which the average is demonstrably heightened by the heat of the earth. Whatever the distribution of rain may be, these springs are in their average warmer than the air, all the year round (the alterations of temperature which they exhibit in the course of the year are communicated to them by the soil through which they flow). The amount by which the average of a meteorologico-geological spring exceeds the atmospheric average, depends upon the depth to which the meteoric waters have sunk down into the interior of the earth, where the temperature is constant, before they again make their appearance in the form of a spring; this amount consequently possesses no climatological interest. The climatologist must, however, know these springs, in order that he may not mistake them for purely meteorological springs. The meteorologico-geological springs may also be approximated to the aerial average by an enclosure or channel. The springs were observed on particular fixed days, four or five times a month. The elevation above the sea, both of the place where the temperature of the air was observed, and of the different springs was carefully taken into account."

After the completion of the elaboration of his observations at Marienberg, Dr. Hallmann passed the winter of 1852—1853 in Italy, and found *abnormally cold* springs in the vicinity of ordinary ones. This is the name he gives "to those springs which demonstrably bring down cold from above. These springs are to be regarded as subterranean drains of open lakes or subterranean accumulations of water situated at a great elevation, from which the waters pour down very rapidly in fissures and clefts, and break forth at the foot of the mountain or chain of mountains in the form of springs. The idea of the abnormally and metamorphic transformation of rocks, the greater importance has been acquired for the consideration of the waters impregnated with gases and salts which circulate in the interior of the earth, and which, when they burst forth at the surface as thermal springs, have already fulfilled the greater part of their formative, alterative, or destructive activity.

c. *Vapour and Gas Springs, Salses, Mud-volcanoes, Naphtha-fire.*

(Amplification of the Picture of Nature. *Cosmos*, vol. i. pp. 221—223).

In the General Representation of Nature, I have shown by well ascertained examples, which, however, have not been sufficiently taken into consideration, how the salses in the various stages through which they pass, from the first eruptions accompanied by flames, to the subsequent condition of simple eruptions of mud, form as it were an intermediate step between hot springs and true volcanoes, which throw out fused earths, either in the form of disconnected cinders, or as newly formed rocks, often arranged in many beds one over the other. Like all transitions and intermediate steps both in organic and inorganic nature, the salses and mud-volcanoes deserve a more careful consideration than was bestowed upon them by the older geognosists, from the want of special knowledge of the facts.

The salses and naphtha springs are sometimes arranged in isolated close groups: like the Macalubi, near Girgenti, in Sicily, which were mentioned even by Solinus, those near Pietra Mala, Barigazzo, and on the Monte Zibio, not far from Sassuolo in the north of Italy, or those near Turbaco in South America; sometimes they appear to be arranged in narrow chains, and these are the most instructive and important.

cold springs is, therefore, as follows:—They are too cold for the elevation at which they come forth; or, which indicates the conditions better, they come forth at too low a part of the mountain for their low temperature." These views, which are developed in the first volume of Hallmann's *Temperaturverhältnissen der Quellen*, have been modified by the author in his second volume (s. 181—183), because in every meteorological spring, however superficial it may be there must be some telluric heat.

We have long known[61] as the outermost members of the Caucasus, in the north-west the mud-volcanoes of Taman,

[61] Humboldt, *Asie Centrale*, t. ii, p. 58. Upon the reasons which render it probable that the Caucasus, which for $\frac{6}{7}$ths of its length, between the Kasbegk and Elburuz, runs from E.S.E. to W.N.W. in the mean parallel of 42° 50′, is the continuation of the volcanic fissure of the Asferah (Aktagh) and Thian-schan, see the work cited above, pp. 54—61. Both the Asferah and Thian-schan oscillate between the parallels of $40\frac{2}{3}$° and 43°. I regard the great Aralo-Caspian depression, the surface of which, according to the accurate measurements of Struve, exceeds the area of the whole of France by nearly 107,520 geographical square miles (*Op. cit. supra*, pp. 309—312), as more ancient than the elevations of the Altai and Thian-schan. The fissure of elevation of the last-mentioned mountain chain has not been continued through the great depression. It is only to the west of the Caspian Sea that we again meet with it, with some alteration in its direction, as the chain of the Caucasus, but associated with trachytic and volcanic phenomena. This geognostic connection has also been recognised by Abich, and confirmed by valuable observations. In a treatise on the connection of the Thian-schan with the Caucasus by this great geognosist, which is in my possession, he says expressly :—"The frequency and decided predominance of a system of parallel dislocations and lines of elevation (nearly from east to west) distributed over the whole district (between the Black Sea and the Caspian) brings the mean axial direction of the great latitudinal central Asiatic mass-elevations, most distinctly westward from the Kosyurt and Bolar systems to the Caucasian Isthmus. The mean direction of the Caucasus, S.E.—N.W., is E.S.E.—W.N.W. in the central parts of the mountain chain, and sometimes even exactly E.—W., as in the Thian-schan. The lines of elevation which unite Ararat with the trachytic mountains Dzerlydagh and Kargabassar near Erzeroum, and in the southern parallels of which Mount Argaeus, Sepandagh, and Sabalan are arranged, constitute the most decided expression of a mean volcanic axial direction, that is to say, of the Thian-schan being prolonged westward through the Caucasus. Many other mountain-directions of Central Asia, however, also revert to this remarkable space, and stand, as elsewhere, in mutual relation to each other, so as to form vast mountain nuclei and maxima of elevation." Pliny (vi, 17), says :—"Persæ appellavere Caucasum montem Graucasim (var. Graucasum, Groucasim, Grocasum), hoc est nive candidum;" in which Bohlen thought the Sanscrit words *kâs*, to shine, and *gravan*, rock, were to be recognised (see my *Asie Centrale*, t. i, p. 109). As Klausen says, in his investigations on the wanderings of Io (*Rheinisches Museum für Philologie*, Jahrg iii, 1845, s. 298), if the name *Graucasus* was corrupted into Caucasus, then a name "in which each of its first syllables gave the Greeks the idea of burning might certainly characterise a burning mountain, with which the history of the Fire-burner (Fire-igniter, πυρκαεύς) would become readily and almost spontaneously associated." It cannot be denied that myths sometimes originate from names, but the production of so great and important a fable, as the Typhonico-caucasic, can certainly not

and in the south-east of the great mountain chain, the naphtha-springs and naphtha-fire of Baku and the Caspian peninsula, Apscheron. The magnitude and connection of this phenomenon was, however, first discovered by Abich, distinguished by his profound knowledge of this part of Asia. According to him, the mud-volcanoes and naphtha-fires of the Caucasus are arranged in a distinctly recognisable manner in certain lines, which stand in unmistakeable relation with the axes of elevation and the directions of dislocation of the strata of rock. The greatest space, of nearly 4,000 square miles, is occupied by genetically connected mud-volcanoes, naphtha-emanations and saline springs in the south-eastern part of the Caucacus, in an isosceles triangle, the base of which is the shore of the Cas-

be derivable from the accidental similarity of sound in the misunderstood name of a mountain. There are better arguments, of which Klausen also mentions one. From the actual association of Typhon and the Caucasus, and from the express testimony of Pherecydes of Syros (in the time of the 58th Olympiad), it is clear that the eastern extremity of the world was regarded as a volcanic mountain. According to one of the Scholia to Apollonius (*Scholia in Apoll. Rhod.*, ed. Schaefferi, 1813, v. 1210, p. 524), Pherecydes says, in the Theogony, "that Typhon, when pursued, fled to the Caucasus, and that then the mountain burnt (or was set on fire); that from thence Typhon fled to Italy, when the island Pithecusa was thrown around (as it were, poured around) him." But Pithecusa is the island Ænaria (now Ischia), upon which the Epomeus (Epopon) cast forth fire and lava, according to Julius Obsequens, 95 years before our era, then during the reigns of Titus and Diocletian, and lastly, in the year 1302, according to the statement of Tolomeo Fiadoni of Lucca, who was at that time Prior of Santa Maria Novella. "It is singular," as Boeckh, the profound student of antiquity, writes to me, "that Pherecydes should make Typhon fly from the Caucasus because it burnt, as he himself is the originator of subterraneous fire; but that his residence upon the Caucasus rests upon the occurrence of volcanic eruptions there, appears to me to be undeniable." Apollonius Rhodius (*Argon.* lib. ii, v. 1212—1217, ed. Beck) in speaking of the birth of the Colchian Dragon, also places in the Caucasus the rock of Typhon, on which the giant was struck by the lightning of Jupiter. Although the lava-streams and crater-lakes of the high land of Kely, the eruptions of Ararat and Elburuz, or the currents of obsidian and pumice-stone from the old craters of the Riotandagh, may be placed in a pre-historic period, still the many hundred flames which even now break forth from fissures in the Caucasus, both from mountains of seven or eight thousand feet in height and from broad plains, may have been a sufficient reason for regarding the entire mountain district of the Caucasus as a Typhonic seat of fire.

pian Sea near Balachani (to the north of Baku) and one of the mouths of the Kur (Araxes), near the hot springs of Sallian. The apex of such a triangle is situated near the Schagdagh in the elevated valley of Kinalughi. There, at the boundary of a dolomitic and slate formation, at an elevation of 8350 feet above the Caspian Sea, close to the village of Kinalughi itself, break forth the perpetual fires of the Schagdagh, which have never been extinguished by meteorological occurrences. The central axis of this triangle corresponds with the direction which the earthquakes, so often experienced in Schamacha upon the banks of the Pyrsagat, appear constantly to follow. When the northwestern direction just indicated is traced further, it strikes upon the hot sulphurous springs of Akti, and then becomes the line of strike of the principal crest of the Caucasus where it rises up into the Kasbegk and bounds Daghestan. The salses of the lower region, which are often regularly arranged in series, gradually become more numerous towards the shore of the Caspian, between Sallian, the mouth of the Pyrsagat (near the island of Swinoi), and the peninsula of Apscheron. They present traces of repeated mud eruptions in earlier times, and often bear at their summits small cones, from which combustible and often spontaneously ignited gas is poured forth, and which are exactly similar in form to the *hornitos* of Jorullo in Mexico. Considerable eruptions of flame were particularly frequent between 1844 and 1849, at the Oudplidagh, Nahalath, and Turandagh. Close to the mouth of the Pyrsagat on the mud volcano Toprachali, "black marly fragments, which at the first glance might be confounded with dense basalt, and extremely fine-grained doleritic rocks" are found (a proof of the exceptional, greatly increased intensity of the subterranean heat). At other points on the peninsula of Apscheron, Lenz found slag-like fragments as products of eruption; and during the great eruption of flame of Backlichli (7th February, 1839), small hollow balls, like the so-called *ashes* of the true volcanoes, were carried by the wind to a long distance.[62]

[62] Humboldt, *Asie Centrale*, t. ii, pp. 511 and 513. I have already (t. ii, p. 201) called attention to the fact that Edrisi does not mention the fire of Baku, although it is described diffusely as a Nefala-land, that is to say, rich in burning naphtha springs, by Massudi Cothbeddin, two

In the north-western extremity towards the Cimmerian Bosphorus are the mud volcanoes of the peninsula of Taman, which form one group with those of Aklanisowka and Jenikale near Kertsch. One of the salses of Taman exhibited an eruption of mud and gas on the 27th of February, 1793, in which, after much subterranean noise, a column of fire half enveloped in black smoke (dense aqueous vapour ?) rose to a height of several hundred feet. It is a remarkable phenomenon, and instructive as regards the nature of the *Volcancitos de Turbaco*, that the gas of Taman, which was tested in 1811 by Frederick Parrot and Engelhardt, was *not inflammable* ; whilst the gas collected by Göbel in the same place, 23 years later, burnt, from the mouth of a glass tube, with a bluish flame like all emanations from the salses in the south-eastern Caucasus, but also, when carefully analysed, contained in 100 parts 92.8 of carburetted hydrogen and 5 parts of carbonic oxide gas.[63]

A phenomenon certainly nearly allied to these in its origin, although different as regards the matter produced, is presented by the eruptions of boracic acid vapours in the Tuscan Maremma, known under the names of *lagoni*, *fummarole*, *soffioni*, and even *volcani*, near Possara, Castel Novo, and Monte Cerboli. The vapours have an average temperature of 205° to 212°, and according to Pella, in certain points, as much as 347°. They rise in part directly from clefts in the rocks, and partly from stagnant pools, in which they throw up small cones of fluid clay. They are seen to diffuse themselves in the air in whitish eddies. The boracic acid, which is brought up by the aqueous vapours from the bosom of the earth, cannot be obtained when the vapours of the *soffioni* are condensed in very wide and long tubes, but becomes diffused in the atmosphere in consequence of its volatility. The acid is only procured in the beautiful establishments of Count Larderel, when the orifices of the

hundred years before, in the tenth century (see Frähn, *Ibn Fozlan*, p. 245, and on the etymology of the Median word *naphtha*, *Asiatic Journal*, vol. xiii, p. 124).

[63] Compare Moritz von Engelhardt and F. Parrot, *Reise in die Krym und den Kaukasus*, 1815, Th. i, s. 71, with Göbel, *Reise in die Steppen des süd lichen Russlands*, 1838, Th. i, s. 249—253, and Th. ii, s. 138—144.

soffioni are covered directly by the fluid of the basin.[64] According to Payen's excellent analysis, the gaseous emanations contain 0·57 of carbonic acid, 0·35 of nitrogen, and only 0·07 of oxygen, and 0·001 of sulphuric acid. Where the boracic acid vapours permeate the clefts of the rock, they deposit sulphur. According to Sir Roderick Murchison's investigations the rock is in part of a chalky nature, and in part an eocene formation, containing nummulites—a *macigno*, which is penetrated by the uncovered and elevated serpentine[65] of the neighbourhood (near Monte Rotondo). In this case, and in the crater of Volcano, asks Bischof, do not hot aqueous vapours act upon and decompose boracic minerals, such as rocks rich in datolithe, axinite or tourmaline?[66]

In the variety and grandeur of the phenomena, the system of soffioni in Iceland exceeds anything that we are acquainted with on the continent. Actual mud-springs burst forth in the fumarole-field of Krisuvek and Reykjalidh, from small basins with crater-like margins in a bluish gray

[64] Payen, *De l'acide boracique des Suffioni de la Toscane*, in the *Annales de Chimie et de Physique*, 3me série, t. i, 1841, pp. 247—255; Bischof, *Chem. und Physik. Geologie*, Bd. i, s. 669—691; *Etablissements industriels de l'acide boracique en Toscane*, by the Count de Larderel, p. 8.

[65] Sir Roderick Impey Murchison, *On the vents of hot vapour in Tuscany*, 1850, p. 7 (see also the earlier geognostic observations of Hoffmann, in *Karsten's und Dechen's Archiv für Mineral.* Bd. xiii, 1839, s. 19). From old but trustworthy traditions, Targioni Tozzeti asserts that some of these boracic acid springs which are constantly changing their place of eruption were once seen to be luminous (ignited) at night. In order to increase the geological interest of the observations of Murchison and Pareto upon the volcanic relations of the serpentine formation in Italy, I may here advert to the fact that the flame of the Asiatic Chimæra (near the town of Deliktasch, the ancient Phaselis in Lycia, on the west coast of the Gulf of Adalia) which has been burning for several thousand years, also rises from a hill on the slope of the Solimandagh, in which serpentine in position and blocks of limestone have been found. Rather more to the south, on the small island of Grambusa, the limestone is deposited upon dark-coloured serpentine. See the important work of Admiral Beaufort (*Survey of the Coasts of Caramania*, 1818, pp. 40 and 48), whose statements are confirmed by the specimens of rocks just brought home (May, 1854), by a highly talented artist, Albrecht Berg (Pierre de Tchihatcheff, *Asie Mineure*, 1853, t. i, p. 407.)

[66] Bischof, *op. cit.* s. 682.

clay.[67] Here also the fissures of the springs may be traced in determinate directions.[68] There is no portion of the earth, where hot springs, salses and gas-eruptions occur, that has been made the subject of such admirable and complete chemical investigations as those on Iceland, which we owe to the acute and persevering exertions of Bunsen. Nowhere, perhaps, in such a great extent of country, or so near the surface, is such a multifarious spectacle of chemical decompositions, conversions, and new formations to be witnessed.

Passing from Iceland to the neighbouring American continent we find in the State of New York, in the neighbourhood of Fredonia, not far from Lake Erie, a multitude of jets of inflammable gas (carburetted hydrogen), breaking forth from fissures in a basin of Devonian sandstone strata, and partly employed for the purpose of illumination. Other springs of inflammable gas, near Rushville, assume the form of mud cones; and others, in the valley of the Ohio, in Virginia, and on the Kentucky river, also contain chloride of sodium, and are there connected with weak naphtha springs. But on the other side of the Caribbean Sea, on the north coast of South America, 11½ miles south-south-east from the harbour of Cartagena de Indias, near the pleasant village of Turbaco, a remarkable group of salses or mud-volcanoes exhibits phenomena, which I was the first to describe.

In the neighbourhood of Turbaco, where one enjoys a magnificent view of the colossal snowy mountains (*Sierras Nevadas*) of Santa Marta, on a desert spot in the midst of the primeval forest, rise the *Volcancitos*, to the number of 18 or 20. The largest of the cones, which consist of blackish gray loam, are from 19 to 23 feet in height, and probably 80 feet in diameter at the base. At the apex of each cone is a circular orifice of 20 to 28 inches in diameter, surrounded by a small mud-wall. The gas rushes up with great violence, as in Taman, forming bubbles, each of which, according to my measurements in graduated vessels, contains 10—12 cubic inches. The upper part of the funnel is filled with

[67] Sartorius von Waltershausen, *Physisch-geographische Skizze von Island*, 1847, s. 123; Bunsen "upon the processes of formation of the volcanic rocks of Iceland," Poggend. *Annalen*, Bd. lxxxiii, s. 257.

[68] Waltershausen, *op. cit.* s. 118.

water, which rests upon a compact floor of mud. The eruptions are not simultaneous in neighbouring cones, but in each one a certain regularity was observable in the periods of the eruptions. Bonpland and I, standing on the outermost parts of the group, counted pretty regularly 5 eruptions every 2 minutes. On bending down over the small orifice of the crater a hollow sound is perceived in the interior of the earth, far below the base of the cone, usually 20 seconds *before* each eruption. A very thin burning wax taper was instantly extinguished in the gas, which was twice collected with great care; this was also the case with a glowing chip of the wood *Bombax Ceiba*. The gas could not be ignited. Lime water was not rendered turbid by it; no absorption took place. When tested for oxygen with nitrous acid gas, this gas showed no trace of the former in one experiment; in a second case, when the gas of the Volcancitos had been confined for many hours in a bell glass with water, it exhibited rather more than one hundredth of oxygen, which had probably been evolved from the water and accidentally intermixed.

From these analytical results I then declared, perhaps not very incorrectly, that the gas of the Volcancitos of Turbaco was nitrogen gas, which might be mixed with a small quantity of hydrogen. At the same time I expressed my regret in my journal, that in the state of chemistry at that time (April, 1801), no means were known by which, in a mixture of nitrogen and hydrogen gases, the numerical proportions of the mixture might be determined. The expedient, by the employment of which three thousandths of hydrogen may be detected in a gaseous mixture, was only discovered by Gay-Lussac and myself four years afterwards,[69] During the half-century that has elapsed since my residence in Turbaco, and my astronomical survey of the Magdalena river, no traveller had occupied himself scientifically with the small mud-volcanoes just described, until, at the end of December, 1850, my friend Joaquin Acosta,[70] so well versed

[69] Humboldt and Gay-Lussac, *Mémoire sur l'analyse de l'air atmosphérique* in the *Journal de Physique, par Lamétherie*, t. lx, p. 151 (see my *Kleinere Schriften*, Bd. i, s. 346).

[70] "It is with emotion that I have just visited a place which you made known fifty years ago. The appearance of the small volcanoes of

in modern geognosy and chemistry, made the remarkable observation that at present "the cones diffuse a bituminous odour ;" (of which no trace existed in my time) ; "that some petroleum floats upon the surface of the water in the small orifices, and that the gas pouring out may be ignited upon every mud-cone of Turbaco." Does this, asks Acosta, indicate an alteration of the phenomena brought about by internal processes, or simply an error in the earlier experiments ? I would admit the latter freely, if I had not preserved the leaf of the journal on which the experiments were recorded in detail,[71] on the very morning on which

Turbaco is such as you have described ; there is the same luxuriance of vegetation, the same form of cones of clay, and the same ejection of liquid and muddy matter ; nothing has changed, unless it be the nature of the gas which is evolved. I had with me, in accordance with the advice of our mutual friend, M. Boussingault, all that was necesssary for the chemical analysis of the gaseous emanations, and even for making a freezing mixture for the purpose of condensing the aqueous vapour, as the doubt had been expressed to me that nitrogen might have been confounded with this vapour. But this apparatus was by no means necessary. As soon as I arrived at the *Volcancitos,* the distinct odour of bitumen set me in the right course ; I commenced by lighting the gas upon the very orifice of each small crater. Even now one sees on the surface of the liquid, which rises intermittently, a delicate film of petroleum. The gas collected *burns away entirely,* without any residue of nitrogen(?) and without depositing sulphur (when in contact with the atmosphere). Thus the *nature of the phenomenon has completely changed since your journey, unless we admit an error of observation,* justified by the less advanced state of experimental chemistry at that period. I no longer doubt that the great eruption of *Galera Zamba,* which illuminated the country in a radius of 100 kilometres (62 miles), is a salses-like phenomenon, developed on a great scale, since there exist hundreds of little cones, vomiting saline clay, upon a surface of 400 square leagues. I propose examining the gaseous products of the cones of Tubarà, which are the most distant salses from your *Volcancitos* of Turbaco. From the powerful manifestations which have caused the disappearance of a part of the peninsula of Galera Zamba, now become an island, and from the appearance of a new island raised from the bottom of the sea in 1848, and which has since disappeared, I am led to think that it is near Galera Zamba, to the west of the delta of the Rio Magdalena, that the principal focus of the phenomenon of salses in the province of Carthagena is situated" (from a letter from Colonel Acosta to A. von Humboldt, Turbaco, 21 December, 1850). See also Mosquera, *Memoria politica sobre la Nueva Granada,* 1852, p. 73 ; and Lionel Gisborne, *The Isthmus of Darien,* p. 48.

[71] During the whole of my American expedition I always adhered strictly to the advice of Vauquelin, under whom I worked for some time

they were made. I find nothing in them that could make me at all doubtful now; and the observation already referred

before my voyage: to write down and preserve the details of every experiment on the same day. From my journals of the 17th and 18th April, 1801, I here copy the following:—"As, therefore, the gas showed scarcely 0.01 of oxygen from experiments with phosphorus and nitrous acid gas, and not 0.02 of carbonic acid with lime-water, the question is, what are the other 97 hundredths? I supposed, first of all, carburetted and sulphuretted hydrogen; but no sulphur is deposited on the margins of the small craters in contact with the atmosphere, and no odour of sulphuretted hydrogen was to be perceived. The problematical part might appear to be pure nitrogen, for, as above mentioned, *nothing was ignited by a burning taper;* but I know, from the time of my analyses of fire-damp, that a light hydrogen gas, free from any carbonic acid, which merely stood at the top of a gallery did not ignite, but extinguished the pit candles, whilst the latter burnt clearly in deep places, when the air was considerably mixed with nitrogen gas. The residue of the gas of the Volcancitos is, therefore, probably to be regarded as nitrogen, with a portion of hydrogen gas, the quantitative amount of which we do not at present know. Does the same carbonaceous schist that I saw further westward on the Rio Sinu, or marl and clay, lie below the Volcancitos? Does atmospheric air penetrate through narrow fissures into cavities formed by water and become decomposed in contact with blackish gray loam, as in the pits in the saline clay of Hallein and Berchtholdsgaden, where the chambers are filled with gases which extinguish lights? or do the gases, streaming out tense and elastic, prevent the penetration of atmospheric air?" These questions were set down by me in Turbaco 53 years ago. According to the most recent observations of M. Vauvert de Méan (1854) the inflammability of the gas emitted has been completely retained. The traveller brought with him samples of the water which fills the small orifice of the craters of the Volcancitos. In this Boussingault found in the litre: common salt, 6.59 gr.; carbonate of soda, 0.31; sulphate of soda, 0.20; and also traces of borate of soda and iodine. In the mud which had fallen to the bottom, Ehrenberg, by a careful microscopic examination, found no calcareous parts or scoriaceous matter, but quartz granules mixed with micaceous laminæ, and many small crystalline prisms of black Augite, such as often occurs in volcanic tufa; no trace of Spongiolites or Polygastric Infusoria, and nothing to indicate the vicinity of the sea, but on the contrary many remains of Dicotyledonous plants and grasses, and sporangia of lichens, reminding one of the constituents of the *Moya* of Pelileo. Whilst C. Sainte-Claire, Deville, and George Bornemann, in their beautiful analyses of the Macalube di Terrapilata, found 0.99 of carburetted hydrogen in the gas emitted, the gas which rises in the Agua Santa di Limosina, near Catanea, gave them, like Turbaco formerly, 0.98 of nitrogen, without a trace of oxygen (*Comptes rendus de l'Acad. des Sciences*, t. xliii, 1856, pp. 361 and 366).

to (from Parrot's Reports), that "the gas of the mud-volcanoes of the peninsula of Taman in 1811 had the property of preventing combustion, as a glowing chip was extinguished in the gas, and even the ascending bubbles, a foot in diameter, could not be ignited at the moment of their bursting," whilst in 1834, Göbel saw readily inflammable gas burning with a bluish flame at the same place,—leads me to believe that the emanations undergo chemical changes in different stages. Very recently Mitscherlich has, at my request, determined the limits of inflammability of artificially prepared mixtures of nitrogen and hydrogen gases. It appeared that mixtures of 1 part of hydrogen gas and 3 parts of nitrogen gas, not only took fire from a light, but also continued to burn. When the quantity of nitrogen gas was increased, so that the mixture consisted of 1 part of hydrogen and 3½ parts of nitrogen, it was still inflammable, but did not continue burning. *It was only with a mixture of* 1 *part of hydrogen and* 4 *parts of nitrogen gas that no ignition too place.* The gaseous emanations, which from their ready inflammability and the colour of their flame are usually called emanations of pure and carburetted hydrogen, need therefore consist quantitatively only of one-third part of one of the last-mentioned gases. With mixtures of carbonic acid and hydrogen, which occur more rarely, the limits of inflammability prove different again, on account of the capacity for heat of the former. Acosta justly suggests the question:—"Whether a tradition disseminated amongst the inhabitants of Turbaco, descendants of the *Indios de Taruaco*, according to which the Volcancitos formerly all burnt, and were converted from *Volcanes de fuego* into *Volcanes de agua*, by being exorcised and sprinkled with holywater by a pious monk[72], may not refer to a condition which has now returned?" Single great eruptions of flames from mud volcanoes, which both before and since have been very inactive (Taman, 1793; on the Caspian Sea, near Jokmali, 1827; and near Baklichli, 1839; near

[72] Humboldt, *Vues des Cordillères et Monuments des peuples indigènes de l'Amérique*, pl. xli, p. 239. The beautiful drawing of the Volcancitos de Turbaco, from which the copperplate was engraved, was made by my young fellow-traveller, Louis de Rieux. Upon the old Taruaco in the first period of the Spanish *Conquista*, see Herrera, Dec. i, p. 251.

Kuschtschy, 1846, also in the Caucasus), present analogous examples.

The apparently unimportant phenomenon of the salses of Turbaco, has gained in geological interest by the terrible eruption of flame, and the terrestrial changes which occurred in 1839, more than 32 geographical miles to the N.N.E. of Cartagena de Indias, between this harbour and that of Sabanilla, not far from the mouth of the great Magdalena river. The true central point of the phenomenon was the Cape Galera Zamba, which projects 6—8 geographical miles into the sea, in the form of a narrow peninsula. For the knowledge of this phenomenon we are also indebted to Colonel Acosta, of whom science has unfortunately been deprived by an early death. In the middle of the tongue of land there stood a conical hill, from the crater of which smoke (vapours) and gases sometimes poured forth with such violence that boards and large pieces of wood which were thrown into it were cast back again to a great distance. In the year 1839 the cone disappeared during a considerable eruption of fire, and the entire peninsula of Galera Zamba became an island, separated from the continent by a channel of 30 feet in depth. The surface of the sea continued in this peaceful state until on the 7th of October, 1848, at the place of the previous breach, a second terrible eruption of flames[73] appeared, without any perceptible earthquake in the vicinity, lasted for several days, and was visible at a distance of from 40 to 50 miles. The salse only emitted gases, but no solid matters. When the flames had disappeared the sea-bottom was found to be raised into a small sandy islet, which however soon disappeared again. More than 50 volcancitos (cones similar to those of Turbaco) now surround the submarine gas volcano of Galera Zamba, to a distance of from 18 to 23 miles. In a geological point of view we may certainly regard this as the principal seat of the volcanic activity which strives to place itself in contact with the atmosphere, over the whole of the low country from Turbaco to beyond the delta of the Rio Grande de la Magdalena.

[73] Lettre de M. Joaquin Acosta à M. Elie de Beaumont, in the *Comptes rendus de l'Acad. des Sciences*, t. xxix, 1849, pp. 530—534.

The uniformity of the phenomena which are presented in the various stages of their activity, by the salses, mud volcanoes, and gas-springs on the Italian peninsula, in the Caucasus and in South America, is manifested in enormous tracts of land in the Chinese empire. The art of man has there from the most ancient periods known how to make use of this treasure; nay, even led to the ingenious discovery of the Chinese rope-boring, which has only of late become known to Europeans. Borings of several thousand feet in depth are produced by the most simple application of human strength, or rather of the weight of man. I have elsewhere[74] treated in detail of this discovery, and also of the "fire springs," *Ho-tsing*, and "fiery mountains," *Ho-schan*, of Eastern Asia. They bore for water, brine-springs, and inflammable gas, from the south-western provinces, Yun-nan, Kuang-si, and Szu-tschuan on the borders of Thibet, to the northern province Schan-si. When it has a reddish flame, the gas often diffuses a bituminous odour; it is transferred partly in portable and partly in lying bamboo-tubes to remote places, for use in salt-boiling, for heating the houses, or for lighting the streets. In some rare cases supply of carburetted hydrogen gas has been suddenly exhausted, or stopped by earthquakes. Thus we know that a celebrated *Ho-tsing*, situated to the south-west of the town of Khiung-tscheu (latitude 50° 27,′ longitude 101° 6′ East), which was a salt spring burning with noise, was extinguished in the thirteenth century, after it had illuminated the neighbourhood from the second century of our era. In the province of Schan-si, which is so rich in coal, there are some ignited carbonaceous strata. Fiery mountains (*Ho-schan*) are distributed over a great part of China. The flames often rise to a great height, for example, in the mass of rock of the Py-kia-

[74] Humboldt, *Asie Centrale*, t. ii, pp. 519—540; principally from extracts from Chinese works by Klaproth and Stanislas Julien. The old Chinese rope-boring, which was repeatedly employed, and sometimes with advantage, in coal-pits in Belgium and Germany between 1830 and 1842, had been described (as Jobard has discovered) as early as the 17th century, in the Relation of the Dutch Ambassador, Van Hoorn, but the most exact account of this method of boring the fire-springs (*Ho-tsing*) is given by the French missionary, Imbert, who resided so many years in Kia-ting-fu (see *Annales de la Propagation de la Foy*, 1829, pp. 369—381).

schan, at the foot of a mountain covered with perpetual snow (lat. 31° 40′), from long, open, inaccessible fissures : a phenomenon which reminds us of the perpetual fire of the Shagdagh mountain in the Caucasus.

On the Island of Java, in the province of Samarang, at a distance of about fourteen miles from the north coast, there are salses similar to those of Turbaco and Galera Zamba. Very variable hills of 25 to 30 feet in height, throw out mud, salt-water, and a singular mixture of hydrogen gas and carbonic-acid[75]; a phenomenon which is not to be confounded with the vast and destructive streams of mud which are poured forth during the rare eruptions of the true, colossal volcanoes of Java (*Gunung Kelut* and *Gunung Idjen*). Some mofette-grottoes or sources of carbonic acid in Java are also very celebrated, particularly in consequence of exaggerations in the statements of some travellers, as also from their connexion with the myth of the Upas poison-tree, already mentioned by Sykes and Loudon. The most remarkable of the six has been scientifically described by Junghuhn, the so-called *Vale of death* of the island (*Pakaraman*) in the mountain Diëng, near Batur. It is a funnel-shaped sinking on the declivity of a mountain, a depression in which the stratum of carbonic acid emitted attains a very different height at different seasons. Skeletons of wild hogs, tigers, and birds are often found in it.[76] The poison-tree, *pohon* (or better *pûhn*) *ûpas* of the Malays (*Antiaris toxicaria* of the traveller Leschenault de

[75] According to Diard, *Asie Centrale,* t. ii, p. 515. Besides the mud volcanoes of Damak and Surabaya, there are upon other islands of the Indian Archipelago the mud volcanoes of Pulu-Semao, Pulu-Kambing, and Pulu-Koti; see Junghuhn, *Java, seine Gestalt und Pflanzendecke,* 1852, Abth. iii, s. 830.

[76] Junghuhn, *Op. cit.,* Abth. i, s. 201, and Abth. iii, s. 854—858. The weaker suffocating caves on Java are *Gua-Upas and Gua-Galan* (the first word is the Sanscrit, *guhâ,* cave). As there can certainly be no doubt that the Grotto del Cane, in the vicinity of the Lago di Agnano is the same that Pliny (ii, cap. 93) described nearly 18 centuries ago, "in agro Puteolano," as "Charonea scrobis mortiferum spiritum exhalans," we must certainly share in the surprise felt by Scacchi (*Memorie geol. sulla Campania,* 1849, p. 48), that in a loose soil, so often moved by earthquakes, so small a phenomenon (the supply of a small quantity of carbonic acid) can have remained unaltered and undisturbed.

la Tour), with its harmless exhalations, has nothing to do with these fatal actions.[77]

I conclude this section on the salses and steam and gas springs, with the description of an eruption of hot sulphurous vapours, which may attract the interest of geognosists on account of the kind of rock from which they are evolved. During my delightful, but somewhat fatiguing passage over the central Cordillera of Quindiu, (it took me 14 or 15 days on foot, and sleeping constantly in the open air, to get over the mountain crest of 11,500 feet from the valley of the Rio Magdalena into the Cauca valley), when at the height of 6810 feet I visited the *Azufral* to the west of the station *el Moral*. In a mica-schist of a rather dark colour, which, reposing upon a gneiss containing garnets, surrounds, with the latter, the elevated granite domes of la Ceja and la Garita del Paramo, I saw hot sulphurous vapours flowing out from the clefts of the rocks in a narrow valley (Quebrada del Azufral). As they are mixed with sulphuretted hydrogen gas and much carbonic acid, a stupefying dizziness is experienced on stooping down to measure the temperature, and remaining long in their vicinity. The temperature of the sulphurous vapours was 117°.7; that of the air 69°; and that of the sulphurous brook, which is probably cooled in the upper parts of its course by the snow-waters of the volcano of Tolima, 84°.6. The mica-schist, which contains some pyrites, is permeated by numerous fragments of sulphur. The sulphur prepared for sale is principally obtained from an ochre-yellow loam, mixed with native sulphur and weathered mica-slate. The operatives (Mestizoes) suffer from diseases of the eyes and muscular paralysis. When Boussingault visited the Azufral de Quindiu, 30 years after me (1831), the temperature of the vapours which he analysed[78] had so greatly diminished, as to fall below that of the open air (71°.6), namely to 66°—68.° The same excellent observer saw the trachytic rock of the neighbouring volcano of Tolima, breaking through the mica-schist, in the Quebrada de Aguas calientes: just as I have very distinctly seen the

[77] Blume, *Rumphia sive Comment. botanicæ*, t. i (1835), pp. 47—59.

[78] Humboldt, *Essai géognostique sur le gisement des Roches dans les deux Hémisphères*, 1823, p. 76; Boussingault, in the *Annales de Chimie et de Physique*, t. lii, 1833, p. 11.

equally eruptive, black trachyte of the volcano of Tunguragua covering a greenish mica-schist containing garnet near the rope-bridge of Penipe. As sulphur has hitherto been found in Europe, not in the primitive rocks as they were formerly called, but only in the tertiary limestone, in gypsum, in conglomerates and in true volcanic rocks, its occurrence in the Azufral de Quindiu ($4\frac{1}{2}°$ N. lat.) is the more remarkable, as it is repeated to the south of the equator between Quito and Cuenca, on the northern slope of the Paramo del Assuay. In the Azufral of the Cerro Cuello (2° 13′ S. lat.), again in mica-schist, at an elevation of 7980 feet, I met with a vast bed of quartz,[79] in which the sulphur is disseminated abundantly in scattered masses. At the time of my journey the fragments of sulphur measured only 6—8 inches, but they were formerly found of as much as 3—4 feet in diameter. Even a naphtha spring rises visibly from mica-schist in the sea-bottom in the gulf of Cariaco near Cumana. There the naphtha gives a yellow colour to the surface of the sea to a distance of more than a thousand feet, and I found that its odour was diffused as far as the interior of the peninsula of Araya.[80]

79 With regard to the elevation of Alausi (near Ticsan) on the Cerro Cuello, see the "Nivellement barométrique, No. 206," in my *Observ. Astron.* vol. i, p. 311.

80 "The existence of a naphtha spring issuing at the bottom of the sea from a mica-schist, rich in garnets, and diffusing, according to the expression of the historian of the *Conquista*, Oviedo, a "resinous, aromatic, and medicinal liquid," is an extremely remarkable fact. All those hitherto known belong to secondary mountains; and this mode of stratification appeared to favour the idea that all the mineral bitumens (Hatchett, *Transact. Linnæan Society*, 1798, p. 129) were due to the destruction of vegetable and animal matters, or to the ignition of coal. The phenomenon of the Gulf of Cariaco acquires fresh importance, if we bear in mind that the same so-called primitive stratum contains subterranean fires, that the odour of petroleum is experienced from time to time at the edge of ignited craters (for example, in the eruption of Vesuvius in 1805, when the volcano threw up scoriæ), and that most of the very hot springs of South America issue from granite (las Trincheras, near Portocabello), gneiss and micaceous schist. More to the eastward of the meridian of Cumana, in descending from the Sierra de Meapire, we first came to the hollow ground (*tierra hueca*), which, during the great earthquakes of 1766, threw up asphalte enveloped in viscous petroleum; and afterwards, beyond this ground, to an infinity of hydrosulphurous hot springs (Humboldt, *Relation Historique*, t. i, pp. 136, 344, 347, and 447).

If we now cast a last glance at the kind of volcanic activity which manifests itself by the production of vapours and gases, either with or without phenomena of combustion, we find sometimes a great affinity, and sometimes a remarkable difference in the matters escaping from fissures of the earth, according as the high temperature of the interior, modifying the action of the affinities, has acted upon homogeneous or very composite materials. The matters which are driven to the surface by this low degree of volcanic activity, are :—aqueous vapour in great quantity, chloride of sodium, sulphur, carburetted and sulphuretted hydrogen, carbonic acid and nitrogen ; naphtha (colourless or yellowish, or in the form of brown petroleum) ; boracic acid and alumina from the mud volcanoes. The great diversity of these matters, of which, however, some (common salt, sulphuretted hydrogen gas, and petroleum), are almost always associated together, shows the unsuitableness of the denomination *salses*, which originated in Italy, where Spallanzani had the great merit of having been the first to direct the attention of geognosists to this phenomenon, which had been long regarded as so unimportant, in the territory of Modena. The name *vapour and gas springs*, is a better expression of the general idea. If many of them, such as the Fumaroles, undoubtedly stand in relation to extinct volcanoes, and are even, as sources of carbonic acid, peculiarly characteristic of a last stage of such volcanoes ; others, on the contrary, appear to be quite independent of the true fiery mountains which vomit forth fused earths. Then, as Abich has already shown in the Caucasus, they follow definite directions in large tracts of country, breaking out of fissures in rocks, both in the plains, even in the deep basin of the Caspian Sea, and in mountain elevations of nearly 8500 feet. Like the true volcanoes, they sometimes suddenly augment their apparently dormant activity by the eruption of columns of fire, which spread terror all around. In both continents, in regions widely separated, they exhibit the same conditions following one upon the other ; but no observation has hitherto justified us in supposing that they are the forerunners of the formation of true volcanoes vomiting lava and cinders. Their activity is of another kind, perhaps originating at a smaller depth, and caused by different chemical processes.

d. *Volcanoes, according to the difference of their formation and activity.—Action by fissures and cauldron-like depressions.—Circumvallation of the craters of elevation.—Volcanic conical and bell-shaped Mountains, with open or closed summits,—Difference of the Rocks through which Volcanoes act.*

(Amplification of the Representation of Nature: *Cosmos,* vol. i., pp. 225—247.)

Amongst the various specific manifestations of force in the reaction of the interior of our planet upon its uppermost strata, the mightiest is that presented by the true Volcanoes: —that is to say, those openings through which, besides gases, solid masses of various materials are forced up from unmeasured depths to the surface, either in a state of igneous fusion, as lava streams, or in the form of cinders, or as products of the finest trituration (ashes). If we regard the words *volcano* and *fiery mountain* as synonymous, in accordance with the old usage of speech, we thus, according to a preconceived and very generally diffused opinion, attach to the idea of volcanic phenomena, the picture of an isolated conical mountain, with a circular or oval orifice at the summit. Such views, however, lose their universality when the observer has the opportunity of wandering through connected volcanic districts, occupying a surface of many thousand square geographical miles; for example, the entire central part of the highlands of Mexico, between the Peak of Orizaba, Jorullo, and the shores of the South Sea; or Central America; or the Cordilleras of New Granada and Quito, between the Volcano of Puracé, near Popayan, that of Pasto and Chimborazo; or the isthmian chain of the Caucasus, between the Kasbegk, Elburuz and Ararat. In lower Italy, between the Phlegraean Fields of the mainland of Campania, Sicily, and the islands of Lipari and Ponza, as also in the Greek Islands, part of the intervening land has not been elevated with the volcanoes, and part of it has been swallowed by the sea.

In the above-mentioned great districts of America and the Caucasus, masses of eruptions—(true Trachytes, and not trachytic conglomerates; streams of obsidian; quarried blocks of pumice-stone, and not pumice boulders transported and deposited by water)—make their appearance, seeming to be quite independent of the mountains, which only rise at a considerable distance. Why should not the surface have been split in many directions during the progressive refrigeration of the upper strata of the earth by radiation of heat, before the elevation of isolated mountains or mountain chains had yet taken place? Why should not these fissures have emitted masses in a state of igneous fusion, which have hardened into rocks and eruptive stones (trachyte, dolerite, melaphyre, margarite, obsidian, and pumice)? A portion of these trachytic or doleritic strata which have broken out in a viscid fluid state, as if from earth-springs,[81] and which were originally deposited in a horizontal position, have, during the subsequent elevation of volcanic cones and bell-shaped mountains, been tilted into a position which by no means belongs to the more recent lavas, produced from igneous mountains. Thus, to advert in the first place to a very well-known European example, in the Val del Bove on Etna (a depression which cuts deeply into the interior of the mountain) the declination of the strata of lava, which alternate very regularly with masses of boulders, is 25° to 30°, whilst, according to Elie de Beaumont's exact determinations, the lava streams which cover the surface of Etna, and which have only flowed from it since its elevation in the form of a mountain, only exhibit a declination of 3° to 5° on an average of 30 streams. These conditions indicate the existence of very ancient volcanic formations, which have broken out from fissures, before the production of the volcano as an igneous mountain. A remarkable phenomenon of this kind is also presented to us by antiquity; a phenomenon which manifested itself on Eubœa, the modern Negropont, in an extended plain, situated at a distance from all active and extinct volcanoes. "The violent earthquakes, which partially shook the island, did not cease until an abyss, which had opened on the plain of Lelantus, threw up a stream of glowing mud (lava)."[82]

[81] *Cosmos*, vol. i, p. 229.

[82] Strabo i, p. 58, ed. Casaub. The epithet διάπυρος, proves that in this case mud-volcanoes are not spoken of. Where Plato, in his geog-

If the oldest formations of eruptive rock (often perfectly similar to the more recent lavas in its composition), which also in part occupy veins, are to be ascribed to a previous fissure of the deeply shaken crust of the earth, as I have long been inclined to think, both these fissures, and the less simple craters of elevation subsequently produced, must be regarded only as *volcanic eruptive orifices*, not as volcanoes themselves. The principal character of these last consists in a connexion of the deep-seated focus with the atmosphere, which is either permanent, or at least renewed from time to time. For this purpose the volcano requires a peculiar framework; for, as Seneca[83] says very appropriately, in a letter to Lucilius, "ignis in ipso monte non alimentum habet, sed viam." The volcanic activity exerts, therefore, a formative action by elevating the soil; and not, as was at one time universally and exclusively supposed, a building action by the accumulation of cinders, and new strata of lava, superposed one upon the other. The resistance experienced in the canal of eruption, by the masses in a state of igneous fluidity when forced in excessive quantities towards the surface, gives rise to the increase in the heaving force. A "vesicular inflation of the soil" is produced, as is indicated by the regular outward declination of the elevated strata. A mine-like explosion, the bursting of the central and highest part of the convex inflation of the soil gives origin sometimes only to what Leopold von Buch has called a *crater of elevation*,[84] that is

nostic phantasies, alludes to these, mixing mythical matter with observed facts, he says distinctly (in opposition to the phenomenon described by Strabo) ὑγροῦ πηλοῦ ποταμοί. Upon the denominations πηλός and ῥύαξ, as volcanic emissions, I have treated on a former occasion (*Cosmos*, vol. i, p. 236), and I shall only advert here to another passage in Strabo (vi, p. 269), in which hardening lava, called πηλὸς μέλας, is most distinctly characterised. In the description of Etna we find:—"The red-hot stream (ῥύαξ) in the act of solidification converts the surface of the earth into stone to a considerable depth, so that whoever wishes to uncover it must undertake the labour of quarrying. For, as in the craters, the stone is molten and then upheaved, the fluid streaming from the summit is a black excrementitious mass (πηλός) falling down the mountain, which, afterwards hardening, becomes a millstone, and retains the same colour that it had before."

[83] *Cosmos*, vol. i, p. 238.

[84] Leopold von Buch, *On Basaltic Islands and Craters of Elevation*, in the *Abhandl. der könig. Akad. der Wiss. zu Berlin*, 1818—1819, s. 51;

to say, a crater-like, round or oval depression, bounded by a *circle of elevation*, a ring-shaped wall, usually broken down in places; sometimes (when the framework of a permanent volcano is to be completed), to a dome-shaped or conical mountain in the middle of the crater of elevation. The latter is then generally open at its summit, and on the bottom of this opening (the crater of the permanent volcano) rise transitory hills of eruption and hills of scoriæ, small and large cones of eruption, which, in Vesuvius, sometimes far exceed the margins of the crater of the cone of elevation. The signs of the first eruption, the old framework, are not however always retained. The high wall of rock which surrounds the inner circular wall (the crater of elevation), is not recog-

and *Physicalische Beschreibung der canarischen Inseln*, 1825, s. 213, 262, 284, 313, 323, and 341. This work, which constitutes an era in the profound knowledge of volcanic phenomena, is the fruit of a voyage to Madeira and Teneriffe from the beginning of April to the end of October, 1815; but Naumann indicates with much justice, in his *Lehrbuch der Geognosie*, that in the letters written in 1802 by Leopold von Buch, from Auvergne (*Geognostische Beobacht. auf Reisen durch Deutschland und Italien*, Bd. ii, s. 282), in reference to the description of Mont d'Or, the theory of craters of elevation and their essential difference from the true volcanoes was already expressed. An instructive counterpart to the three craters of elevation of the Canary Islands (on Gran Canaria, Teneriffe, and Palma) is furnished by the Azores. The admirable maps of Captain Vidal, for the publication of which we are indebted to the English Admiralty, elucidate the wonderful geognostic construction of these islands. On San Michael is situated the enormous Caldeira das sete Cidades, which was formed in the year 1444, almost under Cabral's eyes, a crater of elevation which encloses two lakes, the Lagoa grande and the Lagoa azul, at a height of 876 feet. The Caldeira de Corvo, of which the dry part of the bottom is 1279 feet high, is almost of the same circumference. Nearly three times this height are the craters of elevation of Fayal and Terceira. To the same kind of eruptive phenomena belong the innumerable but ephemeral platforms which were visible only by day, in 1691, in the sea around the island of San George, and in 1757 around San Michael. The periodical inflation of the sea-bottom, scarcely four miles to the west of the Caldeira das sete Cidades, producing a larger and somewhat more permanent island (Sabrina), has already been mentioned (*Cosmos*, vol. i, p. 241). Upon the crater of elevation of Astruni, in the Phlegræan plains, and the trachytic mass driven up in its centre, as an unopened bell-shaped hill, see Leopold von Buch, in Poggend. *Annalen*. Bd. xxxvii, s. 171 and 182. A fine crater of elevation is that of Rocca Monfina, measured and figured in Abich's *Geolog. Beobacht. über die vulkan, Erschein. in Unter-und Mittel Italien*, 1841, Bd. i, s. 113, Taf. ii.

nisable, even in scattered detritus, on many of the largest and most active volcanoes.

It is a great merit of modern times not only to have more accurately investigated the peculiar conditions of the formation of volcanoes by a careful comparison of those which are widely separated from each other, but also to have introduced more definite expressions into language, by which the heterogeneous features of the general outline, as well as the manifestations of volcanic activity are distinguished. If we are not decidedly disinclined to all classifications, because in the endeavour after generalization these always rest only upon imperfect indications, we may conceive the bursting forth of fused masses and solid matter, vapours and gases, in four different ways. Proceeding from the simple to the complex phenomena, we may first mention eruptions from *fissures*, not forming separate series of cones, but producing volcanic rocks superlying each other, in a fused and viscid state; secondly, eruptions through *heaped up cones*, without any circumvallation, and yet emitting streams of lava, as was the case for five years during the destruction of the Island of Lancerote, in the first half of the last century; thirdly, *craters of elevation*, with up-heaved strata, but without central cones, emitting streams of lava only on the outside of the circumvallation, never from the interior, which is soon closed up with detritus; fourthly, closed *bell-shaped mountains* or *cones of elevation*, open at the summit, either enclosed by a circular wall, which is at least partially retained,—as on the Pic of Teneriffe, in Fogo, and Rocca Monfina; or entirely without circumvallation or crater of elevation,—as in Iceland,[85] in the Cordilleras of Quito, and the central parts of Mexico. The open cones of elevation of this fourth class maintain a permanent connection between the fiery interior of the earth and the atmosphere, which is more or less effective at undetermined intervals of time. Of the dome-shaped and bell-shaped trachytic and doleritic mountains which have remained closed at the summit, there appear, according to my observations, to be more than of the open cones whether active or extinct, and far more than of the true volcanoes. Dome-shaped and bell-shaped

[85] Sartorius von Waltershausen, *Physisch-geographische Skizze von Island*, 1847, s. 107.

mountains, such as Chimborazo, Puy de Dôme, Sarcouy, Rocca Monfina and Vultur, give the landscape a peculiar character, by which they contrast pleasingly with the schistose peaks, or the serrated forms of limestone.

In the tradition preserved to us so picturesquely by Ovid regarding the great volcanic phenomenon of the peninsula of Methone, the production of such a bell-shaped and unopened mountain is indicated with methodical clearness. "The force of the winds imprisoned in dark caves of the earth, and seeking in vain for an opening, drive up the heaving soil (*extentam tumefecit humum*), as when one fills a bladder or leather bag with air. By gradual hardening, the high projecting eminence has retained the form of a hill." I have already elsewhere adverted to the fact of how completely different this Roman representation is from Aristotle's narration of the volcanic phenomenon upon Hiera, a newly formed Aeolic (Liparian) Island, in which "the subterranean, mightily urging blast does indeed also raise a hill, but afterwards breaks it up to pour forth a fiery shower of ashes." The elevation is here clearly represented as preceding the eruption of flame (Cosmos, vol. i, p. 240). According to Strabo, the elevated dome-like hill of Methana had also opened in fiery eruptions, at the close of which an agreeable odour was diffused in the night time. It is very remarkable that the latter was observed under exactly similar circumstances during the volcanic eruption of Santorin, in the autumn of 1650, and was denominated "a consoling sign, that God would not yet destroy his flock," in the penitential sermon delivered and written shortly afterwards by a monk.[86] Does not this pleasant odour afford

[86] It has been a much disputed point, to what particular locality of the plain of Troezen, or the peninsula of Methana, the description of the Roman poet may refer. My friend, Ludwig Ross, the great Greek antiquarian and chorograph, who has had the advantage of many travels, thinks that the immediate vicinity of Troezen presents no locality which can be referred to as the bladder-like hills, and that, by a poetic license, Ovid has removed the phenomenon described with such truth to nature, to the plain. "To the south of the peninsula of Methana, and east of the plain of Troezen," writes Ross, "lies the island Calauria, well known as the place where Demosthenes, being pressed by the Macedonians, took poison in the temple of Neptune. A narrow arm of the sea separates the limestone rocks of Calauria from the coast; from this arm of the sea (passage, πόρος) the town and island take their present

indications of naphtha? The same thing is also referred to by Kotzebue, in his Russian voyage of discovery, in connection with an igneous eruption (1804) of the volcanic island of Umnack, newly elevated from the sea in the Aleutian Archipelago. During the great eruption of Vesuvius, on the 12th August, 1805, which I observed in company with Gay-Lussac, the latter found a bituminous odour prevailing at times in the ignited crater. I bring together these little-noticed facts, because they contribute to confirm the close concatenation of all manifestations of volcanic activity, the intimate connection of the weak salses and naphtha springs with the true volcanoes.

Circumvallations, analogous to those of the craters of elevation, also present themselves in rocks which are very different from trachyte, basalt and porphyritic schists, for example according to Elie de Beaumont's acute observation, in the granite of the French Alps. The mountain mass of Oisans, to which the highest[87] summit of France, Mont

name. In the middle of the strait, united with Calauria by a low causeway, probably of artificial origin, lies a small conical islet, comparable in form to an egg cut through the middle. It is volcanic throughout, consisting of greyish yellow and yellowish red trachyte, mixed with eruptions of lava and scoriæ, and is almost entirely destitute of vegetation. Upon this islet stands the present town of Poros, on the place of the ancient Calauria. The formation of the islet is exactly similar to that of the more recent volcanic islands in the Bay of Thera (Santorino). In his animated description, Ovid has probably followed a Greek original or an old tradition" (Ludw. Ross, in a letter to me dated November, 1845). As a member of the French scientific expedition, Virlet has set up the opinion that the volcanic upheaval may have been only a subsequent increase of the trachytic mass of the peninsula of Methana. This increase occurs in the north-west extremity of the peninsula, where the black burnt rock, called Kammeni-petra, resembling the Kammeni, near Santorin, betrays a more recent origin. Pausanias communicates the tradition of the inhabitants of Methana, that, on the north coast, before the now celebrated sulphurous springs burst forth, fire rose out of the earth (see Curtius, *Peloponnesos,* Bd. i, s. 42 and 46). On the "indescribable pleasant odour" which followed the stinking sulphurous odour, near Santorino (Sept. 1650), see Ross, *Reisen auf den griech. Inseln des ägäischen Meeres,* Bd. i, s. 196. Upon the odour of naphtha in the fumes of the lava of the Aleutian island Umnack, which appeared in 1796, see Kotzebue's *Entdeckungs-Reise,* Bd. ii, s. 106, and Léopold de Buch, *Description phys. des Iles Canaries,* p. 458.

87 The highest summit of the Pyrenees, that is, the Pic de Nethou (the eastern and highest peak of the Maladetta or Malahita group), has

Pelvoux, near Briançon, (12,905 feet) belongs, forms an amphitheatre of thirty-two geographical miles in circumference, in the centre of which is situated the small village of la Bérarde. The steep walls of this circular space rise to a height of more than 9600 feet. The circumvallation itself is gneiss; all the interior is granite.[88] In the Swiss and Savoy Alps, the same formation presents itself repeatedly in small dimensions. The *Grand-Plateau* of Mont-Blanc, in which Bravais and Martins encamped for several days, is a closed amphitheatre with a nearly flat bottom at an elevation of nearly 12,811 feet; from the midst of which the colossal pyramid of the summit rises.[89] The same upheaving forces produce similar forms, although modified by the composition of the different rocks. The annular and cauldron-like valleys (valleys of elevation), described by Hoffman, Buckland, Murchison, and Thurmann, in the sedimentary rocks of the north of Germany, in Herefordshire, and the Jura mountains of Porrentruy, are also connected with the phenomena here described, as well as, although with a less degree of analogy, some elevated plains of the Cordilleras enclosed on all sides by mountain masses, in which are situated the towns of Caxamarca (9362 feet), Bogota (8729 feet), and Mexico (7469 feet), and in the Himalayas the cauldron-like valley of Caschmir (5819 feet).

Less related to the craters of elevation than to the above described simplest form of volcanic activity (the action from mere fissures), are the numerous *Maars* amongst the extinct volcanoes of the Eifel; cauldron-like depressions in non-volcanic-rock (Devonian slate), and surrounded by slightly elevated margins, formed by themselves. "These are as

been twice measured trigonometrically; its height, according to Reboul, is 11,443 feet (3481 metres), and, according to Coraboeuf, 11,167 feet (3404 metres). It is, therefore, 1705 feet lower than Mont Pelvoux, in the French Alps, near Briançon. The next in height to the Pic de Nethou in the Pyrenees, are the Pic Posets or Erist, and of the group of the Marboré, the Montperdu, and the Cylindre.

[88] *Mémoire pour servir à la Description Géologique de la France*, t. ii. p. 339. Upon "valleys of elevation" and "encircling ridges" in the Silurian formation, see the admirable description of Sir Roderick Murchison in "The Silurian System," pt. i, pp. 427—442.

[89] Bravais and Martins, *Observ. faites au Sommet et au Grand Plateau du Mont-Blanc*, in the *Annuaire Météorol. de la France pour* 1850, p. 131.

it were the funnels of mines, indications of mine-like eruptions," resembling the remarkable phenomenon described by me of the human bones scattered upon the hill of la Culca [90] during the earthquake of Riobamba (4 February, 1797). When single *Maars*, not situated at any great height, in the Eifel, in Auvergne, or in Java, are filled with water, such former craters of explosion may in this state be denominated *cratères-lacs;* but it seems to me that this term should not be taken as a synonymous name for Maar, as small lakes have been found by Abich and myself on the summits of the highest volcanoes, on true cones of elevation in extinguished craters: for example, on the Mexican volcano of Toluca at an elevation of 12,246 feet, and on the Caucasian Elburuz at 19,717 feet. In the volcanoes of the Eifel we must carefully distinguish from each other two kinds of volcanic activity of very unequal age,—the true volcanoes emitting streams of lava; and the weaker eruptive phenomena of the Maars. To the former belong the basaltic stream of lava, rich in olivine, and cleft into upright columns, in the valley of Uesbach near Bertrich;[91] the volcano of Gerolstein, which is seated in a limestone containing dolomite, deposited in the form of a basin in the Devonian grauwacke schists; and the long ridge of the Mosenberg (1753 feet above the sea) not far from Bettenfeld to the west of Manderscheid. The last named volcano has three craters, of which the first and second, those furthest to the north, are perfectly round, and covered with peat mosses; whilst from the third and most

[90] *Cosmos*, vol. v, p. 173. I have twice visited the volcanoes of the Eifel, when geognosy was in very different states of development, in the autumn of 1794, and in August, 1845; the first time in the vicinity of the lake of Laach and the monastery there, which was then still inhabited by monks; the second time, in the neighbourhood of Bertrich, the Mosenberg, and the adjacent Maars, but never for more than a few days. As in the latter excursion I had the good fortune to be able to accompany my intimate friend, the mining surveyor, Von Dechen, I have been enabled by many years' correspondence, and the communication of important manuscript memoirs to make free use of the observations of this acute geognosist. I have often indicated by quotation marks, as is my wont, what I have borrowed, word for word, from his communications.

[91] H. von Dechen, *Geognost. Uebersicht der Umgegend von Bad Bertrich*, 1847, s. 11—51.

southern[92] crater, there flows down a vast, reddish brown, deep stream of lava, separated into a columnar form, towards the valley of the little Kyll. It is a remarkable phenomenon, foreign to lava-producing volcanoes in general, that neither on the Mosenberg nor on the Gerolstein, nor in other true volcanoes of the Eifel are the lava-eruptions visibly surrounded at their origin by a trachytic rock, but, as far as they are accessible to observation, proceed directly from the Devonian strata. The surface of the Mosenberg does not at all prove what is hidden in its depths. The scoriæ containing augite, which by cohesion pass into basaltic streams, contain small, calcined fragments of slate, but no trace of enclosed trachyte. Nor is the latter to be found enclosed in the crater of the Rodderberg, notwithstanding that it lies in the immediate vicinity of the Siebengebirge, the greatest trachytic mass of the Rhine district.

"The Maars appear," as the mining surveyor Von Dechen has ingeniously observed, "to belong in their formation to about the same epoch as the eruption of the lava-streams of the true volcanoes. Both are situated in the vicinity of deeply cut valleys. The lava-producing volcanoes were decidedly active at a time when the valleys had already attained very nearly their present form; and we also see the most ancient lava-streams of this district pouring down into the valleys." The Maars are surrounded by fragments of Devonian slates and by heaps of gray sand and tufa-margins. The Laacher lake, whether it be regarded as a large Maar, or, with my old friend C. von Oeynhausen, as part of a large cauldron-like valley in the clay slate (like the basin of Wehr), exhibits some volcanic eruptions of scoriæ upon the ridge surrounding it, as is the case on the Krufter Ofen, the Veitskopf and Laacher Kopf. It is not, however, merely the entire want of lava-streams, such as are to be observed on the Canary Islands upon the outer margin of true craters of elevation and in their immediate vicinity,—it is not the inconsiderable

[92] Stengel, in *Nöggerath, das Gebirge von Rheinland und Westphalen,* Bd. i, s. 79, Taf. iii. See also C. von Oeynhausen's admirable explanations of his geognostic *Map of the Lake of Laach,* 1847, pp. 34, 39, and 42, including the Eifel and the basin of Neuwied. Upon the Maars, see Steininger, *Geognostische Beschreibung der Eifel,* 1853, s. 113. His earliest meritorious work, "*Die erloschenen Vulkane in der Eifel und am Nieder-Rhein,*" belongs to the year 1820.

elevation of the ridge surrounding the Maar, that distinguishes this from craters of elevation; the margins of the Maars are destitute of a regular stratification of the rock, falling, in consequence of the upheaval, constantly outwards. The Maars sunk in the Devonian slate, appear, as has already been observed, like the craters of mines, into which, after the violent explosion of hot gases and vapours, the looser ejected masses (*Rapilli*), have for the most part fallen back. As examples I shall only mention here the Immerather, the Pulvermaar, and the Meerfelder Maar. In the centre of the first mentioned, the dry bottom of which, at a depth of two hundred feet, is cultivated, are situated the two villages of Ober- and Unter-Immerath. Here, in the volcanic tufa of the vicinity, exactly as on the Laacher lake, mixtures of felspar and augite occur in spheroids, in which particles of black and green glass are scattered. Similar spheroids of mica, hornblende and augite, full of vitrified portions are also contained in the tufa veins of the Pulvermaar near Gillenfeld, which, however, is entirely converted into a deep lake. The regularly circular Meerfelder Maar, covered partly with water and partly with peat, is characterized geognostically by the proximity of the three craters of the great Mosenberg, the most southern of which has furnished a stream of lava. The Maar, however, is situated 639 feet below the long ridge of the volcano, and at its northern extremity, not in the axis of the series of craters, but more to the north-west. The average elevation of the Maars of the Eifel above the surface of the sea falls between 922 feet (Laacher lake ?) and 1588 feet (Mosbrucher Maar).

As this is peculiarly the place in which to call attention to the uniformity and agreement exhibited by volcanic activity in its production of material results, in the most different forms of the outer framework (as Maars, as circumvallated craters of elevation, or cones opened at the summit), I may mention the remarkable abundance of crystallized minerals which have been thrown out by the Maars in their first explosion, and which still in part lie buried in the tufas. In the environs of the Laacher lake this abundance is certainly greatest, but other Maars also, for example the Immerather, and the Meerfelder

Maar so rich in bombs of olivine, contain fine crystallized masses. We may here mention, zircon, hauyne, leucite,[93] apatite, nosean, olivine, augite, rhyacolite, common felspar (orthoclase), glassy felspar (sanidine), mica, sodalite, garnet, and titanic iron. If the number of beautifully crystallized minerals on Vesuvius be so much greater (Scacchi counts 43 species), we must not forget, that very few of them are ejected from the volcano, and that the greater number belongs to the portion of the so-called eruptive matters of Vesuvius, which, according to the opinion of Leopold von Buch,[94] "are quite foreign to Vesuvius, and to be referred to a tufaceous covering diffused far beyond Capua, which was upheaved by the rising cone of Vesuvius, and has probably been produced by a deeply-seated submarine volcanic action."

Certain definite directions of the various phenomena of volcanic activity are unmistakeable even in the Eifel. "The eruptions, producing lava-streams, of the upper Eifel lie in one fissure, nearly 32 English miles in length, from Bert-

[93] Leucite (of the same kind from Vesuvius, from Rocca di Papa in the Albanian mountains, from Viterbo, from the Rocca Monfina, according to Pilla, sometimes of more than 3 inches in diameter, and from the dolerite of the Kaiserstuhl in the Breisgau), occurs also "in position as leucite-rock in the Eifel, on the Burgberg, near Rieden. The tufa in the Eifel incloses large blocks of leucitophyre near Boll and Weibern." I cannot resist the temptation to borrow the following important observation from a chemico-geognostic memoir read by Mitscherlich a few weeks since before the Academy of Berlin. "Aqueous vapours alone may have effected the eruptions of the Eifel; but they would have divided olivine and augite into the finest drops and powder, if they had met with them in a fluid state. With the fundamental mass of the erupted matters fragments of the old, broken up rock are most intimately mixed, for example on the Dreiser Weiher, and these are frequently caked together. The larger olivine masses and the masses of augite even usually occur surrounded by a thick crust of this mixture; a fragment of the old rock never occurs in the olivine or augite,—both were consequently formed before they reached the spot where the breaking up took place. Olivine and augite had therefore separated from the fluid basaltic mass before this met with an accumulation of water or a spring which caused its expulsion." See also upon the bombs an older memoir by Leonard Horner, in the *Transactions of the Geological Society*, 2nd series, vol. iv, pt. 2, 1836, p. 467.

[94] Leopold von Buch, in Poggend. *Annalen*, Bd. xxxvii, s. 179. According to Scacchi, the eruptive matters belong to the first outbreak of Vesuvius in the year 79. Leonhard's *Neues Jahrbuch für Mineral.* 1853, s. 259.

rich to the Goldberg near Ormond, directed from south-east to north-west; on the other hand the Maars, from the Meerfelder Maar to Mosbruch and the Laacher lake, follow a line of direction from south-west to north-east. These two primary directions intersect each other in the three Maars of Daun. In the neighbourhood of the Laacher lake trachyte is nowhere visible on the surface. The occurrence of this rock below the surface is only indicated by the peculiar nature of the perfectly felspar-like pumice-stone of Laach, and by the bombs of augite and felspar thrown out. But the trachytes of the Eifel, composed of felspar and large crystals of hornblende, are only visibly distributed amongst basaltic mountains: as in the Sellberg (1893 feet) near Quiddelbach, in the rising ground of Struth, near Kelberg, and in the wall-like mountain chain of Reimerath near Boos."

Next to the Lipari and Ponza Islands few parts of Europe have probably produced a greater mass of pumice-stone than this region of Germany, which, with a comparatively small elevation, presents such various forms of volcanic activity in its Maars (*cratères d'explosion*), basaltic rocks, and lava-emitting volcanoes. The principal mass of the pumice-stone is situated between Nieder Mendig and Sorge, Andernach and Rübenach; the principal mass of the *duckstein*, or *Trass* (a very recent conglomerate, deposited by water), lies in the valley of Brohl, from its opening into the Rhine upwards to Burgbrohl, near Plaidt and Kruft. The Trass-formation of the Brohl-valley contains, together with fragments of grauwacke-slate and pieces of wood, small fragments of pumice-stone, differing in nothing from the pumice-stone which constitutes the superficial covering of the region, and even that of the duckstein itself. Notwithstanding some analogies which the Cordilleras appear to present, I have always doubted whether the Trass can be ascribed to eruptions of mud from the lava-producing volcanoes of the Eifel. I rather suppose, with H. von Dechen, that the pumice-stone was thrown out dry, and that the Trass was formed in the same way as other conglomerates. "Pumice-stone is foreign to the Siebengebirge; and the great pumice-eruption of the Eifel, the principal mass of which still lies above the *loess* (Trass) and alternates therewith in particular parts, may, in accordance with the presumption to which the local conditions lead, have taken place in the valley of the Rhine, above Neuwied, in the great Neuwied basin, perhaps near Urmits, on the left bank of the Rhine. From the friability of the material the place of eruption may have disappeared without leaving any traces, by the subsequent action of the current of the Rhine. In the entire tract of the Maars of the Eifel, as in that of its volcanoes from Bertrich to Ormond, no pumice-stone is found. That of the Laacher lake is limited to the rocks upon its margin; and on the other Maars the small fragments of felspathic rock, which lie in the volcanic sand and tuff, do not pass into pumice."

We have already touched upon the relative antiquity of the Maars and of the eruptions of the lava-streams, which differ so much from them, compared with that of the formation of the valleys. "The trachyte of the Siebengebirge appears to be much older than the valley-formation, and even older than the Rhenish brown-coal. Its appearance has been independent of the cutting of the valley of the Rhine, even if we should ascribe this valley to the formation of a fissure. The formation of the valleys is more recent than the Rhenish brown-coal, and more recent than the Rhenish basalt; but older than the volcanic eruptions with lava-streams, and older than the great pumice-eruption and the Trass. Basalt formations decidedly extend to a more recent period than the formation of trachyte, and the principal mass of the basalt is, therefore, to be regarded as younger than the trachyte. In the present declivities of the valley of the Rhine many basaltic groups (the quarry of Unkel, Rolandseck, Godesberg), were only laid bare by the opening of the valley, as up to that time they were probably enclosed in the Devonian grauwacke rocks."

The Infusoria, whose universal diffusion, demonstrated by Ehrenberg, upon the continents, in the greatest depths of the sea and in the upper strata of the atmosphere, is one of the most brilliant discoveries of our time, have their principal seat in the volcanic Eifel, in the Rapilli, Trass-strata, and pumice-conglomerates. Organisms with silicious shields fill the valley of Brohl and the eruptive matters of Hochsimmer; sometimes, in the Trass, they are mixed with uncarbonised twigs of coniferæ. According to Ehrenberg, the whole of this microcosm is of fresh-water formation, and marine Polythalamia[95] only show themselves exceptionally in the uppermost deposit of the friable, yellowish *loess* at the foot and on the declivities of the Siebengebirge (indicating its former brackish coast-nature).

Is the phenomenon of Maars limited to Western Germany? Count Montlosier, who was acquainted with the Eifel by personal observations in 1819, and who pronounces the Mosenberg to be one of the finest volcanoes that he ever saw, (like Rozet) regards the *Gouffre de Tazenat*, the *Lac Pavin* and *Lac de la Godivel*, in Auvergne, as Maars or craters of explosion. They are cut into very different kinds of rock,—in granite, basalt, and domite (trachytic rock), and surrounded at the margins with scoriæ and rapilli.[96]

The frameworks which are built up by a more powerful eruptive activity of volcanoes, by upheaval of the soil and emission of lava, appear in at least six different forms, and reappear with this variety in their forms in the most distant zones of the earth. Those who are born in volcanic districts amongst basaltic and trachytic mountains, are often genially impressed in spots where the same forms greet them. Mountain forms are amongst the most important determining elements of the physiognomy of nature,—they give the district either a cheerful, or a stern and magnificent character, according as they are adorned with vegetation or surrounded by a dreary barrenness. I have quite recently endea-

[95] Upon the antiquity of formation of the valley of the Rhine, see H. von Dechen, *Geognost. Beschreibung des Siebengebirges*, in the *Verhandl. des Naturhist. Vereins der Preuss. Rheinlande und Westphalens*, 1852, s. 556—559. The infusoria of the Eifel are treated of by Ehrenberg in the *Monatsber. der Akad. der Wiss. zu Berlin*, 1844, s. 337, 1845, s. 133 and 148, and 1846, s. 161—171. The *Trass* of Brohl, which is filled with crumbs of pumice-stone containing infusoria, forms hills of as much as 850 feet in height.

[96] See Rozet, in the *Mémoires de la Société Géologique*, 2me série, t. i, p. 119. On the island of Java also, that wonderful seat of multifarious volcanic activity, there occur "craters without cones, as it were flat volcanoes" (Junghuhn, *Java, seine Gestalt und Pflanzendecke*, Lief. vii, p. 640) between Gunung Salak and Perwakti, analogous to the Maars as "craters of explosion." Destitute of any elevated margins, they are situated partly in perfectly flat districts of the mountains, have angular fragments of the burst rocky strata scattered around them, and now only emit vapours and gases.

voured to bring together, in a separate atlas, a number of outlines of the Cordilleras of Quito and Mexico, sketched from my own drawings. As basalt occurs sometimes in conical domes, somewhat rounded at the summit, sometimes in the form of closely-arranged twin-mountains of unequal elevation, and sometimes in that of a long horizontal ridge bounded at each extremity by a more elevated dome, so we principally distinguish in trachyte the majestic dome-form[97] (Chimborazo, 21,422 feet), not to be confounded with the form of the unopened but less massive bell-shaped mountains. The conical form is most perfectly[98] exhibited in Cotopaxi (18,877 feet), and next to this in Popocatepetl[99] (17,727 feet), as seen on the beautiful shores of the lake of Tezcuco, or from the summit of the ancient Mexican step-pyramid of Cholula; and in the volcano of Orizaba[100] (17,374 feet, according to Ferrer 17,879 feet). A strongly truncated conical form[1] is exhibited by the Nevado de Cayambe-Urcu (19,365 feet), which is intersected by the equator, and by the volcano of Tolima (18,129 feet), visible above the primæval forest at the foot of the Paramo de Quindiu, near the little town of Ibague.[2] To the astonishment of geognosists an elongated ridge is formed by the volcano of Pichincha (15,891 feet), at the less elevated extremity of which the broad, still ignited crater[3] is situated.

Fallings of the walls of craters, induced by great natural phenomena, or their rupture by mine-like explosion from

[97] Humboldt, *Umrisse von Vulkanen der Cordilleren von Quito und Mexico, ein Beitrag zur Physiognomik der Natur,* Tafel iv (*Kleinere Schriften,* Bd. i, s. 133—205).

[98] *Umrisse von Vulkanen,* Tafel vi.

[99] *Op. cit. sup.* Tafel viii (*Kleinere Shriften,* Bd. i, s. 463—467). On the topographical position of Popocatepetl (*smoking mountain,* in the Aztec language), near the (recumbent) *White woman,* Iztaccihuatl, and its geographical relation to the western lake of Tezcuco and the pyramid of Cholula situated to the eastward, see my *Atlas Géographique et Physique de la Nouvelle Espagne,* pl. 3.

[100] *Umrisse von Vulkanen,* Tafel ix; the Star-mountain, in the Aztec language Citlaltepetl; *Kleinere Schriften,* Bd. i, s. 467—470, and my *Atlas Géogr. et Phys. de la Nouvelle Espagne,* pl. 17.

[1] *Umrisse von Vulkanen,* Tafel ii.

[2] Humboldt, *Vues des Cordillères et Monumens des peuples indigènes de l'Amérique* (fol.), pl. lxii.

[3] *Umrisse von Vulkanen,* Tafel i and x (*Kleinere Schriften,* Bd. i, s. 1—99).

the depths of the interior produce remarkable and contrasting forms in conical mountains: such as the cleavage into double pyramids of a more or less regular kind in the Carguairazo (15,667 feet), which suddenly fell in[4] on the night of the 19th July, 1698, and in the still more beautiful pyramids[5] of Ilinissa (17,438 feet); and a crenulation of the upper walls of the crater, in which two very similar peaks, opposite to each other, betray the previous primitive form (Capac-Urcu, Cerro del Altar, now only 17,456 feet in height). Amongst the aborigines of the highlands of Quito, between Chambo and Lican, between the mountains of Condorasto and Cuvillan, the tradition has been universally preserved that fourteen years before the invasion of Huayna Capac, the son of the Inca Tupac Yupanqui, and after eruptions which lasted uninterruptedly for seven or eight years, the summit of the last-mentioned volcano fell in, and covered the entire plateau, in which New Riobamba is situated, with pumice-stone and volcanic ashes. The volcano, originally higher than Chimborazo, was called in the Inca or Quichua language, *capac*, the king or prince of mountains (*urcu*), because the natives saw its summit rise to a greater height above the lower snow line, than that of any other mountain of the neighbourhood.[6] The great Ararat, the summit

[4] *Umrisse von Vulkanen*, Tafel iv.

[5] *Ibid.* Tafel iii, and vii.

[6] Long before the visit of Bouguer and La Condamine (1736) to the plateau of Quito, long before any measurements of the mountains by astronomers, the natives knew that Chimborazo was higher than any other Nevado in that region. They had detected two lines of level which remained almost exactly the same all the year round,—that of the lower limit of perpetual snow,—and that of the elevation to which a single, occasional snow-fall reached down. As in the equatorial region of Quito, the snow-line, as I have proved by measurements elsewhere (*Asie Centrale*, t. iii, p. 255), only varies about 190 feet in elevation on six of the most colossal peaks; and as this variation, as well as smaller ones caused by local conditions, is imperceptible to the naked eye when seen from a great distance (the height of the summit of Mont Blanc is the same as that of the lower equatorial snow-limit), this circumstance gives rise within the tropics to an apparently uninterrupted regularity of the snowy covering, that is to say, the form of the snow-line. The pictorial representation of this horizontality is astounding to the physicists who are only accustomed to the irregularity of the snowy covering in the variable, so-called temperate zones. The uniformity of elevation of the snow about Quito, and the knowledge of the

of which (17,084 feet) was reached by Friedrich Parrot in the year 1829, and by Abich and Chodzko in 1845 and 1850, forms, like Chimborazo, an un-opened dome. Its vast lava-streams have burst forth far below the snow-line. A more important character in the formation of Ararat is a lateral chasm, the deeply-cut Valley of Jacob, which may be compared with the *Val del Bove* of Etna. In this, according to Abich's observation, the inner structure of the nucleus of the trachytic dome-shaped mountain, first becomes really visible, as this nucleus and the upheaval of the whole of Ararat are much more ancient than the lava-streams.[7] The Kasbegk and Tschegem which have broken out upon the same principal Caucasian mountain ridge (E.S.E.—W.N.W.) as the Elburuz (19,716 feet) are also cones without craters at their summits, whilst the colossal Elburuz bears a crater-lake upon its summit.

As conical and dome-like forms are by far the most frequent in all regions of the earth, the isolated occurrence of the long ridge of the volcano of Pichincha, in the group of volcanoes of Quito, becomes all the more remarkable. I have occupied myself long and carefully with the study of its structure, and, besides its profile view, founded upon

maximum of its oscillation, presents perpendicular bases of 15,777 feet above the surface of the sea, and of 6396 feet above the plateau in which the cities of Quito, Hambato, and Nuevo Riobamba are situated; bases which, combined with very accurate measurements of angles of elevation, may be employed for determining distance in many topographical labours which are to be rapidly executed. The second of the level-lines here indicated, the horizontal which bounds the lower portion of a single occasional snow-fall, is decisive as to the relative height of the mountain domes which do not reach into the region of perpetual snow. Of a long chain of such mountains, which have been erroneously supposed to be of equal height, many are below the temporary snow-line, and thus the snow-fall decides as to the relative height. I have heard such considerations as these upon perpetual and accidental snow-limits from the mouths of rough country people and herdsmen in the mountains of Quito, where the Sierras Nevadas are often close together although they are not connected by the same line of perpetual snow. Grandeur of nature sharpens the perceptive faculties in particular individuals amongst the coloured aborigines, even when they are on the lowest steps of civilization.

[7] Abich, *Bulletin de la Société de Géographie*, 4me série, t. i (1851), p. 517, with a very beautiful representation of the form of the old volcano.

numerous angular measurements, have also published a topographical sketch of its transverse valleys.[8] Pichincha forms a wall of black trachytic rock (composed of augite and oligoclase) more than nine miles in length, elevated upon a fissure in the most western Cordilleras, near the South Sea, but without the axis of the high mountain ridge coinciding in direction with that of the Cordillera. Upon the ridge of the wall, the three domes, set up like castles, follow from S.W. to N.E.: Cuntur-guachana, Guagua-Pichincha (the child of the old volcano) and el Picacho de los Ladrillos. The true volcano is called the Father or the Old Man, Rucu-Pichincha. It is the only part of the long mountain ridge that reaches into the region of perpetual snow, and therefore rises to an elevation which exceeds the dome of Guagua-Pichincha, the child, by about 190 feet. Three tower-like rocks surround the oval crater, which lie somewhat to the south-west, and therefore beyond the axial direction of a wall which is on the average 15,406 feet in height. In the spring of 1802, I reached the eastern rocky tower accompanied only by the Indian, Felipe Aldas. We stood there upon the extreme margin of the crater, about 2451 feet above the bottom of the ignited chasm. Sebastian Wisse, to whom the physical sciences are indebted for so many interesting observations during his long residence in Quito, had the courage to pass several nights, in the year 1845, in a part of the crater where the thermometer fell towards sunrise to 28°. The crater is divided into two portions by a rocky ridge, covered with vitrified scoriæ. The eastern portion lies more than a thousand feet deeper than the western, and is now the real seat of volcanic activity. Here a cone of eruption rises to a height of 266 feet. It is surrounded by more than seventy ignited fumaroles, emitting sulphurous vapours.[9] From this circular eastern crater, the cooler parts of which are now covered with tufts of rushy grasses, and a *Pourretia* with Bromelia-like leaves, it is probable that the eruptions of fiery scoriæ, pumice, and ashes of Rucu-Pichincha took place in 1539, 1560, 1566, 1577, 1580, and 1660. The city

[8] Humboldt, *Vues de Cordillères,* p. 295, pl. lxi, and *Atlas de la Rélat. Hist. du Voyage*, pl. 27.

[9] *Kleinere Schriften*, Bd. i, s. 61, 81, 83, and 88.

of Quito was then frequently enveloped in darkness for days together by the falling, dust-like rapilli.

To the rarer class of volcanic forms which constitute elongated ridges belong, in the old world, the Galungung, with a large crater, in the western part of Java;[10] the doleritic mass of the Schiwelutsch, in Kamtschatka, a mountain-chain upon the ridge of which single domes rise to a height of 10,170 feet;[11] Hecla, seen from the north-west side, in the normal direction upon the principal and longitudinal fissure over which it has burst forth, as a broad mountain-chain, furnished with various small peaks. Since the last eruptions of 1845 and 1846, which yielded a lava-stream of 8 geographical miles in length and in some places more than 2 miles in breadth, similar to the stream from Etna in 1669, five caldron-like craters lie in a row upon the ridge of Hecla. As the principal fissure is directed N. 65° E., the volcano, when seen from Selsundsfjäll, that is from the south-west side, and therefore in transverse section, appears as a pointed conical mountain.[12]

If the forms of volcanoes are so remarkably different (Cotopaxi and Pichincha) without any variation in the matters thrown out, and in the chemical processes taking place in the depths of their interior, the relative position of the cones of elevation is sometimes still more singular. Upon the island of Luzon, in the group of the Philippines, the still active volcano of Taal, the most destructive eruption of which was that of the year 1754, rises in the midst of a large lake, inhabited by crocodiles (called the *laguna de Bombon*). The cone, which was ascended in Kotzebue's voyage of discovery, has a crater-lake, from which again a cone of eruption, with a second crater, rises.[13] This descrip-

[10] Junghuhn, *Reise durch Java*, 1845, s. 215, Tafel xx.

[11] See Adolf Erman's *Reise um die Erde*, which is also very important in a geognostic point of view, Bd. iii, s. 271 and 207.

[12] Sartorius von Waltershausen, *Physisch-geographische Skizze von Island*, 1847, s. 107, and his *Geognostischer Atlas von Island*, 1853, Tafel xv and xvi.

[13] Otto von Kotzebue, *Entdeckungs-Reise in die Südsee und in die Berings-Strasse*, 1815—1818, Bd. iii, s. 68; *Reise-Atlas von Choris*, 1820, Tafel 5; Vicomte d'Archiac, *Histoire des Progrès de la Géologie*, 1847, t. i, p. 544; and Buzeta, *Diccionario Geogr. estad. Historico de las islas Filipinas*, t. ii (Madrid, 1851), pp. 436 and 470—471, in which, however,

tion reminds one involuntarily of Hanno's journal of his voyage, in which an island is referred to, enclosing a small lake, from the centre of which a second island rises. The phenomenon is said to occur twice, once in the Gulf of the Western Horn, and again in the Bay of the Gorilla Apes, on the West African coast.[14] Such particular descriptions may be believed to rest upon actual observation of nature!

The smallest and greatest elevation of the points at which the volcanic energy of the interior of the earth shows itself permanently active at the surface, is a hypsometric consideration possessing that interest for the physical description of the earth which belongs to all facts relating to the reaction of the fluid interior of the planet upon its surface. The degree of the upheaving force[15] is certainly evidenced in the height of volcanic conical mountains, but an opinion as to the influence of comparative elevation upon the frequency and violence of eruptions must be given with great caution. Individual contrasts of the frequency and strength of similar actions in very high or very low volcanoes, cannot be decisive in this case, and our knowledge of the many hundred active volcanoes, supposed to exist upon continents and islands, is still so exceedingly imperfect that the only decisive method, that of average numbers, is as yet misapplied. But such average numbers, even if they should furnish the definite result at what elevation of the cones a quicker return of the eruptions is manifested, would still leave room for the doubt that the incalculable contingencies occurring

the double encircling of a crater in the crater-lake, mentioned alike accurately and circumstantially by Delamare, in his letter to Arago (November, 1842, *Comptes rendus de l'Acad. des Sciences,* t. xvi, p. 756) is not referred to. The great eruption in December, 1754 (a previous and more violent one took place on the 24th September, 1716), destroyed the old village of Taal, situated on the south-western bank of the lake, which was subsequently rebuilt at a greater distance from the volcano. The small island of the lake upon which the volcano rises is called *Isla del Volcan.* (Buzeta *loc. cit.*) The absolute elevation of the volcano of Taal is scarcely 895 feet. It is, therefore, like Cosima, one of the lowest. At the time of the American expedition of Captain Wilkes (1842) it was in full activity. See *United States Exploring Expedition,* vol. v. p. 317.

[14] Humboldt, *Examen Critique de l'Hist. de la Géogr.* t. iii, p. 135; *Hannonis Periplus,* in Hudson's *Geogr. Græci min.* t. i, p. 45.

[15] *Cosmos,* vol. i, p. 227.

in the network of fissures, which may be stopped up with more or less ease, may act together with the elevation; that is to say, the distance from the volcanic focus. The phenomenon is consequently an uncertain one, as regards its causal connexion.

Adhering cautiously to matters of fact, where the complication of the natural phenomena and the deficiency of historical records as to the number of eruptions in the lapse of ages have not yet allowed us to discover laws, I am contented with establishing five groups for the comparative hypsometry of volcanoes, in which the classes of elevation are characterised by a small but certain number of examples. In these five groups I have only referred to conical mountains rising isolated and furnished with still ignited craters, and consequently to true and still active volcanoes, not to unopened dome-shaped mountains, such as Chimborazo. All cones of eruption which are dependent upon a neighbouring volcano, or which, when at a distance from the latter, as upon the island of Lancerote, and in the Arso on the Epomeus of Ischia, have preserved no permanent connection between the interior of the earth and the atmosphere, are here excluded. According to the testimony of the most zealous observer of the vulcanicity of Etna, Sartorius von Waltershausen, this volcano is surrounded by nearly 700 larger and smaller cones of eruption. As the measured elevations of the summits relate to the level of the sea, the present fluid surface of the planet, it is of importance here to advert to the fact that insular volcanoes,—of which some (such as the Javanese volcano Cosima,[16] at the entrance of the Straits of Tsugar, described by Horner and Tilesius) do not project a thousand feet, and others, such as the Peak of Teneriffe,[17] are more than 12,250 feet above the surface of

[16] For the position of this volcano, which is only exceeded in smallness by the volcano of Tanna, and that of the Mendaña, see the fine map of Japan by F. von Siebold, 1840.

[17] I do not mention here, with the Peak of Teneriffe, amongst the insular volcanoes, that of Mauna-Roa, the conical form of which does not agree with its name. In the language of the Sandwich Islanders, *mauna* signifies *mountain*, and *roa*, both *long* and *much*. Nor do I mention Hawaii, upon the height of which there has so long been a dispute, and which has been described as a trachytic dome not opened at the summit. The celebrated crater Kiraueah (a lake of molten,

the sea,—have raised themselves by volcanic forces above a sea-bottom, which has often been found 20,000 feet, nay, in one case, more than 45,838 feet, below the present surface of the ocean. To avoid an error in the numerical proportions it must also be mentioned that, although distinctions of the first and fourth classes,—volcanoes of 1000 and 18,000 feet (1066 and 19,188 English feet)—appear very considerable for volcanoes on continents, the ratios of these numbers are quite changed if (from Mitscherlich's experiments upon the melting point of granite, and the not very probable hypothesis of the uniform increase of heat in proportion to the depth in arithmetical progression) we infer the upper limit of the fused interior of the earth to be about 121,500 feet below the present sea level. Considering the tension of elastic vapours, which is vastly increased by the stopping of volcanic fissures, the differences of elevation of the volcanoes hitherto measured are certainly not considerable enough to be regarded as a hindrance to the elevation of the lava and other dense masses to the height of the crater.

Hypsometry of Volcanoes.

First group, from 700 *to* 4000 *Paris or* 746 *to* 4264 *English feet in height.*

The volcano of the Japanese island *Cosima*, to the south of Jezo: 746 feet, according to Horner.

The volcano of the Liparian island *Volcano:* 1305 English feet, according to F. Hoffmann.[18]

Gunung Api (signifying *Fiery Mountain* in the Malay language), the volcano of the island of Banda: 1949 feet.

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boiling lava) lies to the eastward, near the foot of the Mauna-Roa, according to Wilkes, at an elevation of 3970 feet. See the excellent description in Charles Wilkes' *Exploring Expedition*, vol iv, pp. 165—196.

[18] Letter from F. Hoffmann to Leopold von Buch, upon the Geognostic Constitution of the Lipari Islands, in Poggend. *Annalen*, Bd. xxvi, 1832, s. 59. Volcano, 1268 feet, according to the recent measurement of C. Sainte-Claire Deville, had violent eruptions of scoriæ and ashes in the year 1444, at the end of the 16th century, in 1731, 1739, and 1771. Its fumaroles contain ammonia, borate of selenium, sulphuret of arsenic, phosphorus, and, according to Bornemann, traces of iodine. The last three substances occur here for the first time amongst volcanic products (*Comptes rendus de l'Acad. des Sciences*, t. xliii, 1856, p. 683).

The volcano of Izalco,[19] in the state of San Salvador (in Central America) which was first ascended in the year 1770, and which is in a state of almost constant eruption: 2132 feet, according to Squier.

Gunung Ringgit, the lowest volcano of Java: 2345 feet, according to Junghuhn.[20]

Stromboli: 2958 feet, according to F. Hoffmann.

Vesuvius, the *Rocca del Palo,* on the highest northern margin of the crater: the average of my two barometrical measurements[21] of 1805 and 1822 gives 3997 feet.

The volcano of *Jorullo,* which broke out in the elevated plateau of Mexico[22] on the 29th September, 1759: 4266 feet.

Second group, from 4000 *to* 8000 *Paris or* 4264 *to* 8528 *English feet in height.*

Mont Pelé, of Martinique: 4707 feet, according to Dupuget.

The *Soufrière,* of Guadaloupe: 4867 feet, according to C. Deville.

Gunung Lamongan, in the most eastern part of Java: 5341 feet, according to Junghuhn.

Gunung Tengger, which has the largest crater[23] of all the volcanoes of Java: height at the cone of eruption of Bromo, 7547 feet, according to Junghuhn.

The volcano of *Osorno* (Chili): 7550 feet, according to Fitzroy.

The volcano of *Pico*[24] (Azores): 7614 feet, according to Captain Vidal.

The volcano of the island of *Bourbon:* 8002 feet, according to Berth.

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[19] Squier, in the tenth annual meeting of the *American Association,* Newhaven, 1850.

[20] See Franz Junghuhn's exceedingly instructive work, *Java, seine Gestalt und Pflanzendecke,* 1852, Bd. i, s. 99. Ringgit has been nearly extinct, since its fearful eruption in the year 1586, which cost the lives of many thousand people.

[21] The summit of Vesuvius is, therefore, only 260 feet higher than the Brocken.

[22] Humboldt, *Vues des Cordillères,* pl. xliii, and *Atlas géogr. et physique,* pl. 29.

[23] Junghuhn, *Op. cit. sup.* Bd. i, s. 68 and 98.

[24] See my *Relation Historique,* t. i, p. 93, especially with regard to the distance at which the summit of the volcano of the island of Pico has sometimes been seen. Ferrer's old measurement gave 7918 feet, and therefore 304 feet more than the certainly more careful survey of Captain Vidal in 1843.

Third group, from 8000 *to* 12,000 *Paris or* 8528 *to* 12,792 *English feet in height.*

The volcano of *Awatscha* (Peninsula of Kamtschatka), not to be confounded[25] with the rather more northern *Strjeloschnaja Sopka,* which is usually called the volcano of Awatscha by the English navigators: 8912 feet, according to Erman.

The volcano of *Antuco*[26] or *Antoïo* (Chili): 8920 feet, according to Domeyko.

The volcano of the island of *Fogo*[27] (Cape Verd Islands): 9154 feet, according to Charles Deville.

The volcano of *Schiwelutsch* (Kamtschatka): the north-eastern summit 10,551 feet, according to Erman.[28]

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[25] Erman, in his interesting geognostic description of the volcanoes of the peninsula of Kamtschatka, gives the Awatschinskaja or Gorelaja Sopka as 8912 feet, and the Strjeloschnaja Sopka, which is also called Korjaskaja Sopka, as 11,822 feet (*Reise,* Bd. iii, s. 494 and 540). See with regard to these two volcanoes, of which the former is the most active, Leopold de Buch, *Descr. Physique des Iles Canaries,* pp. 447—450. Erman's measurement of the volcano of Awatscha agrees best with the earliest measurements of Mongez (8739) during the expedition of La Perouse (1787), and with the more recent one of Captain Beechy (9057 feet). Hofmann in Kotzebue's voyage, and Lenz in Lutke's voyage, found only 8170 and 8214 feet; see Lutke, *Voyage autour du Monde,* t. iii, pp. 67—84. The admiral's measurement of the Strjeloschnaja Sopka gave 11,222 feet.

[26] See Pentland's table of elevations in Mrs. Somerville's *Physical Geography,* vol. ii, p. 452; Sir Woodbine Parish, *Buenos-Ayres and the Province of the Rio de la Plata,* 1852, p. 343; Pöppig, *Reise in Chile und Peru,* Bd. i, s. 411—434.

[27] Is it probable that the height of the summit of this remarkable volcano is gradually diminishing? A barometrical measurement by Baldey, Vidal, and Mudge, in the year 1819, gave 2975 metres or 9760 feet; whilst a very accurate and practised observer, Sainte-Claire Deville, who has done such important service to the geognosy of volcanoes, only found 2790 metres or 9154 feet in the year 1842 (*Voyage aux Iles Antilles et à l'Ile de Fogo,* p. 155). Captain King had a little while before determined the height of the volcano of Fogo to be only 2686 metres or 8813 feet.

[28] Erman, *Reise,* Bd. iii, s. 271, 275, and 297. The volcano Schiwelutsch, like Pichincha, has a form which is rare amongst active volcanoes, namely, that of a long ridge (*chrebet*), upon which single domes and crests (*grebni*) rise. Dome-shaped and conical mountains are always indicated in the volcanic district of the peninsula by the name *sopki.*

Etna:[29] according to Smyth, 10,871 feet.

Peak of Teneriffe: 12,161 feet, according to Charles Deville.[30]

The volcano *Gunung Semeru*, the highest of all mountains on the island of Java: 12,237 feet, according to Junghuhn's barometrical measurement.

The volcano *Erebus*, lat. 77° 32′, the nearest to the south pole:[31] 12,366 feet, according to Sir James Ross.

The volcano *Argæus*,[32] in Cappadocia, now *Erdschisch-Dagh*, south-south-east of Kaisarieh: 12,603 feet, according to Peter von Tschichatscheff.

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[29] For an account of the remarkable agreement of the trigonometrical with the barometrical measurement of Sir John Herschel, see *Cosmos*, vol. i, p. 6.

[30] The barometrical measurement of Sainte-Claire Deville (*Voy. aux Antilles*, pp. 102—118), in the year 1842, gave 3706 metres or 12,161 feet, nearly agreeing with the result (12,184 feet) of Borda's second trigonometrical measurement in the year 1776, which I was enabled to publish for the first time from the manuscript in the Dépôt de la Marine (Humboldt, *Voy. aux Régions Equinox.* t. i, pp. 116 and 275—287). Borda's first trigonometrical measurement, undertaken in conjunction with Pingré in the year 1771, gave, instead of 12,184 feet, only 11,142 feet. The cause of the error was the false reading of an angle (33′ instead of 53′), as was told me by Borda himself, to whose great personal kindness I was indebted for much useful advice before my voyage on the Orinoco.

[31] I follow Pentland's estimate of 12,367 feet, especially because in Sir James Ross' *Voyage of Discovery in the Antarctic Regions*, vol. i, p. 216, the height of the volcano, the eruptions of smoke and flame from which were seen even in the day time, is given in round numbers at 12,400 feet.

[32] With regard to Argæus, which Hamilton was the first to ascend and measure barometrically (at 12,708 feet or 3905 metres), see Peter von Tschichatscheff, *Asie Mineure* (1853), t. i, pp. 441—449, and 571. In his excellent work (*Researches in Asia Minor*), William Hamilton obtained as the mean of one barometrical measurement and several angles of elevation 13,000 feet; but if the height of Kaisarieh is 1000 feet less than he supposes, it would be only 12,000 feet. See Hamilton, in *Trans. Geolog. Society*, vol. v, pt. 3, 1840, p. 596. Towards the south-east from Argæus (Erdschisch Dagh) in the great plain of Eregli, numerous very small cones of eruption rise to the south of the village of Karabunar and the mountain group Karadscha-Dagh. One of these, furnished with a crater, has a singular shape like that of a ship, running out in front like a beak. This crater is situated in a salt lake, on the road from Karabunar to Eregli, at a distance of fully four miles from the former place. The hill bears the same name (Tschichatscheff, t. i, p. 455; William Hamilton, *Researches in Asia Minor*, vol. ii, p. 217).

Fourth group, from 12,000 *to* 16,000 *Paris or* 12,792 *to* 17,056 *English feet in height.*

The volcano of *Tuqueres,*[33] in the highlands of the Provincia de los Pastos: 12,824 feet, according to Boussingault.

The volcano of *Pasto:*[34] 13,453 feet, according to Boussingault.

The volcano *Mauna-Roa:*[35] 13,761 feet, according to Wilkes.

The volcano of *Cumbal,*[36] in the Provincia de los Pastos: 15,621 feet, according to Boussingault.

The volcano *Kliutschewsk*[37] (Kamtschatka): 15,766 feet, according to Erman.

The volcano *Rucu-Pichincha:* 15,926 feet, according to Humboldt's barometrical measurements.

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33 The height here given is properly that of the grass-green mountain lake, *Laguna verde,* on the margin of which is situated the solfatara examined by Boussingault (Acosta, *Viajes Cientificos á los Andes Ecuatoriales,* 1849, p. 75).

34 Boussingault succeeded in reaching the crater, and determined the altitude barometrically; it agrees very nearly with that which I made known approximately 23 years before, on my journey from Popayan to Quito.

35 The altitude of few volcanoes has been so over-estimated as that of the Colossus of the Sandwich Islands. We see it gradually fall from 18,410 feet (the estimate given in Cook's third voyage), 16,486 feet in King's, and 16,611 feet in Marchand's measurement, to 13,761 feet by Captain Wilkes, and 13,524 feet by Horner in Kotzebue's voyage. The grounds of the last-mentioned result were first made known by Leopold von Buch in the *Description Physique des Iles Canaries,* p. 379. See Wilkes, *Exploring Expedition,* vol. iv, pp. 111—162. The eastern margin of the crater is only 13,442 feet. The assumption of a greater height, considering the asserted freedom from snow of the Mauna-Roa (lat. 19° 28′) would also be in contradiction to the result that according to my measurements in the Mexican continent in the same latitude, the limit of perpetual snow has been found at 14,775 feet (Humboldt, *Voyage aux Régions Equinox.* t. i, p. 97; *Asie Centrale,* t. iii, p. 269 and 359).

36 The volcano rises to the west of the village of Cumbal, which is itself situated 10,565 feet above the sea-level (Acosta, p. 76).

37 I give the result of Erman's repeated measurements in September, 1829. The height of the margin of the crater is exposed to alterations by frequent eruptions, for in August, 1828, measurements which might inspire equal confidence gave an altitude of 16,033 feet. Compare Erman's *Physikalische Beobachtungen auf einer Reise um die Erde,* Bd. i, s. 400 and 419, with the historical account of the journey, Bd. iii, s. 358—360.

The volcano *Tungurahua:* 16,494 feet, according to a trigonometrical measurement[38] by Humboldt.

The volcano of *Puracé*,[39] near Popayan: 17,010 feet, according to José Caldas.

Fifth group, from 16,000 *to more than* 20,000 *Paris or from* 17,056 *to* 21,320 *English feet in height.*

The volcano *Sangay*, to the south-west of Quito: 17,128 feet, according to Bouguer and La Condamine.[40]

The volcano *Popocatepetl:*[41] 17,729 feet, according to a trigonometrical measurement by Humboldt.

The volcano of *Orizaba:*[42] 17,783 feet, according to Ferrer.

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[38] Bouguer and La Condamine, in the inscription at Quito, give 16,777 feet for Tungurahua before the great eruption of 1772, and the earthquake of Riobamba (1797), which gave rise to great depressions of mountains. In the year 1802 I found the summit of the volcano trigonometrically to be only 16,494 feet.

[39] The barometrical measurement of the highest peak of the Volcan de Puracé by Francisco José Caldas, who, like my dear friend and travelling companion, Carlos Montufar, fell a sacrifice to his love for the independence and freedom of his country, is given by Acosta (*Viajes Cientificos*, p. 70) at 5184 metres (17,010 feet). I found the height of the small crater, which emits sulphureous vapours with a violent noise (Azufral del Boqueron) to be 14,427 feet; Humboldt, *Recueil d' Observ. Astronomiques et d' Operations Trigonométriques*, vol. i, p. 304.

[40] The Sangay is extremely remarkable from its uninterrupted activity and its position, being removed somewhat to the eastward from the eastern Cordillera of Quito, to the south of the Rio Pastaza, and at a distance of 120 miles from the nearest coast of the Pacific,—a position which (like that of the volcanoes of the Celestial mountains in Asia) by no means supports the theory according to which the eastern Cordilleras of Chili are free from volcanic eruptions on account of their distance from the sea. The talented Darwin has not omitted referring in detail to this old and widely diffused volcanic littoral theory in the *Geological Observations on South America*, 1846, p. 185.

[41] I measured Popocatepetl, which is also called the *Volcan Grande de Mexico*, in the plain of Tetimba, near the Indian village San Nicolas de los Ranchos. It seems to me to be still uncertain which of the two volcanoes, Popocatepetl or the peak of Orizaba, is the highest (see Humboldt, *Receuil d' Observ. Astron.*, vol. ii, p. 543).

[42] The peak of Orizaba, clothed with perpetual snow, the geographical position of which was quite erroneously indicated on all maps before my journey, notwithstanding the importance of this point for

Elias Mount[43] (on the west coast of North America): 17,855 feet, according to the measurements of Quadra and Galeano.

The volcano of *Tolima*:[44] 18,143 feet, according to a trigonometrical measurement by Humboldt.

The volcano of *Arequipa*:[45] 18,883 feet, according to a trigonometrical measurement by Dolley.

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navigation near the landing-place in Vera Cruz, was first measured trigonometrically from the Encero by Ferrer, in 1796. The measurement gave 17,879 feet. I attempted a similar operation in a small plain near Xalapa. I found only 17,375 feet, but the angles of elevation were very small, and the base-line difficult to level. See Humboldt, *Essai Politique sur la Nouv. Espagne,* 2me éd. t. i, 1825, p. 166; *Atlas du Mexique* (Carte des fausses positions), pl. x, and *Kleinere Schriften,* Bd. i, s. 468.

[43] Humboldt, *Essai sur la Géographie des Plantes,* 1807, p. 153. The elevation is uncertain, perhaps more than $\frac{1}{15}$th too high.

[44] I measured the truncated cone of the volcano of Tolima, situated at the northern extremity of the Paramo de Quindiu, in the Valle del Carvajal, near the little town of Ibague, in the year 1802. The mountain is also seen at a great distance upon the plateau of Bogotá. At this distance Caldas obtained a tolerably approximate result (18,430 feet) by a somewhat complicated combination in the year 1806; *Semanario de la Nueva Granada, nueva edicion, aumentada por J. Acosta,* 1849, p. 349.

[45] The absolute altitude of the volcano of Arequipa has been so variously stated that it becomes difficult to distinguish between mere estimates and actual measurements. Dr. Thaddäus Hänke, of Prague, the distinguished botanist of Malaspina's voyage round the world, ascended the volcano of Arequipa in the year 1796, and found at the summit a cross which had been erected there 12 years before. By a trigonometrical operation Hänke found the volcano to be 3180 toises (20,235 feet) above the sea. This altitude, which is far too great, was probably the result of an erroneous assumption of the elevation of the town of Arequipa, in the vicinity of which the operation was performed. Had Hänke been provided with a barometer, a botanist entirely unpractised in trigonometrical measurements, would certainly not have resorted to such means after ascending to the summit. The first who ascended the volcano after Hänke was Samuel Curzon, from the United States of North America (*Boston Philosophical Journal,* 1823, *November,* p. 168). In the year 1830 Pentland estimated the altitude at 5600 metres (18,374 feet), and I have adopted this number (*Annuaire du Bureau des Longitudes,* 1830, p. 325) for my *Carte Hypsométrique de la Cordillère des Andes,* 1831. There is a satisfactory agreement (within $\frac{1}{47}$th) between this and the trigonometrical measurement of a French naval officer, M. Dolley, for which I was indebted in 1826 to the kind communication of Captain Alphonse de Moges in Paris. Dolley found

The volcano *Cotopaxi*:[46] 18,881 feet, according to Bouguer.

The volcano *Sahama*[47] (Bolivia): 22,354 feet, according to Pentland.

The volcano with which the fifth group ends is more than

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the summit of the volcano of Arequipa (trigonometrically) to be 11,031 feet, and the summit of Charcani 11,860 feet above the plateau in which the town of Arequipa is situated. If now we fix the town of Arequipa at 7841 feet, in accordance with the barometrical measurements of Pentland and Rivero (Pentland, 7852 feet in the Table of Altitudes to the *Physical Geography* of Mrs. Somerville, 3rd ed. vol. ii, p. 454; Rivero, in the *Memorial de Ciencias Naturales*, t. ii, Lima, 1828, p. 65; Meyen, *Reise um die Erde*, Theil. ii, 1835, s. 5), Dolley's trigonometrical operation will give for the volcano of Arequipa 18,881 feet (2952 toises), and for the volcano Charcani, 19,702 feet (3082 toises). But Pentland's Table of Altitudes, above cited, gives for the volcano of Arequipa 20,320 English feet, 6190 metres (19,065 Paris feet), that is to say, 1945 feet more than the determination of 1830, and somewhat too identical with Hänke's trigonometrical measurement in the year 1796! In opposition to this result the volcano is stated, in the *Anales de la Universidad de Chile*, 1852, p. 221, only at 5600 metres or 18,378 feet: consequently 590 metres lower! A sad condition of hypsometry!

46 Boussingault, accompanied by the talented Colonel Hall, has nearly reached the summit of Cotopaxi. He attained, according to barometrical measurement, to an altitude of 5746 metres or 18,855 feet. There was only a small space between him and the margin of the crater, but the great looseness of the snow prevented his ascending further. Perhaps Bouguer's statement of altitude is rather too small, as his complicated trigonometrical calculation depends upon the hypothesis as to the elevation of the city of Quito.

47 The Sahama, which Pentland (*Annuaire du Bureau des Longitudes*, 1830, p. 321) distinctly calls an active volcano, is situated, according to his new map of the Vale of Titicaca (1848), to the eastward of Arica in the western Cordillera. It is 928 feet higher than Chimborazo, and the relative height of the lowest Japanese volcano Cosima to the Sahama is as 1 to 30. I have hesitated in placing the Chilian Aconcagua, which, stated by Fitzroy in 1835 at 23,204 feet, is, according to Pentland's correction, 23,911 feet, and according to the most recent measurement (1845) of Captain Kellet of the frigate Herald, 23,004 feet, in the fifth group, because from the contradictory opinions of Miers (*Voyage to Chili*, vol. i, p. 283) and Charles Darwin (*Journal of Researches into the Geology and Natural History of the Various Countries visited by the Beagle*, 2nd ed. p. 291), it remains doubtful whether this colossal mountain is a still ignited volcano. Mrs. Somerville, Pentland, and Gilliss (*Naval Astr. Exped.* vol. i, p. 126), also deny its activity. Darwin says:—"I was surprised at hearing that the Aconcagua was in action the same night (15th January, 1835), because this mountain most rarely shows any sign of action."

twice as high as Etna, and five times and a half as high as Vesuvius. The scale of volcanoes that I have suggested, starting from the lowly Maars (mine-craters without a raised framework, which have cast forth olivine bombs surrounded by half-fused fragments of slate) and ascending to the still burning Sahama 22,354 feet in height, has shown us that there is no necessary connexion between the maximum of elevation, the smaller amount of the volcanic activity and the nature of the visible species of rock. Observations confined to single countries may readily lead us to erroneous conclusions. For example, in the part of Mexico which lies in the torrid zone, all the snow-covered mountains, that is to say the culminating points of the whole country, are certainly volcanoes; and this is also usually the case in the Cordilleras of Quito, if the dome-shaped trachytic mountains, not opened at the summit (Chimborazo and Corazon), are to be associated with volcanoes; on the other hand, in the eastern chain of the Bolivian Andes, the highest mountains are entirely non-volcanic. The Nevados of Sorata (21,292 feet), and Illimani (21,153 feet) consist of grauwacke schists, which are penetrated by porphyritic masses,[48] in which (as a proof of this penetration), fragments of schist are enclosed. In the eastern Cordillera of Quito, south of the parallel of 1° 35′ the high summits (Condorasto, Cuvillan, and the Collanes) lying opposite to the trachytes, and also entering the region of perpetual snow, are also mica-slate and firestone. According to our present knowledge of the mineralogical nature of the most elevated parts

[48] These penetrating porphyritic masses show themselves in peculiar vastness, near the Illimani, in Cenipampa (15,949 feet) and Totorapampa (13,709 feet); and a quartzose porphyry containing mica, and enclosing garnets and at the same time angular fragments of silicious schist forms the superior dome of the celebrated argentiferous Cerro de Potosi (Pentland in MSS. of 1832). The Illimani, which Pentland estimated first at 7315 (23,973 feet), and afterwards at 6445 (21,139 feet) metres, has also been, since 1847, the object of a careful measurement by the engineer Pissis, who, on the occasion of his great trigonometrical survey of the Llanura de Bolivia, found the Illimani to be on the average 6509 metres (21,349 feet) in height, by three triangles between Calamarca and La Paz: this only differs about 64 metres (210 feet) from Pentland's last determination. See *Investigaciones Sobre la Altitud de los Andes,* in the *Anales de Chile,* 1852, p. 217 and 221.

of the Himalaya, which we owe to the meritorious labours of B. H. Hodgson, Jacquemont, Joseph Dalton Hooker, Thomson, and Henry Strachey, the *primary* rocks, as they were formerly called, granite, gneiss and mica-slate, appear to be visible here also, although there are no trachytic formations. In Bolivia, Pentland has found fossil shells in the Silurian schists on the Nevado de Antacaua, 17,482 feet above the sea, between La Paz and Potosi. The enormous height to which from the testimony of the fossils collected by Abich from Daghestan, and by myself from the Peruvian Cordilleras (between Guambos and Montan), the chalk formation is elevated, reminds us very vividly that non-volcanic sedimentary strata, full of organic remains, and not to be confounded with volcanic tufaceous strata, show themselves in places where for a long distance around, melaphyres, trachytes, dolerites, and other pyroxenic rocks, which we regard as the seat of the upheaving, urging forces, remain concealed in the depths. In what immeasurable tracts of the Cordilleras and the districts bordering them upon the east, is no trace of any granitic formation visible!

The frequency of the eruptions of a volcano, appearing to depend, as I have already repeatedly observed, upon multifarious and very complicated causes, no general law can safely be established with regard to the relation of the absolute elevation to the frequency and degree of the renewal of combustion. If in a small group the comparison of Stromboli, Vesuvius, and Etna, may mislead us into the belief that the number of eruptions is in an inverse ratio to the elevation of the volcanoes, other facts stand in direct contradiction to this proposition. Sartorius von Waltershausen, who has done such good service to our knowledge of Etna, remarks that on the average furnished by the last few centuries, an eruption of this volcano is to be expected every six years, whilst in Iceland, where no part of the island is really secure from destruction by submarine fire, the eruptions of Hecla, which is 5756 feet lower, are only observed every 70 or 80 years.[49] The group of volcanoes of Quito presents a still more remarkable contrast. The volcano of Sangay, 17,000 feet in height, is far more active than the little conical mountain Stromboli (2958 feet); it is of all known volca-

[49] Sartorius von Waltershausen, *Skizze von Island*, s. 103 and 107.

noes the one which exhibits, every quarter of an hour, the greatest quantity of fiery, widely-luminous eruptions of scoriæ. Instead of losing ourselves in hypotheses upon the causal relations of inaccessible phenomena, we will rather dwell here upon the consideration of six points of the surface of the earth, which are peculiarly important and instructive in the history of volcanic activity,—*Stromboli*, the Lycian *Chimæra*, the old volcano of *Masaya*, the very recent one of *Izalco*, the volcano *Fogo* on the Cape Verd Islands, and the colossal *Sangay*.

The *Chimæra* in Lycia, and *Stromboli*, the ancient Strongyle, are the two igneous manifestations of volcanic activity, the historic proof of whose permanence extends the furthest back. The conical hill of Stromboli, a doleritic rock, is twice the height of the island of Volcano (Hiera, Thermessa), the last great eruption of which occurred in the year 1775. The uninterrupted activity of Stromboli is compared by Strabo and Pliny with that of the island of Lipari, the ancient Meligunis; but they ascribe to "its flame," that is, its erupted scoriæ, "a greater purity and luminosity, with less heat."[50] The number and form of the small fiery chasms are very variable. Spallanzani's description of the bottom of the crater, which was long regarded as exaggerated has been completely confirmed by an experienced geognosist, Friedrich Hoffmann, and also very recently, by an acute naturalist, A. de Quatrefages. One of the incandescent chasms has an opening of only 20 feet in diameter; it resembles the pit of a blast furnace, and the ascent and overflow of the fluid lava, are seen in it every hour, from a position on the margin of the crater. The ancient, permanent eruptions of Stromboli still sometimes serve for the guidance of the mariner, and, as amongst the Greeks and Romans, afford uncertain predictions of the weather, by the observation of the direction of the flame and of the ascend-

[50] Strabo, lib. vi, p. 276, ed. Casaubon; Pliny, *Hist. Nat.* iii, 9:—"Strongyle, quæ a Lipara liquidiore flamma tantum differt; e cujus fumo quinam flaturi sint venti, in triduo prædicere incolæ traduntur." See also Urlichs, *Vindiciæ Plinianæ*, 1853, Fasc. i, p. 39. The volcano of Lipara (in the north-eastern part of the island), once so active, appears to me to have been either the Monte Campo Bianco, or the Monte di Capo Castagno. (See Hoffmann, in Poggend. *Annalen*, Bd. xxvi, s. 49—54.)

ing column of vapour. Polybius, who displays a singularly exact knowledge of the state of the crater, connects the multifarious signs of an approaching change of wind, with the myth of the earliest sojourn of Æolus upon Strongyle, and still more with observations upon the then violent fire upon Volcano (the "holy island of Hephæstos"). The frequency of the igneous phenomena has of late exhibited some irregularity. The activity of Stromboli, like that of Etna, according to Sartorius von Waltershausen, is greatest in November and the winter months. It is sometimes interrupted by isolated intervals of rest; but these, as we learn from the experience of centuries, are of very short duration.

The *Chimæra* in Lycia, which has been so admirably described by Admiral Beaufort, and to which I have twice referred,[51] is no volcano, but a perpetual burning spring—a

[51] *Cosmos,* vol. i, p. 220, and vol. v, p. 212. Albert Berg, who had previously published an artistic work, *Physiognomie der Tropischen Vegetation von Südamerika,* visited the Lycian Chimæra, near Deliktasch and Yanartasch, from Rhodes and the Gulf of Myra in 1853. (The Turkish word *tâsch* signifies *stone,* as *dâgh* and *tâgh,* signify *mountain; deliktasch* signifies *perforated stone,* from the Turkish, *delik,* a *hole.*) The traveller first saw the serpentine rocks near Adrasan, whilst Beaufort met with the dark-coloured serpentine deposited upon limestone, and perhaps deposited in it, even near the island Garabusa (not Grambusa), to the south of Cape Chelidonia. "Near the ruins of the ancient temple of Vulcan rise the remains of a Christian church in the later Byzantine style: the remains of the nave and of two side chapels. In a fore-court, situated to the east, the flame breaks out of a fire-place-like opening about 2 feet broad and 1 foot high in the serpentine rock. It rises to a height of 3 or 4 feet and (as a naphtha-spring?) diffuses a pleasant odour, which is perceptible to a distance of 40 paces. Near this large flame, and without the chimney-like opening, numerous very small, constantly ignited, lambent flames make their appearance from subordinate fissures. The rock which is in contact with the flame is much blackened, and the soot deposited is collected to alleviate smarting of the eye-lids and especially for colouring the eye-brows. At a distance of three paces from the flame of the Chimæra the heat which it diffuses is scarcely endurable. A piece of dry wood ignites when it is held in the opening and brought near the flame without touching it. Where the old ruined walls lean against the rock, gas also pours forth from the interstices of the stones of the masonry, and this, probably from its being of a lower temperature or differently composed does not ignite spontaneously, but whenever it is brought in contact with a light. Eight feet below the great flame in the interior of the ruins there is a round opening, 6 feet in depth, but only 3 feet wide,

gas spring always ignited by the volcanic activity of the interior of the earth. It was visited a few months ago by a talented artist, Albert Berg, for the purpose of making a picturesque survey of this locality, celebrated even in periods of high antiquity (since the times of Ctesias and Scylax of Caryanda), and of collecting the rocks from which the Chimæra breaks forth. The descriptions of Beaufort, Professor Edward Forbes, and Lieutenant Spratt in the "Travels in Lycia" are completely confirmed. An eruptive mass of serpentine rock penetrates the dense limestone in a ravine, which ascends from south-east to north-west. At the north-western extremity of this ravine, the serpentine rock is cut off, or perhaps only concealed, by a curved ridge of limestone rocks. The fragments brought home are partly green and fresh, partly brown and in a weathered state. In both serpentines diallage is clearly recognisable.

The volcano of *Masaya*,[52] the fame of which was already widely spread in the beginning of the 16th century, under the name of *el Infierno de Masaya*, and gave occasion for reports to the Emperor Charles V., is situated between the two lakes of Nicaragua and Managua, to the south-west of the charming Indian village of Nindiri. For centuries together it presented the same rare phenomenon that we have

which was probably arched over formerly, as a spring of water breaks out in it in the wet seasons, near a fissure over which a small flame plays." (From the traveller's manuscripts.) On a plan of the locality, Berg shows the geographical relations of the alluvial strata, of the (tertiary?) limestone, and of the serpentine rocks.

52 The oldest and most important notice of the volcano of Masaya is contained in a manuscript of Oviedo's, first edited fourteen years ago by the meritorious historical compiler, Ternaux-Compans,—*Historia de Nicaragua* (cap. v to x), see pp. 115—197. The French translation forms one volume of the *Voyages, Relations et Mémoires Originaux pour servir à l'Histoire et à la Découverte de l'Amérique.* See also Lopez de Gomara, *Historia General de las Indias* (Zaragoza, 1553), fol. cx, b; and amongst the most recent works, Squier. *Nicaragua, its People, Scenery, and Monuments,* 1853, vol. i, p. 211—223, and vol. ii, p. 17. So widely famed was the incessantly active volcano of Masaya, that a special monograph of this mountain exists in the royal library at Madrid, under the title of *Entrada y Descubrimiento del Volcan de Masaya, que está en la Prov. de Nicaragua, fecha por Juan Sanchez del Portero.* The author was one of those who let themselves down into the crater in the wonderful expeditions of the Dominican monk, Fray Blas de Inesta (Oviedo, *Hist. de Nicaragua,* p. 141).

described in the volcano of Stromboli. From the margin of the crater, the waves of fluid lava, set in motion by vapours, were seen rising and falling in the incandescent chasm. The Spanish historian, Gonzalez Fernando de Oviedo, first ascended the Masaya in July 1529, and made comparisons with Vesuvius, which he had previously visited (1501), in the suite of the Queen of Naples as her *xefe de guardaropa.* The name *Masaya,* belongs to the Chorotega language of Nicaragua, and signifies *burning* mountain. The volcano, surrounded by a wide lava-field (*mal-pays*), which it has probably itself produced, was at that time reckoned amongst the mountain group of the "nine burning Maribios." In its ordinary condition, says Oviedo, the surface of the lava, upon which black scoriæ float, stands several hundred feet below the margin of the crater; but sometimes the ebullition is suddenly so great, that the lava nearly reaches the upper margin. The perpetual luminous phenomenon, as Oviedo definitely and acutely states, is not caused by an actual flame,[53] but by vapours illuminated from below. It is said to have been of such intensity that on the road from the volcano towards Granada, at a distance of more than three leagues, the illumination of the district was almost equal to that of the full moon.

Eight years after Oviedo, the volcano was ascended by the Dominican monk, Fray Blas del Castillo, who enter-

[53] In the French translation of Ternaux-Compans (the Spanish original has never been published), we find at pp. 123 and 132 :—"It cannot, however, be said precisely that a flame issues from the crater, but a smoke as hot as fire; it is not seen from far during the day, but is well seen at night. The volcano gives as much light as the moon a few days before it is at the full." This old observation upon the problematical mode of illumination of a crater, and the strata of air lying above it, is not without importance, on account of the doubt, so often raised in recent times, as to the disengagement of hydrogen gas from the craters of volcanoes. Although in the ordinary condition here indicated *the Hell of Masaya* did not throw out scoriæ or ashes (Gomara adds, *cosa que hazen otros volcanes*), it has nevertheless sometimes had true eruptions of lava; the last of which probably occurred in the year 1670. Since that date the volcano has been quite extinct, after a perpetual luminosity had been observed for 140 years. Stephens, who ascended it in 1840, found no perceptible trace of ignition. Upon the Chorotega language, the signification of the word Masaya, and the Maribios, see Buschmann's ingenious ethnographical researches, *Ueber die Aztekischen Ortsnamen,* s. 130, 140, and 171.

tained the absurd opinion that the fluid lava in the crater was liquid gold, and associated himself with an equally avaricious Flemish Franciscan, Fray Juan de Gandavo. The pair availing themselves of the credulity of the Spanish settlers, established a joint-stock company to obtain the metal at the common cost. They themselves, Oviedo adds satirically, declared that as ecclesiastics they were free from any pecuniary contributions. The report upon the execution of this bold undertaking, which was sent to the Bishop of Castilla del Oro, Thomas de Verlenga, by Fray Blas del Castillo (the same person who is denominated Fray Blas de Inesta in the writings of Gomara, Benzoni, and Herrera), was only made known (in 1840) by the discovery of Oviedo's work upon Nicaragua. Fray Blas, who had previously served on board ship as a sailor, proposed to imitate the method of hanging upon ropes over the sea, by which the natives of the Canary Islands collect the colouring matter of the Orchil (*Lichen Roccella*), on precipitous rocks. For months together all sorts of preparations were made, in order to let down a beam of more than 30 feet in length, by means of a windlass and crane, so that it might project over the deep abyss. The Dominican, his head covered with an iron helmet and a crucifix in his hand, was let down with three other members of the association; they remained for a whole night in this part of the solid crater bottom, from which they made vain attempts to dip out the supposed liquid gold with earthen vessels, placed in an iron pot. Not to frighten the shareholders they agreed[54] that,

[54] "The three companions agreed to say that they had found great riches; and Fray Blas, whom I had known as an ambitious man, gives, in his relation, the oath which he and his associates took upon the Gospel, to persist for ever in their opinion that the volcano contained gold and silver in a state of fusion!" Oviedo, *Descr. de Nicaragua*, cap. x, pp. 186 and 196). The Cronista de las Indias is, however, very indignant (cap. 5) that Fray Blas narrated that "Oviedo had begged the Hell of Masaya from the Emperor as his armorial bearings." Such a geognostic memento would certainly not have been in opposition to the heraldic customs of the period, for the courageous Diego de Ordaz, who boasted of having reached the crater of the Popocatepetl when Cortez first penetrated into the valley of Mexico, bore this volcano as an heraldic distinction, as did Oviedo the constellation of the Southern Cross, and earliest of all Columbus (*Exam. crit.* t. iv, pp. 235—240), a fragment of a map of the Antilles.

when they were drawn up again they should say that they had found great riches, and that the *Infierno* of Masaya, deserved in future to be called *el Paraiso del Masaya.* The operation was afterwards repeated several times, until the Governor of the neighbouring city of Granada, conceived some suspicion of the deceit, or perhaps of a fraud upon the revenue, and forbad any "further descents on ropes into the crater." This took place in the summer of 1538; but in 1551 Juan Alvarez, the Dean of the Chapter of Leon, again received from Madrid the naïve permission "to open the volcano, and procure the gold that it contained." Such was the popular credulity of the sixteenth century! But even in Naples in the year 1822, Monticelli and Covelli were obliged to prove by chemical analysis, that the ashes thrown out from Vesuvius onthe 28th October contained no gold![55]

The volcano of Izalco, situated on the west coast of Central America, 32 miles northwards from San Salvador, and eastward from the harbour of Sonsonate, broke out 11 years after the volcano of Jorullo, deep in the interior of Mexico. Both eruptions took place in a cultivated plain, and after the prevalence of earthquakes and subterranean noises (*bramidos*) for several months. A conical hill rose in the *Llano de Izalco,* and with it simultaneously an eruption of lava poured from its summit on the 23rd February, 1770. It still remains undecided, how much is to be attributed, in the rapidly increasing height, to the upheaval of the soil, and how much to the accumulation of erupted scoriæ, ashes and tufa-masses; only this much is certain, that since the first eruption, the new volcano, instead of soon becoming extinguished like Jorullo, has remained uninterruptedly active, and often serves as a beacon light for mariners near the landing place in the Bay of Acajutla. Four fiery eruptions are counted in an hour, and the great regularity of the phenomenon has astonished its few accurate observers.[56] The violence of the eruptions was variable, but not the time of their occurrence. The elevation which the volcano of Izalco has now attained since the last eruption of 1825, is calculated at about 1600 feet, nearly the same as the elevation of Jorullo above the

[55] Humboldt, *Views of Nature,* p. 368.

[56] Squier, *Nicaragua, its People and Monuments,* vol. ii, p. 104. (John Bailey, *Central America,* 1850, p. 75).

original cultivated plain; but almost four times that of the crater of elevation (Monte Nuovo) in the Phlegræan Fields, to which Scacchi[57] ascribes a height of 432 feet from accurate measurement. The permanent activity of the volcano of Izalco, which was long considered as a safety-valve for the neighbourhood of San Salvador, did not however preserve the town from complete destruction on Easter eve in this year (1854).

One of the Cape Verd Islands, which rises between S. Jago and Brava, early received from the Portuguese the name of *Ilha do Fogo*, because, like Stromboli, it produced fire uninterruptedly from 1680 to 1713. After a long repose, the volcano of this island resumed its activity in the summer of the year 1798, soon after the last lateral eruption of the Peak of Teneriffe in the crater of Chahorra, which is erroneously denominated the volcano of Chahorra as if it were a distinct mountain.

The most active of the South American volcanoes, and indeed of all those which I have here specially indicated, is the *Sangay*, which is also called the *Volcan de Macas*, because the remains of this ancient city, so populous in the early period of the Conquista, are situated upon the Rio Upano, only 28 geog. miles to the south of it. The colossal mountain, 17,128 feet in height, has risen on the eastern declivity of the eastern Cordillera, between two systems of tributaries of the Amazons, those of the Pastaza and the Upano. The grand and unequalled fiery phenomenon which it now exhibits, appears only to have commenced in the year 1728. During the astronomical measurements of degrees by Bouguer and La Condamine (1738 to 1740), the Sangay served as a perpetual fire signal.[58] In the year 1802, I myself heard its thunder for months together, especially in the early morning, in Chillo, the pleasant country seat of the Marquis de Selvalegre near Quito, as half a century previously, Don Jorge Juan had perceived the *ronquidos del*

[57] *Memorie geologiche sulla Campania*, 1849, p. 61. I found the height of the volcano of Jorullo to be 1682 feet above the plain in which it rose, and 4266 feet above the sea-level.

[58] La Condamine, *Journal du Voyage à l'Equateur*, p. 163; and in the *Mesure de Trois Degrés de la Méridienne de l'Hémisphère Austral*, p. 56.

Sangay, somewhat further towards the north-east, near Pintac, at the foot of the Antisana.[59] In the years 1842 and 1843, when the eruptions were associated with most noise, the latter was heard most distinctly not only in the harbour of Guayaquil, but also further to the south along the coast of the Pacific Ocean, as far as Payta and San

[59] In the country house of the Marquis of Selvalegre, the father of my unfortunate companion and friend, Don Carlos Montufar, one was often inclined to ascribe the *bramidos*, which resembled the discharge of a distant battery of heavy artillery, and which with the same wind, the same clearness of the atmosphere and the same temperature, were so extremely unequal in their intensity, not to the Sangay, but to the Guacamayo, a mountain forty miles nearer, at the foot of which a road leads from Quito, over the Hacienda de Antisana to the plains of Archidona and the Rio Napo. (See my special map of the province Quixos, No. 23 of my *Atlas géogr. et phys. de l'Amérique*, 1814—1834). Don Jorge Juan, who heard the Sangay thundering when closer to it than I have been, says decidedly that the *bramidos*, which he calls *ronquidos del Volcan* (*Relacion del Viage á la America Meridional*, pt. i, t. 2, p. 569), and perceived in Pintac, a few miles from the Hacienda de Chillo, belong to the Sangay or Volcan de Macas, whose *voice*, if I may make use of the expression, is very characteristic. This voice appeared to the Spanish astronomer to be peculiarly harsh, for which reason he calls it a snore (*un ronquido*) rather than a roar (*bramido*). The very disagreeable noise of the volcano Pichincha, which I have frequently heard at night in the city of Quito, without its being followed by any earthquake, has something of a clear rattling sound as though chains were rattled, and masses of glass were falling upon each other. On the Sangay, Wisse describes the noise to be, sometimes like rolling thunder, sometimes distinct and sharp, as if one were in the vicinity of platoon firing. Payta and San Buenaventura (in the Choco) where the bramidos of the Sangay, that is to say, its roaring, were heard, are distant from the summit of the volcano in a south-western direction, 252 and 348 geog. miles. (See *Carte de la Prov. Du Choco*, and *Carte hypsométrique des Cordillères*, Nos. 23 and 3 of my *Atlas Géogr. et Physique*). Thus, in this mighty spectacle of nature, reckoning in the Tungurahua and the Cotopaxi, which is nearer to Quito, and the roar of which I heard in February, 1803, in the Pacific Ocean (*Kleinere Schriften*, Bd. i, s. 384), the voices of four volcanoes are perceived at adjacent points. The ancients also mention "the difference of the noise," emitted at different times on the Æolian Islands by the same fiery chasm (*Strabo*, lib. vi. p. 276). During the great eruption (23rd January, 1835) of the volcano of Conseguina, which is situated on the coast of the Pacific, at the entrance of the Bay of Fonseca, in Central America, the subterranean propagation of the sound was so great, that it was most distinctly perceived on the plateau of Bogotá, at a distance equal to that from Etna to Hamburgh (Acosta, *Viajes Cientificos de M. Boussingault á los Andes*, 1849, s. 56).

Buenaventura, at a distance equal to that of Berlin from Basle, the Pyrenees from Fontainebleau, or London from Aberdeen. Although, since the commencement of the present century, the volcanoes of Mexico, New Granada, Quito, Bolivia, and Chili have been visited by some geognosists, the Sangay, which exceeds the Tungurahua in elevation, has unfortunately remained entirely neglected, in consequence of its solitary position, at a distance from all roads of communication. It was only in December 1849 that an adventurous and highly informed traveller, Sebastian Wisse, after a sojourn of five years on the chain of the Andes, ascended it, and nearly reached the extreme summit of the snow-covered, precipitous cone. He not only made an accurate chronometric determination of the wonderful frequency of the eruptions, but also investigated the nature of the trachyte which, confined to such a limited space, breaks through the gneiss. As has already been remarked,[60] 267 eruptions were counted in one hour, each lasting on an average 13″.4, and, which is very remarkable, unaccompanied by any concussion perceptible on the ashy cone. The erupted matter, enveloped in much smoke, sometimes of a gray and sometimes of an orange colour, is principally a mixture of black ashes and rapilli, but it also consists partly of cinders, which rise perpendicularly, are of a globular form and a diameter of 15 or 16 inches. In one of the more violent eruptions, however, Wisse counted only 50 or 60 red hot stones as being simultaneously thrown out. They usually fall back again into the crater, but sometimes they cover its upper margin, or visible by their luminosity at a distance, glide down at night, upon a portion of the cone, which, when seen from a great way off, probably gave origin to the erroneous notion of La Condamine, "that there was an effusion of burning sulphur and bitumen." The stones rise singly one after the other, so that some of them are falling down, whilst others have only just left the crater. By an exact determination of time, the visible space of falling (calculated therefore to the margin of the crater) was ascertained to be on the average only 786 feet. On Etna, according to the measurements of Sartorius von Waltershausen and the astronomer D. Christian Peters, the ejected stones attain an elevation of as much as 2665

[60] *Cosmos*, see page 182.

feet above the walls of the crater. Gemellaro's estmates during the eruption of Etna in 1832, gave even three times this elevation! The black, erupted ashes form layers of three or four hundred feet in thickness upon the declivities of the Sangay for a circle of nearly fourteen miles in circumference. The colour of the ashes and rapilli gives the upper part of the cone a fearfully stern character. We must here again call attention to the colossal size of this volcano, which is six times greater than that of Stromboli, as this consideration is strongly in opposition to the absolute belief that the lower volcanoes always have the most frequent eruptions.

The grouping of volcanoes is of more importance than their form and elevation, because it relates to the great geological phenomenon of upheaval upon fissures. These groups, whether according to Leopold von Buch, they rise in lines, or united around a central volcano, indicate the parts of the crust of the earth, where the eruption of the fused interior has found the least resistance, in consequence either of the reduced thickness of the rocky strata, of their natural structure, or of their having been originally fissured. Three degrees of latitude are occupied by the space in which the volcanic energy is formidably manifested in Etna, in the Æolian Islands, in Vesuvius, and the parched land (the Phlegræan Fields) from Puteoli (Dicæarchia) to Cumæ, and as far as the fire-vomiting Epopeus on Ischia, the Tyrrhenian island of Apes, Ænaria. Such a connexion of analogous phenomena could not escape the notice of the Greeks. Strabo says, "The whole sea commencing from Cumæ as far as Sicily is penetrated by fire, and has in its depths certain conduits communicating with each other and with the continent.[61] In such a

[61] See Strabo, lib. v, p. 248, Casaubon:—ἔχει κοιλίας τινάς; and lib. vi, p. 276. Upon a double mode of production of islands the geographer of Amasia expresses himself (vi, p. 258) with much geological acumen. "Some islands," says he (and he names them), "are fragments of the mainland; others have proceeded from the sea, as still happens. For the islands of the high sea (those which lie far out in the sea) were probably upheaved from the depths; whilst, on the contrary, it is more reasonable to consider those situated at promontories and separated by a strait, as torn from the mainland." The small group of the Pithecusæ consists of Ischia, originally called Ænaria, and Procida (Prochyta). The reason why this group was considered to be an ancient habitation of apes, why the Greeks and the Italian Tyrrhenians, conse-

(combustible) nature, as all describe it, appear, not only Etna, but also the districts around Dicæarchia and Naples, and around Baiæ and Pithecusa;" and from this arose the fable that Typhon lay under Sicily, and that, when he turned himself, flames and water burst forth, nay sometimes even small islands with boiling water. "Frequently between Strongyle and Lipara (in this wide district) flames have been seen bursting forth at the surface of the sea, the fire opening itself a passage out of the cavities in the depths and pressing upwards with force." According to Pindar[69] the body of Typhon is of

quently Etruscans, gave it such a name (apes were called ἄριμοι, in the Tyrrhenian; Strabo, lib. xiii, p. 626) remains very obscure, and is perhaps connected with the myth, according to which the old inhabitants were transformed into apes by Jupiter. The name of the apes, ἄριμοι, might relate to Arima or Arimer of Homer (*Iliad*, ii, 783) and Hesiod (*Theog.* v. 301). The words ειν 'Αρίμοις of Homer, are contracted into one word in some codices, and in this contracted form we find the name in the Roman writers (Virgil, *Æneid*, ix, 716: Ovid, *Metamorph.* xiv, 88). Pliny (*Hist. Nat.* iii, 5) even says decidedly:—"Ænaria, Homero Inarime dicta, Græcis Pithecusa." . . . . The Homeric country of the Arimer, Typhon's resting-place, was sought, even in ancient times in Cilicia, Mysia, Lydia, in the volcanic Pithecusæ, at the crater Puteolanus, and in the Phrygian Phlegræa, beneath which Typhon once lay, and even in the Katakekaumene. That apes should have lived within historical times upon Ischia, at such a distance from the African coast is the more improbable, because, as I have already observed elsewhere, the ancient presence of the apes upon the Rock of Gibraltar does not appear to be proved, since Edrisi (in the 12th century) and other Arabian geographers, who describe the Straits of Hercules in such detail, do not mention them. Pliny also denies the apes of Ænaria, but derives the name of the Pithecusæ in a most improbable manner from πιθος, *dolium* (*a figlinis doliorum*). "It appears to me," says Böckh, "to be the main point in this investigation, that Inarima is a name of the Pithecusæ produced by learned interpretation and fiction, just as Corcyra became Scheria; and that Æneas was probably only connected with the Pithecusæ (Æneæ insulæ) by the Romans, who find their progenitors everywhere in these regions. Nævius also testifies to their connection with Æneas in the first book of the Punic War."

[62] Pind. *Pyth.* i, 31. See *Strabo*, v, pp. 245 and 248, and xiii, p. 627. We have already observed (*Cosmos*, vol. v, p. 208), that Typhon fled from the Caucasus to Lower Italy, as though the myth would indicate that the volcanic eruptions in the latter country were of less antiquity than those upon the Caucasian Isthmus. The consideration of mythical views in popular belief cannot be separated either from the geography or the history of volcanoes. The two often reciprocally illustrate each other. That which was regarded upon the

such extent that "Sicily and the sea-girt heights above Cumæ (called Phlegra, or the burnt field,) lie upon the shaggy breast of the monster."

Thus Typhon (the raging Enceladus) was, in the popular fancy of the Greeks, the mythical symbol of the unknown cause of volcanic phenomena lying deep in the interior of the earth. By the position and the space which he occupied were indicated the limitation and the co-operation of particular volcanic systems. In the fanciful geological picture of the interior of the earth, in the great contemplation of the

surface of the earth as the mightiest of moving forces (Aristotle, *Meteorol.*.ii, 8, 3), the wind, the inclosed *pneuma*, was recognised as the universal cause of vulcanicity (of fire-vomiting mountains and earthquakes). Aristotle's contemplation of nature was founded upon the mutual action of the external and the internal subterranean air, upon a theory of transpiration, upon differences of heat and cold, moisture and dryness (Aristotle, *Meteor.* ii, 8, 1, 25, 31, and ii, 9, 2). The greater the mass of the wind inclosed "in subterranean and submarine passages," and the more it is obstructed in its natural, essential property of moving far and quickly, the more violent are the eruptions. "Vis fera ventorum, cæcis inclusa cavernis" (Ovid, *Metamorph.* xv, 299). Between the wind and the fire there is a peculiar relation. (Tὸ πῦρ ὅταν μετὰ πνεύματος ᾖ, γίνεται φλὸξ καὶ φέρεται ταχέως; Aristotle, *Meteorol.* ii, 8, 3.—καὶ γὰρ τὸ πῦρ οἷον πνεύματός τις φύσις; Theophrastus, *De Igne*, § 30, p. 715). The wind (*pneuma*) suddenly set free from the clouds, sends the consuming and widely luminous lightning flash (πρηστήρ). "In the Phlegræa, the Katakekaumene of Lydia," says Strabo (lib. xiii, p. 628), "three chasms, fully forty stadia from each other, are still shown, which are called the wind-bags; above them lie rough hills, which are probably piled up by the red-hot masses blown up." He had already stated (lib. i, p. 57) "that between the Cyclades (Thera and Therasia) flames of fire burst forth from the sea for four days together, so that the whole sea boiled and burnt; and an island composed of calcined masses was gradually raised as if by a lever." All these well described phenomena are ascribed to the compressed wind, acting like elastic vapours. Ancient physical science troubled itself but little about the peculiar essentials of material bodies; it was dynamic, and depended on the measure of the moving force. We find the opinion that the increasing heat of the planet with the depth is the cause of volcanoes and earthquakes, first expressed towards the close of the third century by a Christian bishop in Africa under Diocletian (*Cosmos*, vol. v, p. 196). The Pyriphlegethon of Plato, as a stream of fire circulating in the interior of the earth, nourishes all lava-giving volcanoes, as we have already mentioned in the text. In the earliest presentiments of humanity, in a narrow circle of ideas, lie the germs of that which we now think we may explain under the form of other symbols.

universe which Plato establishes in the Phædo (p. 112—114) this co-operation is still more boldly extended to all volcanic systems. The lava-streams derive their materials from the Pyriphlegethon, which "after it has repeatedly rolled around beneath the earth," pours itself into Tartarus. Plato says expressly that the fire-vomiting mountains, wherever such occur upon the earth, blow upwards small portions from the Pyriphlegethon (" *οὗτος δ'ἐστὶν ὃν ἐπονομάζουσι Πυριφλεγέθοντα, οὗ καὶ οἱ ῥύακες ἀποσπάσματα ἀναφυσῶσιν, ὅπῃ ἂν τύχωσι τῆς γῆς*"). This expression (p. 113 B.) of the expulsion with violence refers to a certain extent to the moving force of the previously enclosed wind, then suddenly breaking through, upon which the Stagirite afterwards, in the Meteorology, founded his entire theory of vulcanicity.

According to these ancient views the linear arrangement of volcanoes is more distinctly characterized in the consideration of the entire body of the earth, than their grouping around a central volcano. The serial arrangement is most remarkable in those places where it depends upon the situation and extension of fissures, which, usually parallel to each other, pass through great tracts of country in a linear direction (like Cordilleras). Thus, to mention only the most important series of closely approximated volcanoes, we find in the new continent those of *Central America*, with their appendages in *Mexico*; those of *New Granada* and *Quito*, of *Peru, Bolivia*, and *Chili*; in the old continent the *Sunda Islands* (the Indian Archipelago, especially Java), the peninsula of *Kamtschatka* and its continuation in the *Kurile Islands*, and the *Aleutian Islands*, which bound the nearly closed Behring's Sea on the south. We shall dwell upon some of the principal groups; individual details, by being brought together, lead us to the causes of phenomena.

The linear volcanoes of Central America, according to the older denominations the volcanoes of Costa Rica, Nicaragua, San Salvador, and Guatemala, extend from the volcano Turrialva near Cartago to the volcano of Soconusco, over six degrees of latitude, between 10° 9 and 16° 2, in a line the general direction of which is from S.E. to N.W., and which, with the few curvatures which it undergoes, has a length of 540 geog. miles. This length is about equal to the distance from Vesuvius to Prague. The most closely approximated of them, as if they had broken out upon one and the same fissure only 64 miles in length, are the eight volcanoes, situated between the Laguna de Managua and the Bay of Fonseca, between the volcano of Momotombo and that of Conseguina, the subterranean noise of which was heard in Jamaica and on the highlands of Bogotá in the year 1835 like the fire of artillery. In Central America and the whole southern part of the new continent, and generally from the Chonos Archipelago in Chili to the most northern volcanoes of Mount Edgecombe on the small island near Sitka,[63] and Mount Elias on Prince William's Sound, for a length of 6400 geog. miles, the volcanic fissures have everywhere broken out in the western part, or that nearest to the Pacific Ocean. Where the line of the Central American volcanoes enters with the volcano of Conchagua into the state of San Salvador, in the latitude of $13\frac{1}{2}°$ (to the north of the Bay of Fonseca) the direction of the volcanoes changes at once with that of the west coast. The series of the former then strikes E.S.E.—W.N.W.; indeed, where the burning mountains are again so closely approximated that five, still more or less active, are counted in the short distance of 120 miles, the direction is nearly E.—W. This deviation corresponds with a great dilatation of the continent towards the east in the peninsula of Honduras, where the coast tends also suddenly, exactly east and west, from Cape Gracias à Dios to the Gulf of Amatique for 300 miles, after it had been previously running from north to south for the same distance. In the group of elevated volcanoes of Guatemala (lat. 14° 10′) the series again acquires its old direction, N. 45° W., which it continues as far as the Mexican boundary towards Chiapa and the isthmus of Huasacualco. North-West of the volcano of Soconusco to that

[63] Mount Edgecombe, or the St. Lazarus mountain, upon the small island (Croze's Island, near Lisiansky), which is situated to the westward, near the northern half of the larger island Sitka or Baranow, in Norfolk Sound, was seen by Cook, and is a hill partly composed of basalt abounding in olivine, and partly of felspathic trachyte. Its height is only 2770 feet. Its last great eruption, which produced much pumice-stone, was in the year 1796 (Lutké, *Voyage autour du Monde,* 1836, t. iii, p. 15). Eight years afterwards Captain Lisiansky reached the summit, which contains a crater-lake. He found at that time no signs of activity anywhere on the mountain.

of Tuxtla, not even an extinct trachytic cone has been discovered; in this quarter, granite abounding in quartz and mica-schist predominate.

The volcanoes of Central America do not crown the adjacent mountain chains, but rise along the foot of the latter, usually completely separated from each other. The greatest elevations lie at the two extremities of the series. Towards the South, in Costa Rica, both seas are visible from the summit of the Irasu (the volcano of Cartago), to which, besides its elevation (11,081 feet), its central position contributes. To the south-east of Cartago there stand mountains of ten or eleven thousand feet: the *Chiriqui* (11,262 feet) and the *Pico Blanco* (11,740 feet). We know nothing of the nature of their rock, but they are probably unopened trachytic cones. Further towards the south-east, the elevations diminish in Veragua to six and five thousand feet. This appears also to be the average height of the volcanoes of Nicaragua and San Salvador; but towards the north-western extremity of the whole series, not far from the new city of Guatemala, two volcanoes again rise above 13,000 feet. The maxima consequently fall into the *third* group of my attempted hypsometric classification of volcanoes, coinciding with Etna and the Peak of Teneriffe, whilst the greater number of the heights lying between the two extremities, scarcely exceed Vesuvius by 2000 feet. The volcanoes of Mexico, New Granada, and Quito belong to the fifth group, and usually attain an elevation of more than 17,000 feet.

Although the continent of Central America increases considerably in breadth from the isthmus of Panama, through Veragua, Costa Rica, and Nicaragua, to the latitude of $11\frac{1}{2}°$, the great area of the lake of Nicaragua and the small elevation of its surface (scarcely 128 feet[64] above the two seas), gives rise to such a degradation of the land exactly in this district, that by it an overflow of air from the Caribbean Sea into the Great South Sea is often caused, bringing danger to the voyager in the so-called Pacific

[64] Even under the Spanish Government in 1781, the Spanish engineer, Don José Galisteo, had found for the surface of the Laguna of Nicaragua an elevation only six feet greater than that given by Baily in his different levellings in 1838 (Humboldt, *Relation Historique*. t. iii, p. 321).

Ocean. The north-east storms thus excited have received the name of *Papagayos*, and sometimes rage without intermission for four or five days. They have the remarkable peculiarity that, during their continuance the sky usually remains quite cloudless. The name is borrowed from the part of the west coast of Nicaragua between Brito or Cabo Desolado and Punta S. Elena (from 11° 22′ to 10° 50′), which is called Golfo del Papagayo, and includes the small bays of Salinas and S. Elena to the south of the Puerto de San Juan del Sur. On my voyage from Guayaquil to Acapulco, I was able to observe the Papagayos in all their violence and peculiarity for more than two whole days (9th—11th March, 1803), although rather more to the south, in less than 9° 13′ of latitude. The waves rose higher than I have ever seen them ; and the constant visibility of the disc of the sun in the bright, blue arch of heaven, enabled me to measure the height of the waves by altitudes of the sun taken upon the ridge of the wave and in the trough, by a method which had not been tried at that time. All Spanish, English[65], and American voyagers ascribe the above-described storms of the Southern Ocean to the north-east trade-wind of the Atlantic.

In a new work[66] which I have undertaken with much

[65] See Sir Edward Belcher, *Voyage round the World*, vol. i, p. 185. According to my chronometric longitude I was in the Papagayo-storm 19° 11′ to the west of the meridian of Guayaquil, and consequently 99° 9′ west, and 880 miles west of the shore of Costa Rica.

[66] My earliest work upon seventeen linear volcanoes of Guatemala and Nicaragua is contained in the Geographical Journal of Berghaus (*Hertha*, Bd. vi, 1826, pp. 131—161). Besides the old Chronista Fuentes (lib. ix, cap. 9), I could then only make use of the important work of Domingo Juarros, *Compendio de la Historia de la Ciudad de Guatemala*, and of the three maps by Galisteo (drawn in 1781, at the command of the Mexican Viceroy, Matias de Galvez), by José Rossi y Rubi (Alcalde Mayor de Guatemala, 1800), and by Joaquin Ysasi and Antonio de la Cerda (Alcalde de Granada) which I possessed principally in manuscript. In the French translation of his work upon the Canary Islands, Leopold von Buch has given a masterly extension of my first sketch (*Descr. Physique des Isles Canaries*, 1836, pp. 500—514), but the uncertainty of geographical synonyms and the confusion of names caused thereby gave rise to many doubts, which have been for the most part removed by the fine maps of Baily and Saunders; by Molina's *Bosquejo de la Republica de Costa Rica*, and by the great and very meritorious work of Squier (*Nicaragua, its People and Monuments*,

assiduity,—partly from materials already published, and partly from manuscript notes,—upon the linear volcanoes

with Tables of the Comparative Heights of the Mountains in Central America, 1852, vol. i, p. 418, and vol. ii, p. 102). The important work which is promised us by Dr. Oerstedt, under the title of *Schilderung der Naturverhältnisse von Nicaragua und Costa Rica,* besides the admirable botanical and geological discoveries which constitute the primary object of the undertaking, will also throw light upon the geognostic nature of Central America. Dr. Oersted passed through that region in various directions from 1846 to 1848, and brought back a collection of rocks to Copenhagen. I am indebted to his friendly communications for interesting corrections of my fragmentary work. From a careful comparison of the materials with which I am acquainted, including those collected by Hesse, the Prussian Consul-General in Central America, which are of great value, I bring together the volcanoes of Central America in the following manner, proceeding from south to north :—

Above the central plateau of Cartago (4648 feet), in the republic of Costa Rica (lat. 10° 9′) rise the three volcanoes of Turrialva, Irasu, and Reventado, of which the first two are still ignited.

*Volcan de Turrialva** (height about 11,000 feet) is, according to Oersted, only separated from the Irasu by a deep, narrow ravine. Its summit, from which columns of smoke rise, has not yet been ascended.

The volcano *Irasu**, also called the volcano of *Cartago* (11,100 feet) to the north-east of the volcano Reventado, is the principal vent of volcanic activity in Costa Rica, but still remarkably accessible, and towards the south divided into terraces in such a manner that one may on horseback, almost reach the elevated summit, from which the two oceans, the sea of the Antilles and the Pacific, may be seen at once. The cone of ashes and rapilli, which is about a thousand feet in height, rises out of a wall of circumvallation (a crater of elevation). In the flatter, north-eastern part of the summit, lies the true crater, of 7500 feet in circumference, which has never emitted lava-streams. Its eruptions of scoriæ have often (1723, 1726, 1821, 1847) been accompanied by destructive earthquakes, the effect of which has been felt from Nicaragua or Rivas to Panama (Oersted). During a very recent ascent of the Irasu, in the beginning of May, 1855, by Dr. Carl Hoffmann, the crater of the summit and its eruptive orifices have been more accurately investigated. The altitude of the volcano is stated from a trigonometrical measurement by Galindo, at 12,000 Spanish feet, or, taking the *vara cast.*=0.43 of a toise, at 11,000 feet. (*Bonplandia,* Jahrgang, 1856, No. 3).

El Reventado (about 9500 feet), with a deep crater, of which the southern margin has fallen in, and which was formerly filled with water.

of Central America, twenty-nine volcanoes are numbered, whose former or present varied activity may be stated

The volcano *Barba* (more than 8419 feet), to the north of San José, the capital of Costa Rica; with a crater which contains several small lakes.

Between the volcanoes Barba and Orosi, there follows a series of volcanoes which intersects the principal chain, running S.E.—N.W. in Costa Rica and Nicaragua, almost in the opposite direction, east and west. Upon such a fissure stand, furthest to the eastward, *Miravalles* and *Tenorio* (each of these volcanoes is about 4689 feet); in the centre, to the south-east of Orosi, the volcano *Rincon*, also called *Rincon de la Vieja** (Squier, vol. ii, p. 102) which exhibits small eruptions of ashes every spring at the commencement of the rainy season; and furthest to the westward, near the little town of Alajuela, the volcano Votos* (7513 feet) which abounds in sulphur. Dr. Oersted compares this phenomenon of the direction of volcanic activity upon a transverse fissure, with the east and west direction, which I found in the Mexican volcanoes from sea to sea.

Orosi,* still active, in the most southern part of the State of Nicaragua (5222 feet); probably the *Volcan del Papagayo*, on the chart of the *Deposito Hidrografico*.

The two volcanoes, *Mandeira* and *Ometepec** (4157 and 5222 feet) upon a small island in the western part of the Laguna de Nicaragua, named by the Aztec inhabitants of the district after these two mountains (*ome tepetl* signifies two mountains; see Buschmann, *Aztekische Ortsnamen*, pp. 178 and 171). The insular volcano Ometepec, erroneously named Ometep by Juarros (*Hist. de Guatemala*, t. i, p. 51), is still in activity. It is figured by Squier (vol. ii, p. 235).

The extinct crater of the island *Zapatera*, but little elevated above the sea-level. The period of its ancient eruptions is quite unknown.

The volcano of *Momobacho*, on the western shore of the Laguna de Nicaragua, somewhat to the south of the city of Granada. As this city is situated between the volcanoes of Momobacho (the place is also called Mombacho, Oviedo, *Nicaragua*, ed. Ternaux, p. 245), and Masaya, the pilots indicate sometimes the one and sometimes the other of these conical mountains by the indefinite name of the Volcano of Granada.

The volcano *Massaya* (Masaya) which has already been treated of in detail (pp. 258—261) was once a Stromboli, but has been extinct since the great eruption of lava in 1670. According to the interesting reports of Dr. Scherzer (*Sitzungsberichte der Philos. Hist. Classe der Akad. der Wiss. zu Wien*, Bd. xx, s. 58) dense clouds of vapour were again emitted in April, 1853, from a newly opened crater. The volcano of Massaya is situated between the two lakes of Nicaragua and Managua to the west of the city of Granada. Massaya is not synonymous with Nindiri; but, as Dr. Oersted expresses himself, *Massaya* and *Nindiri*,* with certainty. The natives make the number more than one-third greater, taking into account a quantity

form a twin volcano, with two summits and two distinct craters, both of which have furnished lava-streams. The lava-stream of 1775 from the Nindiri reached the lake of Managua. The equal height of these two volcanoes, situated so close to each other, is stated at only 2450 feet.

*Volcan de Momotombo** (7034 feet), burning, and often giving forth a thundering noise, but without smoking, in lat. 12° 28′, at the northern extremity of the Laguna de Managua, opposite to the small island Momotombito, so rich in sculptures (see the representation of Momotombo in Squier, vol. i, pp. 233 and 302—312). The Laguna de Managua lies 28 feet higher than the Laguna de Nicaragua, which is more than double its size, and has no insular volcano.

From hence, to the Bay of Fonseca or Conchagua, at a distance of 23 miles from the coast of the Pacific, a line of six volcanoes runs from S.E. to N.W.; closely approximated to each other and bearing the common name of *los Maribios* (Squier, vol. i, p. 419; vol. ii, p. 123).

*El Nuevo,** erroneously called Volcan de las Pilas, because the eruption of the 12th April, 1850, took place at the foot of this mountain; a great eruption of lava almost in the plain itself! (Squier, vol. ii, pp. 105—110).

*Volcan de Telica,** visited, during its activity, by Oviedo as early as the sixteenth century (about 1529), to the east of Chinendaga, near Leon de Nicaragua, and consequently a little out of the direction previously stated. This important volcano, which emits much sulphurous vapour from a crater 320 feet in depth, was ascended, a few years since, by my scientific and talented friend Professor Julius Fröbel. He found the lava composed of glassy felspar and augite (Squier, vol. ii, pp. 115—117). At the summit, at an elevation of 3517 feet, there is a crater, in which the vapours deposit great masses of sulphur. At the foot of the volcano is a mud-spring (Salse?).

The volcano *el Viejo,** the northernmost of the crowded line of six volcanoes. It was ascended and measured in the year 1838 by Captain Sir Edward Belcher. The result of the measurement was 5559 feet. A more recent measurement, by Squier, gave 6002 feet. This volcano, which was very active in Dampier's time, is still burning. The fiery eruptions of scoriæ are frequently seen in the city of Leon.

The volcano *Guanacaure,* somewhat to the north, without the range from el Nuevo to the Viejo, at a distance of only 14 miles from the shore of the Bay of Fonseca.

The volcano *Conseguina,** upon the cape which projects at the southern extremity of the Bay of Fonseca (lat. 12° 50′), celebrated for the fearful eruption, preceded by earthquakes, of the 23rd January, 1835. The great darkness during the fall of ashes, similar to that which has of old eruptive basins, which were probably only lateral eruptions on the declivity of one and the same mountain.

sometimes been caused by the volcano Pichincha, lasted for 43 hours. At a distance of a few feet, firebrands could not be perceived. Respiration was obstructed, and a subterranean noise, like the discharge of heavy artillery, was heard not only in Balize on the peninsula of Yucatan, but also upon the coast of Jamaica, and upon the plateau of Bogotá, in the latter case at an elevation of more than 8500 feet above the sea, and at a distance of nearly five hundred and sixty geographical miles (Juan Galindo, in Silliman's *American Journal*, vol. xxviii, 1835, pp. 332—336; Acosta, *Viajes á los Andes*, 1849, p. 56, and Squier, vol. ii, pp. 110—113; figures pp. 163 and 165). Darwin (*Journal of Researches during the Voyage of the Beagle*, 1845, p. 291) calls attention to a remarkable coincidence of phenomena:—After a long slumber, Conseguina, in Central America, and Aconcagua and Corcovado (S. lat. $32\frac{3}{4}$° and $43\frac{1}{2}$°) in Chili, broke out on the same day (accidentally ?).

Volcano of *Conchagua*, or of Amalapa, at the north of the entrance to the Bay of Fonseca, opposite to the volcano Conseguina, near the beautiful Puerto de la Union, the harbour of the neighbouring town of San Miguel.

From the state of Costa Rica to the volcano of Conchagua, therefore, the close series of twenty volcanoes follows a direction from S.E. to N.W., but on entering near Conchagua into the State of San Salvador which, in the short distance of 160 geog. miles exhibits five still more or less active volcanoes, the line, like the Pacific coast itself, turns more E.S.E.—W.N.W., and indeed almost E.—W., whilst on the eastern, Caribbean coast (towards the Cape Gracias á Dios) the land suddenly bulges out in Honduras and los Mosquitos (see above, p. 269). It is only, as there remarked, to the north of the high volcanoes of Old Guatemala, towards the Laguna de Atitlan, that the former general direction N. 45° W. again occurs, until at last, in Chiapa, and on the isthmus of Tehuantepec, the abnormal direction E.—W. is again manifested, but in non-volcanic chains. Besides Conchagua, the following four volcanoes belong to the State of San Salvador :—

The volcano of *San Miguel Bosotlan** (lat. 13° 35′), near the town of the same name, the most beautiful and regular of trachytic cones next to the insular volcano Ometepec, in the lake of Nicaragua, (Squier, vol. ii, p. 196). The volcanic forces are very active in Bosotlan, in which a great eruption of lava occurred on the 20th of July, 1844.

Volcano of *San Vicente*,* to the west of the Rio de Lempa, between the towns of Sacatecoluca and Sacatelepe. A great eruption of ashes took place, according to Juarros, in 1643; and in January, 1835, a long continued eruption occurred with destructive earthquakes.

Volcano of *San Salvador* (lat. 13° 47′), near the city of the same

Amongst the isolated conical and bell-shaped mountains, which are there called volcanoes, many may, indeed, consist

name. The last eruption was that of 1656. The whole surrounding country is exposed to violent earthquakes; that of the 16th of April, 1854, which was preceded by no noises, overthrew nearly all the buildings in San Salvador.

Volcano of *Izalco,** near the village of the same name, often producing ammonia. The first eruption recorded in history occurred on the 23rd February, 1770; the last widely-luminous eruptions were in April, 1798, 1805 to 1807, and 1825 (see above, p. 261, and Thompson, *Official Visit to Guatemala*, 1829, p. 512).

*Volcan de Pacaya** (lat. 14° 23′), about 14 miles to the south-east of the city of New Guatemala, on the small Alpine lake Amatitlan, a very active and often flaming volcano; an extended ridge with three domes. The great eruptions of 1565, 1651, 1671, 1677, and 1775 are known; the last, which produced much lava, is described by Juarros as an eye-witness.

Next follow the two volcanoes of Old Guatemala, with the singular appellations *de Agua* and *de Fuego,* near the coast, in latitude 14° 12′.

Volcan de Agua, a trachytic cone near Escuintla, higher than the Peak of Teneriffe, surrounded by masses of obsidian (indications of old eruptions?). The volcano, which reaches into the region of perpetual snow, has received its name from the circumstance that, in September, 1541, a great inundation (caused by earthquake and the melting of snow?) was ascribed to it; this destroyed the first established city of Guatemala, and led to the building of the second city, situated to the north-north-west, and now called *Antigua Guatemala.*

*Volcan de Fuego,** near Acatenango, 23 miles in a west-north-west direction from the so-called water-volcano. With regard to their relative position, see the rare map of the Alcalde Mayor, Don José Rossi y Rubi, engraved in Guatemala, and sent to me thence as a present: *Bosquejo del espacio que media entre los estremos de la Provincia de Suchitepeques y la Capital de Guatemala,* 1800. The Volcan de Fuego is still active, but now much less so than formerly. The older great eruptions were those of 1581, 1586, 1623, 1705, 1710, 1717, 1732, 1737, and 1799, but it was not only these eruptions, but also the destructive earthquakes which accompanied them, that moved the Spanish Government in the second half of the last century to quit the second seat of the city (where the ruins of la Antigua Guatemala now stand), and compel the inhabitants to settle further to the north, in the new city of Santiago de Guatemala. In this case, as at the removal of Riobamba, and several other towns near the volcanoes of the chain of the Andes, a dogmatic and vehement dispute was carried on in reference to the difficult selection of a locality "of which it might be asserted, according to previous experience, that it was but little exposed to the action of neighbouring volcanoes (lava-streams, eruptions of scoriæ and of trachyte and dolerite, but having always been unopened, have never exhibited any igneous activity since the time of their upheaval. *Eighteen* are to be regarded as still active; *seven* of these have thrown up flames, scoriæ and lava-streams in the present century (1825, 1835, 1848, and 1850); and *two*[67] at the end of the last century (1775 and 1799). The deficiency of lava-streams in the mighty volcanoes of the Cordilleras of Quito has recently given occasion to the repeated assertion that this deficiency is equally general in the volcanoes of Central America. Certainly, in the majority of cases, eruptions of scoriæ and ashes have been unaccompanied by any effusion of lava—as for exam-

earthquakes!)" In 1852, during a great eruption, the Volcan de Fuego poured forth a lava-stream towards the shore of the Pacific. Captain Basil Hall measured, under sail, both the volcanoes of Old Guatemala, and found for the Volcan de Fuego 14,665 feet, and for the Volcan de Agua, 14,903 feet. The foundation of this measurement has been tested by Poggendorff. He found the mean elevation of the two mountains to be less, and reduced it to about 13,109 feet.

*Volcan de Quesaltenango** (lat. 15° 10′), burning since 1821, and smoking, near the town of the same name; the three conical mountains which bound the Alpine lake Atitlan (in the mountain chain of Solola) on the south, are also said to be ignited. The volcano of *Tajamulco,* referred to by Juarros, certainly cannot be identical with the volcano of Quesaltenango, as the latter is at a distance of 40 geog. miles to the N.W., of the village of Tajamulco, to the south of Tejutla.

What are the two volcanoes of *Sacatepeques* and *Sapotitlan,* mentioned by Funel, or Brué's *Volcan de Amilpas?*

The great volcano of *Soconusco,* situated on the borders of Chiapa, 28 geog. miles to the south of Ciudad Real, in lat. 16° 2′.

At the close of this long note I think I must again mention that the barometric determinations of altitude here adduced are partly derived from Espinache, and partly borrowed from the writings and maps of Baily, Squier, and Molina.

[67] The following 18 volcanoes, constituting therefore nearly the half of all those referred to by me as active in former or present times, are to be regarded as at present more or less active:—Irasu and Turrialva, near Cartago, el Rincon de la Vieja, Votos(?) and Orosi; the insular volcano Ometepec, Nindiri, Momotomba, el Nuevo, at the foot of the trachytic mountain Las Pilas, Telica, el Viejo, Conseguina, San Miguel Bosotlan, San Vicente, Izalco, Pacaya, Volcan de Fuego (de Guatemala), and Quesaltenango. The most recent eruptions are those of el Nuevo, near las Pilas, on the 18th April, 1850; San Miguel Bosotlan, 1848; Conseguina, and San Vicente, 1835; Izalco, 1825; Volcan de Fuego, near New Guatemala, 1799 and 1852; and Pacaya, 1775.

ple, at present in the volcano of Izalco ; but the descriptions which have been given by eye-witnesses of the lava-producing eruptions of the four volcanoes, Nindiri, el Nuevo, Conseguina, and San Miguel de Bosotlan, give an opposite testimony[68].

I have purposely dwelt at length upon the details of the position and close approximation of the linear volcanoes of Central America, in the hope that some day a geognosist, who has previously given a profound study to the active volcanoes of Europe, and the extinct ones of Auvergne, the Vivarais or the Eifel, and who also (this is of the greatest importance) knows how to describe the mineralogical composition of the different rocks in accordance with the present state of our knowledge, may feel himself impelled to visit this region, which is so near and so accessible. Even if the traveller should devote himself exclusively to geognostic investigations, there still remains much to be done here,—especially the oryctognostic determination of the trachytic, doleritic, and melaphyric rocks ; the separation of the primitive mass upheaved, and of the portion of the elevated mass which has been covered over by subsequent eruptions ; the seeking out and recognition of true, slender, uninterrupted lava-streams, which are only too frequently confounded with accumulations of erupted scoriæ. Conical mountains, which have never been opened, rising in a dome or bell-like form, such as Chimborazo, are therefore to be clearly separated from volcanoes which have been, or still are, active, throwing out scoriæ and lava-streams, like Vesuvius and Etna, or scoriæ and ashes alone, like Pichincha or Cotopaxi. I know nothing that promises to impart a more brilliant impetus to our knowledge of volcanic activity, which is still very deficient in multiplicity of observations in large and connected continental districts. As the material results of such a labour, collections of rocks would be brought home from many isolated, true vol-

[68] Compare Squier, *Nicaragua*, vol. ii, p. 103, with pp. 106 and 111, as also his previous small work *On the Volcanoes of Central America*, 1850, p. 7; Leopold de Buch, *Iles Canaries*, p. 506, where reference is made to the lava-stream which broke out of the volcano Nindiri in 1775, and which has been recently again seen by a very scientific observer, Dr. Oersted.

canoes, and unopened trachytic cones, together with the non-volcanic masses which have been broken through by both; the subsequent chemical analyses, and the chemico-geological inferences deduced from the analyses, would open a field equally wide and fertile. Central America and Java have the unmistakeable superiority over Mexico, Quito, and Chili, that in a greater space they exhibit the most variously formed and most closely approximated stages of volcanic activity.

At the point where the characteristic series of the volcanoes of Central America terminates on the borders of Chiapa with the volcano of Soconusco (lat. 16° 2′), there commences a perfectly different system of volcanoes—the Mexican. The isthmus of Huasacualco and Tehuantepec, so important for the trade with the coast of the Pacific, like the state of Oaxaca, situated to the north-west, is entirely without volcanoes, and, perhaps, even destitute of unopened trachytic cones. It is only at a distance of 160 geog. miles from the volcano of Soconusco, that the small volcano of Tuxtla rises near the coast of Alvarado (lat. 18° 28′). Situated on the eastern slope of the Sierra de San Martin, it had a great eruption of flames and ashes on the 2nd of March, 1793. An exact astronomical determination of the position of the colossal snowy mountains and volcanoes in the interior of Mexico (the old Anahuac) led me, after my return to Europe, while inserting the maxima of elevations in my chart of New Spain, to the exceedingly remarkable result, that there is in this place, from sea to sea, a parallel of the volcanoes and greatest elevations which oscillates by only a few minutes to and from the parallel of 19°. The only volcanoes and, at the same time, the only mountains covered with perpetual snow in the country, and consequently elevations varying from 12,000 to 3,000 feet,—the volcanoes of Orizaba, Popocatepetl, Toluca, and Colima,—lie between the latitudes of 18° 59′ and 19° 20′, and thus indicate the direction of a fissure of volcanic activity of 360 geog. miles in length[69]. In the same direction (lat. 19° 9′), between the

[69] See all the bases of these Mexican local determinations, and their comparison with the observations of Don Joaquin Ferrer, in my *Recueil d'Observations Astron.* vol. ii, pp. 521, 529, and 536—550, and *Essai Politique sur la Nouvelle-Espagne*, t. i, pp. 55—59, and 176, t. ii.

volcanoes of Toluca and Colima, at a distance of 116 and 128 geog. miles from them, the new volcano of Jorullo (4265 feet) rose on the 14th September, 1759, in a broad plain, having an elevation of 2583 feet. The local position of this phenomenon in relation to the situation of the other Mexican volcanoes, and the circumstance that the fissure from east to west which I here indicate intersects the direction of the great mountain chain striking from south-south-east to north-north-west almost at right angles, are geological phenomena no less important than the distance of the eruption of Jorullo from the seas, the evidences of its upheaval which I have represented graphically in detail, the innumerable fuming hornitos which surround the volcano, and the fragments of granite, which I found immersed in the lava poured forth from the principal volcano of Jorullo, in a district which is destitute of granite for a long distance.

The following table contains the special local determinations and elevations of the series of volcanoes of Anahuac, upon a fissure which, running from sea to sea, intersects the fissure of elevation of the great range of mountains :—

p. 173. I had myself early raised doubts with regard to the astronomical determination of the position of the volcano of Colima, near the coast of the Pacific (*Essai Polit.* t. i, p. 68, t. ii, p. 180). According to angles of altitude taken by Captain Basil Hall while under sail, the volcano is situated in lat. 19° 36′, and consequently half a degree further north than I concluded to be its position from Itineraries; certainly without absolute determinations for Selagua and Petatlan, upon which I depended. The latitude, 19° 25′, which I have given in the text, is, like the determination of altitude (12,005 feet), from Captain Beechey (*Voyage,* pt. ii, p. 587). The most recent map by Laurie (*The Mexican and Central States of America,* 1853) gives 19° 20′ for the latitude. The latitude of Jorullo may also be wrong by 2—3 minutes, as I was then occupied entirely with geological and topographical investigations, and neither the sun nor stars were visible for determinations of latitude. (See Basil Hall, *Journal written on the Coast of Chili, Peru, and Mexico,* 1824, vol. ii, p. 379; Beechey, *Voyage,* pt. ii, p. 587; and Humboldt, *Essai Polit.* t. i, p. 68, t. ii, p. 180). In the true and exceedingly artistic views of the volcano of Colima, drawn by Moritz Rugendas, which are preserved in the Berlin Museum, we distinguish two adjacent mountains,—the true volcano, which constantly emits smoke, and is covered with but little snow, and the more elevated Nevada, which rises far into the region of perpetual snow.

Sequence from E. to W.	Latitude.	Elevation above the sea in feet.
Volcano of Orizaba....	19° 2′ 17″	17,879
Nevado Iztaccihuatl ..	19 10 3	15705
Volcano Popocatepetl ..	18 59 47	17726
Volcano of Toluca	19 11 33	15168
Volcano of Jorullo	19 9 0	4265
Volcano of Colima	19 20 0	12005

The prolongation of the parallel of volcanic activity in the tropical zone of Mexico, leads, at a distance of 506 miles westward from the shores of the Pacific to the insular group Revillagigedo, in the vicinity of which Collnet saw pumice-stone floating, and perhaps still farther on, at a distance of 3360 geog. miles to the great volcano Mauna Roa (19° 28′), without causing any upheaval of islands in the intervening space!

The group of linear volcanoes of Quito and New Granada includes a volcanic zone which extends from 2° S. lat. to nearly 5° N. lat. The extreme boundaries of the area in which the reaction of the interior of the earth upon its surface is now manifested, are the uninterruptedly active Sangay, and the Paramo and Volcan de Ruiz, the most recent conflagration of which was in the year 1829, and which was seen smoking by Carl Degenhardt from the Mina de Santana in the province of Mariquita in 1831 and from Marmato in 1833. The most remarkable traces of great eruptive phenomena next to the Ruiz, are exhibited from north to south, by the truncated cone of the volcano of Tolima (18,129 feet), celebrated by the recollection of the destructive eruption of the 12th March, 1595; the volcanoes of Puracé (17,006 feet) and Sotara near Popayan; that of Pasto (13,450 feet), near the city of the same name; of the Monte de Azufre (12,821 feet), near Tuquerres; of Cumbal (15,618 feet), and of Chiles, in the province de los Pastos; then follow the historically celebrated volcanoes of the true high land of Quito, to the south of the equator, of which four,—namely, Pichincha, Cotopaxi, Tungurahua, and

Sangay,—certainly cannot be regarded as extinct volcanoes. Although to the north of the mountain group of the Robles, near Popayan, as we shall shortly more fully show in the tripartition of the vast chain of the Andes, it is only the central Cordillera, and not the western one, nearer to the sea-coast, that exhibits a volcanic activity; on the other hand, to the south of this group, where the Andes form only two parallel chains, so frequently mentioned by Bouguer and La Condamine in their writings, volcanoes are so equally distributed, that the four volcanoes of the Pastos, as well as Cotocachi, Pichincha, Iliniza, Carguairazo, and Yana-Urcu, at the foot of Chimborazo, have broken out upon the western chain, nearest to the sea; and upon the eastern Cordillera, Imbabura, Cayambe, Antisana, Cotopaxi, Tungurahua (opposite to Chimborazo towards the east, but still nearly approximated to the middle of the narrow elevated plateau), the Altar de los Collanes (Capac-Urcu), and Sangay. If we include the northernmost group of the linear volcanoes of South America in one view, the opinion so often expressed in Quito, and to a certain extent founded on historical documents, of the migration of the volcanic activity and increase of intensity from north to south, acquires, at all events, a certain amount of probability. It is true that in the south, and indeed close to the colossal Sangay, which acts like Stromboli, we find the ruins of the "Prince of Mountains," Capac-Urcu, which is said to have exceeded Chimborazo in height, but which fell in and became extinct in the latter part of the fifteenth century (fourteen years before the capture of Quito by the son of the Inca Tupac Yupangui), and has never again resumed its former activity.

The space of the chain of the Andes which is not occupied by groups of volcanoes is far greater than is usually supposed. In the northern part of South America, from the Volcan de Ruiz and the conical mountain Tolima, the two most northern volcanoes of the series of New Granada and Quito, over the isthmus of Panama as far as the vicinity of Costa Rica, where the series of volcanoes of Central America commences, there is a country which is frequently and violently convulsed by earthquakes, and in which flaming salses, but no true volcanic eruptions, are known.

The length of this tract amounts to 628 geog. miles. Nearly double this length (occupying a space of 968 geog. miles) is a tract of country free from volcanoes, from the Sangay, the southern termination of the group of New Granada and Quito, to the Chacani, near Arequipa, the commencement of the series of volcanoes of Peru and Bolivia. So complicated and various in the same mountain chain, must have been the coincidence of the conditions upon which depend the formation of permanently open fissures, and the unimpeded communication of the molten interior of the earth with the atmosphere. Between the groups of trachytic and doleritic rocks, through which the volcanic forces become active, lie rather shorter spaces, in which prevail granite, syenite, mica-schists, clay-slates, quartzose porphyries, silicious conglomerates, and limestones, of which (according to Leopold von Buch's investigation of the organic remains brought home by Degenhardt and myself), a considerable portion belong to the chalk formation. The gradually increased frequency of labradoritic rocks, rich in pyroxene and oligoclase, announces to the observant traveller (as I have already elsewhere shown) the transition of a zone hitherto closed and non-volcanic, and often very rich in silver in porphyries, destitute of quartz and full of glassy felspar, into the volcanic regions, which still freely communicate with the interior of the earth.

The more accurate knowledge which we have recently attained of the position and boundaries of the five groups of volcanoes (the groups of Anahuac or tropical Mexico, of Central America, of New Granada, and Quito, of Peru and Bolivia, and of Chili) shows that, in the part of the Cordilleras which extends from $19\frac{1}{4}°$ north, to 46° south latitude, (and, consequently, taking into account the curves caused by alterations in the axial direction, for a distance of nearly 5000 geog. miles,) not much[70] more than half

[70] The following is the result of the determination of the length and latitude of the five groups of linear volcanoes in the chain of the Andes, as also the statement of the distance of the groups from each other: a statement illustrating the relative proportions of the volcanic and non-volcanic areas.

I. *Group of the Mexican Volcanoes:* The fissure upon which the volcanoes have broken out is directed from east to west, from (calculation gives 2540 against 2428 geog. miles) is occupied by volcanoes. If we examine the distribution of the space

the Orizaba to the Colima, for a distance of 392 geog. miles, between latitudes 19° and 19° 20′. The Volcano of Tuxtla lies isolated 128 miles to the east of Orizaba, near the coast of the Gulf of Mexico, and in a parallel (18° 28′) which is half a degree further south.

II. *Distance* of the Mexican group from the next group, that of Central America (from the volcano of Orizaba to the volcano of Soconusco, in the direction E.S.E.—W.N.W.) 300 miles.

III. *Group of the Volcanoes of Central America:* Its length from S.E. to N.W., from the volcano of Soconusco to Turrialva, in Costa Rica, more than 680 miles.

IV. *Distance* of the group of Central America from the series of volcanoes of New Granada and Quito, 628 miles.

V. *Group of the Volcanoes of New Granada and Quito:* Its length from the eruption in the Paramo de Ruiz to the north of the Volcan de Tolima, to the volcano of Sangay, 472 miles. The portion of the chain of the Andes between the volcano of Puracé, near Popayan, and the southern part of the volcanic mountain group of Pasto is directed N.N.E.—S.S.W. Far to the eastward from the volcanoes of Popayan, at the sources of the Rio Fragua, there is a very isolated volcano, which I have inserted upon my general map of the mountain group of the South American Cordilleras, from the statements of missionaries from Timana, which were communicated to me: distance from the sea-shore, 152 miles.

VI. *Distance* of the volcanic group of New Granada and Quito, from the group of Peru and Bolivia, 960 miles, the greatest length destitute of volcanoes.

VII. *Group of the Series of Volcanoes of Peru and Bolivia*, from the Volcan de Chacani and Arequipa to the volcano of Atacama ($16\frac{1}{4}$°—$21\frac{1}{2}$°) 420 miles.

VIII. *Distance* of the group of Peru and Bolivia from the volcanic group of Chili, 540 geog. miles. From the portion of the desert of Atacama, on the border of which the volcano of San Pedro rises, to far beyond Copiapo, even to the volcano of Coquimbo (30° 5′), in the long Cordillera to the west of the two provinces Catamarca and Rioja, there is no volcanic cone.

IX. *Group of Chili*, from the volcano of Coquimbo to the volcano San Clemente, 968 miles.

These estimates of the length of the Cordilleras, with the curvature which results from the change in the direction of the axis, from the parallel of the Mexican volcanoes in $19\frac{1}{4}$° of north latitude, to the volcano of San Clemente in Chili (46° 8′ S. lat.), give for a distance of 4968 miles, a space of 2540 miles which is covered by five linear groups of volcanoes free from volcanoes between the five volcanic groups, we find the maximum distance of two groups from one another between the volcanic series of Quito and Peru. This is fully 960 miles, whilst the most closely approximated groups are the first and second, those of Mexico and Central America. The four interspaces between the five groups are severally 300, 628, 960, and 540 miles. The great distance of the southernmost volcano of Quito from the most northern of Peru, is, at the first glance, the more remarkable, because, according to old custom, we usually term the measurement of degrees upon the high land of Quito, the *Peruvian* measurement. Only a small southern portion of the Peruvian chain of the Andes is volcanic. The number of volcanoes, according to the lists which I have prepared after a careful criticism of the newest materials, is as follows:—

Names of the five groups of linear Volcanoes of the New Continent, from 19° 25′ north, to 46° 8′ south latitude.	No. of Volcanoes included in each group.	No. of Volcanoes which are to be regarded as still ignited.
Group of Mexico[71]	6	4
Group of Central America[72]	29	18
Group of New Granada and Quito[73]	18	10
Group of Peru and Bolivia[74]	14	3
Group of Chili[75]	24	13

(Mexico, Central America, New Granada with Quito, Peru with Bolivia, and Chili); and a space probably quite free from volcanoes of 2428 miles. The two spaces are nearly equal. I have given very definite numerical relations, as obtained by the careful criticism of my own maps and those of others, in order to give rise to a greater desire to improve them. The longest portion of the Cordilleras free from volcanoes is that between the groups of New Granada with Quito and Peru with Bolivia. It is accidentally equal to that occupied by the volcanoes of Chili.

[71] The group of volcanoes of Mexico includes the volcanoes of Orizaba,* Popocatepetl,* Toluca (or Cerro de San Miguel de Tutucuitlapilco), Jorullo,* Colima,* and Tuxtla.* Here, as in similar lists, the still active volcanoes are indicated by asterisks.

According to these data the total number of volcanoes in the five American groups is 91, of which 56 belong to the

[72] The series of volcanoes of Central America is enumerated in the notes 66 and 67.

[73] The group of New Granada and Quito includes the Paramo y Volcan de Ruiz,* the volcanoes of Tolima, Puracé,* and Sotará, near Popayan; the Volcan del Rio Fragua, an affluent of the Caqueta; the volcanoes of Pasto, el Azufral,* Cumbal,* Tuquerres,* Chiles, Imbaburu, Cotocachi, Rucu-Pichincha, Antisana(?), Cotopaxi,* Tungurahua,* Capac-Urcu, or Altar de los Collanes(?), and Sangay.*

[74] The group of Southern Peru and Bolivia, includes from north to south the following 14 volcanoes:—

Volcano of *Chacani* (also called *Charcani*, according to Curzon and Meyen), belonging to the group of Arequipa and visible from the town; it is situated on the right bank of the Rio Quilca, in lat. 16° 11′, according to Pentland, the most accurate geological observer of this region, 32 miles to the south of the Nevado de Chuquibamba, which is estimated at more than 19,000 feet in height. Manuscript records in my possession give the volcano of Chacani a height of fully 19,601 feet. Curzon saw a large crater in the south-eastern part of the summit.

Volcano of *Arequipa*,* lat. 16° 20′, 12 miles to the north-east of the town. With regard to its height (18,879 feet?) see p. 252. Thaddäus Hänke, the botanist of the expedition of Malaspina (1796), Samuel Curzon from the United States of North America (1811) and Dr. Weddell (1847) have ascended the summit. In August, 1831, Meyen saw large columns of smoke rising; a year previously the volcano had thrown out scoriæ, but never lava-streams (Meyen's *Reise um die Erde*, Th. ii, s. 33).

Volcan de Omato, lat. 16° 50′; it had a violent eruption in the year 1667.

Volcan de Uvillas or *Uvinas*, to the south of Apo; its last eruptions were in the sixteenth century.

Volcan de Pichu-Pichu, 16 miles to the east of the town of Arequipa (lat. 16° 25′), not far from the Pass of Cangallo, 9673 feet above the sea.

Volcan Viejo, lat 16° 55′, an enormous crater, with lava-streams and much pumice-stone.

The six volcanoes just mentioned, constitute the group of Arequipa.

Volcan de Tacora or *Chipicani*, according to Pentland's fine map of the lake of Titicaca, lat. 17° 45′, height 19,738 feet.

Volcan de Sahama,* 22,354 feet in height, lat. 18° 7′; a truncated cone of the most regular form; see p. 253. The volcano of Sahama is (according to Pentland) 927 feet higher than the continent of South America. I reckon as volcanoes, besides those which are still burning and active, those volcanic

Chimborazo, but 6650 feet lower than Mount Everest in the Himalaya, which is now regarded as the highest peak of Asia. According to the last official report of Colonel Waugh, of the 1st March, 1856, the four highest mountains of the Himalayan chain are:—*Mount Everest* (Gaurischanka) to the north-east of Katmandu, 29,000 feet,—the *Kuntschinjinga*, to the north of Darjiling, 28,154 feet,—the *Dhaulagiri* (Dhavalagirir), 26,825 feet, and *Tschumalari* (Chamalari), 23,946 feet.

Volcano of *Pomarape*, 21,699 feet, lat. 18° 8′, almost a twin mountain with the following volcano.

Volcano of *Parinacota*, 22,029 feet, lat. 18° 12′.

The group of the four trachytic cones Sahama, Pomarape, Parinacota, and Gualatieri, lying between the parallels of 18° 7′ and 18° 25′, is, according to Pentland's trigonometric measurement, higher than Chimborazo, or more than 21,422 feet.

Volcano of *Gualatieri*,* 21,962 feet, lat. 18° 25′, in the Bolivian province Carangas; very active, according to Pentland (*Hertha*, Bd. xiii, 1829, s. 21).

Not far from the *Sahama-group*, 18° 7′ to 18° 25′, the series of volcanoes and the entire chain of the Andes, which lies to the westward of it, suddenly change their strike, and pass from the direction S.E.—N.W. into that from north to south, which becomes general as far as the Straits of Magellan. I have treated of this important turning point, the notch in the shore near Arica (18° 28′) which has an analogue on the west coast of Africa in the Gulf of Biafra, in the first volume of *Cosmos*, p. 296.

Volcano of *Isluga*, lat. 19° 20′, in the province of Tarapaca, to the west of Carangas.

Volcan de San Pedro de Atacama, on the north-eastern border of the Desierto of the same name, in lat. 22° 16′, according to the new plan of the arid sandy desert (*Desierto*) of Atacama, by Dr. Philippi, 16 miles to the north-east of the small town of San Pedro, not far from the great Nevado de Chorolque.

There is no volcano from 20½° to 30°, and after an interruption of more than 568 miles, the volcanic activity first reappears in the volcano of Coquimbo. For the existence of a volcano of Copiapo (lat. 27° 28′) is denied by Meyen, whilst it is asserted by Philippi, who is well acquainted with the country.

[75] Our geographical and geological knowledge of the group of volcanoes, which we include in the common name of the linear volcanoes of Chili, is indebted for the first incitement to its completion, and even for the completion itself, to the acute investigations of Captain

formations whose old eruptions belong to historic periods, or of which the structure and eruptive masses (craters of

Fitzroy in the memorable expedition of the ships Adventure and Beagle, and to the ingenious and more detailed labours of Charles Darwin. The latter, with his peculiar generalizing view, has grasped the connexion of the phenomena of earthquakes and eruptions of volcanoes under one point of view. The great natural phenomenon which destroyed the town of Copiapo on the 22nd of November, 1822, was accompanied by the upheaval of a considerable tract of country on the coast; and during the exactly similar phenomenon of the 20th February, 1835, which did so much injury to the city of Concepcion, a submarine volcano broke out with fiery eruptions near the shore of the island of Chiloe, near Bacalao Head, and raged for a day and a half. All this, depending upon similar conditions, has also occurred formerly, and strengthens the belief that the series of rocky islands which lies opposite to the *Fjords* of the mainland to the south of Valdivia and of the Fuerte Maullin, and includes Chiloe, the Archipelago of Chonos and Huaytecas, the Peninsula de Tres Montes, and the Islas de la Campana, de la Madre de Dios, de Santa Lucia and los Lobos, from 39° 53′ to the entrance of the Straits of Magellan, is the crest of a submerged western Cordillera projecting above the sea. It is true that no open trachytic cone, no volcano, belongs to these *fractis excequore terris*, but individual submarine eruptions, sometimes followed and sometimes preceded by mighty earthquakes, appear to indicate the existence of this western fissure (Darwin, *On the connexion of volcanic phænomena, the formation of mountain chains, and the effect of the same powers, by which continents are elevated:* in the *Trans. Geol. Society*, 2nd series, vol. v, pt. 3, 1840, pp 606—615, and 629—631; Humboldt, *Essai Politique sur la Nouvelle Espagne*, t. i. p. 190, and t. ii. p. 287).

The series of 24 volcanoes included in the group of Chili is as follows, counting from north to south, from the parallel of Coquimbo to 46° S. lat. :—

(*a.*) *Between the parallels of Coquimbo and Valparaiso*:—

Volcan de Coquimbo (lat. 30° 5′); Meyen, th. i. s. 385.

Volcano of *Limari*.

Volcano of *Chuapri*.

Volcano of *Aconcagua**, W.N,W., of Mendoza, lat. 32° 39′; altitude 23,004 feet, according to Kellet (See p. 253, note), but according to the most recent trigonometric measurement of the engineer Amado Pissis (1854), only 22,301 feet; consequently, rather lower than the Sahama, which Pentland now assumes to be 22,350 feet (Gillis, *U.S. Naval Astron. Exped. to Chili*, vol. i. p. 13). The geodetic basis of measurement of Aconcagua at 6797 metres, which required eight triangles, has been developed by M. Pissis, in the *Anales de la Universidad de Chile*, 1852, p. 219.

elevation and eruption, lavas, scoriæ, pumice-stones and obsidians) characterise them, without reference to any tra-

The Peak of *Tupungato* is stated by Gilliss to be 22,450 English, or 21,063 Paris, feet in height, and in lat. 33° 22′; but in the map of the province of Santiago by Pissis (Gilliss, p. 45), it is estimated at 22,016 English, or 20,655 Paris, feet. The latter number is retained (as 6710 metres) by Pissis in the *Anales de Chile*, 1850, p. 12.

(*b*.) *Between the parallels of Valparaiso and Concepcion:*

Volcano of *Maypu**, according to Gilliss (vol. i, p. 13), in lat. 34° 17′, (but in his general map of Chili, 33° 47′, certainly erroneously), and 17,662 feet in height. Ascended by Meyen. The trachytic rock of the summit has broken through upper jurassic strata, in which Leopold von Buch detected *Exogyra Couloni*, *Trigonia costata* and *Ammonites biplex* from elevations of 9600 feet (*Description Physique des Iles Canaries*, 1836, p. 471). No lava streams, but eruptions of flame and scoriæ from the crater.

Volcano of *Peteroa**, to the east of Talca, in lat. 34° 53′; a volcano which is frequently in activity, and which, according to Molina's description, had a great eruption on the 3rd December, 1762. It was visited in 1831 by the highly-gifted naturalist, Gay.

Volcan de Chillan, lat. 36° 2′; a region which has been described by the missionary Havestadt of Münster. In its vicinity is situated the Nevado Descabezado (35° 1′), which was ascended by Domeyko, and which Molina declared (erroneously) to be the highest mountain of Chili. Its height has been estimated by Gilliss at 13,100 feet (*U.S. Naval Astr. Exped.*, 1855, vol. i. pp. 16 and 371).

Volcano of *Tucapel*, to the west of the city of Concepcion; also called Silla Veluda; perhaps an unopened trachytic mountain, which is in connection with the active volcano of Antuco.

(*c*) *Between the parallels of Concepcion and Valdivia:*

Volcano of *Antuco**, lat. 37° 7′; geognostically described in detail by Pöppig; a basaltic crater of elevation, from the interior of which a trachytic cone ascends, with lava-streams, which break out at the foot of the cone, and more rarely from the crater at the summit (Pöppig, *Reise in Chile and Peru*, Bd. i. s. 364). One of these streams was still flowing in the year 1828. The indefatigable Domeyko found the volcano in full activity in 1845, and its height only 8920 feet (Pentland, in Mary Somerville's *Physical Geography*, vol. i. p. 186). Gilliss states the height at 9242 feet, and mentions new eruptions in the year 1853. According to intelligence communicated to me by the distinguished American astronomer, Gilliss, a new volcano rose out of the depths in the interior of the Cordillera between Antuco and the Descabezado on the 25th of November, 1847, forming a hill* of 320 feet. The sulphureous and fiery eruptions were seen for more than a year dition, as volcanoes which have long been extinct. Unopened trachytic cones and domes, or unopened long trachytic ridges, such as Chimborazo and Iztaccihuatl, are excluded. This is also the sense given to the word *volcano* by Leopold von Buch, Charles Darwin, and Friedrich Naumaun in their geographical narratives. I give the name of still active volcanoes to those which when seen from their immediate vicinity, still exhibit signs of greater or less degrees of their activity, and some which have also presented great and well-attested eruptions in recent times. The qualification "seen from their immediate vicinity," is of great importance, as the present existence of activity is denied to many volcanoes, because, when observed from the plain, the thin vapours, which ascend from the crater at a great height, remain invisible to the eye. Thus it was even denied, at the time of my American travels, that Pichincha and the great volcano of Mexico (Popocatepetl) were still active although an enter-

by Domeyko. Far to the eastward of the volcano of Antuco, in a parallel chain of the Andes, Pöppig states that there are two other active volcanoes,—Punhamuidda* and Unalavquen*.

Volcano of *Callaqui*.

*Volcan de Villarica**, lat. 39° 14′.

Volcano of *Chiñal*, lat. 39° 35′.

*Volcan de Panguipulli**, lat. 40¾°, according to Major Philippi.

(*d*) *Between the Parallels of Valdivia and the southernmost Cape of the Island of Chiloe:*

Volcano of *Ranco*.

Volcano of *Osorno* or *Llanquihue*; lat. 41° 9′; height 7443 feet.

Volcan de Calbuco,* lat. 41° 12′.

Volcano of *Guanahuca* (Guanegue?)

Volcano of *Minchinmadom*, lat. 42° 48′, height 7993 feet.

Volcan del Corcovado,* lat. 43° 12′, height 7509 feet.

Volcano of *Yanteles* (Yntales), lat. 43° 29′, height 8030 feet.

Upon the last four volcanoes, see Captain Fitzroy, *Exped. of the Beagle*, vol. iii, p. 275, and Gilliss, vol. i, p. 13.

Volcano of *San Clemente*, opposite to the Peninsula de Tres Montes, which consists, according to Darwin, of granite, lat. 46° 8′. On the great map of South America, by La Cruz, a more southern volcano de los Gigantes is given, opposite the Archipelago de la Madre de Dios, in lat. 51° 4′. Its existence is very doubtful.

The latitudes in the foregoing table of volcanoes are for the most part derived from the maps of Pissis, Allan Campbell, and Claude Gay, in the admirable work of Gilliss (1855).

prising traveller, Sebastian Wisse,[76] counted 70 still burning orifices (fumaroles) around the great active cone of eruption in the crater of Pichincha; and I was myself a witness,[77] at the foot of the volcano in the Malpais del Llano de Tetimpa, in which I had to measure a base-line, of an extremely distinct eruption of ashes from Popocatepetl.

In the series of volcanoes of New Granada and Quito, which in 18 volcanoes includes 10 that are still active, and is about twice the length of the Pyrenees, we may indicate, from north to south as four smaller groups or subdivisions:—the Paramo de Ruiz and the neighbouring volcano of Tolima (latitude, according to Acosta, 4° 55′ N.); Purace and Sotara, near Popayan (lat. 2¼°); the Volcanes de Pasto, Tuquerres and Cumbal (lat. 2° 20′ to 0° 50′); and the series of volcanoes from Pichincha, near Quito, to the unintermittently active Sangay (from the equator to 2° South latitude). This last subdivision of the active group is not particularly remarkable amongst the volcanoes of the New World, either by its great length, or by the closeness of its arrangement. We now know, also, that it does not include the highest summit, for the Aconcagua in Chili (lat. 32° 39′), of 23,003 feet, according to Kellet, 23,909 feet, according to Fitzroy and Pentland, besides the Nevados of Sahama (22,349 feet), Parincota (22,030 feet), Gualateiri (21,962 feet), and Pomarape (21,699 feet), all from between 18° 7′ and 18° 25′ south latitude, are regarded as higher than Chimborazo (21,422 feet). Nevertheless, of all the volcanoes of the new continent, the volcanoes of Quito enjoy the most widely spread renown, for to these mountains of the chain of the Andes, to this high land of Quito, attaches the memory of those assiduous astronomical, geodetical, optical, and barometrical labours, directed to important ends, which are associated with the illustrious names of Bouguer and La Condamine. Wherever intellectual tendencies prevail, wherever a rich harvest of ideas has been excited, leading to the advancement of several sciences at the same time, fame remains as it were locally attached for a long time. Such fame has in like manner belonged to Mont Blanc in the Swiss Alps,—not on account

[76] Humboldt, *Kleinere Schriften*, Bd. i, s. 90.

[77] 24th of January, 1804. See my *Essai Politique sur la Nouvelle Espagne*, t. i, p. 166.

of its height, which only exceeds that of Monte Rosa by about 557 feet,—not on account of the danger overcome in its ascent,—but on account of the value and multiplicity of the physical and geological views which ennoble Saussure's name, and the scene of his untiring industry. Nature appears greatest where, besides its impression on the senses, it is also reflected in the depths of thought.

The series of volcanoes of Peru and Bolivia, still entirely belonging to the equinoctial zone, and according to Pentland, only covered with perpetual snow at an elevation of 16,945 feet (Darwin, Journal, 1845, p. 244), attains the maximum of its elevation (22,349 feet) at about the middle of its length in the Sahama group, between 18° 7′ and 18° 25′ south latitude. There, in the neighbourhood of Arica, appears a singular, bay-like bend of the shore, which corresponds with a sudden alteration in the axial direction of the chain of the Andes, and of the series of volcanoes lying to the west of it. Thence, towards the south, the coast line, and also the volcanic fissure, no longer strike from south-east to north-west, but in the direction of the meridian, a direction which is maintained until near the western entrance into the Straits of Magellan, for a distance of more than two thousand miles. A glance at the map of the ramifications and groups of mountains of the chain of the Andes, published by me in the year 1831, exhibits many other similar agreements between the outline of the New Continent, and the near or distant Cordilleras. Thus between the promontories of Aguja and San Lorenzo ($5\frac{1}{2}$° to 1° south latitude), both the coast line of the Pacific and the Cordilleras are directed from south to north, after being directed so long from south-east to north-west, between the parallels of Arica and Caxamarca; and in the same way the coast-line and the Cordilleras run from south-west to north-east, from the mountain group of Imbaburu, near Quito, to that of los Robles,[78] near Popayan.

[78] The mica schist mountain group de los Robles (lat. 2° 2′) and of the Paramo de las Papas (lat. 2° 20′) contains the Alpine lakes, Laguna de S. Iago and L. del Buey, scarcely six miles apart; from the former springs the Cauca, and from the latter the Magdalena, which, being soon separated by a central mountain chain, only unite with each other in the parallel of 9° 27′, in the plains of Mompox and Tenerife. The above-mentioned mountain group between Popayan, Almaguer, and Timana is of great importance in connection with the geological question whether

With regard to the geological causal connection of the agreement, which is so often manifested between the outlines of

the volcanic chain of the Andes of Chili, Peru, Bolivia, Quito, and New Granada, be connected with the mountain chain of the Isthmus of Panama, and in this way with that of Veragua and the series of volcanoes of Costa Rica and Central America in general. In my maps of 1816, 1827, and 1831, the mountain-systems of which have been made more generally known by Brué in Joaquin Acosta's fine map of New Granada (1847) and in other maps, I have shown how the chain of the Andes undergoes a triple division under the northern parallel of 2° 10′; the western Cordillera running between the valley of the Rio Cauca and the Rio Atrato; the middle one between the Cauca and the Rio Magdalena; and the eastern one between the valley of the Magdaléna and the Llanos (plains) which are watered by the affluents of the Marañon and Orinoco. I have been able to indicate the special direction of these three Cordilleras from a great number of points which fall in the series of astronomical local determinations, of which I obtained 152 in South America alone by culminations of stars.

To the east of the Rio Dagua, and to the west of Cazeres, Roldanilla, Toro, and Anserma, near Cartago, the western Cordillera runs S.S.W.—N.N.E., as far as the Salto de San Antonio in the Rio Cauca (lat. 5° 14′) which lies to the south-west of the Vega de Supia. Thence, as far as the Alto del Viento (Cordillera de Abibe, or Avidi, lat. 7° 12′) 9600 feet in height, the chain increases considerably in elevation and bulk, and amalgamates, in the province of Antioquia, with the intermediate or Central Cordillera. Further to the north, towards the sources of the Rios Lucio and Guacuba, the chain ceases, dividing into ranges of hills. The *Cordillera occidental*, which is scarcely 32 miles from the coast of the Pacific near the mouth of the Dagua in the Bahia de San Buenaventura (lat. 3° 50′) is twice this distance in the parallel of Quibdo in the Choco (lat. 5° 48′). This observation is of some importance, because we must not confound with the western chain of the Andes, the country with high hills, and the range of hills, which in this province, so rich in gold dust, runs from south to north from Novita and Tado along the right bank of the Rio San Juan and the left bank of the great Rio Atrato. It is this inconsiderable series of hills that is intersected in the Quebrada de la Raspadura, by the canal of Raspadura (*Canal des Mönches*), which unites two rivers (the Rio San Juan or Noanama and the Rio Quibdo, a tributary of the Atrato) and by their means two oceans (Humboldt, *Essai Politique*, t. i, p. 235); it was this also which was seen in the instructive expedition of Captain Kellet between the Bahia de Cupica (lat. 6° 42′) long and fruitlessly extolled by me, and the sources of the Napipi, which falls into the Atrato. (See Humboldt, *Op. cit.* t. i, p. 231; and Robert Fitzroy, *Considerations on the Great Isthmus of Central America*, in the *Journal of the Royal Geogr. Soc.* vol. xx, 1851, pp. 178, 180, and 186).

The middle chain of the Andes (*Cordillera Central*), constantly the highest, reaching within the limit of perpetual snow, and in its entire continents and the direction of near mountain chains (South America, Alleghanys, Norway, Apennines), it appears difficult to come to any decision.

extent, directed nearly from south to north, like the western chain, commences about 35 miles to the north-east of Popayan with the Paramos of Guanacos, Huila, Iraca, and Chinche. Further on towards the north, between Buga and Chaparral, rise the elongated ridge of the Nevado de Baraguan (lat. 4° 11′), la Montaña de Quindio, the snow-capped, truncated cone of Tolima, the Volcano and Paramo de Ruiz and the Mesa de Herveo. These high and rugged mountain deserts, to which the name of *Paramos* is applied in Spanish, are distinguished by their temperature and a peculiar character of vegetation, and rise in the part of the tropical region which I here describe, according to the mean of many of my measurements, from 10,000 to 11,700 feet above the level of the sea. In the parallel of Mariquita, of the Herveo and the Salto de San Antonio, in the valley of the Cauca, there commences a union of the western and central chains, of which mention has already been made. This amalgamation becomes most remarkable between the above-mentioned Salto and the Angostura and Cascada de Caramanta, near Supia. Here is situated the high land of the province of Antioquia, so difficult of access, which extends, according to Manuel Restrepo, from $5\frac{1}{4}$° to 8° 34′; in this we may mention as points of elevation from south to north: Arma, Sonson, to the north of the sources of the Rio Samana: Marinilla, Rio Negro (6844 feet), and Medellin (4847 feet); the plateau of Santa Rosa (8466 feet) and Valle de Osos. Further on, beyond Cazeres and Zaragoza, towards the confluence of the Cauca and Nechi, the true mountain chain disappears, and the eastern slope of the Cerros de San Lucar, which I saw from Badillas (lat. 8° 1′), and Paturia (lat. 7° 36′), during my navigation and survey of the Magdalena, is only perceptible from its contrast with the broad river-plain.

The eastern Cordillera possesses a geological interest in as much as it not only separates the whole northern mountain system of New Granada from the lowland, from which the waters flow partly by the Caguan and Caqueta to the Amazons, and partly by the Guaviare, Meta, and Apure to the Orinoco, but also unites itself most distinctly with the littoral chain of Caraccas. What is called in systems of veins a *raking* takes place there,—a union of mountain chains which have been elevated upon two fissures of very different directions, and probably even at very different times. The eastern Cordillera departs far more than the two others from a meridional direction, diverging towards the north-east, so that at the snowy mountains of Merida (lat. 8° 10′) it already lies 5 degrees of longitude further to the east, than at its issue from the mountain group de los Robles, near the Ceja and Timana. To the north of the Paramo de la Suma Paz, to the east of the Purificacion, on the western declivity of the Paramo of Chingaza, at an altitude of only 8760 feet, rises, over an oak forest, the fine but treeless and stern plateau of Bogota (lat. 4° 36′). It occupies about 288 geog. square miles and its position presents a remarkable similarity to that of the basin

Although, in the series of volcanoes of Bolivia and Chili, the western branch of the chain of the Andes, which approaches nearest to the Pacific, at present exhibits the greater part of the traces of still existing volcanic activity, yet, a very experienced observer, Pentland, has discovered, at the foot of the eastern chain, more than 180 geog. miles from the sea-coast, a perfectly preserved, but extinct crater, with unmistakeable lava-streams. This is situated upon the summit of a conical mountain, near San Pedro de Cacha, in

of Cashmere, which, however, according to Victor Jacquemont, is about 3410 feet lower at the Wuller lake, and belongs to the south-western declivity of the Himalayan chain. The plateau of Bogota and the Paramo de Chingaza, are followed in the eastern Cordillera of the Andes towards the north-east by the Paramos of Guachaneque, above Tunja; of Zoraca, above Sogamoso; of Chita (16,000 feet ?), near the sources of the Rio Casanare, a tributary of the Meta; of the Almorzadera (12,854 feet), near Socorro; of Cacota (10,986 feet), near Pamplona; of Laura and Porquera near la Grita. Here, between Pamplona, Salazar, and Rosario (between lat. 7° 8′ and 7° 50′) is situated the small mountain group, from which a crest extends from south to north towards Ocaña and Valle de Upar, to the west of the Laguna de Maracaibo, and unites with the most advanced mountains of the Sierra Nevado de Santa Marta (19,000 feet?). The more elevated and vaster crest continues in the original north-easterly direction towards Merida, Truxillo, and Barquisimeto, to unite there, to the eastward of the Laguna de Maracaibo, with the granitic littoral chain of Venezuela, to the west of Puerto Cabello. From the Grita and the Paramo de Porquera the eastern Cordillera rises again at once to an extraordinary height. Between the parallels of 8° 5′ and 9° 7′, follow the Sierra Nevada de Merida (Mucuchies) examined by Boussingault and determined by Codazzi trigonometrically at 15,069 feet; and the four Paramos de Timotes, Niquitao, Boconó, and de las Rosas, full of the most beautiful Alpine plants. (See Codazzi, *Resúmen de la Geografia de Venezuela*, 1841, pp. 12 and 495; and also my *Asie Centrale*, t. iii, pp. 258—262, with regard to the elevation of the perpetual snow in this zone.) The western Cordillera is entirely wanting in volcanic activity, which is peculiar to the central Cordillera as far as the Tolima and Paramo de Ruiz, which, however, are separated from the volcano of Puracé by nearly three degrees of latitude. The eastern Cordillera has a smoking hill near its eastern declivity, at the origin of the Rio Fragua, to the north-east of Mocoa and south-east of Timana, at a greater distance from the shore of the Pacific, than any other still active volcano of the New World. An accurate knowledge of the local relations of the volcanoes to the arrangement of the mountain chains is of the highest importance for the completion of the geology of volcanoes. All the older maps, with the single exception of that of the high land of Quito, can only lead to error.

the valley of Yucay, at an elevation of nearly 12,000 feet (lat. 14° 8′, long. 71° 20′), south-east from Cuzco, where the eastern snowy chain of Apolobamba, Carabaya, and Vilcanoto extends from south-east to north-west. This remarkable point[79] is marked by the ruins of a famous temple of the Inca Viracocha. The distance from the sea of this old lava-producing volcano is far greater than that of Sangay, which also belongs to an eastern Cordillera, and greater than that of Orizaba and Jorullo.

An interval of 540 miles destitute of volcanoes separates the series of volcanoes of Peru and Bolivia from that of Chili. This is the distance of the eruption in the desert of Atacama from the volcano of Coquimbo. At 2° 34′ further to the south, as already remarked, the group of volcanoes of Chili attains its greatest elevation in the volcano of Aconcagua (23,003 feet), which, according to our present knowledge, is also the maximum of all the summits of the new Continent. The average height of the Sahama group is 22,008 feet; consequently 586 feet higher than Chimborazo. Then follow, diminishing rapidly in elevation, Cotopaxi, Arequipa (?), and Tolima, between 18,877 and 18,129 feet in height. I give, in apparently very exact numbers, and without alteration, the results of measurements which are unfortunately compounded from barometrical and trigonometrical determinations, because in this way the greatest inducement will be given to the repetition of the measurements and correction of the results. In the series of volcanoes of Chili, of which I have cited 24, it is unfortunately for the most part only the southern and lower ones, from Antuco to Yantales, between the parallels of 37° 20′ and 43° 40′, that have been hypsometrically determined. These have the inconsiderable elevation of from six to eight thousand feet. Even in Tierra del Fuego itself the summit of the Sarmiento, covered with perpetual snow, only rises, according to Fitzroy, to 6,821 feet. From the volcano of Coquimbo to that of San Clemente the distance is 968 miles.

[79] Pentland, in Mrs. Somerville's *Physical Geography* (1851), vol. i, p. 185. The Peak of Vilcanoto (17,020 feet), situated in lat. 14° 28′, forming a portion of the vast mountain group of that name, closes the northern extremity of the plateau, in which the lake of Titicaca, a small inland sea of 88 miles in length, is situated.

With regard to the activity of the volcanoes of Chili, we have the important testimony of Charles Darwin,[80] who refers very decidedly to Osorno, Corcovado, and Aconcagua as being ignited; the evidence of Meyen, Pöppig, and Gay, who ascended Maipu, Antuco and Peteroa; and that of Domeyko, the astronomer Gilliss, and Major Philippi. The number of active craters may be fixed at thirteen, only five fewer than in the group of Central America.

From the five groups of serial volcanoes of the New Continent, which we have been able to describe from astronomical local determinations, and for the most part also hypsometrically as to position and elevation, let us now turn to the Old Continent, in which, in complete opposition to the New World, the greater part of the approximated volcanoes belong not to the mainland but to the islands. Most of the European volcanoes are situated in the Mediterranean Sea, and indeed (if we include the great and repeatedly active crater between Thera, Therasia, and Aspronisi), in the Tyrrhenian and Ægæan parts; in Asia the most mighty volcanoes are situated to the south and east of the continent on the large and small Sunda Islands, the Moluccas, and the Philippines, in Japan, and the Archipelagoes of the Kurile and Aleutian Islands.

In no other region of the earth's surface do such frequent and such fresh traces of the active communication between the interior and exterior of our planet show themselves, as upon the narrow space of scarcely 12,800 geographical (16,928 English) square miles between the parallels of 10° south and 14° north latitude, and between the meridians of the southern point of Malacca and the western point of the Papuan peninsula of New Guinea. The area of this volcanic island-world scarcely equals that of Switzerland, and is washed by the seas of Sunda, Banda, Solo, and Mindorö. The single island of Java contains a greater number of active volcanoes than the entire southern half of America, although this island is only 544 miles in length, that is, only one-seventh of the length of South America. A new but long-expected light has recently been diffused over the geognostic nature of Java (after previous very imperfect but meritorious works by

[80] See Darwin, *Journal of Researches in Natural History and Geology during the Voyage of the Beagle*, 1845, pp. 275, 291, and 310.

Horsfield, Sir Thomas Stamford Raffles and Reinwardt), by a learned, bold, and untiringly active naturalist, Franz Junghuhn. After a residence of more than twelve years he has given the entire natural history of the country in an instructive work, *Java, its form, vegetable covering, and internal structure.* More than 400 elevations are carefully determined barometrically; the volcanic cones and bell-shaped mountains, 45 in number, are represented in profile, and all but three[81] of them were ascended by Junghuhn. More than half (at least 28) were found to be still burning and active; their remarkable and various profiles are described with extraordinary clearness, and even the attainable history of their eruptions is investigated. No less important than the volcanic phenomena of Java are its sedimentary formations of the Tertiary period, which were entirely unknown to us before the appearance of the complete work just mentioned, although they cover three-fifths of the entire area of the island, especially in the southern parts. In many districts of Java there occur, as the remains of former widely-spread forests, fragments, from three to seven feet in length, of silicified trunks of trees, which all belong to the Dicotyledons. For a country in which at present an abundance of palms and tree ferns grows, this is the more remarkable, because in the Miocene tertiary rocks of the brown-coal formation of Europe, where arborescent Monocotyledons no longer thrive, fossil palms are not unfrequently met with.[82] By a diligent collection of the impressions of leaves and fossilized woods, Junghuhn has been enabled to give us, as the first example of the fossil Flora of a purely tropical region, the ancient Flora of Java, ingeniously elaborated by Göppert from his collection.

As regards the elevation to which they attain, the volcanoes of Java are far inferior to those of the three groups

[81] Junghuhn, *Java*, Bd. i, s. 79.

[82] *Op. cit.* Bd. iii, s. 155, and Göppert, *Die Tertiärflora auf der Insel Java nach den Entdeckungen von Fr. Junghuhn* (1854), s. 17. The absence of Monocotyledons is, however, peculiar to the silicified trunks of trees lying scattered upon the surface, and especially in the rivulets of the district of Bantam; in the subterranean carbonaceous strata, on the contrary, there are remains of palm-wood, belonging to two genera (*Flabellaria* and *Amesoneuron*). See Göppert, s. 31 and 35.

of Chili, Bolivia, and Peru, and even to those of the two groups of Quito with New Granada, and of Tropical Mexico. The maxima attained by these American groups are:—For Chili, Bolivia, and Quito, 21,000 to 23,000 feet, and for Mexico, 18,000 feet. This is nearly ten thousand feet (about the height of Etna), more than the greatest elevation of the volcanoes of Sumatra and Java. On the latter island the highest still burning colossus is the Gunung Semeru, the culminating point of the entire Javanese series of volcanoes. Junghuhn ascended this in September, 1844; the average of his barometric measurements gave 12,233 feet above the surface of the sea, and consequently 1748 feet more than the summit of Etna. At night the centigrade thermometer fell below 6°.2 (43°.2 Fahr.). The old Sanscrit name of Gunung Semeru was *Mahâ-Mêru* (the great Meru); a reminiscence of the time when the Malays received Indian civilisation,—a reminiscence of the Mountain of the World in the north, which, according to the Mahabharata, is the dwelling-place of Brahma, Vishnu, and the seven Dêvarschi.[83] It is remarkable that, as the natives of the plateau of Quito had guessed, before any measurement, that Chimborazo surpassed all the other snowy mountains in the country, the Javanese also knew that the Holy Mountain Mahâ-Mêru, which is but at a short distance from the Gunung Ardjuno (11,031 feet) exhibited the maximum of elevation upon the island, and yet, in this case, in a country free from snow, the greater distance of the summit from the level of the lower limit of perpetual snow could no more serve as a guide to the judgment than the height of an occasional temporary fall of snow.[84]

The elevation of the Gunung Semeru, which exceeds 11,000 (11,726 English) feet, is most closely approached by four other mountains, which were found hypsometrically to be between ten and eleven thousand feet. These are: Gunung[85] Slamat, or mountain of Tegal (11,116

[83] Upon the signification of the word *Mêru*, and the conjectures which Burnouf communicated to me regarding its connection with *mîra* (a Sanscrit word for *sea*), see my *Asie Centrale*, t. i, pp. 114—116, and Lassen's *Indische Alterthumskunde*, Bd. i, s. 847. The latter is inclined to regard the names as not of Sanscrit origin.

[84] See page 240.

[85] *Gunung* is the Javanese word for mountain, in Malayan, *gûnong*.

feet), Gunung Ardjuno (11,031 feet), Gunung Sumbing (11,029 feet), and Gunung Lawu (10,726 feet). Seven other volcanoes of Java attain a height of nine or ten thousand feet; a result which is of the more importance as no summit of the island was formerly supposed to rise higher than six thousand feet.[86] Of the five groups of North and South American volcanoes, that of Guatemala (Central America) is the only one exceeded in *mean* elevation by the Javanese group. Although in the vicinity of Old Guatemala the Volcan del Fuego attains a height of 13,109 feet (according to the calculation and reduction of Poggendorff), and therefore 874 feet more than Gunung Semeru, the remainder of the Central American series of volcanoes only varies between five and seven thousand feet, and not as in Java between seven and ten thousand feet. The highest volcano of Asia is not, however, to be sought in the Asiatic Islands (the Archipelago of the Sunda Islands), but upon the continent; for upon the peninsula of Kamtschatka the volcano Kljutschewsk rises to 15,763 feet, or nearly to the height of the Rucu-Pichincha, in the Cordilleras of Quito.

which singularly enough is not further disseminated over the enormous domain of the Malayan language; see the comparative table of words in my brother's work upon the Kawi language, vol. ii, s. 249, No. 62. As it is the custom to place this word *gunung* before the names of mountains in Java, it is usually indicated in the text by a simple G.

[86] Leopold de Buch, *Description Physique des Iles Canaries*, 1836, p. 419. Not only has Java (Junghuhn, Th. i. s. 61, and Th. ii. s. 547) a colossal mountain, the Semeru of 12,233 feet, which consequently exceeds the Peak of Teneriffe a little in height, but an elevation of 12,256 feet is also attributed to the Peak of Indrapura, in Sumatra, which is also still active, but does not appear to have been so accurately measured (Th. i, s. 78, and profile Map No. 1). The next to this in Sumatra, are the dome of Telaman, which is only one of the summits of Ophir (not 13,834, but only 9603 feet in height), and the Merapi (according to Dr. Horner, 9571 feet) the most active of the thirteen volcanoes of Sumatra, which, however, (Th. ii. s. 294, and Junghuhn's *Battaländer*, 1847, Th. i, s. 25) is not to be confounded, from the similarity of the names, with two volcanoes of Java,—the celebrated Merapi, near Jogjakerta (9208 feet), and the Merapi, which forms the eastern portion of the summit of the volcano Idjen (8595 feet). In the Merapi, it is thought that the holy name *Mêru* is again to be detected, combined with the Malayan and Javanese word *api*, fire.

The principal axis[87] of the closely approximated series of the Javanese volcanoes (more than 45 in number) has a direction W.N.W.—E.S.E. (exactly W. 12° N.), and therefore principally parallel to the series of volcanoes of the eastern part of Sumatra, but not to the longitudinal axis of the island of Java. This general direction of the chain of volcanoes by no means excludes the phenomenon to which attention has very recently been directed in the great chain of the Himalaya, that three or four individual high summits are so arranged together, that the small axes of these partial series form an oblique angle with the primary axis of the chain. This phenomenon of fissure, which has been observed and partially described[88] by Hodgson, Joseph Hooker, and Strachey, is of great interest. The small axes of the subsidiary fissures meet the great axis, sometimes almost at a right angle, and even in volcanic chains, the actual maxima of elevation are often situated at some distance from the major axis. As in most linear volcanoes, no definite proportion is observed in Java, between the elevation and the size of the crater at the summit. The two largest craters are those of Gunung Tengger and Gunung Raon. The former of these is a mountain of the third class, only 8704 feet in height. Its circular crater is, however, more than 21,315 feet, and therefore nearly four geographical miles in diameter. The flat bottom of the crater is a sea of sand, the surface of which lies 1865 feet below the highest point of the surrounding wall, and in which scoriaceous lava-masses project here and there from the layer of pounded rapilli. Even the enormous crater of Kirauea, in Owhyhee, which is filled with glowing lava, does not, according to the accurate trigonometrical survey of Captain Wilkes, and the excellent observations of Dana, attain the size of that of Gunung Tengger. In the middle of the crater of the latter there rise four small cones of eruption, actual circumvallated funnel-shaped chasms, of which only one, *Bromo* (the mythical name Brahma, a word which has the signification of *fire*, in the Kawi although

[87] Junghuhn, *Java,* Bd. i. s. 80.

[88] See Joseph Hooker, *Sketch-Map of Sikhim,* 1850, and in his *Himalayan Journals,* vol. i, 1854, Map of part of Bengal; and also Strachey, *Map of West-Nari,* in his *Physical Geography of Western Tibet,* 1853.

not in the Sanscrit), is now not active. Bromo presents the remarkable phenomenon that from 1838 to 1842 a lake was formed in its funnel, of which Junghuhn has proved that it owes its origin to the influx of atmospheric waters, which have been heated and acidulated by the simultaneous penetration of sulphurous vapours.[89] Next to Gunung Tengger, Gunung Raon has the largest crater, but the diameter of this is about one-half less. The view into the interior is awe-inspiring. It appears to extend to a depth of more than 2398 feet; and yet the remarkable volcano, 10,178 feet in height, which Junghuhn has ascended and so carefully described,[90] is not even named on the meritorious map of Raffles.

Like almost all linear volcanoes, the volcanoes of Java exhibit the important phenomenon, that a simultaneity of great eruptions is observed much more rarely in nearly approximated cones, than in those which are widely separated. When, in the night of the 11th and 12th of August, 1772, the volcano Gunung Pepandajan (7034 feet) burst forth the most destructive eruption that has taken place upon the island within historical periods, two other volcanoes, the Gunung Tjerimaï and Gunung Slamat, became ignited on the same night, although they lie in a straight line at a distance of 184 and 352 miles from Pepandajan.[91] Even if the volcanoes of a series all stand over one focus, the net of fissures through which they communicate is, nevertheless, certainly so constituted that the obstruction of old vapour-channels,

[89] Junghuhn, *Java*, Bd. ii, fig. ix. s. 572, 596, and 601—604. From 1829 to 1848, the small crater of eruption of the Bromo had eight fiery eruptions. The crater-lake, which had disappeared in 1842, had been again formed in 1848, but according to the observations of B. van Herwerden, the presence of the water in the chasm of the cauldron had no effect in preventing the eruption of red-hot, widely-scattered scoriæ.

[90] Junghuhn, Bd. ii. s. 624—641.

[91] The G. Pepandajan was ascended in 1819 by Reinwardt, and in 1837 by Junghuhn. The latter, who has accurately investigated the vicinity of the mountain, consisting of detritus intermingled with numerous angular, erupted blocks of lava, and compared it with the earliest reports, regards the statement, which has been disseminated by so many valuable works, that a portion of the mountain and an area of several square miles sank during the eruption of 1772, as greatly exaggerated (Junghuhn, Bd. ii. s. 98 and 100).

or the temporary opening of new ones, in the course of ages, render simultaneous eruption at very distant points quite conceivable. I may again advert to the sudden disappearance of the column of smoke which ascended from the volcano of Pasto, when, on the morning of the 4th of February, 1797, the fearful earthquake of Riobamba convulsed the plateau of Quito between Tunguragua and Cotopaxi.[92]

To the volcanoes of the island of Java generally, a character of *ribbed* formation is ascribed, to which I have seen nothing similar in the Canary Islands, in Mexico, or in the Cordilleras of Quito. The most recent traveller, to whom we are indebted for such admirable observations upon the structure of the volcanoes, the geography of plants, and the psychrometric conditions of moisture, has described the phenomenon to which I here allude with such decided clearness that I must not omit to call attention to this regularity of form, in order to furnish an inducement to new investigations. "Although," says Junghuhn, "the surface of a volcano 10,974 feet in height, the Gunung Sumbing, when seen from some distance, appears as an uninterruptedly smooth and sloping face of the conical mountain, still, on a closer examination, we find that it consists entirely of separate longitudinal ridges or ribs, which gradually subdivide and become broader as they advance downwards They run from the summit of the volcano, or more frequently from an elevation several hundred feet below the summit, down to the foot of the mountain, diverging like the ribs of an umbrella." These rib-like longitudinal ridges have sometimes a tortuous course for a short distance, but are all formed by approximated clefts of three or four hundred feet in depth, all directed in the same way, and becoming broader as they descend. They are furrows of the surface "which occur on the lateral slopes of all the volcanoes of the island of Java, but differ considerably from each other upon the various conical mountains, in their average depth and the distance of their upper origin from the margin of the crater or from an unopened summit. The Gunung Sumbing (11,029 feet) is one of those volcanoes which exhibit the finest and most regularly formed

[92] *Cosmos,* vol. v, p. 183, and *Voyage aux Régions Equinox,* t. ii, p. 16.

ribs, as the mountain is bare of forest trees and clothed with grass." According to the measurements given by Junghuhn,[93] the number of ribs increases by division in proportion as the declivity decreases. Above the zone of 9000 feet there are, on Gunung Sumbing, only about 10 such ribs; at an elevation of 8,500 feet there are 32; at 5500 feet, 72; and at 3,000 feet, more than 95. The angle of inclination at the same time diminishes from 37° to 25° and 10½°. The ribs are almost equally regular on the volcano Gunung Tengger (8702 feet), whilst on the Gunung Ringgit they have been disturbed and covered[94] by the destructive eruptions which followed the year 1586. "The production of these peculiar longitudinal ribs and the mountain fissures lying between them, of which drawings are given, is ascribed to erosion by streams."

It is certain that the mass of meteoric water in this tropical region is three or four times greater than in the temperate zone, indeed the showers are often like waterspouts, for although, on the whole, the moisture diminishes with the elevation of the strata of air, the great mountain cones exert on the other hand a peculiar attraction upon the clouds, and, as I have already remarked, in other places, volcanic eruptions are in their nature productive of storms. The clefts and valleys (*Barrancos*), in the volcanoes of the Canary Islands, and in the Cordilleras of South America, which have become of importance to the traveller from the frequent descriptions given by Leopold von Buch[95] and myself, because they open up to him the interior of the mountain, and sometimes even conduct him up to the vicinity of the highest summits, and to the circumvallation of a crater of elevation, exhibit analogous phenomena; but although these also at times carry off the accumulated meteoric waters, the original formation of the *barrancos*[96] upon the slopes of the volcanoes

[93] Junghuhn, Bd. ii. s. 241—246.

[94] *Op. cit. sup.* s. 566, 590 and 607—609.

[95] Leopold von Buch, *Phys. Beschr. der Canarischen Inseln*, s. 206, 218, 248, and 289.

[96] *Barranco and Barranca*, both of the same meaning, and sufficiently in use in Spanish America, certainly indicate properly a water-furrow or water-cleft: la quiebra que hacen en la tierra las corrientes de las aguas;—"una torrente que hace barrancas;" but they also indi-

is probably not to be ascribed to these. Fissures, caused by folding in the trachytic mass, which has been elevated whilst soft and only subsequently hardened, have probably preceded all actions of erosion and the impulse of water. But in those places where deep *barrancos* appeared in the volcanic districts visited by me on the declivities of bell-shaped or conical mountains (*en las faldas* de los Cerros barrancosos), no trace was to be detected of the regularity, or radiate ramification with which we are made acquainted by Junghuhn's works in the singular outlines of the volcanoes of Java.[97] The greatest analogy with the form here referred to is presented by the phenomenon to which Leopold von Buch, and the acute observer of volcanoes, Poulet Scrope, have already directed attention, namely, that great fissures almost always open at a right or obtuse angle from the centre of the mountain, radiating (although undivided), in accordance with the normal direction of the declivities, but not transversely to them.

The belief in the complete absence of lava-streams upon the island of Java,[98] to which Leopold von Buch appeared to

cate any chasm. But that the word *barranca* is connected with *barro*, clay, soft, moist loam, and also road-scrapings, is doubtful.

97 Lyell, *Manual of Elementary Geology*, 1855, chap. xxix, p. 497. The most remarkable analogy with the phenomenon of regular ribbing in Java, is presented by the surface of the Mantle of the Somma of Vesuvius, upon the seventy folds of which, an acute and accurate observer, the astronomer Julius Schmidt, has thrown much light (*Die Eruption des Vesuvs im Mai*, 1855, s. 101—109). According to Leopold von Buch, these valley-furrows are not originally rain-furrows (fiumare), but consequences of cracking (folding, *étoilement*) during the first upheaval of the volcano. The usually radial position of the lateral eruptions in relation to the axis of the volcano, also appears to be connected therewith (s. 129).

98 "Obsidian, and consequently pumice-stones, are as rare in Java as trachyte itself. Another very curious fact is the absence of any stream of lava in that volcanic island. M. Reinwardt, who has himself observed a great number of eruptions, says expressly that there have never been instances of the most violent and destructive eruption having been accompanied by lavas."—Léopold de Buch, *Descr. des Iles Canaries*, p. 419. Amongst the volcanic rocks of Java, for which the Cabinet of Minerals at Berlin is indebted to Dr. Junghuhn, dioritic-trachytes are most distinctly recognizable at Burung-agung, s. 255 of the Leidner catalogue, at Tjinas, s. 232, and in the Gunung Parang, situated in the district Batu-gangi. This is conse-

incline in consequence of the observations of Reinwardt, has been rendered more than doubtful by recent observations. Junghuhn, indeed, remarks "that the vast volcano Gunung Merapi has not poured forth coherent, compact lava-streams within the historical period of its eruptions, but has only thrown out fragments of lava (rubbish), or incoherent blocks of stone, although for nine months, in the year 1837, fiery streams were seen at night running down the cone of eruption."[99] But the same observant traveller has distinctly

quently the identical formation of dioritic-trachyte of the volcanoes of Orizaba and Toluca in Mexico, of the island Panaria in the Lipari Islands, and of Ægina in the Ægean Sea!

[99] Junghuhn, Bd. ii. s. 309 and 314. The fiery streaks which were seen on the volcano G. Merapi, were formed by closely approximated streams of scoriæ (*traînées de fragmens*), by non-coherent masses, which roll down during the eruption towards the same side, and strike against each other from their very different weights on the steep declivity. In the eruption of the G. Lamongan on the 26th March, 1847, a moving line of scoriæ of this kind divided into two branches several hundred feet below its point of origin. "The fiery streak," we find it expressly stated (Bd. ii. s. 767), "did not consist of true fused lava, but of fragments of lava rolling closely after one another." The G. Lamongan and the G. Semeru are the two volcanoes of the island of Java, which are found to be most similar, by their activity in long periods, to the Stromboli, which is only about 2980 feet high, as they, although so remarkably different in height (the Lamongan being 5340 and the Semeru 12,235 feet high), exhibited eruptions of scoriæ, the former after pauses of 15 to 20 minutes (eruptions of July, 1838, and March, 1847), and the second of 1½ to 3 hours (eruptions of August, 1836, and September, 1844,) (Bd. ii. s. 554 and 765—769). At Stromboli itself, together with numerous eruptions of scoriæ, small, but rare effusions of lava also occur, which, when detained by obstacles, sometimes harden on the declivities of the cone. I lay great stress upon the various forms of continuity or division, under which completely or partially fused matters are thrown or poured out, whether from the same or different volcanoes. Analogous investigations, undertaken under various zones, and in accordance with guiding ideas, are greatly to be desired, from the poverty and great one-sidedness of the views, to which the four active European volcanoes lead. The question raised by me in 1802 and by my friend Boussingault in 1831,—whether the Antisana in the Cordilleras of Quito has furnished lava-streams? which we shall touch upon hereafter, may perhaps find its solution in the division of the fluid matter. The essential character of a lava-stream is that of a uniform, coherent fluid,—a band-like stream, from the surface of which scales separate during its cooling and hardening. These scales, beneath which the nearly homogeneous lava long continues to flow, upraise

described, in great detail, three black, basaltic lava-streams on three volcanoes :—Gunung Tengger, Gunung Idjen, and Slamat.[100] On the latter the lava-stream, after giving rise to a water-fall, is continued into the tertiary rocks.[1] From such true effusions of lava, which, form coherent masses, Junghuhn very accurately distinguishes, in the eruption of Gunung Lamongan,[2] on the 6th July, 1838, what he calls a *stone-stream*, consisting of glowing and usually angular fragments, erupted in a row. "The crash was heard of the breaking stones, which rolled down, like fiery points, either in a line or without any order." I purposely direct especial attention to the very various modes in which fiery masses appear on the slopes of a volcano, because in the dispute upon the maximum angle of fall of lava-streams, glowing streams of stones (masses of scoriæ) following each other in rows, are sometimes confounded with continuous lava-streams.

As the important problem of the rarity or complete deficiency of lava-streams in Java,—a problem which touches on the

themselves in part, obliquely or perpendicularly, by the inequality of the internal movement and the evolution of hot gases; and when, in this way, several lava-streams, flowing together, form a lava lake, as in Iceland, a field of detritus or fragments is produced on their cooling. The Spaniards, especially in Mexico, call such a district, which is very disagreeable to pass over, a *malpais*. Such lava-fields, which are often found in the plain at the foot of a volcano, remind one of the frozen surface of a lake, with short, upraised ice-blocks.

[100] The name G. Idjen, according to Buschmann, may be explained by the Javanese word *hidjên*, singly, alone, separately :—a derivative from the substantive *hidji* or *widji*, grain, seed, which with *sa* expresses the number one. With regard to the etymology of G. Tengger, see the important work of my brother upon the connections between Java and India (*Kawi-Sprache*, Bd. i, s. 188), where there is a reference to the historical importance of the Tengger Mountain, which is inhabited by a small tribe of people, who, opposed to the now general Mahomedanism of the island, have retained their ancient Indo-Javanic faith. Junghuhn, who has very industriously explained the names of mountains from the Kawi language says (Th. ii. s. 554), that in the Kawi, *Tengger* signifies hill; the word also receives the same signification in Gericke's Javanese Dictionary (*Javaansch-neder-duitsch Woordenbock*, Amst., 1847). Slamat, the name of the high volcano of Tegal, is the well-known Arabic word *selamat*, which signifies happiness and safety.

[1] Junghuhn, Bd. ii. Slamat, s. 153 and 163; Idjen, s. 698; Tengger, s. 773.

[2] Bd. ii. s. 760—762.

internal constitution of volcanoes, and, which I must add, has not been treated with sufficient earnestness, has recently been so often spoken of, the present appears a fitting place in which to bring it under a more general point of view. Although it is very probable that, in a group or series of volcanoes all the members stand in a certain common relation to the general focus, the molten interior of the earth, still each individual presents peculiar physical and chemical processes as regards strength and frequency of activity, degree and form of fluidity, and material difference of products,—peculiarities which cannot be explained by the comparison of the form, and elevation above the present surface of the sea. The gigantic mountain, Sangay, is as uninterruptedly active as the lowly Stromboli; of two neighbouring volcanoes, one throws out pumice-stone without obsidian, the other both at once; one furnishes only loose cinders, the other lava flowing in narrow streams. These characteristic processes, moreover, in many volcanoes appear not to have been always the same at various epochs of their activity. To neither of the two continents is rarity or total absence of lava streams to be peculiarly ascribed. Remarkable distinctions only occur in those groups with regard to which we must confine ourselves to definite historical periods near to our own times. The non-detection of single lava-streams depends simultaneously upon many conditions. Amongst these we may instance the deposition of vast layers of tufa, rapilli, and pumice-stone; the simultaneous and non-simultaneous confluence of several streams, forming a widely extended lava-field covered with detritus; the circumstance that in a wide plain the small conical eruptive-cones, the volcanic platform, as it were, from which, as at Lancerote, the lava had flowed forth in streams, have long since been destroyed. In the most ancient conditions of our unequally cooling planet, in the earliest foldings of its surface, it appears to me very probable that a frequent viscid outflow of trachytic and doleritic rocks, of masses of pumice-stone or perlite, containing obsidian took place from a composite network of fissures, over which no platform has ever been elevated or built up. The problem of such simple effusions from fissures deserves the attention of geologists.

In the series of Mexican volcanoes, the greatest and, since my American travels, the most celebrated phenomenon is the elevation of the newly produced Jorullo, and its effusion of lava. This volcano, the topography of which, founded on measurements, I was the first to make known[3], by its position between the two volcanoes of Toluca and Colima, and by its eruption on the great fissure of volcanic activity[4], which extends from the Atlantic Ocean to the Pacific, presents an important geognostic phenomenon, which has consequently been all the more the subject of dispute. Following the vast lava-stream which the new volcano poured out, I succeeded in getting far into the interior of the crater, and in establishing instruments there. The eruption in a broad and long-peaceful plain in the former province of Michuacan, in the night from the 28th to the 29th of September, 1759, at a distance of more than 120 miles from any other volcano, was preceded for fully two (?) months, namely, from the 29th June in the same year, by an uninterrupted subterranean noise. This differed from the wonderful *bramidos* of Guanaxuato, which I have elsewhere described[5] by the circumstance that it was, as is usually the case, accompanied by earthquakes, which were not felt in the mountain city in January, 1784. The eruption of the new volcano, about 3 o'clock in the morning, was foretold the day before by a phenomenon which, in other eruptions, does not indicate their commencement but their conclusion. At the point where the great volcano now stands, there was formerly a thick wood of the Guayava (*Psidium pyriferum*), so much valued by the natives on account of its excellent fruit. Labourers from the sugar-cane fields (cañaverales) of the Hacienda de San Pedro Jorullo, belonging to the rich Don Andres Pimentel, who was then living in Mexico, had gone out to collect the fruit of the guayava. When they returned to the farm (hacienda) it was remarked with astonishment that their large straw hats were covered with volcanic ashes. Fissures had, consequently, already opened in what is now called the *Malpais*, probably at the foot of the high basaltic dome *el Cuiche*,

[3] *Atlas Géographique et Physique,* accompanying the *Relation Historique,* 1814, pl. 28 and 29.

[4] *Cosmos,* vol. v. pp. 279—280.

[5] *Cosmos,* vol. i. p. 205, and vol. v. p. 179.

which threw out these ashes (rapilli) before any change appears to have occurred in the plain. From a letter of Father Joaquin de Ansogorri, discovered in the Episcopal archives of Valladolid, which was written three weeks after the day of the first eruption, it appears evident that Father Isidro Molina, sent from the neighbouring Jesuits' College of Patzcuaro "to give spiritual comfort to the inhabitants of the Playas de Jorullo, who were extremely disquieted by the subterranean noise and earthquakes," was the first to perceive the increasing danger, and thus caused the preservation of the small population.

In the first hours of the night the black ashes already lay a foot deep; every one fled towards the hill of Aguasarco, a small Indian village, situated 2409 feet higher than the old plain of Jorullo. From this height (so runs the tradition) a large tract of land was seen in a state of fearful fiery eruption, and "in the midst of the flames (as those who witnessed the ascent of the mountain expressed themselves) there appeared, like a black castle (castillo negro), a great, shapeless mass (bulto grande)". From the small population of the district (the cultivation of indigo and cotton was then but very little carried on) even the force of long-continued earthquakes cost no human lives, although, as I learn from manuscript records [6], houses were over-

[6] In my *Essai Politique sur la Nouvelle-Espagne*, in the two editions of 1811 and 1827 (in the latter, t. ii, pp. 165—175), I have, as the nature of that work required, only given a condensed abstract from my journal, without being able to furnish a topographical plan of the vicinity or a chart of the altitudes. From the importance which has been assigned to this great phenomenon of the middle of the last century, I have thought it necessary to complete this abstract here. I am indebted for particular details relating to the new volcano of Jorullo to an official document, written three weeks after the day of the first eruption, but only discovered in the year 1830 by a very scientific Mexican clergyman, Don Juan José Pastor Morales; and also to oral communications from my companion, the Biscayan Don Ramon Espelde, who had been able to examine living eye-witnesses of the first eruption. Morales discovered in the Archives of the Bishop of Michuacan, a report addressed on the 19th of October, 1759, by Joaquin de Ansogorri, Priest in the Indian village la Guacana, to his Bishop. In his instructive work (*Aufenthalt und Reisen in Mexico*, 1836) Burkart has also given a short extract from it (Bd. i. s. 230). At the time of my journey, Don Ramon Espelde was living on the

turned by them near the copper mines of Inguaran, in the small town of Patzcuaro, in Santiago de Ario, and many

plain of Jorullo, and has the merit of having first ascended the summit of the volcano. Some years afterwards he attached himself to the expedition made on the 10th March, 1789, by the Intendente Corregidor, Don Juan Antonio de Riaño. To the same expedition belonged a well-informed German, Franz Fischer, who had entered the Spanish service as a Mining Commissary. By means of the latter the name of the Jorullo first became known in Germany, as he mentioned it in a letter in the *Schriften der Gesellschaft der Bergbaukunde,* Bd. ii., s. 441. But the eruption of the new volcano had already been referred to in Italy,—in Clavigero's *Storia antica del Messico* (Cesena, 1780, t. i, p. 42), and in the poetical work, *Rusticatio Mexicana* of Father Raphael Landivar (ed. altera, Bologna, 1782, p. 17). In his valuable work, Clavigero erroneously places the production of the volcano, which he writes Juruyo, in the year 1760, and enlarges the description of the eruption by accounts of the shower of ashes, extending as far as Queretaro, which had been communicated to him in 1766 by Don Juan Manuel de Bustamente, Governor of the Province of Valladolid de Michuacan, as an eye-witness of the phenomenon. The poet Landivar, an enthusiastic adherent, like Ovid, of our theory of upheaval, makes the Colossus rise, in euphonious hexameters, to the full height of 3 milliaria, and finds the thermal springs (after the fashion of the ancients) cold by day and warm at night. But I saw the thermometer rise to 126½° in the water of the Rio de Cuitimba about noon.

In 1789, and consequently in the same year that the report of the Governor Riaño and the Mining Commissary Franz Fischer, appeared in the *Gazeta de Mexico,* in the fifth part of his large and useful *Diccionario geográfico-histórico de las Indias Occidentales ó America,* in the article *Xurullo,* pp. 374—375) Antonio de Alcedo gave the interesting information that, when the earthquakes commenced (29th June, 1759) in the Playas, the western volcano of Colima, which was in eruption, suddenly became quiet, although it is at a distance of "70 leguas" (as Alcedo says: according to my map only 112 geog. miles!) from the Playas. "It is thought," he adds, "that the materials in the bowels of the earth have met with obstacles to their following their old course; and as they have found suitable cavities (to the east," they have broken out at Jorullo—*para reventar en Xurullo*).—Accurate topographical statements regarding the neighbourhood of the volcano occur also in Juan José Martinez de Lejarza's geographical sketch of the ancient Taraskian country: *Análisis estadístico de la provincia de Michuacan en* 1822 (Mexico, 1824), pp. 125, 129, 130, and 131. The testimony of the author, living at Valladolid in the vicinity of Jorullo, that, since my residence in Mexico, no trace of an increased activity has shown itself in the mountain was the earliest contradiction of the report of a new eruption in the year 1819 (Lyell, *Principles of Geology,* 1855, p. 430). As the position of miles further, but not beyond San Pedro Churumucu. In the Hacienda de Jorullo, during the general nocturnal flight, they forgot to remove a deaf and dumb negro slave. A mulatto had the humanity to return and save him, while the house was still standing. It is still narrated that he was found kneeling, with a consecrated taper in

Jorullo in latitude is not without importance, I have noticed that Lejarza, who otherwise always follows my astronomical determinations of position, and who gives the longitude of Jorullo exactly like myself as 2° 25′ west of the meridian of Mexico (101° 29′ west of Greenwich), differs from me in the latitude. Is the latitude attributed by him to the Jorullo (18° 53′ 30″), which comes nearest to that of the volcano of Popocatepetl (18° 59′ 47″), founded upon recent observations unknown to me? In my *Recueil d'Observ. Astronomiques*, vol. ii, p. 521, I have said expressly, "Latitude *supposée*, 19° 8′, deduced from good astronomical observations at Valladolid, which gave 19° 52′ 8″, and from the Itinerary direction." I only recognized the importance of the latitude of Jorullo, when subsequently I was drawing up the great map of Mexico in the capital city and inserting the E.—W. series of volcanoes.

As in these considerations upon the origin of Jorullo, I have repeatedly mentioned the traditions which still prevail in the neighbourhood, I will conclude this long note by referring to a very popular tradition, which I have already touched upon in another work (*Essai Politique sur la Nouvelle Espagne*, t. ii, 1827, p. 172):—"According to the belief of the natives, these extraordinary changes which we have just described, are the work of the monks, the greatest, perhaps, that they have produced in either hemisphere. At the *Playas de Jorullo*, in the hut that we occupied, our Indian host told us that, in 1759, the Capuchins belonging to the mission preached at the station of San Pedro, but that, not having been favourably received, they charged this beautiful and fertile plain, with the most horrible and complicated imprecations, prophesying that first of all the house would be devoured by flames which would issue from the earth, and that afterwards the surrounding air would become cooled to such a degree that the neighbouring mountains would remain eternally covered with snow and ice. The former of these maledictions having had such fatal consequences, the lower class of Indians already see in the gradual cooling of the volcano, the presage of a perpetual winter."

Next to that of the poet, Father Landivar, the first printed account of the catastrophe was probably that already mentioned in the *Gazeta de Mexico* of the 5th May, 1789 (t. iii, Num. 30, pp. 293—297); it bears the modest title, *Superficial y nada facultativa Descripcion del estado en que se hallaba el Volcán de* Jorullo *la mañana del dia* 10 *de Marzo de* 1789, and was occasioned by the expedition of Riaño, Franz Fischer, and Espelde. Subsequently (1791) in the naval astronomical expedition of Malaspina, the botanists, Mociño and Don Martin Sesse, visited Jorullo, from the Pacific coast.

his hand, before the picture of Nuestra Señora de Guadalupe.

According to the tradition, widely and concordantly spread amongst the natives, the eruption, during the first days, consisted of great masses of rock, scoriæ, sand, and ashes, but always combined with an effusion of muddy water. In the memorable report, already mentioned, of the 19th of October, 1759, the author of which was a man who, possessing an accurate knowledge of the locality, describes what had only just taken place, it is expressly said: Que espele el dicho Volcan arena, ceniza y agua. All eye-witnesses relate (I translate from the description which the Intendant, Colonel Riaño, and the German Mining Commissary, Franz Fischer, who had passed into the Spanish service, have given of the condition of the volcano of Jorullo on the 10th March, 1789), "that before the terrible mountain made its appearance (antes de reventar y aparecerse este terrible Cerro), the earthquakes and subterranean noises became more frequent; but on the day of the eruption itself the flat soil was seen to rise perpendicularly (se observó, que el plan de la tierra se levantaba perpendicularmente), and the whole became more or less inflated, so that blisters (vexigones) appeared, of which the largest is now the volcano (de los que el mayor es hoy el Cerro del Volcan). These inflated blisters, of very various sizes, and partly of a tolerably regular, conical form, subsequently burst (estas ampollas, gruesas vegigas ó conos diferentemente regulares en sus figuras y tamaños, reventáron despues), and threw boiling hot earthy mud from their orifices (tierras hervidas y calientes), as well as scoriaceous stony masses (piedras cocidas? y fundidas), which are still found, at an immense distance, covered with black stony masses."

These historical records, which we might, indeed, wish to see more complete, agree perfectly with what I learnt from the mouths of the natives 14 years after the ascent of Antonio de Riaño. To the questions, whether "the castle mountain," was seen to rise gradually for months or years, or whether it appeared from the very first as an elevated peak, no answer could be obtained. Riaño's assertion that further eruptions had taken place in the first 16 or 17 years, and therefore up to 1776, was declared to be untrue.

According to the tradition, the phenomena of small eruptions of water and mud which were observed during the first days simultaneously with the incandescent scoriæ, are ascribed to the destruction of two brooks, which, springing on the western declivity of the mountain of Santa Ines, and consequently to the east of the Cerro de Cuiche, abundantly irrigated the cane-fields of the former Hacienda de San Pedro de Jorullo, and flowed onwards far to the west to the Hacienda de la Presentacion. Near their origin, the point is still shown where they disappeared in a fissure with their formerly cold waters, during the elevation of the eastern border of the Malpais. Running below the Hornitos, they reappear, according to the general opinion of the people of the country, heated, in two thermal springs. As the elevated part of the Malpais is there almost perpendicular, they form two small waterfalls, which I have seen and represented in my drawing. For each of them the previous name, Rio de San Pedro and Rio de Cuitimba, has been retained. At this point I found the temperature of the steaming water to be 126°·8. During their long course the waters are only heated, but not acidulated. The test papers, which I usually carried about with me, underwent no change; but further on, near the Hacienda de la Presentacion, towards the Sierra de las Canoas, there flows a spring impregnated with sulphuretted hydrogen gas, which forms a basin of 20 feet in breadth.

In order to acquire a clear notion of the complicated outline and general form of the surface of the ground, in which such remarkable upheavals have taken place, we must distinguish hypsometrically and morphologically :—1. The position of the volcanic system of Jorullo in relation to the average level of the Mexican plateau; 2. The convexity of the Malpais, which is covered by thousands of hornitos; 3. The fissure upon which six large, volcanic, mountain-masses have arisen.

On the western portion of the Central Cordillera of Mexico, which strikes from S.S.E. to N.N.W., the plain of the Playas de Jorullo, at an elevation of only 2557 feet above the level of the Pacific, forms one of the horizontal mountain terraces, which, everywhere in the Cordilleras, interrupt the line of inclination of the declivity, and consequently more or less impede the decrease of heat in the superposed strata of the atmosphere. On descending from the central plateau of Mexico (whose mean elevation is 7460 feet), to the corn-fields of Valladolid de Michuacan, to the charming lake of Patzcuaro, with the inhabited islet Janicho and into the meadows around Santiago de Ario, which Bonpland and I found adorned with the dahlias which have since become so well known, we have not descended more than nine hundred or a thousand feet. But in passing from Ario on the steep declivity over Aguasarco into the level of the old plain of Jorullo, we diminish the absolute elevation in this short distance by from 3850 to 4250 feet[7]. The roundish, convex part of the upheaved plain is about 12,790 feet in diameter, so that its area is more than seven square miles. The true volcano of Jorullo and the five other mountains which rose simultaneously with it upon the same fissure, are so situated that only a small portion of the Malpais lies to the east of them. Towards the west, therefore, the number of hornitos is much larger, and when in early morning I issued from the Indian huts of the Playas de Jorullo, or ascended a portion of the Cerro del Mirador, I saw the black volcano projecting very picturesquely above the innumerable white columns of smoke of the "little ovens" (*hornitos*). Both the houses of the Playas and the basaltic hill Mirador are situated upon the level of the old non-volcanic, or, to speak more cautiously, un-upheaved soil. Its beautiful vegetation, in which a multitude of *salvias* bloom beneath the shade of a new species of fan palm (*Corypha pumos*), and of a new alder (*Alnus Jorullensis*), contrasts with the desert, naked aspect of the Malpais. The comparison of the height of the barometer[8] at the point where the upheaval

[7] My barometric measurements give for Mexico 1168 toises (7470 feet), Valladolid 1002 toises (6409 feet), Patzcuaro 1130 toises (7227 feet), Ario 994 toises (6358 feet), Aguasarco 780 toises (4[illegible]89 feet), for the old plain of the Playas de Jorullo 404 toises (2584 feet) (Humboldt, *Observ. Astron.* vol. i, p. 327, *Nivellement Barométrique*, No. 366—370).

[8] If the old plain of the Playas be 404 toises (2584 feet), I find for the maximum of convexity of the Malpais above the sea-level 487 toises (3115 feet); for the ridge of the great lava-stream 600 toises (3838 feet); for the highest margin of the crater 667 toises (4266 feet); for the lowest point of the crater at which we could establish the barometer 644 toises (4119 feet). Consequently the elevation of the summit of Jorullo above the old plain appeared to be 263 toises or 1682 feet.

commences in the Playas, with that at the point immediately at the foot of the volcano, gives 473 feet of relative perpendicular elevation. The house that we inhabited stood only about 500 toises (3197 feet) from the border of the Malpais. At that place there was a small perpendicular precipice of scarcely 12 feet high, from which the heated water of the brook (Rio de San Pedro) falls down. The portion of the inner structure of the soil which I could examine at the precipice, showed black, horizontal, loamy strata, mixed with sand (rapilli). At other points which I did not see, Burkart has observed "on the perpendicular boundary of the upheaved soil, where the ascent of this is difficult, a light gray and not very dense (weathered) basalt, with numerous grains of olivine."[9] This accurate and experienced observer has, however,[10] like myself, on the spot, conceived the idea of a vesicular upheaval of the surface effected by elastic vapours, in opposition to the opinion of celebrated geognosists[11], who ascribe the convexity, which I ascertained by direct measurement, solely to the greater effusion of lava at the foot of the volcano.

The many thousand small eruptive cones (properly rather of a roundish or somewhat elongated, oven-like form) which cover the upheaved surface pretty uniformly, are on the average 4 to 9 feet in height. They have risen almost ex-

[9] Burkart, *Aufenthalt und Reisen in Mexico in den Jahren*, 1825—1834, Bd. i (1836), p. 227.

[10] *Op. cit. sup.* Bd. i, pp. 227 and 230.

[11] Poulett Scrope, *Considerations on Volcanoes*, p. 267; Sir Charles Lyell, *Principles of Geology*, 1853, p. 429; *Manual of Geology*, 1855, p. 580; Daubeny *on Volcanoes*, p. 337. See also "on the elevation hypothesis," Dana, *Geology*, in the *United States Exploring Expedition*, vol. x, p. 369. Constant Prevost, in the *Comptes rendus*, t. xli (1855), pp. 866—876, and 918—923 : *sur les éruptions et le drapeau de l'infaillibilité*." See also, with regard to Jorullo, Carl Pieschel's instructive description of the volcanoes of Mexico, with illustrations by Dr. Gumprecht, in the *Zeitschrift für Allg. Erdkunde of the Geographical Society of Berlin* (Bd. vi, s. 490—517); and the newly published picturesque views in Pieschel's *Atlas der Vulkane der Republik Mexico*, 1856, tab. 13, 14, and 15. The Royal Museum of Berlin, in the department of engravings and drawings, possesses a splendid and numerous collection of representations of the Mexican volcanoes (more than 40 sheets), taken from nature by Moritz Rugendas. Of the most western of all Mexican volcanoes, that of Colima alone, this great master has furnished fifteen coloured views.

clusively on the western side of the great volcano, as indeed, the eastern part towards the Cerro de Cuiche, scarcely constitutes $\frac{1}{25}$th of the entire area of the vesicular elevation of the Playas. Each of the numerous hornitos is composed of weathered basaltic spheres, with fragments separated like concentric shells; I was frequently able to count from 24 to 28 such shells. The balls are flattened into a somewhat spheroidal form, and are usually 15—18 inches in diameter, but vary from 1 to 3 feet. The black basaltic mass is penetrated by hot vapours and broken up into an earthy form, although the nucleus is of greater density, whilst the shells, when detached, exhibit yellow spots of oxide of iron. Even the soft, loamy mass which unites the balls is, singularly enough, divided into curved lamellæ, which wind through all the interstices of the balls. At the first glance I asked myself whether the whole, instead of weathered basaltic spheroids, containing but little olivine, did not perhaps present masses disturbed in the course of their formation. But in opposition to this we have the analogy of the hills of globular basalt, mixed with layers of clay and marl, which are found, often of very small dimensions, in the central chain of Bohemia, sometimes isolated and sometimes crowning long basaltic ridges at both extremities. Some of the hornitos are so much broken up, or have such large internal cavities, that mules when compelled to place their fore-feet upon the flatter ones, sink in deeply, whilst in similar experiments which I made, the hills constructed by the termites, resisted.

In the basaltic mass of the hornitos I found no immersed scoriæ, or fragments of old rocks which had been penetrated, as is the case in the lavas of the great Jorullo. The appellation *Hornos* or *Hornitos* is especially justified by the circumstance that in each of them (I speak of the period when I travelled over the Playas de Jorullo and wrote my journal, 18 September, 1803,) the columns of smoke break out, not from the summit, but laterally. In the year 1780, cigars might still be lighted when they were fastened to a stick and pushed in to a depth of 2 or 3 inches; in some places the air was at that time so much heated by the vicinity of the hornitos, that it was necessary to turn away from one's proposed course. Notwithstanding the refrigeration which, according to the universal testimony of the Indians, the district had undergone within 20 years, I found the temperature in the fissures of the hornitos to range between 199° and 203°; and at a distance of twenty feet from some hills, the temperature of the air was still 108°·5 and 116°·2, at a point where no vapours reached me; the true temperature of the atmosphere of the Playas being at the same time scarcely 77°. The weak sulphuric vapours decolorized strips of test paper, and rose visibly, for some hours after sunrise, to a height of fully 60 feet. The view of the columns of smoke was most remarkable early in a cool morning. Towards midday, and even after 11 o'clock, they had become very low and were visible only from their immediate vicinity. In the interior of many of the hornitos we heard a rushing sound like the fall of water. The small basaltic hornitos are, as already remarked, easily destructible. When Burkart visited the Malpais, 24 years after me, he found that none of the hornitos were still smoking; their temperature being in most cases the same as that of the surrounding air, while many of them had lost all regularity of form by heavy rains and meteoric influences. Near the principal volcano Burkart found small cones, which were composed of a brownish-red conglomerate of rounded or angular fragments of lava, and only loosely coherent. In the midst of the upheaved area, covered with hornitos, there is still to be seen a remnant of the old elevation on which the buildings of the farm of San Pedro rested. The hill, which I have indicated in my plan, forms a ridge directed east and west, and its preservation at the foot of the great volcano is most astonishing. Only a part of it is covered with dense sand (burnt rapilli). The projecting basaltic rock, grown over with ancient trunks of *Ficus indica* and *Psidium*, is, certainly, like that of the Cerro del Mirador and the high mountain masses which bound the plain to the eastward, to be regarded as having existed before the catastrophe.

It remains for me to describe the vast fissure upon which a series of six volcanoes has risen, in the general direction from south-south-west to north-north-east. The partial direction of the first three, less elevated volcanoes situated most southerly is S.W—N.E.; that of the three following near S.—N. The fissure has consequently been curved, and has changed its strike throughout its total length of 10,871 feet. The direction here indicated of the linear but not contiguous mountains is certainly nearly at right angles with the line upon which, according to my observation, the Mexican volcanoes follow each other from sea to sea. But this difference is the less surprising if we consider that a great geognostic phenomenon (the relation of the principal masses to each other across a continent) is not to be confounded with the local conditions and direction of a single group. The long ridge of the great volcano of Pichincha also, is not in the same direction as the series of volcanoes of Quito; and in non-volcanic chains, for example in the Himalaya, the culminating points are often situated, as I have already pointed out, at a distance from the general line of elevation of the chain. They are situated upon partial snowy ridges which even form nearly a right angle with this general line of upheaval.

Of the six volcanic hills which have risen upon the abovementioned fissure, the first three, the more southern ones, between which the road to the copper mines of Inguaran passes, appear, in their present condition, to be of least importance. They are no longer open, and are entirely covered with grayish white, volcanic sand, which however does not consist of pumice-stone, for I have seen nothing either of pumice or obsidian in this region. At Jorullo also, as at Vesuvius according to the assertion of Leopold von Buch and Monticelli, the last covering-fall of ashes appears to have been the white one. The fourth, more northern mountain is the large, true volcano of Jorullo, the summit of which, notwithstanding its small elevation (4265 feet above the sea level, 1151 feet above the Malpais at the foot of the volcano, and 1681 feet above the old soil of the Playas), I had some difficulty in reaching, when I ascended it with Bonpland and Carlos Montufar on the 19th September, 1803. We thought we should be most certain of getting into the crater, which was still filled with hot sulphurous vapours, by ascending the steep ridge of the vast lava-stream, which burst forth from the very summit. The course passed over a crisp, scoriaceous, clear-sounding lava, swelled up in a cokelike, or rather cauliflower-like form. Some parts of it have a metallic lustre: others are basaltic and full of small granules of olivine. When we had thus ascended to the upper surface of the lava-stream at a perpendicular elevation of 711 feet, we turned to the white ash cone, on which, from its great steepness, we could not but fear that during frequent and rapid slips we might be seriously wounded by the rugged lava. The upper margin of the crater, on the south western part of which we placed the instruments, forms a ring of a few feet in width. We carried the barometer from the margin into the oval crater of the truncated cone. At an open fissure air streams forth of a temperature of 200°·6. We now stood 149 feet in perpendicular height below the margin of the crater; and the deepest point of the chasm, the attainment of which we were compelled to give up on account of the dense sulphurous vapours, appeared to be only about twice this depth. The geognostic discovery which had the most interest for us, was the finding of several white fragments, three or four inches in diameter, of a rock rich in felspar baked into the black basaltic lava. I regarded these at first[12] as syenite, but from the

[12] "M. Bonpland and myself were particularly astonished at finding, encased in the basaltic, lithoid and scorified lavas of the volcano of Jorullo, white or greenish white angular fragments of *Syenite*, composed of a little amphibole and a great quantity of lamellar felspar. Where these masses have been split by heat, the felspar has become filamentous, so that the margins of the crack are united in some places by fibres elongated from the mass. In the Cordilleras of South America, between Popayan and Almaguer, at the foot of the *Cerro Broncoso*, I have found actual fragments of *gneiss* encased in a trachyte abounding in pyroxene. These phenomena prove that the trachytic formations have issued from beneath the granitic crust of the globe. Analogous phenomena are presented by the trachytes of the *Siebengebirge* on the banks of the Rhine, and by the inferior strata of Phonolite (*Porphyrschiefer*) of the *Biliner Stein* in Bohemia." (Humboldt, *Essai Géognostique sur le Gisement des Roches*, 1823, pp. 133 and 339. Burkart also (*Aufenthalt und Reisen in Mexico*, Bd. i, s. 230) detected enclosed in the black lava, abounding in olivine, of Jorullo: "Blocks of a metamorphosed syenite. Hornblende is rarely to be recognized distinctly. The blocks of syenite may certainly furnish an incontrovertible proof, that the seat of the focus of the volcano of Jorullo is either in or below the syenite, which shows itself in considerable extent, a few miles (*leguas*) further south, on the left bank of the Rio de las Balsas, flowing into the Pacific Ocean." Dolomieu, and, in 1832, the excellent geognosist, Friedrich Hoffmann, found in Lipari, near

exact examination by Gustav Rose, of a fragment which I brought with me, they probably belong rather to the granite formation, which Burkart has also seen emerging from below the syenite of the Rio de las Balsas. "The inclosure is a mixture of quartz and felspar. The blackish green spots appear to be not hornblende, but mica fused with some felspar. The white fragment baked in is split by volcanic heat, and in the crack white, tooth-like, fused threads run from one margin to the other."

To the north of the great volcano and the scoriaceous lava mountain which it has vomited forth in the direction of the old basalt of the Cerro del Mortero, follow the two last of the six often-mentioned eruptions. These hills also were originally very active, for the people still call the extreme mountain of ashes, *el Volcancito.* A broad fissure opened towards the west, bears the traces of a destroyed crater. The great volcano, like the Epomeo in Ischia, appears to have only once poured out a mighty lava-stream. That its lava-pouring activity endured after the period of its first eruption, is not proved historically; for the valuable letter, so happily discovered, of Father Joaquin de Ansogorri, written scarcely three weeks after the first eruption, treats almost exclusively of the means of making "arrangements for the better pastoral care of the country people who had fled from the catastrophe and become dispersed;" and for the following thirty years we have no records. As the tradition speaks very generally of fires which covered so great a surface, it is certainly to be supposed that all the six hills upon the great fissure, and the portion of the Malpais itself in which the Hornitos have appeared, were simultaneously in combustion. The temperature of the surrounding air, which I measured, allows us to judge of the heat which prevailed there 43 years previously; they remind one of the former condition of our planet, in which the temperature of its atmospheric envelope, and with this the distribution of organic life, might be modified by the thermic action of the interior by means of deep fissures (under any latitude and for long periods of time).

Caneto, fragments of granite, formed of pale red felspar, black mica, and a little pale gray quartz, enclosed in compact masses of obsidian (Poggendorff's *Annalen der Physik*, Bd. xxvi, s. 49).

Since I described the Hornitos which surround the volcano of Jorullo, many analogous platforms in various regions of the world, have been compared with these oven-like little hills. To me, the Mexican ones, from their interior conformation, appear still to stand in a very contrasting and isolated condition. If all upheavals which emit vapours are to be called *eruptive-cones*, the Hornitos certainly deserve the appellation of *Fumaroles*. But the denomination, eruptive-cones, would lead to the erroneous notion that there is evidence that the Hornitos have thrown out scoriæ, or even, like many eruptive-cones, poured forth lava. Very different, for example (to advert to a great phenomenon) are the three chasms in Asia Minor, upon the former boundaries of Mysia and Phrygia, in the ancient burning country (Katakekaumene) "where it is dangerous to dwell (on account of the earthquakes)," which Strabo calls *φῦσαι*, or wind-bags, and which the meritorious traveller, William Hamilton, has rediscovered.[13] Eruptive cones such as are exhibited by the island of Lancerote near Tinguaton, or by Lower Italy, or (of hardly 20 feet in height) by the declivity of the great Kamtschatkan volcano, Awatscha,[14] which was ascended in July, 1824, by my friend and Siberian companion, Ernst Hofmann, consist of scoriæ and ashes surrounding a small crater, which has thrown them out, and has been in return buried by them. In the Hornitos nothing like a crater is to be seen, and they consist—and this is an important character—merely of basaltic balls, with shell-like separated fragments, without any admixture of loose angular scoriæ. At the foot of Vesuvius, during the great eruption of 1794 (and

[13] Strabo, lib. xiii, pp. 579 and 628; Hamilton, *Researches in Asia Minor*, vol. ii, chap. 39. The most western of the three cones, now called Kara Devlit, is raised 532 feet above the plain, and has emitted a great lava-stream in the direction of Koula. Hamilton counted more than thirty small cones in the vicinity. The three chasms (*βόθροι* and *φῦσαι* of Strabo) are craters situated upon conical mountains composed of scoriæ and lavas.

[14] Erman, *Reise um die Erde*, Bd. iii, s. 538; *Cosmos*, vol. v, p. 248, Postels (*Voyage autour du Monde par le Cap. Lutké, partie hist.* t. iii, p. 76) and Leopold von Buch (*Description Physique des Iles Canaries*, p. 448) mention the similarity to the Hornitos of Jorullo. In a manuscript most kindly communicated to me, Erman describes a great number of truncated cones of scoriæ in the immense lava-field to the east of the Baidar Mountains on the peninsula of Kamtschatka.

also in earlier times), eight different, small craters of eruption, (*bocche nuove*) were formed, arranged upon a longitudinal fissure ; they are the so-called *parasitic* cones of eruption, which poured forth lava, and are even by this circumstance entirely distinct from the Hornitos of Jorullo. "Your Hornitos," wrote Leopold von Buch to me, "are not cones accumulated by erupted matters ; they have been upheaved *directly* from the interior of the earth." The production of the volcano of Jorullo itself was compared by this great geologist with that of the Monte Nuovo in the Phlegræan fields. The same notion of the upheaval of six volcanic mountains upon a longitudinal fissure forced itself as the most probable upon Colonel Riaño and the mining commissary Fischer in 1789 (see ante, p. 313), upon myself at the first glance in 1803, and upon Burkart in 1827. With both the new mountains, produced in 1538 and 1759, the same questions repeat themselves. Upon that of Southern Italy, the testimonies of Falconi, Pietro Giacomo di Toledo, Francesco del Nero and Porzio, are circumstantial, near the time of the catastrophe and prepared by educated observers. The celebrated Porzio, who was the most learned of these observers, says :—"Magnus terræ tractus, qui inter radices montis, quem Barbarum incolæ appellant, et mare juxta Avernum jacet, sese *erigere videbatur* et montis subito nascentis figuram imitari. Iste terræ cumulus aperto veluti ore magnos ignes evomuit, pumicesque et lapides, cineresque."[15]

From the geognostic description here completed of the volcano of Jorullo, we will pass to the more eastern parts of Central Mexico (Anahuac). Unmistakeable lava-streams, the principal mass of which is usually basaltic, have been poured out by the peak of Orizaba according to the most recent,

[15] Porzio, *Opera omnia, Med., Phil. et Mathem. in unum collecta*, 1736 : according to Dufrénoy, *Mémoires pour servir à une Description Géologique de la France*, t. iv, p. 272. All the genetic questions are discussed very completely and with praiseworthy impartiality in the 9th edition of Sir Charles Lyell's *Principles of Geology*, 1853, p. 369. Even Bouguer (*Figure de la Terre*, 1749, p. lxvi) was not disinclined to the idea of the upheaval of the volcano of Pichincha. He says :—"It is not impossible that the rock, which is burnt and black, may have been elevated by the action of subterranean fire." See also p. xci.

interesting observations of Pieschel (March, 1854)[16] and H. de Saussure. The rock of the peak of Orizaba, like that of the volcano of Toluca[17] which I ascended, is composed of hornblende, oligoclase, and a little obsidian; whilst the fundamental mass of Popocatepetl is a Chimborazo-rock, composed of very small crystals of oligoclase and augite. At the foot of the eastern slope of Popocatepetl, westward of the town la Puebla de los Angeles, in the Llano de Tetimpa, where I measured the base for the determination of the elevation of the two great Nevados (Popocatepetl and Iztaccihuatl) which bound the valley of Mexico, I found, at a height of 7000 feet above the sea, an extensive and mysterious kind of lava-field It is called the Malpais (rough rubbish-field) of Atlachayacatl, a low trachytic dome, on the declivity of which the river Atlaco rises and runs at an elevation of from 60 to 85 feet above the adjacent plain, from east to west, and consequently at right angles to the volcanoes. From the Indian village of San Nicolas de los Ranchos, to San Buenaventura, I calculated the length of the Malpais at more than 19,200 feet, and its breadth at 6400 feet. It consists of black, partially upraised lava-blocks of a fearfully wild appearance, and only sparingly coated here and there with lichens, contrasting with the yellowish white coat of pumice-stone which covers everything for a long distance round. The latter consists here of coarsely fibrous fragments of two or three inches in diameter, in which hornblende crystals sometimes lie. This coarser pumice-stone sand, is different from the very finely granular sand, which, near the rock el Frayle and at the limit of perpetual snow, on the volcano Popocatepetl, renders the ascent so dangerous, because, when it is set in motion on steep declivities, the sand-mass, rolling down, threatens to overwhelm everything. Whether this lava field of fragments (in Spanish *Malpais,* in Sicily *Sciarra viva,* in Iceland *Odaada-Hraun,*) is due to ancient lateral eruptions of Popocatepetl, situated one above the other, or to the somewhat rounded cone of Tetlijolo (Cerro del Corazon de Piedra) I

[16] *Zeitschrift für Allgemeine Erdkunde,* Bd. iv, s. 398.

[17] For the more certain determination of the minerals of which the Mexican volcanoes are composed, old and recent collections made by myself and Pieschel have been compared.

cannot determine. It is also geognostically remarkable that, further to the east, on the road towards the small fortress Perote, the ancient Aztec Pinahuizapan, between Ojo de Agua, Venta de Soto and el Portachuelo, the volcanic formation of coarsely fibrous, white, friable perlite [18] rises beside a limestone (Marmol de la Puebla) which is probably tertiary. This perlite is very similar to that of the conical hill of Zinapecuaro (between Mexico and Valladolid); and contains, besides laminæ of mica, and lumps of immersed obsidian, a glassy, bluish-gray, or sometimes red, jasper-like streaking. The wide "perlite district" is here covered with a finely granular sand of weathered perlite, which might be taken, at the first glance, for granitic sand, and which, notwithstanding its allied origin, is still easily distinguishable from the true, grayish white pumice-stone sand. The latter is more proper to the immediate vicinity of Perote,—the plateau 7460 feet in height between the two volcanic chains of Popocatepetl and Orizaba, which strike north and south.

When, on the road from Mexico to Vera Cruz, we begin to descend from the heights of the non-quartzose, trachytic porphyry of the Vigas towards Canoas and Jalapa, we again twice pass over fields of fragments and scoriaceous lava:—the first time between the station Parage de Carros and Canoas or Tochtlacuaya, and the second, between Canoas and the station Casas de la Hoya. The first point is called *Loma de Tablas* on account of the numerous upraised, basaltic blocks of lava containing abundance of olivine; the second simply *el Malpais*. A small ridge of the same trachytic porphyry, full of glassy felspar, which forms the eastern limit of the *Arenal* (the perlitic sand-fields) near la Cruz Blanca and Rio Frio (on the western declivity of the heights of las Vigas) separates the two branches of the lava-field which have just been mentioned,—the Loma de Tablas, and the much broader Malpais. Those of the country people who are well acquainted with the district assert that the band of scoriæ is elongated towards the south-south-east, and consequently towards the Cofre de Perote. As I have

[18] The beautiful marble of la Puebla comes from the quarries of Tecali, Totomehuacan and Portachuelo, to the south of the high trachytic mountain, el Pizarro. I have also seen limestone cropping out near the terrace-pyramid of Cholula, on the way to la Puebla.

myself ascended the Cofre and made many measurements on it,[19] I have been but little inclined to conclude, from a

[19] The Cofre de Perote stands nearly isolated to the south-east of the Fuerte or Castillo de Perote, near the eastern slope of the great plateau of Mexico; but its great mass belongs to an important range of heights, which, forming the margin of the slope, extends in a north and south direction, from Cruz Blanca and Rio Frio towards las Vigas (lat. 19° 37′ 37″) past the Cofre de Perote (lat. 19° 28′ 57″, long. 97° 7′ 20″) to the westward of Xicochimalco and Achilchotla to the Peak of Orizaba (lat. 19° 2′ 17″, long. 97° 13′ 56″), parallel to the chain (Popocatepetl—Iztaccihuatl) which separates the cauldron-valley of the Mexican lakes from the plain of la Puebla. (For the grounds of these determinations see my *Recueil d'Observ. Astron*, vol. ii, pp. 529—532 and 547, and also *Analyse de l'Atlas du Mexique*, or *Essai Politique sur la Nouvelle Espagne*, t. i, pp. 55—60). As the Cofre has raised itself abruptly in a field of pumice-stone many miles in width, it appeared to me in my winter ascent (the thermometer fell at the summit, on the 7th February, 1804, to 28°·4) to be extremely interesting, that the covering of pumice-stone, the thickness and height of which I measured barometically at several points both in ascending and descending, rose more than 780 feet. The lower limit of the pumice-stone, in the plain between Perote and Rio Frio, is 1187 toises (7590 feet) above the level of the sea; the upper limit on the northern declivity of the Cofre 1309 toises (8370 feet); thence through the Pinahuast, the Alto de los Caxones (1954 toises = 12,496 feet), where I could determine the latitude by the sun's meridian altitude up to the summit itself, no trace of pumice-stone was to be seen. During the upheaval of the mountain, a portion of the coat of pumice-stone of the great Arenal, which has probably been levelled in strata by water, was carried up. I inserted a drawing of this zone of pumice-stone in my journal (February, 1804) on the spot. It is the same important phenomenon which was described by Leopold von Buch in the year 1834 on Vesuvius, where horizontal strata of pumice-tufa were raised by the elevation of the volcano to a greater height indeed, 1900 or 2000 feet towards the Hermitage del Salvatore (*Poggendorff's Annalen*, Bd. xxxvii, s. 175—179). The surface of the dioritic trachyte rock on the Cofre, at the point where I found the highest pumice-stone, was not withdrawn from observation by snow. The limit of perpetual snow lies in Mexico under the latitudes of 19° or 19¼°, only at the average elevation of 2310 toises (14,770 feet), and the summit of the Cofre, up to the foot of the small, house-like cubical rock where I set up the instruments, reaches 2098 toises, or 13,418 feet above the sea level. According to angles of altitude the cubical rock is 21 toises or 134 feet in height; consequently the total altitude, which cannot be reached on account of the perpendicular wall of the rock is 13,552 feet above the sea. I found only single spots of sporadic snow, the lower limit of which was 12,150 feet; about 700 or 800 feet below the upper limit of

prolongation of the lava-stream which is certainly very probable (it is so represented in my *Profiles* tab. 9 and 11, and in *the Nivellement Barométrique*), that it may have flowed from this mountain, the form of which is so remarkable. The Cofre de Perote, which is nearly 1400 feet higher than the peak of Teneriffe, but inconsiderable in comparison with the giants Popocatepetl and Orizaba, forms, like Pichincha, a long rocky ridge, upon the southern extremity of which stands the small cubical rock (la Peña), the form of which gave origin to the ancient Aztec name of Nauhcampatepetl. In ascending the mountain I saw no trace of the falling in of a crater, or of eruptive orifices on its declivities; no masses of scoriæ, and no obsidians, perlites or pumice-stones belonging to it. The blackish gray rock is very uniformly composed of much hornblende and a species of felspar, which is not glassy felspar (sanidine) but oligoclase; this would show the entire rock, which is not porous, to be a dioritic trachyte. I describe the impressions which I experienced.

forest-trees in beautiful pine-trees: *Pinus occidentalis,* mixed with *Cupressus sabinoides* and *Arbutus Madroño.* The oak, *Quercus xalapensis,* had accompanied us only to an absolute elevation of 10,340 feet. (Humboldt, *Nivellement barométr. des Cordillères,* Nos. 414—429). The name of *Nauhcampatepetl,* which the mountain bears in the Mexican language, is derived from its peculiar form, which also induced the Spaniards to give it the name of Cofre. It signifies "quadrangular mountain" for *nauhcampa,* formed from *nahui,* the numeral four, signifies, as an adverb *from four sides,* but as an adjective (although the Dictionaries do not state this), undoubtedly *quadrangular* or *four-sided,* as this signification is attached to the compound *nauhcampa ixquich.* An observer, very well acquainted with the country, M. Pieschel, supposes the existence of an old crater-opening on the eastern declivity of the Cofre de Perote (*Zeitschrift für Allgem. Erdkunde, herausg, von Gumprecht,* Bd. v, s. 125). I drew the view of the Cofre, given in my *Vues des Cordillères,* pl. xxxiv, in the vicinity of the castle of San Carlos de Perote, at a distance of about eight miles. The ancient Aztek name of Perote was Pinahuizapan, and signifies (according to Buschmann) the beetle *pinahuiztli* (regarded as an evil omen, and employed superstitiously in fortune-telling: see Sahagun, *Historia Gen. de las Cosas de Nueva España,* t. ii, 1829, pp. 10—11) on the water; the name of this beetle is derived from *pinahua,* to be ashamed. From the same verb is derived the above-mentioned local name Pinahuast (*pinahuaztli*) of this district; as well as the name of a shrub (Mimosaceæ?) *pinahuihuiztli,* translated *herba verecunda* by Hernandez, the leaves of which fall down when touched.

If the terrible, black lava-field—Malpais—(upon which I have here purposely dwelt in order to counteract the too one-sided consideration of exertions of volcanic force from the interior), did not flow from the Cofre de Perote itself at a lateral opening, still the upheaval of this isolated mountain 13,553 feet in height, may have caused the formation of the Loma de Tablas. During such an upheaval, longitudinal fissures and networks of fissures may be produced far and wide by folding of the soil, and from these, molten masses may have poured directly, sometimes as dense masses, and sometimes as scoriaceous lava, without any formation of true mountain platforms (open cones or craters of elevation). Do we not seek in vain in the great mountains of basalt and porphyritic-slate, for central points (crater-mountains) or lower, circumvallated, circular chasms, to which their common production might be ascribed? The careful separation of that which is genetically different in phenomena:—the formation of conical mountains with permanently open craters and lateral openings; of circumvallated craters of elevation and Maars; of upraised closed bell-shaped mountains or open cones, or matters poured out from coalescent fissures—is a gain to science. It is so because the multiplicity of opinions which is necessarily called forth by an enlarged horizon of observation, and the strict critical comparison of that which exists, with that which is asserted to be the only mode of production, are most powerful inducements to investigation. Even upon European soil, however, on the island of Eubœa, so rich in hot springs, a vast lava-stream has been poured out,[20] within the historical period, from a chasm in the great plain of Lelanton, at a distance from any mountain.

In the volcanic group of Central America, which follows the Mexican group towards the south, and in which eighteen conical and bell-shaped mountains may be regarded as still active, four (Nindiri, el Nuevo, Conseguina, and San Miguel de Bosotlan) have been recognized as producing lava.[21] The mountains of the third volcanic group, that of Popayan and Quito, have already for more than a century enjoyed the re-

[20] Strabo, lib. i, p. 58, lib. vi, p. 269, ed. Casaubon; *Cosmos,* vol. i, p. 236, and vol. v, p. 225.

[21] See page 278.

putation of furnishing no lava-streams, but only incoherent, glowing scoriaceous masses, thrown out of the single summital crater, and often rolling down in a linear arrangement. This was even the opinion[22] of La Condamine, when he left the highlands of Quito and Cuença in the spring of 1743. Fourteen years afterwards, when he returned from an ascent of Vesuvius (4th June, 1755), in which he accompanied the sister of Frederick the Great, the Margravine of Baireuth, he had the opportunity of expressing himself warmly, in a meeting of the French Academy, upon the want of true lava-streams (*laves coulées par torrens de matières liquefiées*)

[22] "I have never known," says La Condamine, "lava-like matter in America, although M. Bouguer and myself have encamped for whole weeks and months upon the volcanoes, and especially upon those of Pichincha, Cotopaxi, and Chimborazo. Upon these mountains I have only seen traces of calcination, without liquefaction. Nevertheless, the kind of blackish crystal, commonly called *Piedra de Gallinaço* in Peru (obsidian), of which I have brought home several fragments, and of which a polished lens of seven or eight inches in diameter, may be seen in the cabinet of the *Jardin du Roi*, is nothing but a glass formed by volcanic action. The materials of the stream of fire which flows continually from that of Sangai, in the province of Macas, to the south-east of Quito, are no doubt lava, but we have only seen this mountain from a distance, and I was no longer at Quito at the time of the last eruptions of the volcano of Cotopaxi, when vents opened upon its flanks, from which ignited and liquid matters were seen to issue in streams, which must have been of a similar nature to the lava of Vesuvius" (La Condamine, *Journal de Voyage en Italie*, in the *Mémoires de l'Acad. des Sciences*, 1757, p. 357, *Historie*, p. 12). The two examples, especiallythe first, are not happily chosen. The Sangay was first scientifically examined in December of the year 1849, by Sebastian Wisse; what La Condamine, at a distance of 108 miles, took for luminous lava flowing down, and "an effusion of burning sulphur and bitumen," consists of red-hot stones and scoriaceous masses, which sometimes, pressed closely together, slip down on the steep declivities of the cone of ashes (*Cosmos*, see above, p. 264). On Cotopaxi, as on Tungurahua, Chimborazo, and Pichincha, or on Puracé, and Sotara near Popayan, I have seen nothing that could be looked upon as narrow lava-streams, which had flowed from these colossal mountains. The incoherent, glowing masses of 5—6 feet in diameter, often containing obsidian, which Cotopaxi has scattered abroad during its eruptions, impelled by floods of melting snow and ice, have reached far into the plain, where they form rows partially diverging in a radiate form. La Condamine also says very truly elsewhere (*Journal du Voyage à l'Equateur*, p. 160):—"These fragments of rock, as large as the hut of an Indian, form series of rays, which start from the volcano as from a common centre."

from the volcanoes of Quito. The *Journal d'un Voyage en Italie,* which was read at the meeting of the 20th April, 1757, only appeared in 1762 in the *Mémoires* of the Academy of Paris, and is of some geognostic importance in the history of the recognition of old extinct volcanoes in France, because in this journal, La Condamine, with his peculiar acuteness, and without knowing of the certainly earlier observations of Guettard,[23] expresses himself very decidedly upon the existence of ancient crater-lakes and extinct volcanoes in middle and northern Italy and in the south of France.

This remarkable contrast between the narrow and undoubted lava-streams of Auvergne thus early recognized, and the often too absolutely asserted absence of any effusion of lava in the Cordilleras, occupied me seriously during the whole period of my expedition. All my journals are full of considerations upon this problem, the solution of which I long sought in the absolute elevation of the summits and in the vastness of the circumvallation, that is to say, the sinking of trachytic conical mountains from mountain-plains of eight or nine thousand (8500—9600 English) feet in elevation and of great breadth. We now know, however, that a volcano of Quito, 17,000 feet in height, which throws out scoriæ (that of Macas), is uninterruptedly much more active than the low volcanoes Izalco and Stromboli; we know that the eastern dome-shaped and conical mountains, Antisana and Sangay, have free slopes towards the plains of the Napo and Pastaza; and the western ones, Pichincha, Iliniza, and Chimborazo, towards the affluents of the Pacific Ocean. In many also the upper part projects without circumvallation eight or nine thousand feet above the elevated plateaux. Moreover, all these elevations above the sea-level, which is regarded, although not quite correctly, as the mean elevation of the earth's surface, are certainly inconsiderable as compared with the depth which we may assume to be that of the seat of volcanic activity, and of the necessary temperature for the fusion of rock-masses.

[23] Guettard's memoir on the extinct volcanoes was read at the Academy in 1752, consequently three years before La Condamine's journey into Italy; but only printed in 1756, consequently during the Italian travels of the astronomer.

The only phenomena resembling narrow lava-eruptions which I discovered in the Cordilleras of Quito, are those presented by the colossal mountain Antisana, the height of which I determined to be 19,137 feet (5833 metres), by a trigonometrical measurement. As the structure furnishes the most important criterion here, I will avoid the systematic denomination *lava*, which confines the idea of the mode of production within too narrow limits, and make use, but quite provisionally, of the names "*rock-débris*" (*Felstrümmern*) or "*detritus dykes*," (*Schuttwällen, traînées de masses volcaniques*). The mighty mountain of Antisana, at an elevation of 13,458 feet, forms a nearly oval plain, more than 12,500 toises (79,950 feet) in long diameter, from which the portion of the mountain covered with perpetual snow rises like an island. The highest summit is rounded off and dome-shaped. The dome is united by a short jagged ridge with a truncated cone lying towards the north. In the plateau, partly desert and sandy, partly covered with grass (the dwelling-place of a very spirited race of cattle, which, owing to the slight atmospheric pressure, easily expel blood from the mouth and nostrils when excited to any great muscular exertion), is situated a small farm (Hacienda), a single house in which we passed four days in a temperature varying between 38°·6 and 48°·2. The great plain, which is by no means circumvallated as in craters of elevation, bears the traces of an ancient sea-bottom. The Laguna Mica, to the westward of the Altos de la Moya, is to be regarded as the residue of the old covering of water. At the margin of the limit of perpetual snow, the Rio Tinajillas bursts forth, subsequently, under the name of Rio de Quixos, becoming a tributary of the Maspa, the Napo, and the Amazon. Two narrow, wall-like dykes, or elevations, which I have indicated upon the plan of Antisana, drawn by me, as *coulées de laves,* and which are called by the natives Volcan de la Hacienda and Yana Volcan (*Yana* signifies black or brown in the Qquechhua language), pass like bands from the foot of the volcano at the lower margin of the perpetual snow-line, and extend, apparently with a very moderate declivity, in a direction N.E.—S.W., for more than 2000 toises (12,792 feet) into the plain. With very little breadth they have probably an elevation of 192 to 213 feet above the soil of the Llanos de la Hacienda, de Santa Lucia, and del Cuvillan. Their declivities are everywhere very rugged and steep, even at the extremities. In their present state they consist of conchoidal and usually sharp-edged fragments of a black basaltic rock, without olivine or hornblende, but containing a few small white crystals of felspar. The fundamental mass has frequently a lustre like that of pitchstone, and contains an admixture of obsidian, which was especially recognizable in very large quantity, and more distinctly, in the so-called Cueva de Antisana, the elevation of which we found to be 15,942 feet. This is not a true cavern, but a shed formed by blocks of rock which had fallen against and mutually supported each other, and which preserved the mountain cowherds and also ourselves during a fearful hailstorm. The Cueva lies somewhat to the north of the Volcan de la Hacienda. In the two narrow dykes, which have the appearance of cooled lava-streams, the tables and blocks appear in part inflated like cinders or even spongy at the edges, and in part weathered and mixed with earthy detritus.

Analogous but more complicated phenomena are presented by another also band-like mass of rocks. On the eastern declivity of the Antisana, probably about 1280 feet perpendicularly below the plain of the Hacienda in the direction of Pinantura and Pintac, there lie two small round lakes, of which the more northern is called Ansango, and the southern Lecheyacu. The former has an insular rock, and is surrounded by rolled pumice-stone, a very important point. Each of these lakes marks the commencement of a valley; the two valleys unite, and their enlarged continuation bears the name of Volcan de Ansango, because from the margins of the two lakes narrow lines of rock débris, exactly like the two dykes of the plateau which we have described above, do not, indeed, fill up the valley, but rise in its midst like dams to a height of 213 and 266 feet. A glance at the local plan which I published in the "Geographical and Physical Atlas" of my American travels (pl. 26), will illustrate these conditions. The blocks are again partly sharp-edged, and partly scorified and even burnt like coke at the edges. It is a basaltic, black, fundamental mass, with sparingly scattered glassy felspar; some fragments are blackish brown and of a dull pitch stone-like lustre. Basaltic as the fundamental mass appears, however, it is entirely destitute of the olivine which occurs so abundantly on the Rio Pisque and near Gualla-bamba, where I saw basaltic columns of 72 feet in height and 3 feet thick, which contained both olivine and horn-blende scattered in them. In the dyke of Ansango numerous tablets, cleft by weathering, indicate porphyritic slates. All the blocks have a yellowish gray crust from weathering. As the detritus-ridge (called los derrumbamientos, la reventazon, by the natives, who speak Spanish), may be traced from the Rio del Molina, not far from the farm of Pintac, up to the small crater-lakes surrounded by pumice-stone (chasms filled with water), the opinion has grown up naturally, and, as it were, of itself, that the lakes are the openings from which the blocks of stone came to the surface. A few years before my visiting the district, the ridge of fragments was in motion for weeks upon the inclined surface, without any perceptible previous earthquake, and some houses near Pintac were destroyed by the pressure and shock of the blocks of stone. The detritus-ridge of Ansango is still without any trace of vegetation, which is found, although very sparingly, upon the two more weathered and certainly older eruptions of the plateau of Antisana.

How is this mode of manifestation of volcanic activity, the action of which I am describing, to be denominated ?[24] Have we here to do with lava-streams ? or only with semi-scorified and ignited masses, which are thrown out unconnected, but in chains pressed closely upon each other (as on Cotapaxi in very recent times)? Have the dykes of Yana Volcan and Ansango been perhaps merely solid fragmentary masses, which burst forth without any fresh elevation of temperature from the interior of a volcanic conical mountain, in which they lay loosely accumulated and therefore badly supported, their movement being caused by the concussion of an earthquake, impelled by shocks or falls and giving rise to small local earthquakes ? Is no one of the three manifes-

[24] "There are few volcanoes in the chain of the Andes," says Leopold von Buch, "which have presented streams of lava, and none have ever been seen around the volcanoes of Quito. Antisana, upon the eastern chain of the Andes, is the only volcano of Quito upon which M. de Humboldt saw, near the summit, something analogous to a stream of lava; this stream was exactly like obsidian" (*Descr. des Iles Canaries*, 1836, pp. 468 and 488).

tations of volcanic activity here indicated, different as they are, applicable in this case? and have the linear accumulations of rock-detritus been upheaved upon fissures in the spots where they now lie (at the foot and in the vicinity of a volcano)? The two dykes of fragments, in this so slightly inclined plateau, called Volcan de la Hacienda and Yana Volcan, which I once considered, although only conjecturally, as cooled lava-streams, now appear to me, as far as I can remember, to present but little in support of the latter opinion. In the Volcan de Ansango, where the line of fragments may be traced without interruption, like a river-bed, to the pumice margins of two small lakes, the fall, or difference of level between Pinantura 1482 toises (9476 feet), and Lecheyacu 1900 toises (12,150 feet), in a distance of about 7700 toises (49,239 feet), by no means contradicts what we now believe we know of the small average angles of inclination of lava-streams. From the difference of level of 418 toises (2674 feet), there is an inclination of 3° 6′. A partial elevation of the soil in the middle of the floor of the valley would not appear to be any hindrance, because the back swell of fluid masses impelled up valleys has been observed elsewhere, for example, in the eruption of Scaptar Jökul in Iceland, in 1783 (Naumann, Geognosie, Bd. i, s. 160).

The word lava indicates no peculiar mineral composition of the rock; and when Leopold von Buch says that everything is lava that flows in the volcano and attains new positions by its fluidity, I add that that which has not again become fluid, but is contained in the interior of a volcanic cone, may change its position. Even in the first description[25] of my attempt to ascend the summit of Chimborazo (only published in 1837, in Schumacher's *Astronomische Jahrbuch*), I expressed this opinion in speaking of the remarkable "fragments of augitic porphyry which I collected on the 23rd June, 1802, in loose pieces of from twelve to fourteen inches in diameter, upon the narrow ridge of rock leading to the summit at an elevation of 19,000 feet. They had small, shining cells, and were porous and of a red colour. The blackest of them are sometimes light like pumice-stone, and as though freshly altered by fire. They

[25] Humboldt, *Kleinere Schriften*, Bd. i, s. 161.

have not, however, flowed out in streams like lava, but have *probably* been expelled at fissures on the declivity of the previously upheaved, bell-shaped mountain." This genetic explanation might find abundant support in the assumptions of Boussingault, who regards the volcanic cones themselves "as an accumulation of angular trachytic fragments, upheaved in a solid condition, and heaped up without any order. As after the upheaval the broken rocky masses occupy a greater space than before they were shattered, great cavities remain amongst them, movement being produced by pressure and shock (the action of the volcanic vapour-force being abstracted)." I am far from doubting the partial occurrence of such fragments and cavities, which become filled with water in the Nevados, although the beautiful, regular, and, for the most part, perfectly perpendicular trachytic columns of the Pico de los Ladrillos, and Tablahuma on Pichincha, and, above all, over the small basin Yana-Cocha on Chimborazo, appear to me to have been formed on the spot. My old and valued friend, Boussingault, whose chemico-geognostic and meteorological opinions I am always ready to adopt, regards what is called the Volcan de Ansango, and what now appears to me as an eruption of fragments from two small lateral craters (on the western Antisana, below Chussulongo) as upheavals of blocks[26] upon long fissures. As

[26] "We differ entirely with regard to the pretended stream of Antisana towards Pinantura. I regard this stream (*coulée*) as a recent upheaval analogous to those of Calpi (Yana Urcu), Pisque, and Jorullo. The trachytic fragments have acquired a greater thickness towards the middle of the stream. Their stratum is thicker towards Pinantura than at points nearer Antisana. The fragmentary condition is an effect of local upheaval, and in the Cordillera of the Andes earthquakes may often be produced by heaping up" (letter from M. Boussingault, dated August, 1834). See page 270. In the description of his ascent of Chimborazo (December, 1831), Boussingault says: —"The mass of the mountain consists, in my opinion, of a heap of trachytic ruins piled up on each other without any order. These trachytic fragments of a volcano, which are often of enormous size, are upheaved in the solid state; their edges are sharp, and nothing indicates that they had been in a fused or even a softened condition. Nowhere, on any of the equatorial volcanoes, do we observe anything that would allow us to infer a lava-stream. Nothing has ever been thrown out from these craters except masses of mud, elastic fluids and ignited, more or less scorified trachytic blocks, which have frequently been scattered to considerable distances" (Humboldt, *Kleinere Schriften*,

he has acutely investigated this region 30 years after myself, he insists upon the analogy which appears to him to be presented by the geognostic relations of the eruption of Ansango to Antisana, and those of Yana Urcu (of which I made a particular plan) to Chimborazo. I was the less inclined to believe in a direct upheaval upon fissures throughout the entire linear extent of the tract of fragments at Ansango, because this, as I have already repeatedly mentioned, leads at its upper extremity, to the two chasms now filled with water. Non-fragmentary, wall-like upheavals of great length and uniform direction, are however not unknown to me, as I have seen and described them in our hemisphere, in Chinese Mongolia, in granite banks with a floetz-like bedding[27].

Antisana had an eruption[28] in the year 1580, and another in the beginning of the last century, probably in 1728. Near the summit, on the north-north-east side, we observe a black mass of rock, upon which even freshly fallen snow does not adhere. At this point, a black column of smoke was seen ascending for several days in the spring of 1801, at a time when the summit was on all sides perfectly free from clouds. On the 16th March, 1802, Bonpland, Carlos Montufar, and myself reached a ridge of rock, covered with pumice-stone, and black, basaltic scoriæ in the region of perpetual snow, at an elevation of 2837 toises (18,142 feet), and consequently 2358 feet higher than Montblanc. The snow was firm enough to bear us on

Bd. i, s. 200). With regard to the first origin of the opinion of the upheaval of solid masses in the form of heaped-up blocks, see Acosta, in the *Viajes á los Andes Ecuatoriales par M. Boussingault,* 1849, pp. 222—223. The movement of the heaped-up fragments, induced by earth-shocks and other causes, and the gradual filling up of the interstices, may, according to the assumptions of the celebrated traveller, produce a gradual sinking of volcanic mountain peaks.

27 Humboldt, *Asie Centrale,* t. ii, pp. 296—301 (Gustav Rose, *mineral-geognostische Reise nach dem Ural, dem Altai und dem Kasp. Meere,* Bd. i, s. 599). Narrow, much elongated granitic walls may have risen, during the earliest foldings of the earth's crust, over fissures analogous to the remarkable, still open ones, which are found at the foot of the volcano of Pichincha: as the Guaycos of the city of Quito, of 30—40 feet in width (see my *Kleinere Schriften,* Bd. i, s. 24).

28 La Condamine, *Mesure des trois premiers Degrés du Meridien dans l'Hémisphère Austral,* 1751, p. 56.

many points near the ridge of rock, which is so rare under the tropics (temperature of the atmosphere, 28°·8—34°·5). On the southern declivity, which we did not ascend, at the Piedro de Azufre, where scales of rock sometimes separate of themselves by weathering, masses of pure sulphur of 10—12 feet in length, and 2 feet in thickness, are found; sulphurous springs are wanting in the vicinity.

Although in the eastern Cordillera the volcano of Antisana, and especially its western declivity (from Ansango and Pinantura, towards the village of Pedregal) is separated from Cotopaxi by the extinct volcano of Passuchoa[29] with its widely distinguishable crater (la Peila), by the Nevado Sinchulahua and by the lower Rumiñaui, there is still a certain resemblance between the rocks of the two giants. From Quinche onwards the whole eastern chain of the Andes has produced obsidian, and yet el Quinche, Antisana, and Passuchoa belong to the basin in which the city of Quito is situated; whilst Cotopaxi bounds another basin, that of Lactacunga, Hambato and Riobamba. The small knot of mountains of the Altos of Chisinche separates the two basins like a dam; and what is remarkable

[29] Passuchoa, separated by the farm el Tambillo from the Atacazo, does not any more than the latter attain the region of perpetual snow. The elevated margin of the crater, la Peila, has fallen in towards the west, but projects towards the east like an amphitheatre. The tradition runs that at the end of the sixteenth century, the Passuchoa, which had previously been active, ceased its manifestations of activity on the occasion of an eruption of Pichincha, which proves the communication between the vents of the opposite eastern and western Cordilleras. The true basin of Quito, closed like a dam,—on the north by a mountain group between Cotocachi and Imbaburo, and on the south, by the Altos de Chisinche (between 0° 20′ N. and 0° 41′ S.), is for the most part divided longitudinally by the mountain ridges of Ichimbio and Poingasi. To the eastward lies the valley of Puembo and Chillo; to the westward the plain of Inaquito and Turubamba. In the eastern Cordillera follow from north to south,—Imbaburo, the Faldas de Guamani, and Antisana, Sinchulahua, and the perpendicular, black wall, crowned with turret-like points, of Rumiñaui (Stone-eye); in the western Cordillera, Cotocachi, Casitagua, Pichincha, Atacazo, and Corazon, upon the slopes of which blooms the splendid Alpine plant, the red *Ranunculus Gusmani*. This has appeared to me to be the place to give, in brief terms, a morphological representation, drawn from my own experience, of the form of a spot which is so important and classical in respect to volcanic geology.

enough, considering its smallness, the waters of the northern slope of Chisinche pass by the Rios de San Pedro, de Pito, and de Guallabamba into the Pacific, whilst those of the southern declivity flow through the Rio Alaques and the Rio de San Felipe into the Amazons and Atlantic Ocean. The union of the Cordilleras by mountain knots and dykes (sometimes low, like the Altos just mentioned; sometimes equal to Mont Blanc in height, as on the road over the Paso del Assuay) appears to be a more recent and also a less important phenomenon than the upheaval of the divided parallel mountain chain itself. As Cotopaxi, the greatest of the volcanoes of Quito, presents much analogy in its trachytic rock with the Antisana, so also we again meet with the rows of blocks (lines of fragments) which have already occupied us so long, even in greater number upon the slopes of Cotopaxi.

It was especially our business when travelling to trace these rows to their origin, or rather to the point where they are concealed beneath the perpetual covering of snow. We ascended upon the south-western declivity of the volcano from Mulalo (Mulahalo), along the Rio Alaques, which is formed of the Rio de los Baños and the Rio Barrancas, up to Pansache (12,066 feet), where we inhabited the spacious Casa del Paramo in the grassy plain (el Pajonal). Although up to this time much snow had fallen at night, we nevertheless got to the eastward of the celebrated Cabeza del Inga, first into the Quebrada and Reventazon de las Minas, and afterwards still further to the east over the Alto de Suniguaicu to the chasm of the Lion Mountain (Puma-Urcu), where the barometer only showed an elevation of 2263 toises, or 14,471 feet. Another line of fragments which, however, we only saw from a distance, has moved from the eastern part of the snow-clad ash-cone towards the Rio Negro (an affluent of the Amazon) and Valle vicioso. It is uncertain whether these blocks were all thrown out of the crater at the summit to a great height in the air, as glowing, scoriaceous masses fused only at the edges (some angular, some rounded, of 6 or 8 feet in diameter, rarely conchoidal like those of Antisana), falling on the declivity of Cotopaxi and, hastened in their movement by the rush of the melted snow water; or whether, without passing through the air they were forced out through lateral fissures of the volcano, as the word *reventazon* would indicate. Soon returning from Suniguaicu and the Quebrada del Mestizo, we examined the long and broad ridge which, striking from N.W. to S.E., unites Cotopaxi with the Nevado de Quelendaña. Here the blocks arranged in rows are wanting, and the whole appears to be a dam-like upheaval, upon the ridge of which are situated the small conical mountain el Morro and, nearer to the horse-shoe shaped Quelendaña, several marshes and two small lakes (Lagunas de Yauricocha and de Verdecocha). The rock of el Morro and of the entire linear volcanic upheaval was greenish-gray porphyritic slate, separated into layers of eight inches thick, which dipped very regularly towards the east at 60°. Nowhere was there any trace of true lava-streams[30].

[30] It is particularly remarkable that the vast volcano of Cotopaxi, which manifests an enormous activity, although, indeed, usually only after long periods, and acts destructively upon the neighbourhood, especially by the inundations which it produces, exhibits no visible vapours between its periodical eruptions, when seen either in the plateau of Lactacunga, or from the Paramo de Pansache. From several comparisons with other colossal volcanoes, such a phenomenon is certainly not to be explained from its height of 19,180 feet, and the great tenuity of the strata of air and vapour corresponding with this elevation. No other Nevado of the equatorial Cordilleras shows itself so often free from clouds and in such great beauty as the truncated cone of Cotopaxi, that is to say the portion which rises above the limit of perpetual snow. The uninterrupted regularity of this ash-cone is much greater than that of the ash-cone of the Peak of Teneriffe, on which a narrow projecting rib of obsidian runs down like a wall. Only the upper part of the Tungurahua is said formerly to have been distinguished in an almost equal degree by the regularity of its form, but the terrible earthquake of the 4th February, 1797, called the *Catastrophe of Riobamba*, has deformed the mountain cone of Tungurahua by fissures and the falling in of parts and the descent of loosened wooded fragments, as also by the accumulation of débris. At Cotopaxi, as even Bouguer observed, the snow is mixed in particular spots with crumbs of pumice-stone, when it forms a nearly solid mass. A slight inequality in the mantle of snow is visible towards the north-west, where two fissure-like valleys run down. Black rocky ridges ascending to the summit are seen nowhere from afar, although in the eruptions of the 24th June and 9th December, 1742, a lateral opening showed itself halfway up the snow-covered ash-cone. "There opened," says Bouguer (*Figure de la Terre*, p. lxviii; see also La Condamine, *Journal du Voyage à l'Equateur*, p. 159), "a new mouth towards the middle of the part

In the island of Lipari, which abounds in pumice-stone, a lava-stream of pumice-stone and obsidian runs constantly covered with snow, whilst the flame always issued at the top of the truncated cone." Quite at the top, close to the summit, some horizontal, black streaks, parallel to each other, but interrupted, are detected. When examined with the telescope under various illuminations they appeared to me to be rocky ridges. The whole of this upper part is steeper, and almost close to the truncation of the cone forms a wall-like ring of unequal height, which, however, is not visible at a great distance with the naked eye. My description of this nearly perpendicular uppermost circumvallation, has already attracted the particular attention of two distinguished geologists,—Darwin (*Volcanic Islands*, 1844, p. 83), and Dana (*Geology of the U.S. Explor. Exped.*, 1849, p. 356). The volcanoes of the Galapagos Islands, Diana's Peak in St. Helena, Teneriffe, and Cotopaxi, present analogous formations. The highest point which I determined by angles of altitude in the trigonometrical measurement of Cotopaxi, was situated in a black convexity. It is, perhaps, the inner wall of the higher and more distant margin of the crater; or is the freedom from snow of the protruding rock caused at once by steepness and the heat of the crater? In the autumn of the year 1800, the whole upper part of the ash-cone was seen to be luminous, although no eruption, or even emission of visible vapours followed. On the other hand, in the violent eruption of Cotopaxi on the 4th January, 1803, when during my residence on the Pacific coast the thundering noise of the volcano shook the windows in the harbour of Guayaquil (at a distance of 148 geog. miles), the ash-cone had entirely lost its snow, and presented a most threatening appearance. Was such a heating ever observed before? Even very recently, as we learn from that admirable, and courageous female traveller, Ida Pfeiffer (*Meine zweite Weltreise*, Bd. iii, s. 170), the Cotopaxi had, in the beginning of April, 1854, a violent eruption of thick columns of smoke, "through which the fire wound itself like flashing flames." May this luminous phenomenon have been a consequence of the volcanic lightning excited by vaporization? The eruptions have been frequent since 1851.

The great regularity of the snow-covered, truncated cone itself, renders it the more remarkable that to the south-west of the summit there is a small, grotesquely-notched, rocky mass with three or four points at the lower limit of the region of perpetual snow, where the conical form commences. The snow remains upon it only in small patches, probably on account of its steepness. A glance at my representation (*Atlas Pittoresque du Voyage*, pl. 10), shows its relation to the ash-cone most distinctly. I approached nearest to this blackish-gray, probably basaltic rocky mass, in the Quebrada and Reventazon de Minas. Although this widely visible hill, of very strange appearance, has been generally known for centuries in the whole province as the Cabeza del Inga, two very different hypotheses, nevertheless, prevail with regard to its origin amongst the coloured aborigines (*Indios*),—according to the one, it is merely asserted, that the rock down to the north of Caneto, from the well-preserved, extinct crater of the Monte di Campo Bianco towards the sea, in which the fibres of the former substance run, singularly enough, parallel to the direction of the stream[31]. The

is the fallen summit of the volcano, which formerly ended in a point, without any statement of the date at which the occurrence took place; according to the second hypothesis, this is placed in the year (1533) in which the Inca Atahuallpa was strangled in Caxamarca, and thus connected with the terrible fiery eruption of Cotopaxi, described by Herrera, which took place in the same year, and also with the obscure prophecy of Atahuallpa's father, Huayna Capac, regarding the approaching fall of the Peruvian Empire. Is that which is common to both hypotheses,—namely, the opinion that this fragment of rock formerly constituted the apex of the cone,— the traditional echo, or obscure remembrance of an actual occurrence? The aborigines, it may be said, in their uncultivated state, would probably notice facts and preserve them in remembrance, but would be unable to rise to geognostic combinations. I doubt the correctness of this objection. The idea that a truncated cone, "in losing its apex," may have thrown it off unbroken, as large blocks were thrown out during subsequent eruptions, may present itself even to very uncultivated minds. The terraced pyramid of Cholula, a work of the Tolteks, is truncated. The natives could not suppose that the pyramid was not originally completed. They therefore invented the fable that an aerolite, falling from heaven, destroyed the apex; nay, portions of the aerolite were shown to the Spanish conquerors. Moreover, how can we place the first eruption of the volcano of Cotopaxi at a period when the ash-cone (the result of a series of eruptions) was already in existence? It seems probable to me, that that the Cabeza del Inga, was produced at the spot which it now occupies; that it was upheaved there, like the Yana-Urcu at the foot of Chimborazo, and like the Morro on Cotopaxi itself, to the south of Suniguaica, and to the north-west of the small lake Yurak-cocha (in the Qquechhua language, the White Lake).

With regard to the name of the Cotopaxi, I have stated in the first volume of my *Kleinere Schriften*, (s. 463,) that only the first part of it could be explained from the Qquechhua language, being the word *ccotto*, heap or mass, but that *pacsi* was unknown. La Condamine (p. 53) explains the whole name of the mountain, saying "in the language of the Incas, the name signifies *shining mass*." Buschmann, however, remarks that, in this case, *pacsi* is replaced by the word *pacsa*, which is certainly quite different from it, and which signifies *lustre, brilliancy*, especially the mild lustre of the moon; to express "*shining mass*," moreover, in accordance with the spirit of the Qquechhua language, the position of the two words would have to be reversed,—*pacsaccotto*.

[31] Friedrich Hoffmann, in Poggendorff's *Annalen*, Bd. xxvi, 1832, s. 48.

extended pumice quarries, four miles and a half from Lactacunga, present, according to my investigation of the local conditions, an analogy with this occurrence on Lipari. These quarries, in which the pumice-stone, divided into horizontal beds, has exactly the appearance of a rock in position, excited even the astonishment of Bouguer in 1737[32]. "On volcanic mountains," he says, "we only find simple fragments of pumice-stone of a certain size; but at seven leagues to the south of Cotopaxi; in a point which corresponds with our tenth triangle, pumice-stone forms entire rocks, ranged in parallel banks of 5 to 6 feet in thickness in a space of more than a square league. Its depth is not known. Imagine what a heat it must have required to fuse this enormous mass, and in the very spot where it now occurs; for it is easily seen that it has not been deranged, and that it has cooled in the place where it was liquefied. The inhabitants of the neighbourhood have profited by this immense quarry, for the small town of Lactacunga, with some very pretty buildings, has been entirely constructed of pumice-stone, since the earthquake which overturned it in 1698."

The pumice quarries are situated near the Indian village of San Felipe, in the hills of Guapulo and Zumbalica, which are elevated 512 feet above the plateau and 9990 feet above the sea level. The uppermost layers of pumice-stone are, therefore, five or six hundred feet below the level of Mulalo, the once beautiful villa of the Marquis of Maenza (at the foot of Cotopaxi), also constructed of blocks of pumice-stone, but now completely destroyed by frequent earthquakes. The subterranean quarries are at unequal distances from the two active volcanoes, Tungurahua and

[32] Bouguer, *Figure de la Terre*, p. lxviii. How often, since the earthquake of the 19th July, 1698, has the little town of Lactacunga been destroyed and rebuilt with blocks of pumice-stone from the subterranean quarries of Zumbalica! According to historical documents communicated to me during my sojourn in the country, from copies of the old ones which have been destroyed, and from more recent original documents partially preserved in the archives of the town, the destructions occurred in the years 1703 and 1736, on the 9th December, 1742, 30th November, 1744, 22nd February, 1757, 10th February, 1766, and 4th April, 1768,—therefore seven times in 65 years! In the year 1802 I found four-fifths of the town still in ruins in consequence of the great earthquake of Riobamba on the 4th February, 1797.

Cotopaxi: 32 miles from the former, and about half that distance from the latter. They are reached by a gallery. The workmen assert that from the horizontal solid layers, of which a few are surrounded by loamy pumice fragments, quadrangular blocks of 20 feet, divided by no transverse fissures, might be procured. The pumice-stone, which is partly white and partly bluish gray, consists of very fine and long fibres, with a silky lustre. The parallel fibres have sometimes a knotted appearance, and then exhibit a singular structure. The knots are formed by roundish particles of finely porous pumice-stone, from 1—1½ line in breadth, around which long fibres curve so as to inclose them. Brownish black mica in small six-sided tables, white crystals of oligoclase, and black hornblende are sparingly scattered in it; on the other hand, the glassy felspar, which elsewhere (Camaldoli, near Naples) occurs in pumice-stone, is entirely wanting. The pumice-stone of Cotopaxi is very different from that of the quarries of Zumbalica[33]: its fibres are short, not parallel, but curved in a confused manner. Magnesia-mica, however, is not peculiar to pumice-stone, for it is also found in the fundamental mass of the trachyte[34] of Cotopaxi. At the more southern volcano, Tungurahua, pumice-stone appears to be entirely wanting. There is no trace of obsidian in the vicinity of the quar-

[33] This difference has also been recognized by the acute Abich, (*Ueber Natur und Zusammenhang vulkanischer Bildungen*, 1841, s. 83).

[34] The rock of Cotopaxi has essentially the same mineralogical composition, as that of the nearest volcanoes, Antisana and Tungurahua. It is a trachyte, composed of oligoclase and augite, and consequently a Chimborazo-rock: a proof of the identity of the same kind of volcanic mountain in masses in the opposite Cordilleras. In the specimens collected by me in 1802, and by Boussingault in 1831, the fundamental mass is partly light or greenish gray, with a pitchstone-like lustre and translucent at the edges; partly black, nearly resembling basalt, with large and small pores, which possess shining walls. The inclosed oligoclase is distinctly limited; sometimes in very brilliant crystals, very distinctly striated on the cleavage planes; sometimes in small fragments and difficult of detection. The intermixed augites are brownish and blackish green and of very variable size. Dark laminæ of mica and black metallic grains of magnetic iron are rarely and probably quite accidentally sprinkled through the mass. In the pores of a mass containing much oligoclase, there was some native sulphur, probably deposited by the all-penetrating sulphurous vapours.

ries of Zumbalica, but I have found black obsidian with a conchoidal fracture in very large masses, immersed in bluish gray weathered perlite, amongst the blocks thrown out from Cotopaxi and lying near Mulalo. Of this, fragments are preserved in the Royal Collection of Minerals at Berlin. The pumice-stone quarries here described, at a distance of sixteen miles from the foot of Cotopaxi, appear therefore, to judge from their mineralogical nature, to be quite foreign to that mountain, and only to stand in the same relation to it, which all the volcanoes of Pasto and Quito, occupying many thousand square miles, present to the volcanic focus of the equatorial Cordilleras. Have these pumice-stones been the centre and interior of a proper crater of elevation, the external wall of which has been destroyed in the numerous convulsions which the surface of the earth has here undergone? or have they been deposited here upon fissures in apparent rest, during the most ancient foldings of the earth's crust? For the assumption of aqueous sedimentary alluvia, such as are often exhibited in volcanic tufaceous masses mixed with remains of plants and shells, is attended with still greater difficulties.

The same questions are suggested by the great mass of pumice-stone, at a distance from all intumescent volcanic platforms, which I found on the Rio Mayo in the Cordillera of Pasto, between Mamendoy and the Cerro del Pulpito, 36 miles from the active volcano of Pasto. Leopold von Buch has also called attention to a similar perfectly isolated eruption of pumice-stone described by Meyen, which, consisting of boulders, forms a hill of 320 feet in height, near the village of Tollo, to the east of Valparaiso, in Chili. The volcano Maypo, which upheaves jurassic strata in its rise, is two full days' journey from this eruption of pumice-stone[35]. The Prussian Ambassador in Washington, Friedrich von Gerolt, to whom we are indebted for the first

[35] "The volcano of Maypo (S. lat. 34° 15′) which has never ejected pumice-stone, is at a distance of two days' journey from the ridge of Tollo, which is 320 feet in height and entirely composed of pumice-stone, inclosing vitreous felspar, brown crystals of mica, and small fragments of obsidian. It is, therefore, an (independent) isolated eruption, quite at the foot of the Andes and close to the plain." Leop. de Buch, *Desc. Phys. des Iles Canaries,* 1836, p. 470.

coloured geognostic map of Mexico, also mentions "a subterranean quarry of pumice-stone at Bauten," near Huichapa, 32 miles to the south-east of Queretaro, at a distance from all volcanoes[36]. The geological explorer of the Caucasus, Abich, is inclined to believe from his own observations, that the vast eruption of pumice-stone near the village Tschegem, in the little Kabarda, on the northern declivity of the central chain of the Elburuz, is, as an effect of fissure, much older than the elevation of the very distant conical mountain just menioned.

If, therefore, the volcanic activity of the earth, by radiation of heat into space during the diminution of its original temperature, and in the contraction of the superior cooling strata, produces fissures and wrinkles (*fractures et rides*), and therefore simultaneous sinking of the upper and upheaval of the lower parts[37], we must naturally regard, as the measure and evidence of this activity in the various regions of the earth, the number of recognizable volcanic platforms (open, conical, and dome-shaped mountains) upheaved upon fissures. This enumeration has been repeatedly and often very imperfectly attempted: eruptive hills

[36] Federico de Gerolt, *Cartas Geognosticas de los Principales Distritos Minerales de Mexico*, 1827, p. 5.

[37] On the solidification and formation of the crusts of the earth, see *Cosmos*, vol. i, pp. 164—166. The experiments of Bischof, Charles Deville, and Delesse have thrown a new light upon the folding of the body of the earth. See also the older, ingenious considerations of Babbage, on the occasion of his thermic explanation of the problem presented by the temple of Serapis to the north of Puzzuoli, in the *Quarterly Journal of the Geological Society of London*, vol. iii, 1847, p. 186; Charles Deville, *Sur la Diminution de Densité dans les Roches en passant de l'état cristallin à l'état vitreux*, in the *Comptes rendus de l'Acad. des Sciences*, t. xx, 1845, p. 1453; Delesse, *Sur les Effets de la Fusion*, t. xxv, 1847, p. 455; Louis Frapolli *Sur la Caractère Géologique*, in the *Bull. de la Soc. Géol. de France*, 2me série, t. iv, 1847, p. 627; and above all, Elie de Beaumont, in his important work, *Notice sur les Systèmes de Montagnes*, 1852, t. iii. The following three sections deserve the particular attention of geologists: *Considérations sur les Soulèvements dûs à une diminution lente et progressive du volume de la Terre*, p. 1330; *Sur* l'Ecrasement Transversal *nommé* refoulement *par Saussure, comme une des causes de l'élévation des Chaînes de Montagnes*, pp. 1317, 1333, and 1346; *Sur la Contraction que les Roches fondues éprouvent en cristallisant, tendant dès le commencement du refroidissement du Globe à rendre sa masse interne plus petite que la capacité de son enveloppe extérieure*, p. 1235.

and solfataras, belonging to one and the same system, have been referred to as distinct volcanoes. The magnitude of the space in the interior of continents which has hitherto remained closed to all scientific investigation, has not been so great an obstacle to the solidity of this work as is commonly supposed, as islands and regions near the coast are generally the principal seat of volcanoes. In a numerical investigation, which cannot be brought to a full conclusion in the present state of our knowledge, much is already gained when we attain to a result which is to be regarded as a lower limit, and when we can determine with great probability upon how many points the fluid interior of our earth has remained in active communication with the atmosphere within the historical period. Such an activity usually manifests itself simultaneously in eruptions from volcanic platforms (conical mountains), in the increasing heat and inflammability of thermal springs and naphtha wells, and in the increased extent of circles of commotion, phenomena which all stand in intimate connection and in mutual dependence[38]. Here again, also, Leopold von Buch has the great merit of having (in the supplements to the *Physical Description of the Canary Islands*) for the first time undertaken to bring the volcanic system of the whole earth, after the fundamental distinction of Central and Linear Volcanoes, under one cosmical point of view. My own more recent, and, probably for this reason, more complete enumeration, undertaken in accordance with principles which I have already indicated (pp. 245 and 271) and therefore excluding unopened bell-shaped mountains and mere eruptive cones, gives, as the probable *lower numerical limit* (*nombre limite inférieur*), a result which differs considerably from all pre-

[38] "The hot springs of Saragyn at the height of fully 5600 feet are remarkable for the part played by the carbonic acid gas which traverses them at the period of earthquakes. At this epoch, the gas, like the carbonated hydrogen of the peninsula of Apscheron, increases in volume and becomes heated, before and during the earthquakes in the plain of Ardebil. In the peninsula of Apscheron, the temperature rises 36°, until spontaneous inflammation occurs at the moment when and the spot where an igneous eruption takes place, which is always prognosticated by earthquakes in the provinces of Chemakhi and Apscheron." Abich, in the *Mélanges Physiques et Chimiques,* t. ii, 1855, pp. 364—365 (see *Cosmos,* vol. v, p. 175).

vious ones. It is an attempt to indicate the volcanoes which have been active within the historical period.

The question has been repeatedly raised whether in those parts of the earth's surface, in which the greatest number of volcanoes are crowded together, and the reaction of the interior of the earth upon the hard (solid) crust manifests the most activity, the fused part may not lie nearer to the surface? Whatever be the course adopted to determine the average thickness of the solid crust of the earth in its maximum: whether it be the purely mathematical one which is presented by theoretical astronomy[39], or the simpler course, founded upon the law of the increase of heat with depth and the temperature of fusion of rocks[40], still the solution of this problem presents a great number of values which are at present undetermined. Amongst these we

[39] W. Hopkins, *Researches on Physical Geology* in the *Phil. Transact. for* 1839, pt. ii, p. 311, for 1840, pt. i, p. 193, and for 1842, pt. i, p. 43; also with regard to the necessary relations of stability of the external surface; *Theory of Volcanoes* in the *British Association Report for* 1847, pp. 45—49.

[40] *Cosmos*, vol. v. pp. 35—37; Naumann, *Geognosie*, Bd. i, pp. 66—76; Bischof, *Wärmelehre*, s. 382; Lyell, *Principles of Geology*, 1853, pp. 536—547 and 562. In the very interesting and instructive work, *Souvenirs d'un Naturaliste*, by A. de Quatrefages, 1854, t. ii, p. 469, the upper limit of the fused liquid strata, is brought up to the small depth of 20 kilometres: "as most of the silicates fuse at 1231°." "This low estimate," as Gustav Rose observes, "is founded in an error. The temperature of 2372°, which is given by Mitscherlich as the melting point of granite (*Cosmos*, vol. i, p. 26) is certainly the minimum that we can admit. I have repeatedly had granite placed in the hottest parts of a porcelain furnace, and it was always but imperfectly fused. The mica alone fuses with the felspar to form a vesicular glass; the quartz becomes opaque, but does not fuse. This is the case with all rocks which contain quartz; and this means may even be made use of for the detection of quartz in rocks, in which its quantity is so small that it cannot be discovered with the naked eye,—for example in the syenite of Plauen, and in the diorite, which we brought in 1829 from Alapajewsk in the Ural. All rocks which contain no quartz, or any other minerals so rich in silica as granite, such as basalt for example, fuse more readily than granite to form a perfect glass in the porcelain furnace; but not over the spirit lamp with a double current, which is nevertheless certainly capable of producing a temperature of 1231°." In Bischof's remarkable experiments, on the fusion of a globule of basalt, even this mineral appeared, from some hypothetical assumptions to require a temperature 264° higher than the melting point of copper. (*Wärmelehre des Innern unsers Erdkörpers*, s. 473).

have to mention: the influence of an enormous pressure upon fusibility,—the different conduction of heat by heterogeneous rocks,—the remarkable enfeebling of conductibility with a great increase of temperature, treated of by Edward Forbes,—the unequal depth of the oceanic basin,—and the local accidents in the connection and nature of the fissures, which lead down to the fluid interior! If the greater vicinity of the upper limit of the fluid interior in particular regions of the earth may explain the frequency of volcanoes and the greater multiplicity of communication between the depths and the atmosphere, this vicinity again may depend either upon the relative average differences of elevation of the sea-bottom and the continents, or upon the unequal perpendicular depth at which the surface of the molten fluid mass occurs, in various geographical longitudes and latitudes. But where does such a surface commence? Are there not intermediate degrees between perfect solidity and perfect mobility of the parts?—states of transition which have frequently been referred to in the discussions relative to the plasticity of some Plutonic and volcanic rocks which have been elevated to the surface, and also with regard to the movement of glaciers. Such intermediate states abstract themselves from mathematical considerations, just as much as the condition of the so-called fluid interior under an enormous pressure. If it be not even very probable that the temperature everywhere continues to increase with the depth in arithmetical progression, local intermediate disturbances may also occur, for example, by subterranean basins (cavities in the hard mass), which are from time to time partially-filled from below with fluid lava and vapours resting upon it[41]. Even the immortal author of the *Protogæa* allows these cavities to play a part in the theory of the diminishing central heat:—"Postremo credibile est contrahentem se refrigeratione crustam *bullas* reliquisse, ingentes pro rei magnitudine id est sub vastis fornicibus *cavitates*."[42]

[41] *Cosmos,* vol. v, p. 168. See also with regard to the unequal distribution of the icy soil, and the depth at which it commences, independently of geographical latitude, the remarkable observations of Captain Franklin, Erman, Kupffer, and especially of Middendorff (*loc. cit. sup*, s. 42, 47 and 167).

[42] Leibnitz in the *Protogæa,* § 4.

The more improbable it is that the thickness of the crust already solidified is the same in all regions, the more important is the consideration of the number and geographical position of the volcanoes which have been open in historical periods. Such an examination of the geography of volcanoes can only be perfected by frequently renewed attempts.

I. Europe.

Etna,
Volcano in the Liparis,
Stromboli,
Ischia,
Vesuvius,
Santorin,
Lemnos,

All belong to the great basin of the Mediterranean, but to its European and not to its African shores; and all these seven volcanoes are still or have been active in known historical periods; the burning mountain Mosychlos in Lemnos, which Homer names the favourite seat of Hephaestos was only destroyed and sunk beneath the waves of the sea by earthquakes, together with the island of Chryse, after the time of the great Macedonian (*Cosmos*, vol. i, p. 246; Ukert, *Geogr. der Griechen und Römer*, Th. ii, Abth. 1, s. 198). The great upheaval of the three Kaimenes in the middle of the Gulf of Santorin (partly inclosed by Thera, Therasia, and Aspronisi) which has been repeated several times within about 1900 years (from 186 B.C. to 1712 of our epoch) had in their production and disappearance a remarkable similarity with the relatively unimportant phenomenon of the temporary formation of the islands which were called Graham, Julia, and Ferdinandea, between Sciacca and Pantellaria. Upon the peninsula of Methana, which has already been frequently mentioned (*Cosmos*, vol. i, p. 239; vol. v, p. 229), there are distinct traces of volcanic eruptions in the reddish brown trachyte which rises from the limestone near Kaïmenochari and Kaïmeno (Curtius, *Pelop.* Bd.ii. s. 439).

Of prehistoric volcanoes with fresh traces of the emission of lava from craters there are, counting from north to south, those of the Eifel (*Mosenberg, Geroldstein*) furthest to the north; the great crater of elevation in which Schemnitz is situated; Auvergne (*Chaîne des Puys* or of the *Monts Dômes, le Cône du Cantal, les Monts-Dore*); Vivarais, in which the ancient lavas have broken out from gneiss (*Coupe d'yAsac*, and the cone of *Montpezat*); Velay: eruptions of scoriæ from which no lavas issue; the Euganean hills; the Alban mountains, Rocca Monfina and Vultur, near Teano and Melfi; the extinct volcanoes about Olot and Castell Follit in Catalonia;[43] the island group, *las Columbretes*, near the coast of Valencia (the sickle-shaped larger island Columbraria of the Romans, upon which Montcolibre, latitude 39°54′ according to Captain Smyth, is full of obsidian and cellular trachyte); the Greek island Nisyros, one of the Carpathian Sporades, of a perfectly round form, in the middle of which, at an elevation of 2270 feet according to Ross, there is a deep, walled cauldron with a strongly detonating solfatara, from which at one time radiating lava-streams poured themselves into the sea, where they now form small promontories, and furnished volcanic millstones in Strabo's time (Ross, *Reisen auf den griechischen Inseln*, Bd. ii, s. 69 and 72—78). For the British islands we have here still to mention, on account of the antiquity of the formations, the remarkable effects of submarine volcanoes upon the strata of the lower Silurian formation (Llandeilo strata) cellular volcanic fragments being baked into these strata, whilst, according to Sir Roderick Murchison's important observation, even eruptive trapp-masses penetrate into lower Silurian strata in the Corndon mountains (Shropshire and Montgomeryshire);[44] the dyke-phenomena of the isle of Arran; and the other points in which the interference of volcanic activity is visible, although no traces of true platforms are to be discovered.

[43] With regard to Vivarais and Velay, see the very recent and accurate researches of Girard in his *Geologischen Wanderungen*, Bd. i, (1856) s. 161, 173 and 214. The ancient volcanoes of Olot were discovered by the American geologist Maclure in 1808, visited by Lyell in 1830, and well described and figured by the latter in his *Manual of Geology* 1855, pp. 535—542.

[44] Sir Roderick Murchison, *Siluria*, pp. 20 and 55—58 (Lyell, *Manual*, p. 563).

II. Islands of the Atlantic Ocean.

The volcano Esk, upon the island of Jan Mayen, ascended by the meritorious Scoresby and named after his ship; height scarcely 1600 feet. An open, not ignited summit-crater; basalt, rich in pyroxene and *trass*.

South-west of the Esk, near the North Cape of Egg Island, another volcano, which, in April 1818, presented high eruptions of ashes every four months.

The Beerenberg, 6874 feet in height, in the broad, north-eastern part of Jan Mayen (lat. 71° 4′) is not known to be a volcano.[45]

Volcanoes of Iceland: Oeräfa, Hecla, Rauda-Kamba . . .

Volcano of the island of Pico[46] in the Azores: a great eruption of lava from the 1st May to the 5th June, 1800.

The Peak of Teneriffe.

Volcano of Fogo,[47] one of the Cape de Verde Islands.

Prehistoric volcanic activity.—This on Iceland is less definitely attached to certain centres. If we divide the volcanoes of the island, with Sartorius von Waltershausen, into two classes, of which those of the one have only had a single eruption, whilst those of the other repeatedly emit lava-streams at the same principal fissure, we must refer to the former, Rauda-Kamba, Scaptar, Ellidavatan, to the south-east of Reykjavik . . . .; to the second, which exhibits a permanent individuality, the two highest volcanoes of Iceland Oeräfa (more than 6390 feet) and Snaefiall, Hecla, &c. Snaefiall has not been in activity within the memory of man, whilst Oeräfa is known by the fearful eruptions of 1362 and 1727 (Sart. von Waltershausen, *Skizze von Island*, s. 108

[45] Scoresby, *Account of the Arctic Regions*, vol. i, pp. 155—169, tab. v and vi.

[46] Léop. von Buch, *Descr. des Iles Canaries*, pp. 357—369, and Landgrebe, *Naturgeschichte der Vulkane*, 1855, Bd. i, s. 121—136; and with regard to the circumvallations of the craters of elevation (*Caldeiras*) upon the Islands of Saint Michael, Fayal and Terceira (from the maps of Captain Vidal) (see page 226). The eruptions of Fayal (1672) and Saint George (1580 and 1808) appear to be dependent upon the principal volcano, the Pico.

[47] See pages 248 and 262.

and 112). In Madeira,[48] the two highest mountains, the conical Pico Ruivo, 6060 feet in height, and the Pico de Torres, which is but little known, covered on their steep declivities with scoriaceous lavas, cannot be regarded as the central point of the former volcanic activity on the whole island, as in many parts of the latter, especially towards the coasts, eruptive-orifices and even a large crater, that of the Lagoa, near Machico, are met with. The lavas, thickened by confluence, cannot be traced far as separate streams. Remains of ancient Dicotyledonous and Fern-like vegetation, carefully investigated by Charles Bunbury, are found buried in upheaved strata of volcanic tufa and loam, sometimes covered by more recent basalt. Fernando de Noronha, lat. 3° 50′ S. and 2° 27′ to the east of Pernambuco: a group of very small islands; phonolitic rocks containing hornblende,—no crater, but vein-fissures filled with trachyte and basaltic amygdaloid, penetrating white tufa layers.[49] The island of Ascension; highest summit 2868 feet; basaltic lavas with more glassy felspar than olivine sprinkled through them, and well bounded streams traceable up to the eruptive cone of trachyte. The latter rock of light colours, often broken up like tufa, predominates in the interior and south-east of the island. The masses of scoriæ thrown out from Green Mountain, inclose immersed angular fragments[50] containing syenite and granite, which remind one of the lavas of Jorullo. To the westward of Green Mountain, there is a large open crater. Volcanic bombs, partly hollow, of as much as 10 inches in diameter lie scattered about in innumerable quantities, together with large masses of obsidian. Saint Helena: the whole island volcanic, the beds of lava in the interior rather felspathic; basaltic towards the coast, penetrated by innumerable dykes as at Flagstaff Hill. Between Diana Peak and Nestlodge, in the central series of mountains, is the curved and crescentic shaped fragments of a wider, destroyed crater full of scoriæ and cellular lava

[48] Results of the observations upon Madeira by Sir Charles Lyell and Hartung in the *Manual of Geology* 1855, pp. 515—525.

[49] Darwin, *Volcanic Islands* 1844, p. 23, and Lieutenant Lee, *Cruise of the U.S. Brig Dolphin*, 1854, p. 80.

[50] See the admirable description of Ascension in Darwin's *Volcanic Islands*, pp. 40 and 41.

"the mere wreck[51] of one great crater is left"). The beds of lava are not limited and consequently cannot be traced as true streams of small breadth. Tristan da Cunha (lat. 37° 3′ S., long. 11°26′W.) discovered as early as 1506 by the Portuguese; a small circular island of six miles in diameter, in the centre of which a conical mountain is situated, described by Captain Denham as about 8300 feet in height and composed of volcanic rock (Dr. Petermann's *Geogr. Mittheil.* 1855, No. iii, s. 84). To the south-east, but in 53° S. latitude, lies the equally volcanic Thompson's Island and between the two in the same direction, Gough Island, also called Diego Alvarez. Deception Island, a slender, narrowly opened ring (S. lat. 62° 55′), and Bridgeman's Island belonging to the South Shetlands group; both volcanic, with layers of ice, pumice-stone, black ashes and obsidian; perpetual eruption of hot vapours (Kendal, *Journal of the Geographical Society*, vol. i, 1831, p. 62). In February, 1842, Deception Island was seen to produce flames simultaneously at 13 points in the ring (Dana in *United States Explor. Exped.* vol. x, p. 548). It is remarkable that, as so many islands in the Atlantic Ocean are volcanic, neither the entire flat islet of Saint Paul[52] (Peñedo de S. Pedro), one degree to the north of the equator; nor the Falklands (with thin quartzose clay-slate), South Georgia or Sandwich land, appear to offer any volcanic rock. On the other hand a region of the Atlantic Ocean, about 0° 20′ to the south of the equator, longitude 22° W., is regarded as the seat of a submarine volcano.[53] In this vicinity Krusenstern saw black columns of smoke rise out of the sea (19th May 1806), and in 1836 volcanic ashes collected at the same point (south-east from the above mentioned rock of Saint Paul) on two occasions,

[51] Darwin, pp. 84 and 92, with regard to "the great hollow space or valley southward of the central curved ridge, across which the half of the crater must once have extended. It is interesting to trace the steps, by which the structure of a volcanic district becomes obscured and finally obliterated" (See also Seale, *Geognosy of the Island of Saint Helena*, p. 28).

[52] St. Paul's Rocks. (See Darwin, pp. 31—33 and 125).

[53] Daussy on the probable existence of a submarine volcano in the Atlantic, in the *Comptes rendus de l'Acad. des Sciences*, t. vi, 1858, p. 512; Darwin, *Volcanic Islands*, p. 92; Lee, *Cruise of the U.S. Brig Dolphin*, pp. 2—55 and 61.

were exhibited to the Asiatic Society of Calcutta. According to very accurate investigations by Daussy, singular shocks and agitation of the sea, ascribed to the commotion of the sea-bottom by earthquakes, have been observed in this *volcanic region*, as it is called in the new and beautiful American chart of Lieutenant Samuel Lee (*Track of the Surveying Brig Dolphin,* 1854), five times between 1747 and Krusenstern's circumnavigation of the globe. and seven times from 1806 to 1836. But during the recent expedition of the brig Dolphin (January 1852), as previously (1838), during Wilkes's exploring expedition, nothing remarkable was observed, although the brig was ordered "on account of Krusenstern's volcano" to make investigations with the lead between the equator and 7° S. latitude, and about 18° to 27° longitude.

III. Africa.

It is stated by Captain Allan that the volcano Mongo-ma Leba in the Cameroon Mountains (4°12′ N. lat.), westward of the mouth of the river of the same name in the Bight of Biafra, and eastward of the Delta of the Kowara, or Niger, emitted an eruption of lava in the year 1838. The four high volcanic islands of Annabon, St. Thomas, Isla do Principe, and San Fernando Po, which run on a fissure in a direct linear series from SS.W. to NN.E., point to the Cameroons, which, according to the measurements of Captain Owen and Lieutenant Boteler, rises to the great altitude of nearly 13,000 feet.[54]

A volcano (?) a little to the west of the Snowy Mountain Kignea in Eastern Africa, about 1°20′ S. lat. was discovered by the missionary Krapf in 1849, near the source of the River Dana, about 320 geographical miles north-west of the coast of Mombas. In a parallel nearly two degrees more southerly than the Kignea is situated another snowy mountain, the Kilimandjaro, which was discovered by the missionary Rebmann in 1847, perhaps scarcely 200 geographical miles from the same coast. A little to the westward lies a third snowy mountain, the Doengo Engai, seen by Captain

[54] Gumprecht, *Die vulkanische Thätigkeit auf dem Festlande von Afrika, in Arabien und auf den Inseln des rothen Meeres*, 1849, s. 18.

Short. The knowledge of the existence of these mountains is the result of laborious and hazardous researches.

Evidences of pre-historical volcanic action in the great continent, the interior of which between the seventh degree north and the twelfth degree south latitude (the parallels of Adamaua and the Lubalo Mountain, which acts as a water-shed,) still remains so unexplored, are furnished, according to Rüppell, by the country surrounding the Lake Tzana, in the kingdom of Gondar, as well as by the basaltic lavas, trachytes, and obsidian strata of Shoa, according to Rochet d'Hericourt, whose mineralogical specimens, quite analogous to those of Cantal and Mont Dore, may have been examined by Dufrenoy (*Comptes rendus*, t. xxii. pp. 806—810). Though the conical mountain Koldghi in Cordofan is not now seen either in a burning or smoking state, yet it appears that the existence of a black, porous, and vitrified rock has been ascertained there.[55]

In Adamaua, south of the great Benue river, rise the isolated mountain-masses of Bagele and Alantika, which from their conical and dome-like forms appeared to Dr. Barth, on his journey from Kuka to Iola, to resemble trachyte mountains. According to Petermann's notices from the note-books of Overweg, (of whose researches natural science was so early deprived) that traveller found in the district of Gudsheba, westward of the lake of Tshad, separate basaltic cones, rich in olivine and columnar in form, which were sometimes intersected by layers of the red, clayey-sandstone, and sometimes by those of quartzose granite.

The small number of now ignited volcanoes in the undivided continents, whose coast-lands are sufficiently known, is a very remarkable phenomenon. Can it be that in the unknown regions of Central Africa, especially south of the equator, large basins of water exist, analogous to Lake Uniames (formerly called by Dr. Cooley, N'yassi), on whose shores rise volcanoes, like the Demavend near the Caspian Sea? Much as the natives are accustomed to move about over the country, none of them have hitherto brought us the least notice of any such thing!

[55] *Cosmos*, vol. 1, p. 244, note ‡. For the whole of the phenomena hitherto known in Africa, see Landgrebe, *Naturgeschichte der Vulkane*, Bd. i, s. 195—219.

IV. Asia.

a. The Western and Central part.

The volcano of Demavend,[56] in a state of ignition, but, according to the accounts of Olivier, Morier and Taylor Thomson (1837), smoking only moderately, and not uninterruptedly.

The volcano of Medina (eruption of lava in 1276).

The volcano of Djebel el-Tir (Tair or Tehr), an insular mountain 895 feet high, between Loheia and Massaua in the Red Sea.

The volcano of Peshan, northward of Kutsche in the great mountain-chain of the Thian-schan or Celestial Mountains in Central Asia; eruptions of lava within the true historical period, from the year 89 up to the beginning of the seventh century of our era.

The volcano of Ho-cheu, called also sometimes in the very circumstantial Chinese geographies the volcano of Turfan; 120 geographical miles from the great Solfatara of Urumtsi, near the eastern extremity of the Thian-schan, in the direction of the beautiful fruit country of Hami.

The volcano of Demavend, which rises to a height of up-

[56] The height of Demavend above the sea was given by Ainsworth at 14,695, but after correcting a barometrical result, probably attributable to an error of the pen (*Asie Centrale,* t. iii, p. 327), it amounts, according to Ottman's tables to fully 18,633 feet. A somewhat greater elevation, 20,085 feet, is given by the angles of altitude worked by my friend, Captain Lemm, of the Russian navy, in the year 1839, and which are certainly very correct, but the distance is not trigonometrically laid down, and rests on the presumption that the volcano of Demavend is 66 versts distant from Teheran (one equatorial degree being equal to $104\frac{3}{10}$ versts). Hence it would appear that the Persian volcano of Demavend, covered with perpetual snow, situated so near the southern shore of the Caspian Sea, but distant 600 geographical miles from the Colchian coast of the Black Sea, is higher than the great Ararat by about 2989 feet and the Caucasian Elburuz by probably 1600 feet. On the Demavend, see Ritter, *Erdkunde von Asien,* Bd. vi, Abth. i, s. 551—571, and on the connection of the name Albordj, taken from the mythic and therefore vague geography of the Zend-nation, with the modern name Elburz (Koh Alburz of Kazwini) and Elburuz, see *ibid.* s. 43—49, 424, 552, and 555.

wards of 19,000 feet, lies nearly 36 geographical miles from the southern shore of the Caspian Sea, in Mazenderan, and almost at the same distance from Resht and Asterabad, on the chain of the Hindu-kho which slopes suddenly down to the west in the direction of Herat and Meshid. I have elsewhere (*Asie Centrale*, t. i, pp. 124—129 ; t. iii, pp. 433—435) mentioned the probability that the Hindu-kho of Chitral and Kafiristan is a westerly continuation of the mighty Kuen-lün, which bounds Tibet towards the north and intersects the Bolor Mountains in the Tsungling. The Demavend belongs to the Persian or Caspian Elburz, a system of mountains which must not be confounded with the Caucasian ridge of the same name (now called Elburuz), and which lies 7½° further north and 10° further west. The word Elburz is a corruption of Alborj, or Mountain of the World, which is connected with the ancient cosmogony of the Zends.

While the volcano of Demavend, according to the generality of geognostic views on the direction of the mountain-chains of Central Asia, bounds the great Kuen-lun chain near its western extremity, another igneous appearance at its eastern extremity, the existence of which I was the first to announce (*Asie Centrale*, t. ii, pp. 427 and 483), deserves particular notice. In the course of the important researches which I recommended to my respected friend and colleague in the Institute, Stanislas Julien, with the view of deriving information from the rich geographical sources of old Chinese literature on the subject of the Bolor, the Kuen-lun, and the Sea of Stars, that intelligent investigator discovered in the great Dictionary published in the beginning of the eighteenth century by the Emperor Yong-ching a description of the "eternal flame" which issues from an opening in the hill called Shin-khien, on the eastern slope of the Kuen-lun. This luminous phenomenon, however deeply seated it may be, cannot well be termed a volcano. It appears to me rather to present an analogy with the Chimæra in Lycia, near Deliktash and Yanartash, which was so early known to the Greeks. This is a stream of fire, an issue of gas constantly kindled by volcanic action in the interior of the earth (See page 256, note 50).

Arabian writers inform us, though for the most part without quoting any precise year, that lava-eruptions have taken place during the middle ages on the south-western shore of Arabia, in the insular chain of the Zobayr, in the Straits of Bab-el-Mandeb and Aden (Wellsted, *Travels in Arabia*, vol. ii, pp. 466—468), in Hadhramaut, in the Strait of Ormuz, and at different points in the western portion of the Persian Gulf. These eruptions have always occurred on a soil which had already been in pre-historical times the seat of volcanic action. The date of the eruption of a volcano at Medina itself, 12½° northward of the Straits of Bab-el-Mandeb, was found by Burckhardt in Samhudy's Chronicle of the famous city of that name in the Hedjaz. It took place on the 2nd November, 1276. According to Seetzen, however, Abulmahasen states that an igneous eruption had occurred there in 1254, which is twenty-two years earlier (see *Cosmos*, vol. i, p. 246). The volcanic island of Djebel-tair, in which Vincent recognized the "burnt-out island" of the *Periplus Maris Erythræi*, is still active and emits smoke, according to Botta and the accounts collected by Ehrenberg and Russegger (*Reisen in Europa, Asien und Africa*, Bd. ii, Th. 1, 1843, s. 54). For information respecting the entire district of the Straits of Bab-el-Mandeb, with the basaltic island of Perim,—the crater-like circumvallation, within which lies the town of Aden,—the island of Seerah with streams of obsidian, covered with pumice,—the island-groupes of the Zobayr and the Farsan (the volcanic nature of the latter was discovered by Ehrenberg in 1825) I refer my readers to the interesting researches of Ritter in his *Erdkunde von Asien*, Bd. viii, Abth. 1, s. 664—707, 889—891, and 1021—1034.

The volcanic mountain-chain of the Thian-schan (*Asie Centrale*, t. i, pp. 201—203; t. ii, pp. 7—51), a range which intersects Central Asia between Altai and Kuen-lun from east to west, formed at one period the particular object of my investigations, so that I have been enabled to add to the few notices obtained by Abel-Rémusat from the Japanese Encyclopædia, some fragments of greater importance discovered by Klaproth, Neumann, and Stanislas Julien (*Asie Centrale*, t. ii, pp. 39—50 and 335—364). The length of the Thian-schan is eight times greater than that of the Pyrenees, if we include the Asferah which is on the other side of the intersected meridian-chain of the Kusyurt-Bolor, stretching westward as far as the meridian of Samarcand, and in which Ibn Haukal and Ibn-al-Vardi describe streams of fire, and notices luminous (?) fissures emitting sal ammoniac (see the account of Mount Botom, *ut supra*). In the history of the dynasty of Thang it is expressly stated that on one of the slopes of the Pe-shan, which continually emits fire and smoke, the rocks burn, melt and flow to the distance of several *li*, like a "stream of melted fat. The soft mass hardens as it cools." It is impossible to describe more characteristically the appearance of a stream of lava. Moreover, in the forty-ninth book of the great geography of the Chinese empire, which was printed at Pekin from 1789 to 1804 at the expense of the state, the burning mountains of the Thian-schan are described as "still active." Their position is very central, being nearly equi-distant (1520 geographical miles) from the nearest shore of the Frozen Ocean and from the mouth of the Indus and Ganges, 1020 miles from the Sea of Aral, 172 and 208 miles from the salt-lakes of Issikal and Balkasch. Information respecting the flames issuing from the mountain of Turfan (Hotscheu) has also been furnished by the pilgrims of Mecca, who were officially examined at Bombay in the year 1835 (*Journal of the Asiatic Soc. of Bengal*, vol. iv, 1835, pp. 657—664). When may we hope to see the volcanoes of Peschan and Turfan, Barkul and Hami explored by some scientific traveller, by way of Gouldja on the Ili, which may be easily reached.

The better knowledge now possessed of the position of the volcanic mountain chain of the Thian-schan has very naturally given rise to the question whether the fabulous territory of Gog and Magog where "eternal fire" is said to burn at the bottom of the River El Macher, is not in some way connected with the eruptions of the Peschan or the volcano of Turfan. This oriental myth, which had its origin westward of the Caspian Sea, in the *Pylis Albaniæ* near Derbend, has travelled, like all other myths, far towards the East. Edrisi gives an account of the journeying of one Salam el Terdjeman, the dragoman of one of the Abbasside-Chalifs, in the first half of the ninth century, from Bagdad to the Land of Darkness. He proceeded through the steppe of Baschkir to the snowy-mountain of Cocaïa, which is surrounded by the great wall of Magog (Madjoudj). Amédée Jaubert, to whom we are indebted for important supplements to the Nubian geographers, has shown that the fires which burn on the slope of the Cocaïa have nothing volcanic in their nature (*Asie Centrale*, t. ii, p. 99). Edrisi places the Lake of Tehama further to the south. I think I have said enough to show the probability of the Tehama being identical with the great Lake of Balkasch, into which the Ili flows, and which is only 180 miles further south. A century and a half later than Edrisi, Marco Polo placed the wall of Magog among the mountains of In-schan, to the east of the elevated plain of Gobi, in the direction of the River Hoang-ho and the Chinese wall, respecting which, singularly enough, the famous Venetian traveller is as silent as he is on the subject of the use of tea. The In-shan, the limit of the territory of Prester John, may be regarded as the eastern prolongation of the Thian-schan (*Asie Centrale*, t. ii, pp. 92—104).

The two conical volcanic mountains, the Petschan and Hotshen of Turfan, which formerly emitted lava, and which are separated from each other at a distance of about 420 geographical miles by the gigantic block of mountains called the Bogdo-Oola, crowned with eternal snow and ice, have long been erroneously considered an isolated volcanic group. I think I have shown that the volcanic action north and south of the long chain of the Thian-schan here, as well as in the Caucasus, stands in close geognostic connection with the limits of the circle of terrestrial commotion, the hot-springs, the solfataras, the sal-ammoniacal fissures and beds of rock-salt.

According to the view I have already frequently expressed, and in which the writer most profoundly acquainted with the Caucasian mountain system (Abich) now coincides, the Caucasus itself is only a continuation of the ridge of the volcanic Thian-schan and Asferah on the other side of the great Aralo-Caspian depression.[57] This is therefore the place, in connection with the phenomena of the Thian-shan, to cite as belonging to pre-historical periods the four extinct volcanoes of Elburuz, 18,494 feet in height, Ararat 17,112 feet, Kasbegk 16,532 feet, and Savalan 15,760 feet

[57] *Asie Centrale*, t. ii, pp. 9, and 54—58. See also page 208, note 61, of the present volume.

high.[58] In point of height these mountains stand between Cotopaxi and Mont Blanc. The Great Ararat (Agri-dagh), ascended for the first time on the 27th September, 1829, by Friedrich von Parrot, several times during 1844 and 1845 by Abich, and lastly in 1850 by Colonel Chodzko, is dome-shaped, like Chimborazo, with two extremely small elevations on the border of the summit, but without any crater at the apex. The most extensive and probably the latest pre-historical lava-eruptions of Ararat have all issued below the limit of perpetual snow. The nature of these eruptions is two-fold; they are sometimes trachytic with glassy feldspar, interspersed with pyrites which readily weather, and sometimes doleritic, composed of labradorite and augite, like the lavas of Etna. The doleritic lavas of Ararat are considered by Abich to be more recent than the trachytic. The points of emission of the lava-streams, which are all beneath the limit of perpetual snow, are frequently indicated (as, for example, in the extensive grassy plain of Kip-ghioll, on the north-western slope) by eruptive cones and by small craters encircled by scoriæ. Although the deep valley of St. James which extends to the very summit of Ararat, and gives a peculiar character to its form, even when seen at a distance, exhibits much resemblance to the Val del Bove on Etna, and displays the internal structure of the Dome, yet there is this striking difference between them, that in the valley of St. James massive trachytic rock alone is found, and no streams of lava, beds of scoriæ or rapilli.[59] The Great and Little Ararat, the first of which is shown by the geodetic labours of Wasili Fedorow, to be 3′4″ more northerly and 6′42″ more westerly than the other, rise on the southern edge of the great plain

[58] Elburuz, Kasbegk, and Ararat, according to communications from Struve, *Asie Centrale*, t. ii, p. 57. The height of the extinct volcano of Savalan, westward of Ardebil, as given in the text is founded on a measurement of Chanykow. See Abich in the *Mélanges Phys. et Chim*, t. ii, p. 361. To save tedious repetition in the citation of the sources on which I have drawn, I would here explain that everything in the geological section of *Cosmos*, relating to the important Caucasian isthmus, is borrowed from manuscript essays of the years 1852 and 1855 communicated to me by Abich in the kindest and friendliest manner for my unrestricted use.

[59] Abich, *Notice Explicative d'une Vue de l'Ararat*, in the *Bulletin de la Soc. de Géographie de France*, 4ème série, t. i, p. 516.

through which the Araxes flows in a large bend. They both stand on an elliptic volcanic plateau, whose major axis runs south-east and north-west. The Kasbegk and the Tshegem have likewise no summit crater, although the former has thrown out vast eruptions towards the north, in the direction of Wladikaukas. The greatest of all these extinct volcanoes, the trachytic cone of the Elburuz, which has risen out of the talc and dioritic schistous mountains, rich in granite, of the valley of the River Backsan, has a crater-lake. Similar crater-lakes occur in the rugged highlands of Kely, from which streams of lava flow out between eruption-cones. Moreover, the basalts are here, as well as in the Cordilleras of Quito, widely separated from the trachyte-system; they commence from twenty-four to thirty-two miles south of the chain of the Elburuz, and of the Tschegem on the Upper Phasis or Rhion valley.

β. *The north-eastern portion (the Peninsula of Kamtschatka).*

The peninsula of Kamtschatka, from Cape Lopatka, which, according to Krusenstern is in lat. 51°3′, as far north as to Cape Ukinsk, belongs, in common with the island of Java, Chili and Central America, to those regions in which the greatest number of volcanoes, and, it may be added, of still active volcanoes, are compressed within a very small area. Fourteen of these are reckoned in Kamtschatka within a range of 420 geographical miles. In Central America I find in a space of 680 miles, from the volcano of Coconusco to Turrialva in Costa Rica, twenty-nine volcanoes, eighteen of which are still burning; in Peru and Bolivia, over a space of 420 miles, from the volcano Chacani to that of San Pedro de Atacama, fourteen volcanoes, of which only three are at present active, and in Chili, over a space of 960 miles, from the volcano of Coquimbo to that of San Clemente, twenty-four volcanoes. Of the latter, thirteen are known to have been active within the periods of time embraced in historical records

Our acquaintance with the Kamtschatkan volcanoes, in respect to their form, the astronomical determination of their position and their height, has been vastly extended in recent times by Krusenstern, Horner, Hofmann, Lenz, Lütke, Postels, Captain Beechey, and above all by Adolph Erman. The peninsula is intersected lengthwise by two parallel mountain chains, in the most easterly of which the volcanoes are accumulated. The loftiest of these attain a height of from 11,190 to 15,773 feet. They lie in the following order from south to north :

The Opalinskian volcano (the Pic Koscheleff of Admiral Krusenstern) lat. 51° 21′. According to Captain Chwostow, this mountain rises to the height of the Peak of Teneriffe, and was extremely active at the close of the 18th century.

The Hodutka Sopka (51° 35′). Between this and the one just noticed, there lies an unnamed volcanic cone (51° 32′), which, however, according to Postels, seems, like the Hodutka, to be extinct.

Poworotnaja Sopka (52° 22′), according to Captain Beechey, 7930 feet high (Erman's *Reise*, t. iii, p. 253; Leop. von Buch, *Iles Can.* p. 447).

Assatschinskaja Sopka (52° 2′); great discharges of ashes, particularly in the year 1828.

The Wiljutschinsker volcano (52° 52′); according to Captain Beechey 7373 feet, according to Admiral Lütke 6744 feet high. Distant only 20 geographical miles from the harbour of Petropolowski on the north side of the Bay of Torinsk.

Awatschinskaja or Gorelaja Sopka (53° 17′), according to Erman, 8910 feet high; first ascended during the expedition of La Pérouse in 1787 by Mongez and Bernizet; afterwards by my dear friend and Siberian fellow-traveller, Ernst Hofmann (in July, 1824, during the circumnavigation of the globe by Kotzebue; by Postels and Lenz during the expedition of Admiral Lütke in 1828, and by Erman in September 1829. The latter made the important geognostic observation that the upheaving trachyte had pierced through slate and grey-wacke (a silurian rock). The still smoking volcano had a terrific eruption in October 1837, there having previously been a slight one in April, 1828 (Postels in Lütke, *Voyage*, t. Bd. s, 67—84; Erman, *Reise*, *Hist. Bericht*, Bd. iii, s. 494 and 534—540).

In the immediate neighbourhood of the Awatscha-volcano (see page 248) lies the Koriatskaja or Strjeloschnaja

Sopka (lat. 53° 19′), 11,210 feet high, according to Lütke, t. iii, p. 84. This mountain is rich in obsidian, which the Kamtschatkans so late as the last century made into arrow-heads, as the Mexicans and the ancient Greeks used to do.

Jupanowa Sopka, lat. according to Erman's calculation (*Reise*, Bd. iii, s. 469) 53° 32′. The summit is pretty flat, and the traveller just mentioned expressly states "that this Sopka, on account of the smoke it emits, and its perceptible subterranean rumbling, is always compared to the mighty Schiwelutsch, and reckoned among the undoubted igneous mountains." Its height, as measured by Lütke from the sea, is 9055 feet.

Kronotskaja Sopka, 10,609 feet, at the lake of the same name, lat. 54° 8′; a smoking crater on the summit of the very sharp-pointed conical mountain (Lütke, *Voyage*, t. iii, p. 85).

The volcano Schiwelutsch, 20 miles south-east of Jelowka, respecting which we possess an admirable work by Erman (*Reise*, Bd. iii, s. 261—317, and *Phys. Beob.*, Bd. i, s. 400—403) previous to whose journey the mountain was almost unknown. Northern peak, lat. 56° 40′, height 10,544 feet; southern peak, lat. 56° 39′, height 8793 feet. When Erman ascended the Schiwelutsch in September, 1829, he found it smoking vehemently. Great eruptions took place in 1739, and between 1790 and 1810; the latter consisting, not of flowing, melted lava, but of ejections of loose volcanic stones. C. von Dittmar relates that the northern peak fell in during the night from the 17th to 18th February 1854. At that time an eruption which still continues took place, accompanied by genuine streams of lava.

Tolbatschinskaja Sopka; smoking violently, but in earlier times frequently changing the openings through which it ejected its ashes. According to Erman, lat. 55° 51′ and height 8313 feet.

Uschinskaja Sopka; closely connected with the Kliutschewsker volcano; lat. 56° 0′, height 11,723 feet (Buch, *Can.* p. 452; Landgrebe, *Volkane*, vol. i, p. 375).

Kliutschewskaja Sopka (56° 4′): the highest and most active of all the volcanoes of the peninsula of Kamtschatka; thoroughly examined by Erman, both geologically and hypsometrically. According to Kraschenikoff's report, the

Kliutschewsk had great igneous eruptions from 1727 to 1731, as also in 1767 and 1795. On the 11th of September 1829, Erman performed the hazardous feat of ascending the volcano, and was an eye-witness of the ejection of red-hot stones, ashes, and vapour from the summit, while at a great distance below it an immense stream of lava flowed from a fissure on the western declivity. Here also the lava is rich in obsidian. According to Erman (*Beob.*, vol. i, pp. 400—403 and 419) the geographical latitude of the volcano is 56°4′, and its height in September 1829 was, on a very accurate calculation, 15,763 feet. In August 1828, on the other hand, Admiral Lütke, on taking angles of altitude at sea, at a distance of 160 knots (40 nautical miles) found the summit of Kliutschewsk 16,498 feet high (*Voyage*, t. iii, p. 86; Landgrebe, *Vulkane*, Bd. i, s. 375—386). This measurement, and a comparison of the admirable outline drawings of Baron von Kittlitz, who accompanied Lütke's expedition on board the Seniawin, with what Erman himself observed in September 1829, led the latter to the conclusion that, in this short period of thirteen months, great changes had taken place in the form and height of the summit. "I am of opinion," says Erman (*Reise*, vol. iii, p. 359), "that we can scarcely be wrong in assuming the height of the summit in August 1828, to have been 266 feet more than in September 1829, during my stay in the neighbourhood of Kliutschi, and that therefore its height at the former of these periods must have been 16,029 feet." In the case of Vesuvius I found, by my own calculations (founded on Saussure's barometrical measurement in 1773), of the Rocca del Palo, the highest northern margin of the crater, that up to the year 1805, that is to say, in the course of thirty-two years, this northern margin of the crater had sunk 35½ feet, while from 1773 to 1822, or forty-nine years, it had risen (apparently) 102 feet (*Views of Nature*, 1850, pp. 376—378). In the year 1822, Monticelli and Covelli calculated the Rocca del Palo at 3990 feet, and I at 4022 feet; I then gave 3996 as the most probable result for that period. In the spring of 1855, thirty-three years later, the delicate barometrical measurements of the Olmutz astronomer, Julius Schmidt, again brought out 3990 feet (*Neue Bestimm. am Vesuv.* 1856, s. i, 16 and 33). It would be curious to know how much should here be attributed to imperfection of measurement and barometrical formula. Investigations of this kind might be multiplied on a larger scale and with greater certainty if, instead of often repeated complete trigonometrical operations or, in the case of accessible summits, the more practicable, though less satisfactory barometrical measurements, operators would confine themselves to determining, even to fractions of seconds, at comparative periods of twenty-five or fifty years, the simple angle of altitude of the margin of the summit, from the same point of observation, and one which could with certainty be found again. On account of the influence of terrestrial refraction, I would recommend that, in each of the normal epochs, the mean result of three days' observations at different hours should be taken. In order to obtain, not only the general result of the increase or diminution of the angle, but also the absolute amount of the change in feet, the distance would require to be determined previously only once for all. What a rich source of knowledge relative to the twenty volcanic Colossi of the Cordilleras of Quito, would not the angles of altitude, determined for more than a century by the labours of Bouguer and La Condamine have provided, had those travellers accurately designated as fixed and permanent points the stations whence they measured the angles of altitude of the summits. According to C. von Dittmar the Kliutschewsk was entirely quiescent since the eruption of 1841 until the lava burst forth again in 1853. The falling in, however, of the summit of the Schiwelutsch interrupted the new action (*Bulletin de la Classe Physico-Mathém. de l'Acad. des Sc. de St. Pétersbourg*, t. xiv, 1856, p. 246).

Four more volcanoes, mentioned in part by Admiral Lütke, and in part by Postels, namely the Apalsk, still smoking, to the south-east of the village of Bolscheretski, the Schischapinskaja Sopka (lat. 55° 11′), the cone of Krestowsk (lat. 56° 4′), near the Kliutschewsk group, and the Uschkowsk, I have not cited in the forogoing series from want of more exact specification. The central mountain-range of Kamtschatka, especially in the plain of Baidaren, lat. 57° 20′, eastward of Sedanka, presents (as if it had been "the field of an ancient crater of about four wersts, that is to say, the same number of kilometres, in diameter"), the remarkable geological phenomenon of effusions of lava and scoriæ from a blistery and often brick-coloured volcanic rock, which in its turn has penetrated through fissures in the earth, at the greatest possible distance from any framework of raised cones (Erman, *Reise*, Bd. iii, s. 221, 228 and 273; Buch, *Iles Canaries* p. 454). The analogy is here very striking with what I have already circumstantially explained regarding the Malpays, the problematic fields of débris in the elevated plain of Mexico (see page 315).

V. Islands of Eastern Asia.

From Torres Strait, which, in the 10th degree of southern latitude, separates New-Guinea and Australia, and from the smoking volcano of Flores to the most northern of the Aleutian Isles (lat. 55°) there is a multitude of islands, for the most part volcanic, which, considered in a general geological point of view, it would be somewhat difficult, on account of their genetic connection, to divide into separate groups, and which increase considerably in circumference towards the south. Beginning at the north we first observe that the curved series[60] of the Aleutians, issuing from the American peninsula of Alaska, connect the old and the new continents together by means of the island Attu, near Copper Island and Behring's Island, while to the south they close in the waters of Behring's Sea. From Cape Lopatka, at the southern extremity of the peninsula of Kamtschatka, we find succeeding each other in the direction from north to south first, the Archipelago of the Kuriles, bounding on the east the Saghalien or Ochotsk Sea, rendered famous by La Pérouse, next Jesso, probably in former times connected with the island of Krafto[61] (Saghalin, or Tschoka), and

60 See Dana's remarks on the curvatures of ranges of islands, whose convexity in the South Sea is almost always directed towards the south or south-east, in the *United States' Explor. Exped.* by Wilkes, vol. x (*Geology* by James Dana), 1849, p. 419.

61 The island of Saghalin, Tschoka, or Tarakai, is called by the Japanese mariners Krafto (written Karafuto). It lies opposite the mouth of the Amoor (the Black River, Saghalian Ula), and is inhabited by the Ainos, a race mild in disposition, dark in colour, and sometimes rather hairy. Admiral Krusenstern was of opinion, as were also previously

lastly the tri-insular empire of Japan, across the narrow Strait of Saugar (Niphon, Sitkok and Kiu-Siu, according to Siebold's admirable map, between 41° 32′ and 30° 18′). From the volcano of Kliutschewsk, the northernmost on the east coast of the peninsula of Kamtschatka, to the most southern Japanese volcano-island of Tanega-Sima, in the Van Diemen's Channel, explored by Krusenstern, the direction of the igneous action as indicated in the numerous rents of the earth's crust, is precisely from north-east to south-west. The range is carried on by the island of Jakuno-Sima, on which a conical mountain rises to the height of 5838 feet (1780 metres), and which separates the two straits of Van Diemen and Colnet,—by the Linschote Archipelago of Siebold,—by Captain Basil Hall's sulphur island, Lung-Huang-Schan, and by the small group of the Loo-choo and Majicosima, which latter approaches within a distance of 92 geographical miles the eastern margin of the great island of the Chinese coasts, Formosa or Tay-wan.

the companions of La Pérouse (1787) and Broughton (1797), that Saghalin was connected with the Asiatic continent by a narrow, sandy isthmus (lat. 52° 5′); but from the important Japanese notices communicated by Franz von Siebold, it appears that, according to a chart drawn up in the year 1808, by Mamia Rinsô, the chief of an Imperial Japanese commission, Krafto is not a peninsula, but an island surrounded on all sides by the sea (Ritter, *Erdkunde von Asien*, vol. ii, p. 488). The conclusion of Mamia Rinsô has been very recently completely verified, as mentioned by Siebold, when the Russian fleet lay at anchor in the year 1855, in the Baie de Castries (lat. 51° 29′) near Alexandrowsk, and consequently to the south of the conjectured isthmus, and yet was able to retire into the mouth of the Amoor (lat. 52° 24′). In the narrow channel in which the isthmus was formerly supposed to be, there were in some places only 5 fathoms water. The island is beginning to acquire some political importance on account of the proximity of the great stream of Amoor or Saghalin. Its name, pronounced Karafto or Krafto, is a contraction of Kara-fu-to, which signifies, according to Siebold, "the island bordering on Kara." In the Japano-Chinese language *Kara* denotes the most northerly part of China (Tartary), and *fu*, according to the learned writer just mentioned, signifies "lying close by." Tschoka is a corruption of Tsyokaï, and Tarakai originates from a mistake in the name of a single village called Taraika. According to Klaproth (*Asia Polyglotta*, p. 301), Taraikai, or Tarakai, is the native Aino name of the whole island. Compare Leopold Schrenk's and Captain Bernard Wittingham's remarks in Petermann's *Geogr. Mittheilungen*, 1856, s. 176 and 184. See also Perry, *Exped. to Japan*, vol. i, p. 468.

Here at Formosa (N. lat. 25°—26°) is the important point where, instead of the lines of elevation from N.E. to S.W. those in the direction from north to south commence, and continue nearly as far as the parallel of 5° or 6° of southern latitude. They are recognizable in Formosa and in the Philippines (Luzon and Mindañao) over a space of fully twenty degrees of latitude, intersecting the coasts, sometimes on one side and sometimes on both, in the direction of the meridian. They are likewise visible on the east coast of the great island of Borneo, which is connected by the So-lo Archipelago with Mindañao, and by the long narrow island of Palawan with Mindoro. So also in the western portions of the Celebes, with their varied outline, and Gilolo, and lastly (which is especially remarkable) in the longitudinal fissures on which, at a distance of 1400 geographical miles eastward of the group of the Philippines and in the same latitude, the range of volcanic and coral islands of Marian or the Ladrones have been upheaved. Their general direction[62] is north and 10° east.

Having pointed out in the parallel of the carboniferous island of Formosa, the turning point at which the direction of the Kuriles from N.E. to S.W. is changed to that from north to south, I must now observe that a new system of fissures commences to the south of Celebes and the south coasts of Borneo, which, as we have already seen, is cut from east to west. The greater and lesser Sunda islands, from Timor-lant to West-Bali, follow chiefly for the space of 18° of longitude, the mean parallel of 8° south latitude. At the western extremity of Java the mean axis runs somewhat more towards the north, nearly E.S.E. and W.N.W., while from the Strait of Sunda to the southernmost of the Nicobar Isles the direction is from S.E. to N.W. The whole volcanic fissure of elevation (E. to W. and S.E. to N.W.), has consequently an extent of about 2700 geographical miles, or eleven times the length of the

[62] Dana, *Geology of the Pacific Ocean*, p. 16. Corresponding with the meridian lines of the south-east Asiatic island-world, the shores of Cochin-China from the gulph of Tonquin, those of Malacca from the gulph of Siam, and even those of New Holland south of the 25th degree of lat., are for the most part cut off as it were in the direction from north to south.

Pyrenees. Of this space, if we disregard the slight deviation towards the north in Java, 1620 miles belong to the east and west direction, and 1080 to the south-east and north-west.

Thus do general geological considerations on form and range lead uninterruptedly in the island-world on the east coast of Asia (over the immense space of 68° of latitude) from the Aleutian Isles and Behring's Sea to the Moluccas and the Great and Little Sunda Iles. The greatest variety in the configuration of the land is met with in the parallel-zone of 5° north and 10° south latitude. It is very remarkable how generally the line of eruption in the larger portions is repeated in a neighboring smaller portion. Thus a long range of islands lies near the south coast of Sumatra and parallel to it. We find the same appearances in the smaller phenomena of the mineral veins as in the greater ones of the mountain ranges of whole continents. Accompanying débris running by the side of the principal vein, and secondary chains (*chaînes accompagnantes*) lie frequently at considerable distances from each other. They indicate similar causes and similar tendencies of the formative action in the folding in of the crust of the earth. The conflict of powers in the contemporaneous openings of fissures in opposite directions appears sometimes to occasion strange formations in juxtaposition, as may be seen in the Molucca Islands, Celebes, and Kilolo.

After developing the internal geological connection of the East and South Asiatic insular system, in order not to deviate from the long-adopted, though somewhat arbitrary, geographical divisions and nomenclature, we place the southern limit of the Eastern Asiatic insular range (the turning point) at Formosa, where the line of direction runs off from the N.E.—S.W. to the N.—S., in the 24th degree of north latitude. The enumeration proceeds again from north to south, beginning with the eastern, and more American, Aleutian Islands.

The Aleutian Isles, which abound in volcanoes, include, in the direction from east to west, the Fox Islands, among which are the largest of all, Unimak, Unalaschka, and Umnak;—the Andrejanowsk Isles, of which the most famous are Atcha, with three smoking volcanoes, and the great volcano of Tanaga, already delineated by Sauer;— the Rat Islands, and the somewhat distant islands of Blynia, among which, as has been already observed, Attu forms the connecting link to the Commander group (Copper and Behring's Isles) near Asia. There seems no ground for the often-repeated conjecture that the range of continental volcanoes in the direction of NN.E. and SS.W. on the peninsula of Kamtschatka first commences where the volcanic fissure of upheaval in the Aleutian Islands intersects the peninsula beneath the ocean, the Aleutian-fissure thus forming, as it were, a channel of conduction. According to Admiral Lütke's chart of the Kamtschatkan Sea (Behring's-Sea) the island of Attu, the western extremity of the Aleutian range, lies in lat. 52° 46′, and the non-volcanic Copper and Behring's Islands in lat. 54° 30′ to 55° 20′, while the volcanic range of Kamtschatka commences under the parallel of 56° 40′ with the great volcano of Schiwelutsch, to the west of Cape Stolbowoy. Besides, the direction of the fissures of eruption is very different, indeed, almost opposite. The highest of the Aleutian volcanoes, on Unimak, is 8076 feet, according to Lütke. Near the northern extremity of Umnak, in the month of May, 1796, there arose from the sea, under very remarkable circumstances, which have been admirably described in Otto von Kotzebue's "*Entdeckungsreise*" (Bd. ii, s. 106), the island of Agaschagokh (or St. Johannes Theologus) which continued burning for nearly eight years. According to a report published by Krusenstern, this island was, in the year 1819, nearly sixteen geographical miles in circumference, and was nearly 2240 feet high. On the island of Unalaschka the proportions of the trachyte, containing much hornblende, of the volcano of Matuschkin (5474 feet) to the black porphyry (?) and the neighbouring granite, as given by Chamisso, would deserve to be investigated by some scientific observer acquainted with the conditions of modern geology, and able to examine carefully the mineralogical character of the different kinds of rocks. Of the two contiguous islands of the Pribytow group, which lie isolated in the Kamtschatkan sea, that of St. Paul is entirely volcanic, abounding in lava and pumice, while St. George's Island, on the contrary, contains only granite and gneiss.

According to the most exact enumeration we yet possess, the range of the Aleutian Isles, stretching over 960 geographical miles, seems to contain above thirty-four volcanoes, the greater part of them active in modern historical times. Thus we see here (in 54° and 60° latitude, and 160°—196° west longitude) a stripe of the whole floor of the ocean between two great continents in a constant state of formative and destructive activity. How many islands in the course of centuries, as in the group of the Azores, may there not be near becoming visible above the surface of the ocean, and how many more which, after having long appeared, have sunk either wholly or partially unobserved! For the mingling of races, and the migration of nations, the range of the Aleutian Islands furnishes a channel from thirteen to fourteen degrees more southerly than that of Behring's Straits, by which the Tchutches *seem* to have crossed from America to Asia, and even to the other side of the river Anadir.

The range of the Kurile Islands, from the extreme point of Kamtschatka to Cape Broughton (the northernmost promontory of Jesso) in a longitudinal space of 720 geographical miles, exhibits from eight to ten volcanoes, still for the most part in a state of ignition. The northernmost of these, on the island of Alaid, known for its great eruptions in the years 1770 and 1793, is well worthy of being accurately measured, its height being calculated at from 12,000 to 15,000 feet. The much less lofty Pic Sarytshew (4193 feet according to Horner) on Mataua, and the southernmost Japanese Kuriles, Urup, Jetorop, and Kunasiri, have also been very active volcanoes.

We now come in the order of succession of the volcanic range to Jesso, and the three larger Japanese Islands, respecting which the celebrated traveller, Herr von Siebold, has kindly communicated to me a large and important work for assistance in my Cosmos. This will serve to correct whatever was defective in the notices which I borrowed from the great Japanese Encyclopedia in my *Fragmens de Géologie et de Climatologie Asiatiques* (t. i, pp. 217—234), and in *Asie Centrale* (t. ii, pp. 540—552).

The large island of Jesso, which is very quadrangular in its northern portion (lat. 41½° to 45½°), separated by the

Strait of Saugar, or Tsugar, from Niphon, and by that of la Pérouse from the island of Krafto (Kara-fu-to), bounds by its north-east cape the Archipelago of the Kuriles; but not far from the North-west Cape Romanzow on Jesso, which stretches a degree and a half more northward in the strait of La Pérouse, lies, in latitude 45° 11′, the volcanic Pic de Langle (5350 feet) on the little island of Risiri. Jesso itself seems also to be intersected by a range of volcanoes, from Broughton's Southern Volcano Bay nearly all the way to the North Cape, a circumstance the more remarkable as, on the narrow island of Krafto which is almost a continuation of Jesso, the naturalists of la Pérouse's expedition found in the *Baie de Castries* fields of red porous lava and scoriæ. On Jesso itself Siebold counted seventeen conical mountains, the greater number of which appear to be extinct volcanoes. The Kiaka, called by the Japanese Usuga-Take, or Mortar-mountain, on account of a deeply-hollowed crater, and the Kajo-hori are both said to be still in a state of ignition. (Commodore Perry noticed two volcanoes from Volcano Bay near the harbour of Endermo, lat. 42° 17′). The lofty Manye (Krusenstern's conical mountain Pallas) lies in the middle of the island of Jesso, nearly in lat. 44°, somewhat to the E.N.E. of Bay Strogonow.

"The historical books of Japan mention only six active volcanoes before and since our era, namely, two on the island of Niphon, and four on the island of Kiu-siu. The volcanoes of Kiu-siu, the nearest to the peninsula of Corea, reckoning them in their geographical position from south to north, are (1) the volcano of Mitake, on the islet of Sayura-sima, in the bay of Kagosima (province of Satsuma), which lies open to the south, lat. 31° 33′, long. 130° 41′; (2) the volcano Kirisima (lat. 31° 45′) in the district of Naka, province of Finga; 3rd, the volcano Aso jama, in the district Aso (lat. 32° 45′), province of Figo; 4th, the volcano of Vunzen, on the peninsula of Simabara (lat. 32° 44′), in the district of Takaku. The height of this volcano, amounts, according to a barometrical measurement, only to 1253 metres, or 4110 English feet, so that it is scarcely a hundred feet higher than Vesuvius (Rocca del Palo). The most violent eruption of the volcano of Vunzen on record is that of February 1793. Vunzen and Aso jama both lie east-south-east of Nangasaki."

"The volcanoes of the great island of Niphon, again reckoning from south to north, are (1) the volcano of Fusi jama, scarcely 16 geographical miles distant from the southern coast, in the district Fusi, province of Suruga (lat. 35° 18′, long. 138° 35′). Its height, measured in the same way as the volcano of Vunzen, or Kiusiu, by some young Japanese, instructed by Siebold, amounts to 3793 metres, or 12,441 feet; it is therefore fully 320 feet higher than the Peak of Teneriffe, with which it has been already compared by Kämpfer (Wilhelm Heine, *Reise nach Japan*, 1856, Bd. ii, s. 4). The upheaval of this conical mountain is recorded in the fifth year of the reign of Mikado VI (286 years before our era) in these (geognostically remarkable) words:—'In the country of Omi a considerable tract of land sinks, an inland lake is formed, and the volcano Fusi makes its appearance.' The most violent historically recorded eruptions within the Christian era are those of 799, 800, 863, 937, 1032, 1083, and 1707; since the latter period the mountain has been tranquil. 2nd. The volcano of Asama jama, the most central of the active volcanoes in the interior of the country, distant 80 geographical miles from the south-south-east, 52 miles from the north-north-west coast, in the district of Saku (province of Sinano), lat. 36° 22′, long. 138° 38′; thus lying between the meridians of the two capitals, Mijako and Jeddo. The Asama jama had an eruption as early as the year 864, contemporaneously with the Fusi jama; that of the month of July 1783 was particularly violent and destructive. Since that time the Asama jama has maintained a constant state of activity.

"Besides these volcanoes two other small islands with smoking craters have been observed by European mariners, namely, 3rd. The small island of Ivôgasima or Ivôsima (*sima* signifies island, and *ivô* sulphur; *ga* is merely an affix marking the nominative), Krusenstern's *Ile du Volcan*, south of Kiu-siu, in Van Diemen's Strait, 30°.43′ N. lat. and 130° 18′ E. long., distant only fifty-four miles from the above-mentioned volcano of Mitake; the height of the volcano is 2364 feet (715 met). This island is mentioned by Linschoten so early as 1596 in these words : 'The island has a volcano, which is a sulphur, or fiery mountain.' It occurs also on the oldest Dutch sea-charts under the name of *Vulcanus* (Fr. von Siebold, *Atlas vom Jap. Reiche,* Tab. xi). Krusenstern saw it smoking in 1804, as did Captain Blake in 1838, and Guérin and De la Roche Poncié in 1846. The height of the cone, according to the latter navigator, is 2345 feet (715 met.) The rocky islet mentioned as a volcano by Landgrebe in the *Naturgeschichte der Vulkane* (Bd. i, s. 355), and which, according to Kämpfer, is near Firato (Firando), is undoubtedly Ivo-sima, for the group to which Ivo-sima belongs is called *Kiusiu ku sima, i.e.*, the nine islands of Kiusiu, and not the ninty-nine islands. A group of this description occurs near Firato, northward of Nagasaki, and no where else in Japan. (4) The island of Ohosima (Barneveld's Island ; Krusenstern's Ile de Vries), which is considered part of the province of Idsu, on Niphon, and lies in front of the Bay of Vodavara, in 34° 42′ N. lat. and 139° 26′ E. long. Broughton saw smoke issuing from the crater in 1797, a violent eruption of the volcano having taken place a short time previous. From this island a range of smaller volcanic isles stretches out in a southerly direction as far as Fatsi-syô (33° 6′ N. lat.), and continues as far as the Bonin Islands (26° 30′ N. lat. and 142° 5′ E. long.), which, according to A. Postels (Lütke, *Voyage autour du Monde dans les annèes* 1826—29, t. iii, p. 117) are likewise volcanic and are subject to very violent earthquakes."

"These, then, are the eight volcanoes historically known to be active in Japan Proper, in and near the islands of Kiusiu and Niphon. But in addition to these volcanoes a range of conical mountains must also be cited, some of which, marked by very distinct and often deeply indented craters, appear to be volcanoes long since extinct. One of these is the conical mountain of Kaimon, Krusenstern's *Pic Horner* in the southernmost part of the island of Kiusiu, on the coast of Van Diemen's Strait, in the province of Satsum (lat. 31° 9′), scarcely six geographical miles SSW. from the active volcano of Mitake. Another is the Kofusi, or Little Fusi, on Sikok ; and another is on the islet of Kutsunasima. in the province of Ijo (lat. 33° 45′), on the eastern coast of the great straits of Suvo Nada or Van der

Capellen, which separate the three great portions of the Japanese empire, Kiusiu, Sikon, and Niphon. On the latter, or principal island, nine such conical mountains, probably trachytic, are reckoned, the most remarkable of which are, the Sira jama (or White Mountain) in the province of Kaga, lat. 36°5′, and the Tsyo Kai-san, in the province of Deva (lat. 39°10′), both of which are considered loftier than the southerly volcano of Fusi jama, which is upwards of 12,360 feet high. Between these two, in the province of Jetsigo, lies the Jaki jama (or Flame Mountain, lat. 36°53′). The two northernmost conical mountaims in the Saugar Strait, in sight of the great island of Jesso, are, (1) The Ivaki jama, called by Krusenstern, whose illustrations of the geography of Japan have gained him immortal honour, the Pic Tilesius (lat. 40° 42′); and (2) The Jake jama (the Burning Mountain, lat. 41° 20′), in Nambu, at the north-eastern extremity of Niphon, with igneous eruptions from the remotest times."

In the continental portion of the neighbouring peninsula of Corea, or Korai (which, in the parallels of 34° and 34½°, is almost united with Kiusiu by the islands Tsu sima and Iki), notwithstanding its great similarity in form to the peninsula of Kamtschatka, no volcanoes have hitherto been discovered. The volcanic action seems to be confined to the adjoining islands. Thus, in the year 1007, the island-volcano of Tsinmura, called by the Chinese, Tanlo, rose from the sea. A learned Chinese, named Tien-kong-chi, was sent to describe the phenomenon and to execute a picture of it.[63] But it is especially on the island of Se-he-sure (the Quelpaerts of the Dutch) that the mountains exhibit everywhere a volcanic conical form. The central mountain rises, according to Broughton and La Pérouse, to the height of 6395 feet. How many volcanic effects may there not yet remain to be discovered in the Western Archipelago, where the King of the Coreans styles himself the Sovereign of 10,000 Islands!

From the Pic Horner (Kaimon ga take) on the west side of the southern extremity of the Kiusiu, in the Japanese tri-insular empire, there stretches out in a curve which lies

[63] Compare the translations of Stanislas Julien from the Japanese Encyclopædia in my *Asie Centrale*, t. ii, p. 551.

open towards the west, a small range of volcanic islands, comprising, first, between the Van Diemen and Colnet Straits, the Jakuno sima and the Tanega sima; second south of the Strait of Colnet in the Linschoten-group[64] of Siebold (the *Archipel Cécile* of Captain Guérin), which extends as far as the parallel of 29°, the island of Suvase sima, the volcano island of Captain Belcher (lat. 29°39′ and long. 129° 41′) rising, according to De la Roche Poncié, to a height of 2800 feet (855 met.); third, Basil Hall's sulphur island, the Tori-sima, or Bird Island, of the Japanese, the Lung-hoang-shan of Père Gaubil, in lat. 27° 51′ and long. 128° 14′, as fixed by Captain De la Roche Poncié in 1848. As this island is also called Iwôsima, care must be taken not to confound it with its more northerly namesake in Van Diemen's Straits. It has been admirably described by Captain Basil Hall. Between the parallel of 26° and 27° of latitude comes in succession the group of the Lieu-thieu, or Loo-choo Islands, as the natives call them, of which Klaproth published a separate map in 1824, and more to the south-west the small Archipelago of Majicosima, which approaches the great island of Formosa, and is considered by me to be the closing point of the eastern Asiatic islands. Close to the east coast of Formosa (lat. 24°) a great volcanic eruption in the sea was observed by Lieutenant Boyle in 1853 (Commodore Perry, *Exped. to Japan*, vol. i, p. 500). Among the Bonin Islands (Bunasima of the Japanese, lat. 26½° to 27¾° and long. 142° 15′) that called Peel's Island has several craters abounding in sulphur and scoriæ, which do not appear to have been long extinct (Perry, i, pp. 200 and 209).

VI. Islands of Southern Asia.

We comprehend under this division Formosa (Tayvan), the Philippines, the Sunda Islands and the Moluccas. Klaproth first made us acquainted with the volcanoes of Formosa by information extracted from Chinese sources, which are always so copious in their descriptions of nature.[65] They

[64] Compare *Kaart van den Zuid-en Zuidwest-Kust van Japan* door F. von Siebold, 1851.

[65] Compare my *Fragmens de Géologie et de Climatologie Asiatiques*, t. i, p. 82, which appeared immediately after my return from my

are four in number, and of these the Chy-kang (Red Mountain), whose crater contains a hot-water lake, has experienced great igneous eruptions. The small Baschi Islands and the Babuyans, which so late as 1831, according to Meyen's testimony, experienced a violent eruption of fire, connect Formosa with the Philippines, of which the smallest and most broken islands abound most in volcanoes. Leopold von Buch enumerates nineteen lofty isolated conical mountains upon them, which in the country are called *volcanes*, though probably some of them are closed trachytic domes. Dana is of opinion that in southern Luzon there are now only two active volcanoes,—that of Taal, which rises in the Laguna de Bongbong, with an encircling escarpment which incloses another lagoon (see page 243); and in the southern portion of the peninsula of Camarines the volcano of Albay, or Mayon, which the natives call Isaroe. The latter, which is 3197 feet high, experienced great eruptions in the years 1800 and 1814. In the northern portion of Luzon granite and mica-slate, and even sedimentary formations together with coal are diffused.[66]

The far-stretching group of the Soolo (Solo) islands, which are fully 100 in number, and which connect Mindañao and Borneo, is partly volcanic, and partly intersected by coral-reefs. Isolated unopened, trachytic, cone-shaped peaks are indeed often called *Vulcanes* by the Spaniards.

If we carefully examine all that lies to the south of the fifth degree of north latitude (to the south of the Philippines), between the meridians of the Nicobars and the north-west of New Guinea, thus taking in the Sunda Islands, great and

Siberian expedition, and the *Asie Centrale,* in which the opinion expressed by Klaproth, and which I formerly adopted, respecting the probability of the connection of the snowy mountains of the Himalaya with the Chinese province of Yunan and with Nanling north westward of Canton, has been confuted by me. The mountains of Formosa, upwards of 11,000 feet high, as well as Ta-yu-ling which bounds Fukian to the westward, belong to the system of meridian fissures in Upper Assam, in the country of the Burmese, and in the group of the Philippines.

[66] Dana's *Geology, in the Explor. Exped.*, vol. x, p. 540—545; Ernest Hofmann, *Geogn. Beob. auf der Reise von Otto v. Kotzebue,* p. 70; Léop. de Buch, *Déscription Physique des Iles Canaries,* pp. 435—439. See the large and admirable chart of the Islas Filipinas, by the Pilot Don Antonio Morati (Madrid, 1852), in two plates.

small, and the Moluccas, we shall find as the result, given in the great work of Dr. Junghuhn, that "in a circle of islands which surround the almost continental Borneo, there are 109 lofty fire-emitting mountains, and 10 mud-volcanoes." This is not merely an approximate calculation, but an actual enumeration.

Borneo, the *Giava Maggiore* of Marco Polo,[67] has hitherto furnished us with no certain proofs of the existence of any active volcano upon it; but, indeed, it is only a few narrow strips of the shore that we are acquainted with (on the north-west side as far as the small coast-island of Labuan, and as far as Cape Balambangan; on the west coast at the mouth of the Pontianak; and on the south-eastern point in the district of Banjermas-Sing, on account of the gold, diamond and platinum washings). It is not even believed that the highest mountain of the whole island, and perhaps even of the whole South Asiatic island-world, the double-peaked Kina Bailu at the northern extremity, distant only thirty-two geographical miles from the Pirate-coasts, is a volcano. Captain Belcher makes it 13,695 feet high, which is nearly 4000 feet higher than the Gunung Pasaman (Ophir) of Sumatra.[68] On the other hand, Rajah

[67] Marco Polo distinguishes (Part iii, cap. 5 and 8) Giava Minore (Sumatra), where he remained for five months, and where he describes the elephants, which were not to be found in Java itself (Humboldt, *Examen. Crit. de l'Hist. de la Géorg.*, t. ii, p. 218), from what he had before described as Giava (Maggiore), *la quale, secondo dicono i marinai, che bene lo sanno, è l'isola più grande che sia al mondo,*—(which as the sailors say, who know it well, is the largest island in the world. This assertion is even to this day true. From the outlines of the chart of Borneo and Celebes by James Brooke and Captain Rodney Mundy, I find the area of Borneo 51,680 square geographical miles, nearly equal to that of the island of New Guinea, but only one-tenth of the continent of New Holland. Marco Polo's account of the great quantity of gold and treasure which the "Mercanti di Zaiton e del Mangi" exported from thence, shows that by Giava Maggiore he meant Borneo, (as did also Martin Behaim on the Nürnberg globe of 1492, and Johann Ruysch in the Roman edition of Ptolemy, dated 1508, which is so important for the history of the discovery of America).

[68] Captain Mundy's chart (coast of Borneo Proper, 1847,) gives, it is true, 14,000 English feet. See a doubt of this datum in Junghuhn's *Java*, Bd. ii, s. 580. The colossal Kina Bailu is not a conical mountain. In shape it much more resembles the basaltic mountains which occur under all latitudes, and which form a long ridge with two terminal summits.

Brooke mentions a much lower mountain in the province of Sarawak, whose name, Gunung Api (Fire Mountain in the Malay tongue) as well as the scoriæ which lie around it, lead to the conclusion that it was once volcanically active. Large deposits of gold-sand between quartz-veins, the abundance of tin washed down on both shores of the rivers, and the feldspathic porphyry[69] of the Carambo Mountains, indicate a great extension of what are called primitive and transition rocks. According to the only certain information which we possess from a geologist (Dr. Ludwig Horner, son of the meritorious Zurich astronomer and circumnavigator of the globe), there are found in the south-eastern portion of Borneo united in several profitably worked washings, precisely as in the Siberian Ural, gold, diamonds, platinum, osmium, and iridium (but not yet palladium). Formations of serpentine, euphotide, and syenite, lying in great proximity, belong to a range of rocks 3411 feet high, that of the Ratuhs Mountains.[70]

The still active volcanoes on the remaining three great Sunda Islands are reckoned by Junghuhn as follows :—On Sumatra from six to seven, on Java from twenty to twenty-three, on Celebes eleven, and on Flores six. Of the volcanoes of the island of Java we have already (see above page 298) treated in detail. In Sumatra, which has not hitherto been completely investigated, out of nineteen conical mountains of volcanic appearance there are six still active.[71] Those ascertained to be so are the following :—The Gunung Indrapura, about 12,256 feet in height, according to angles of altitude measured from the sea, and probably of equal height with the more accurately measured Semeru or Maha-Meru on Java ;—the Gunung Pasaman, called also Ophir (9602 feet), with a nearly extinguished crater, ascended by Dr. L. Horner ;—the sulphureous Gunung Salasi, with eruptions of ashes in 1833 and 1845 ;—the Gunung Merapi (9751 feet), also ascended by Dr. L. Horner, accompanied by Dr. Korthal, in the year 1834, the

69 Brooke's *Borneo and Celebes,* vol. ii, pp. 382, 384, and 386.

70 Horner, in the *Verhandelingen van het Bataviaasch Genootschap van Kunsten en Wetenschappen,* Deel xvii (1839), s. 284 ; *Asie Centrale,* t. iii, pp. 534—537.

71 Junghuhn, *Java,* Bd. ii, s. 809 ; (*Battaländer,* Bd. i, s. 39).

most active of all the volcanoes of Sumatra, and not to be confounded with the two similarly named mountains of Java;[72]—the Gunung Ipu, a smoking truncated cone;—and the Gunung Dempo, in the inland country of Benkula, reckoned at 9940 feet high.

Four islets forming trachytic cones, of which the Pic Recata and Panahitam (Prince's Island) are the highest, rise above the sea in the Strait of Sunda, and connect the volcanic range of Sumatra with the crowded field of Java, and in like manner the eastern extremity of Java, with its volcano of Idjen, forms, through the medium of the active volcanoes Gunung Batur and Gunung Agung on the neighbouring island of Bali, a connection with the long chain of the smaller Sunda Islands. Here again the range is continued eastward from Bali, by the smoking volcano of Rindjani on the island of Lombok, 12,363 feet high, according to the trigonometrical measurement of M. Melville de Carnbée;—by the Temboro (5862 feet) on the Sumbava, or Sambava, whose eruption of ashes and pumice in April, 1815, obscured the surrounding atmosphere, and was one of the greatest which history has recorded;[73]—and by six conical mountains still partially smoking, on Flores . . . . .

The large and many armed island of Celebes contains six volcanoes, which are not yet all extinct; they lie all together on the narrow north-eastern peninsula of Menado. Beside it spout out streams of hot melted sulphur, into the orifice of one of which, near the road from Sonder to Lamovang, a great traveller and intrepid observer, Count Carlo Vidua, my Piedmontese friend, sank and met his death from the burns he received. As the small island of Banda in the Moluccas consists of the volcano of Guning Api, which was active from 1586 to 1824, and is about 1812 feet high, in the same way the larger island of Ternate is likewise formed by a single conical mountain, 5756 feet high, the Gunung Gama Lama, whose violent eruptions from 1838 to 1849, after more than a century and a half of entire quiescence are described at ten different periods. During the eruption of the 3rd February, 1840, according to Junghuhn, a stream of lava poured out of a fissure near the fort of Toluko, and

[72] See page 300, note 86.

[73] *Java*, Bd. ii, s. 818—828.

flowed down to the shore,[74] "partly issuing in the form of a connected and thoroughly molten stream, and partly consisting of glowing fragments which rolled down and were forced along the plain by the weight of the succeeding masses." If to the more important volcanic cones here individually mentioned we add the numerous small island volcanoes which cannot be here noticed, the total number of the igneous mountains situated to the southward of the parallel of Cape Serangami on Mindañao, one of the Philippines, and between the meridians of the north-west Cape of New Guinea on the east and of the Nicobar and Andaman groups on the west, amounts, as has been already stated, to the large number of 109.[75] This calculation is made in the belief that "on Java forty-five volcanoes, for the most part cone-shaped, and provided with craters, may be counted." Of these, however, only 21, and only from 42 to 45, of the whole number of 109, are recognized as now active, or as having been so, at any period within the reach of history. The mighty Pic of Timor formerly served like Stromboli as a light-house to mariners. On the small island of Pulu Batu (called also P. Komba), a little to the north of Floris, a volcano was seen in 1850 to pour a stream of glowing lava down to the sea-shore. The same thing was observed in 1812, and again in the spring of 1856, in respect to the Pic on the greater Sangir Island, between Magindañao and Celebes. Junghuhn doubts whether the famous conical mountain of Vavani or Ateti, on Amboina, ejected anything more than hot mud in 1674, and considers the island at present as only a solfatara. The great group of the South Asiatic Islands is connected by the division of the Western Sunda Islands with the Nicobar and Andaman, Isles of the Indian Ocean, and by the division of the Moluccas and Philippines with the Papuas, the Pellew Islands and Carolinas of the South Sea. We shall first, however, proceed with the less numerous and more dispersed groups of the Indian Ocean.

VII. The Indian Ocean.

This comprehends the space between the west coast of

74 Junghuhn's *Java,* vol. ii, pp. 840—842. 75 *Ibid,* p. 853.

the peninsula of Malacca, or of the Birman country to the east coast of Africa, thus inclosing in its northern division the Bay of Bengal and the Arabian and Red Seas. We pursue the chain of volcanic activity in the Indian Ocean in the direction from north-east to south-west.

Barren Island, in the Bay of Bengal, a little to the east of the great Andaman Island (lat. 12° 15′), is correctly considered an active cone of eruption, issuing out of a crater of upheaval. The sea forces its way through a narrow opening and fills an internal basin. The appearance presented by this island, which was discovered by Horsburgh in 1791, is exceedingly instructive for the theory of the formation of volcanic structures. We see here in a complete and permanent form what nature exhibits in only a cursory way at Santorin, and at other points of the earth's surface.[76] The eruptions in November 1803 were, like those of Sangay in the Cordilleras of Quito, very distinctly periodical, recurring at intervals of ten minutes (Leop. von Buch in the *Abhandl. der Berl. Akademie*, 1818—1819, s. 62).

The island of Narcondam, to the north of Barren Island, has likewise exhibited volcanic action at a former period, as has also the cone-mountain of the island of Cheduba, which lies more to the north, near the shore of Arracan (10° 52′). (Silliman's *American Journal*, vol. xxxviii, p. 385).

The most active volcano, judging from the frequency of the lava-eruptions, not only in the Indian Ocean but in almost the whole of the south hemisphere between the meridians of the west coast of New Holland and the east coast of America, is that on the island of Bourbon in the group of the Mascareignes. The greater part of the island, particularly the western portion and the interior, is basaltic. Recent veins of basalt, with little admixture of olivine, run through the older rock, which abounds in olivine; beds of lignite are also enclosed in the basalt. The culminating points of the Mountain Island are the *Gros Morne* and the *Trois Salazes*, the height of which La Caille over-estimated at 10,658. The volcanic action is now limited to the southernmost portion, the "Grand pays brûlé." The summit of the

[76] Leop. v. Buch, in the *Abhandl. der Akad. der Wiss. zu Berlin*, 1818 and 1819, s. 62; Lyell, *Princ. of Geology.* (1853), p. 447, where a fine representation of the volcano is given.

volcano of Bourbon, which Hubert describes as emitting, nearly every year, two streams of lava which frequently extend to the sea, is, according to Berth's measurement, 8000 feet high.[77] It exhibits several cones of eruption which have received distinct names, and which alternately send forth eruptions. The eruptions from the summit are infrequent. The lavas contain glassy feld-spar, and are therefore rather trachytic than basaltic. The shower of ashes frequently contains olivine in long, fine threads, a phenomenon which likewise occurs at the volcano of Owhyhee. A violent eruption of these glassy threads, covering the whole island of Bourbon, occurred in the year 1821.

All that we know of the great neighbouring terra incognita of Madagascar is the extensive dispersion of pumice at Tintingue, opposite the French island of St. Marie, and the occurrence of basalt, to the south of the bay of Diego Suarez, near the northernmost Cap d'Ambre, surrounded by granite and gneiss. The southern central-ridge of the Ambohistmene Mountains is calculated (though with little certainty) at about 11,000 feet. Westward of Madagascar, in the northern outlet of the Mozambique Channel, the largest of the Comoro Islands has a burning volcano (Darwin, *Coral Reefs*, p. 122).

The small volcanic island of St. Paul (38° 38′), south of Amsterdam, is considered volcanic, not only on account of its form, which strongly reminds one of that of Santorin, Barren Island, and Deception Island, in the group of the New Shetland Isles, but likewise on account of the repeatedly observed eruptions of fire and vapour in modern times. The very characteristic drawing given by Valentyn in his work on the Banda Islands, relative to the expedition of Willem de Vlaming (November 1696) corresponds exactly, as do also the statements of the latitudes, with the representations in the atlas of Macartney's expedition, and Captain Blackwood's survey (1842). The crater-shaped, circular bay, nearly an English mile across, is everywhere surrounded by precipitate rocks which fall perpendicularly in the interior, with the exception of a narrow opening, through which the sea enters at flood-tide; while those which form

[77] Bory de St. Vincent, *Voyage aux Quatre Isles d'Afrique*, t. ii, p. 429.

the margin of the crater fall away externally with a gentle slope.[78]

The island of Amsterdam which lies 50′ of latitude farther towards the north (37° 48′) consists, according to Valentyn's representation, of a single, well-wooded, somewhat rounded mountain, from the highest ridge of which rises a small cubical rock, almost the same as at the *Cofre de Perote* on the higher plains of Mexico. During the expedition of D'Entrecasteaux (March 1792), the island was seen for two whole days entirely enveloped in flames and smoke. The smell of the smoke seemed to indicate the combustion of wood and earth; columns of vapour were, indeed, thought to rise here and there from the ground near the shore, but the naturalists who accompanied the expedition were decidedly of opinion that the mysterious phenomenon could by no means be ascribed to an eruption [79] of the high mountain, like that

[78] Valentyn, *Beschryving van Oud en Nieuw Oost Indiën*, Deel iii, (1726), p. 70; *Het Eyland St. Paulo*. (Compare Lyell, *Princ.* p. 446).

[79] "We were unable," says D'Entrecasteaux, "to form any conjecture as to the cause of the burning on the island of Amsterdam. The island was in flames throughout its whole extent, and we recognized distinctly the smell of burnt wood and earth. We had felt nothing to lead us to suppose that the fire was the effect of a volcano" (t. i, p. 45). A few pages before, he says, "We remarked, however, as we sailed along the coast, from which the flames were rather distant, little puffs of smoke which seemed to come from the earth like jets; yet we could not distinguish the least trace of fire around them, though we were very close to the land. These jets of smoke which appeared at intervals, were considered by the naturalists of the expedition as certain proofs of subterranean fire. Are we to conclude from this that there were actual combustions of earth,—conflagrations of lignite, the beds of which, covered with basalt and tufa, occur in such abundance on volcanic islands (as Bourbon, Kerguelen-land, and Iceland)? The *Surtarbrand*, on the latter island, derives its name from the Scandinavian myth of the fire-giant Surtr causing the conflagration of the world. The combustion of earth, however, causes no flame in general. As in modern times the names of the islands Amsterdam and St. Paul are unfortunately often confounded on charts, I would here observe, in order to prevent mistakes in ascribing to one observations which apply to the other, they being very different in formation though lying almost under one and the same meridian, that originally (as early as the end of the 17th century) the south island was called St. Paul and the northern one Amsterdam. Vlaming, their discoverer, assigned to the first the latitude of 38°40′, and to the second that of 37°48′ south of the equator. This corresponds in a remarkable manner with

of a volcano. More certain evidences of former genuine volcanic action on the island of Amsterdam may be found in the calculation made by D'Entrecasteaux a century later on the occasion of the expedition in search of La Pérouse (*Voyage*, t. i, p. 43—45), namely, for Amsterdam, according to Beautemps Beaupré, 37° 47′ 46″ (long. 77° 71′); for St. Paul 38° 38′. This near coincidence must be considered accidental, as the points of observation were certainly not exactly the same. On the other hand Captain Blackwood in his Admiralty chart of 1842 gives 38° 44′ and longitude 77° 37′ for St. Paul. On the charts given in the original editions of the voyages of the immortal circumnavigator Cook, those for instance of the first and second expedition (*Voyage to the South Pole and Round the World*, London, 1777, p. 1), as well as of the third and last voyage (*Voyage to the Pacific Ocean*, published by the Admiralty, London, 1784, in 2nd edition, 1785), and even of all the three expeditions (*A General Chart, exhibiting the Discoveries of Captain Cook in his Third and Two Preceding Voyages*, by Lieut. Henry Roberts), the island of St. Paul is very correctly laid down as the most southernly of the two; but in the text of the voyage of D'Entrecasteaux (t. i, p. 44), it is mentioned by way of censure (whether with justice or not I am unable to say, although I have sought after the editions in the libraries of Paris, Berlin, and Göttingen), "that on the special chart of Cook's last expedition the island of Amsterdam is set down as more to the south than St. Paul." A similar reversal of the appellations, quite opposed to the intention of the discoverer, Willem de Vlaming, was frequent in the first third of the present century, as for example on the older and excellent maps of the world by Arrowsmith and Purdy (1833), but there was more than a special chart of Cook's third voyage operating to cause it. There was, 1st, the arbitrary entry on the maps of Cox and Mortimer; 2nd, the circumstance that, in the atlas of Lord Macartney's voyage to China, though the beautiful volcanic island represented smoking is very correctly named St. Paul, under lat. 38° 42′, yet it is absurdly added, "commonly called Amsterdam," and what is still worse, in the narrative of the voyage itself, Staunton and Dr. Gillan uniformly called this "island still in a state of inflammation" Amsterdam, and, they even add (p. 226, after having given the correct latitude in p. 219) "that St. Paul is lying to the northward of Amsterdam;" and 3rdly, there is the same confusion of names by Barrow (*Voyage to Cochin China in the Years* 1792 *and* 1793, pp. 140—157), who also gives the name of Amsterdam to the southern island, emitting smoke and flames, assigning to it at the same time the latitude 38° 42′. Malte Brun (*Précis de la Géographie Universelle*, t. v, 1817, p. 146), very properly blames Barrow, but he errs in also blaming, M. de Rossel and Beautemps-Beaupré. Both of the latter writers give as the latitude of the island of Amsterdam, which is the only one they represent, 37° 47′, and that of the island of St. Paul, because it lies 50′ more to the south, 38° 38′ (*Voy. de D'Entrecastreaux*, 1808, t. 1, pp. 40—46), and to show that the design represents the true island of Amsterdam, discovered by Willem de Vlaming, Beauthe beds of pumice-stone (*uitgebranden puimsteen*), mention of which is made so early as by Valentyn, according to Vlaming's Ship Journal of 1696.

To the south-east of the Cape of Good Hope lie Marion's, or Prince Edward's Island (47° 2′), and Possession Island (lat. 46° 28′ and long. 51° 56′), forming part of the Crozet group. Both of them exhibit traces of former volcanic action,—small conical hills,[80] with eruption-openings surrounded by columnar basalt.

More eastward, and almost in the same latitude, we come to Kerguelen's island (Cook's Island of Desolation), for the first geological account of which we are indebted to the successful and important expedition of Sir James Ross. In the harbour called by Cook Christmas Harbour (lat. 48° 41′, long. 69° 2′), basaltic lavas, several feet thick, are found enclosing the fossil trunks of trees; there also is seen the singular and picturesque *Arched Rock*, a natural passage through a narrow projecting wall of basalt. In the neighbourhood are conical-mountains, the highest of which rise to 2664 feet, with extinct craters,—masses of green-stone and porphyry, traversed by beds of basalt,—and amygdalaid with drusy masses of quartz at Cumberland Bay. The most remarkable of all are the numerous beds of coal, covered with trap-rock (dolerite, as at Meissner in Hessian ?), of a thickness of from a few inches to four feet at the outcrop.[81]

If we take a general survey of the Indian Ocean, we shall find the north-westerly extremity of the Sunda range in Sumatra, which is curved, carried on through the Nicobars and the Great and Little Andamans, while the volcanoes of Barren Island, Narcondam, and Cheduba, almost parallel

temps-Beaupré adds in his atlas a copy of the thickly-wooded island of Amsterdam from Valentyn. I may here observe that the celebrated navigator, Abel Tasman having in 1642, along with Middelburg, called the island of Tonga-Tabu (lat. 21½°) in the Tonga group, by the name of Amsterdam (Burney, *Chronolog. Hist. of the Voyages and Discoveries in the South Sea or Pacific Ocean*, Part iii, pp. 81 and 437); he has also been sometimes erroneously cited as the discoverer of Amsterdam and St. Paul in the Indian Ocean. See Leidenfrost, *Histor. Handwortenbuch*, Bd. v, s. 310.

[80] Sir James Ross, *Voyage in the Southern and Antarctic Regions*, vol. i, pp. 46, and 50—56.

[81] *Ibid.* p. 63—82.

to the coasts of Malacca and Tenasserim, run into the eastern portion of the Bay of Bengal. Along the shores of Orissa and Coromandel, the eastern portion of the bay is destitute of islands, the great island of Ceylon bearing, like that of Madagascar, more of the character of a continent. Opposite the western shore of the Indian peninsula (the elevated plain of Neilgherry and the coasts of Canara and Malabar) a range of three archipelagos lying in a direction from north to south, and extending from 14° north to 8° south latitude (the Laccadives, the Maldives, and the Chagos) is connected by the shallows of Sahia de Malha and Cargados Carajos with the volcanic group of the Mascareignes and Madagascar. The whole of this chain, so far as can be seen, is the work of coral-polypes,—true *Atolls,* or lagoon-reefs; in accordance with Darwin's ingenious conjecture that at this part a large extent of the floor of the ocean forms, not an area of upheaval, but an area of subsidence.

VIII. The South Sea, or Pacific.

If we compare that portion of the earth's surface now covered with water with the aggregate area of the terra firma, (nearly[82] in the proportion of 2.7 to 1), we cannot but be astonished in a geological point of view at the small number of volcanoes which still continue active in the oceanic region. The South Sea, the superficies of which is nearly one-sixth greater than that of the whole terra firma of our planet,—which in the equinoctial region, from the archipelago of Galapagos to the Pellew Islands, is nearly two-fifths of the whole circumference of the earth in breadth, —exhibits fewer smoking volcanoes, fewer openings through which the interior of the planet still continues in active communion with its atmospheric envelope than does the single island of Java. Mr. James Dana, the talented geologist of the great American exploring expedition (1838—1842), under the command of Charles Wilkes, basing his views on his own personal investigations, aided by a careful comparison of all previous reliable observations, and espe-

[82] The result of Prof. Rigaud's levellings at Oxford, according to Halley's old method. See my *Asie Centrale,* t. i, p. 189.

cially by a comprehensive examination of the different opinions on the forms, the distribution and the axial direction of the island groups, on the character of the different kinds of rocks, and the periods of the subsidence and upheaval of extensive tracts of the floor of the ocean, has the indisputable merit of having shed a new light over the island-world of the South Sea. In availing myself of his work, as well as of the admirable writings of Charles Darwin, the geologist of Captain Fitzroy's expedition (1832—1836), without always particularizing them, I trust that the high respect in which I have for so many years held those gentlemen, will secure me from the chance of having my motives misinterpreted.

It is my intention to avoid altogether the divisional terms of Polynesia, Micronesia, Melanesia, and Malaisia,[83] which are not only extremely arbitrary, but founded on totally different principles drawn from the number and size, or the complexion and descent of the inhabitants, and to commence the enumeration of the still active volcanoes of the South Sea with those which lie to the north of the equator. I shall afterwards proceed in the direction from east to west to the islands situated between the equator and the parallel of 30° south latitude. The numerous basaltic and trachytic islands, with their countless craters, formerly at different times eruptive, must on no account be said to be indiscriminately scattered.[84] It is admitted with respect to the greater number of them that their upheaval has taken

[83] D'Urville, *Voy. de la Corvette l'Astrolabe*, 1826—1829, Atlas, pl. i. —1st, Polynesia is considered to contain the eastern portion of the South Sea (the Sandwich Islands, Tahiti, and the Tonga Archipelago; and also New Zealand); 2nd, Micronesia and Melanesia form the western portion of the South Sea; the former extends from Kauai, the westernmost island of the Sandwich group, to near Japan and the Philippines, and reaches south to the equator, comprehending the Marians (Ladrones), the Carolinas and the Pellew Islands; 3rd, Melanesia, so called from its dark-haired inhabitants, bordering on the Malaisia to the north-west, embraces the small archipelago of Viti, or Feejee, the New Hebrides and Solomon's Islands; likewise the larger islands of New Caledonia, New Britain, New Ireland, and New Guinea. The terms Oceania and Polynesia, often so contradictory in a geographical point of view, are taken from Malte-Brun (1813) and from Lesson (1828).

[84] "The epithet *scattered*, as applied to the islands of the ocean (in the arrangement of the groups) conveys a very incorrect idea of their

place on widely extended fissures and submarine mountain-chains, which run in directions governed by fixed laws of region and grouping, and which, just as we see in the continental mountain-chains of Central Asia, and of the Caucasus, belong to different systems; but the circumstances which govern the area over which at any one particular time the openings are simultaneously active, probably depend, from the extremely limited number of such openings, on entirely local disturbances to which the conducting fissures are subjected. The attempt to draw lines through three now simultaneously active volcanoes, whose respective distances amount to between 2400 and 3000 geographical miles asunder, without any intervening cases of eruption (I refer to three volcanoes now in a state of ignition,—Mouna Loa, with Kilauea on its eastern declivity,—the cone-mountain of Tanna, in the new Hebrides; and Assumption Island in the North Ladrones), would afford us no information in regard to the general formation of volcanoes in the basin of the South Sea. The case is quite different if we limit ourselves to single groups of islands, and look back to remote, perhaps pre-historic, epochs when the numerous linearly arranged, though now extinct, craters of the Ladrones (Marian Islands), the New Hebrides and the Solomon's Islands were active, but which certainly did not become

positions. There is a system in their arrangement as regular as in the mountain heights of a continent, and ranges of elevation are indicated, as grand and extensive as any continent presents." *Geology*, by J. Dana, *United States' Exploring Expedition*, under command of Charles Wilkes, vol. x, (1849) p. 12. Dana calculates that there are in the whole of the South Sea, exclusive of the small rock-islands, about 350 basaltic or trachytic and 290 coral islands. He divides them into twenty-five groups, of which nineteen in the centre have the direction of their axis N. 50°—60° W., and the remaining N. 20°—30° E. It is particularly remarkable that these numerous islands, with a few exceptions, such as the Sandwich Islands and New Zealand, all lie between 23° 28′ of north and south latitude, and that there is such an immense space devoid of islands eastward from the Sandwich and the Nukahiva groups as far as the American shores of Mexico and Peru. Dana likewise draws attention to a circumstance which forms a contrast to the insignificant number of the now active volcanoes, namely, that if, as is probable, the Coral Islands, when lying between entirely basaltic islands, have likewise a basaltic foundation, the number of submarine and subaërial volcanic openings may be estimated at more than a thousand (pp. 17 and 24).

gradually extinguished in a direction either from south-east to north-west or from north to south. Though I here name only volcanic island-chains of the high seas, yet the Aleutes and other true coastian islands are analogous to them. General conclusions as to the direction of a cooling process are deceptive, as the state of the conducting medium must operate temporarily upon it, according as it is open or interrupted.

Mouna Loa, ascertained by the exact measurement[85] of the American exploring expedition under Captain Wilkes to be 13,758 feet in height, and consequently 1600 feet higher than the Peak of Teneriffe, is the largest volcano of the South Sea Islands, and the only one that still remains really active in the whole volcanic archipelago of the Hawaii or Sandwich Islands. The summit-craters, the largest of which is nearly 13,000 feet in diameter, exhibit in their ordinary state a solid bottom, composed of hardened lava and scoriæ, out of which rise small cones of eruption, exhaling vapour. The summit openings are on the whole not very active, though in June 1832 and in January 1843, they emitted eruptions of several weeks' duration, and even streams of lava of from 20 to 28 geographical miles in length, extending to the foot of Mouna Kea. The fall (inclination) of the perfectly connected flowing stream[86] was chiefly 6°, frequently 10°, 15°, and even 25°. The conformation of the Mouna Loa is very remarkable from the circumstance of its having no cone of ashes, like the Peak of Teneriffe, Cotopaxi, and so many other volcanoes; it is likewise almost entirely deficient in pumice[87] though the blackish-grey, and more trachytic than basaltic, lavas of the

[85] See *Cosmos*, vol. v, p. 250, note 35.

[86] Dana, *Geology of the U. St. Explor. Exped.*, pp. 208 and 210.

[87] Dana, pp. 193 and 201. The absence of cinder-cones is likewise very remarkable in those volcanoes of the Eifel which emit streams of lava. Reliable information, however, received by the Missionary Dibble from the mouths of eye-witnesses, proves that an eruption of ashes may notwithstanding occur from the summit-crater of Mouna Loa, for he was told that, during the war carried on by Kamehameha against the insurgents in the year 1789, an eruption of hot ashes, accompanied by an earthquake, enveloped the surrounding country in the darkness of night (p. 183). On the volcanic glass threads (the hair of the goddess Pele, who before she went to settle at Hawaii inhabited the now

summit abound in felspar. The extraordinary fluidity of the lavas of Mouna Loa, whether issuing from the summit-crater (Mokua-weo-weo) or from the sea of lava (on the eastern declivity of the volcano, at a height of only 3969 feet above the sea), is testified by the glass threads, sometimes smooth and sometimes crisped or curled, which are dispersed by the wind all over the island. This *hair glass,* which is likewise thrown out by the volcano of Bourbon, is called *Pele's hair* by the Hawaiians, after the tutelary goddess of the country.

Dana has ably demonstrated that Mouna Loa is not the central volcano of the Sandwich Islands, and that Kilauea is not a solfatara.[88] The basin of Kilauea is 16,000 feet (about $2\frac{2}{3}$ geographical miles) across its long diameter, and 7460 feet across its shorter one. The steaming, bubbling, and foaming mass which forms the true lava-pool does not, however, under ordinary circumstances, fill the whole of this cavity, but merely a space whose long diameter measures 14,000 feet and its breadth 5000 feet. The descent to the edge of the crater is graduated. This great phenomenon produces a wonderful impression of silence and solemn repose. The approach of an eruption is not here indicated by earthquakes or subterranean noises, but merely by a sudden rising and falling of the surface of the lava, sometimes to the extent of from 300 or 400 feet up to the complete filling of the whole basin. If, disregarding the immense difference in size, we were to compare the gigantic basin of Kilauea with the small side-craters, (first described by Spallanzani), on the declivity of Stromboli at four-fifths of the height of the mountain, the summit of which has

extinct volcano of Hale-a-Kala—or the House of the Sun—on the island of Mani). See pp. 179 and 199—200.

[88] Dana, p. 205. "The term *Solfatara* is wholly misapplied. A solfatara is an area with steaming fissures and escaping sulphur vapours, and without proper lava ejections; while Kilauea is a vast crater with extensive lava ejections and no sulphur, except that of the sulphur banks, beyond what necessarily accompanies, as at Vesuvius, violent volcanic action." The structural frame of Kilauea, the mass of the great lava-basin, consists also, not of beds of ashes or fragmentary rocks, but of horizontal layers of lava, arranged like lime-stone. Dana, p. 193. (Compare Strzelecki, *Phys. Descr. of New South Wales*, 1845, p. 105—111).

no opening—that is to say, with basins of boiling lava of from 30 to 200 feet in diameter only—we must not forget that the fiery gulfs on the slope of Stromboli throw out ashes to a great height, and even pour out lava. Though the great lava-lake of Kilauea (the lower and secondary crater of the active volcano of Mouna Loa) sometimes threatens to overflow its margin, yet it never actually runs over so as to produce true streams of lava. These occur by currents from below, through subterranean channels, and the formation of new eruptive-openings at a distance of from 1·6 to 20 geographical miles, consequently at points very much lower than the basin. After these eruptions, occasioned by the pressure of the immense mass of lava in the basin of Kilauea, the fluid surface sinks in the basin.[89]

Of the two other high mountains of Hawaii, Mouna Lea and Mouna Hualalai, the former is, according to Captain Wilkes, 190 feet higher than Mouna Loa. It is a conical mountain on whose summit there no longer exists any terminal-crater, but only long extinct mounds of scoriæ. Mouna Hualalai* is fully 10,000 feet high, and is still burning. In the year 1801 an eruption took place, during which the lava reached the sea on the western side. It is to the three colossal mountains of Loa, Kea and Hualalai, which rose from the bottom of the sea, that the island of Hawaii owes its origin. In the accounts given of the numerous ascents of Mouna Loa, among which that of the expedi-

[89] This remarkable sinking of the surface of the lava is confirmed by the relations of numerous voyagers, from Ellis, Stewart, and Douglas to the meritorious Count Strzelecki, Wilkes's expedition and the remarkably observant Missionary Coan. During the great eruption of June, 1840, the connection of the rise of the lava in the Kilauea with the sudden inflammation of the crater of Arare, situated so far below it, was most decidedly shown. The disappearance of the lava poured forth from Arare, its renewed subterranean course, and final re-appearance in greater quantity, do not quite admit of an absolute conclusion as to identity because numerous lava-yielding longitudinal fissures opened simultaneously below the line of the floor of the Kilauea basin. It is likewise very worthy of observation, as bearing on the internal constitution of this singular volcano of Hawahi, that in June, 1832, both craters, that of the summit and that of Kilauea, poured out and occasioned streams of lava, so that they were simultaneously active. (Compare Dana, pp. 184, 188, 193, and 196).

tion of Captain Wilkes was based on investigations of twenty-eight days' duration, mention is made of falls of snow with a degree of cold from 23 to 17½ F. above zero, and of single patches of snow, which could be distinguished with the aid of the telescope at the summit of the volcano, but nothing is ever said of perpetual snow.[90] I have already observed in a former part of this work that the Mouna Loa (13,758 feet) and the Mouna Kea (13,950 feet) are respectively more than 1000 and 821 feet lower than the lowest limit of perpetual snow as found by me in the continental mountains of Mexico under 19½° latitude. On a small island the line of perpetual snow should lie somewhat lower, on account of the less elevated temperature of the lower strata of air in the hottest season of the tropical zone, and on account of the greater quantity of water held in solution in the upper atmosphere.

The volcanoes of Tafoa* and Amargura* in the Tonga-group are both active, and the latter had a considerable eruption of lava on the 9th of July 1847.[91] It is extremely remarkable and is in entire accordance with the stories of the coral animals avoiding the shores of volcanoes either at the time or shortly before in a state of ignition, that the Tonga islands of Tafoa and the cone of Kao, which abound in coral-reefs are entirely destitute of those creatures.[92]

Next follow the volcanoes of Tanna* and Ambrym,* the latter westward of Mallicollo in the archipelago of the New Hebrides. The volcano of Tanna, first described by Reinhold Forster, was found in a full state of eruption on Cook's discovery of the island in 1774. It has since remained constantly active. Its height being only 458 feet, it is one of the lowest fire-emitting cones, along with the volcano of Mendaña, hereafter to be noticed, and the Japanese volcano of Kosima. There is a great quantity of pumice on Mallicollo.

Matthew's Rock ;* a very small smoking rock-island, about 1183 feet high, the eruption of which was observed

[90] Wilkes, pp. 114, 140, and 157; Dana, p. 221. From the perpetual transmutation of the *r* and the *l*, Mauna Loa is often written Roa, and Kilauea, Kirauea.

[91] Dana, pp. 25 and 138.

[92] Dana, *Geology of the U. States Exploring Exped.*, p. 138. (See Darwin, *Structure of Coral Reefs*, p. 60).

by D'Urville in January 1828. It lies eastward of the southern point of New Caledonia.

The volcano of Tinakoro* in the group of Vanikoro or Santa Cruz.

In the same archipelago of Santa Cruz, fully 80 geographical miles NN.W. of Tinakoro, the volcano* seen by Mendaña so early as 1595, rises out of the sea to a height of about 213 feet (lat. 10° 23′ S.). Its eruptions have sometimes been periodical, occurring every ten minutes, and at other times, as on the occasion of the expedition of D'Entrecasteaux, the crater itself and the column of vapour were undistinguishable from each other.

In the Solomon's-group the volcano of the island of Sesarga* is in a state of ignition. On the coast of Guadalcañar, in this neighbourhood, and therefore also at the south-east end of the long range of islands towards the Vanikoro or Santa Cruz group, volcanic eruptive action has likewise been observed.

In the Ladrones, or Marian Islands, at the north end of the range, which seems to have been upheaved from a meridian fissure, Guguan,* Pagon,* and the *Volcan grande* of Asuncion are said to be still in a state of activity.

The direction of the coasts of the small continent of New Holland, and particularly the deviation from that direction seen in the east coast in 25° south latitude (between Cape Hervey and Moreton Bay), seem to be reflected in the zone of the neighbouring eastern islands. The great southern island of New Zealand, and the Kermadec and Tonga groups stretch from the south-west to the north-east, while, on the other hand, the northern portion of the north island of New Zealand (from the Bay of Plenty to Cape Oton), New Caledonia and New Guinea, the New Hebrides, the Solomon's Isles, New Ireland and New Britain run in a direction from south-east to north-west, chiefly N. 48° W. Leopold von Buch[93] first drew attention to this relation between continental masses and neighbouring islands in the Greek Archipelago and the Australian Coral Sea. The islands of the latter sea, too, are not deficient, as both Forster (Cook's companion) and La Billardière formerly observed, in granite and mica-slate,

[93] Léop. von Buch, *Description phys. des iles Canaries,* 1836, pp. 393 and 403—405.

the quartzose rocks formerly called primeval. Dana has likewise collected them on the northern island of New Zealand, to the west of Tipuna, in the Bay of Islands.[94]

New Holland exhibits only on its southern extremity (Australia Felix), at the foot and to the south of the Grampian Mountains, fresh traces of former igneous action, for we learn from Dana that a number of volcanic cones and deposits of lava are found to the north-west of Port Phillip, as also in the direction of the Murray river (Dana, p. 453).

On New Britain* there are at least three cones on the west coast, which have been observed within the historical era, by Tasman, Dampier, Carteret and La Billardière, in a state of ignition and throwing out lava.

There are two active volcanoes on New Guinea,* on the north-eastern coast, opposite New Britain and the Admiralty Islands, which abound in obsidian.

In New Zealand, of which the geology of the north island at least, has been illustrated by the important work of Ernst Dieffenbach, and the admirable investigations of Dana, basaltic and trachytic rocks at various points break through the generally diffused plutonic and sedimentary rocks. This example is the case in a very limited area near the Bay of Islands (lat. 35° 2′), where the ash-cones, crowned with extinct craters, Turoto and Poerua rise; and again, more to the south-east, (between $37\frac{1}{2}°$ and $39\frac{1}{4}°$ lat.), where the volcanic floor runs quite across the centre of the north island, a distance of more than 160 geographical miles from north-east to south-west, from the Bay of Plenty on the east to Cape Egmont on the west. This zone of volcanic action here traverses, (as we have already seen it to do on a much larger scale in the Mexican Continent) in a diagonal fissure from north-east to south-west, the interior chain of mountains which runs lengthwise in a north and south direction, and which seems to give its form to the whole island. On the ridge of this chain stand, as it were, at the points of intersection, the lofty cone of Tongariro* (6198 feet), whose crater is found on the top of the ash-cone, Bidwill, and, somewhat more to the south, Ruapahu

[94] See Dana, *ibid.* p. 438—446, and on the fresh traces of ancient volcanic action in New Holland, pp. 453 and 457; also on the many basaltic columns in New South Wales and Van Diemen's Land, p. 495—510; and E. de Strzelecki, *Phys. Descr. of New South Wales*, p. 112.

(9006 feet). The north-east end of the zone is formed in the Bay of Plenty (lat. 38½), by a constantly smoking solfatara, the island-volcano of Puhia-i-wakati*[95] (White Island). Next follow to the south-west, on the shore itself, the extinct volcano of Putawaki (Mount Edgecombe), 8838 feet high, probably the highest snowy mountain on New Zealand, and in the interior, between Mount Edgecombe and the still burning Tongariro,* which has poured fourth some streams of lava, a lengthened chain of lakes, partly consisting of boiling water. The lake of Taupo, which is surrounded by beautiful glistening leucite and sanidine sand, as well as by mounds of pumice, is nearly 24 geographical miles long, and lies in the centre of the north island of New Zealand, at an elevation, according to Dieffenbach, of 1337 feet above the surface of the sea. The ground for two English square miles round, is entirely covered with solfataras, vapour-holes, and thermal-springs, the latter of which form, as at the Geyser in Iceland, a variety of siliceous precipitates[96]. Westward of Tongariro,* the chief seat of volcanic action, whose crater still ejects vapours and pumice-stone ashes, and at a distance of only sixteen miles from the western shore, rises the volcano of Taranaki (Mount Egmont), 8838 feet high, which was first ascended and measured by Dr. Ernst Dieffenbach in November, 1840. The summit of the cone, which in its outline more resembles Tolima than Cotopaxi, terminates in a plain, out of which rises a steep ash-cone. No traces of present activity, such as are seen on the volcano of the White Island* and on Tongariro* are visible, nor any connected stream of lava. The substance composed of very thin scales, and having a ringing sound, which is seen projecting with sharp points like fish-bones, from among the scoriæ, in the same manner as on one side of the Peak of Teneriffe, resembles porphyritic schist, or clink-stone.

A narrow, long-extended, uninterrupted accumulation of island-groups, erupted from north-western fissures, such as

[95] Ernest Dieffenbach, *Travels in New Zealand*, 1843, vol. i, pp. 337, 355 and 401. Dieffenbach calls White Island "a *smoking* solfatara, but still in *volcanic* activity" (pp. 358 and 407), and on the chart, "in continual ignition."

[96] Dana, pp. 445—448; Dieffenbach, vol. i, pp. 331; 339—341 and 397 On Mount Egmont, see vol. i, pp. 131—157.

New Caledonia and New Guinea, the New Hebrides and Solomon's Island, Pitcairn, Tahiti and the Paumotu Islands, traverses the great Ocean in the Southern hemisphere in a direction from west to east, for a length of 5400 geographical miles, between the parallels of latitude of 12° and 27°, from the meridian of the east coast of Australia as far as Easter Island, and the rock of Sala y Gomez. The western portions of this crowd of islands (New Britain* the New Hebrides,* Vanikoro* in the Archipelago of Santa Cruz, and the Tonga-group*) exhibit at the present time in the middle of the nineteenth century, inflammation and igneous action. New Caledonia, though surrounded by basaltic and other volcanic islands, has nevertheless nothing but Plutonic rock,[97] as is the case with Santa Maria[98] in the Azores, according to Leopold von Buch, and with Flores and Graciosa, according to Count Bedemar. It is to this absence of volcanic action in New Caledonia, where sedimentary formations with seams of coal have lately been discovered, that the great developement of living coral reefs on its shores is ascribed. The Archipelago of the Viti, or Feedjee Islands is at once basaltic and trachytic, though distinguished only by hot springs in the Savu Bay on Vanua Lebu.[99] The Samoa group (Navigator's Islands), north-east of the Feedjee Islands, and nearly north of the still active Tonga-archipelago is likewise basaltic, and is moreover characterised by a countless number of eruption-craters linearly arranged, which are surrounded by tufa-beds with pieces of coral baked into them. The Peak of Tafua, on the island of Upolu, one of the Samoa-group, presents a remarkable degree of geognostic interest. It must not, however, be confounded with the still enkindled peak of Tafua, south of Amargura in the Tonga-archipelago. The Peak of Tafua (2138 feet), which Dana first[100] ascended and measured, has a large crater entirely filled with a thick forest,

97 Darwin, *Volcanic Islands*, p. 125; Dana, p. 140.

98 L. de Buch, *Descr. des I. Can.* p. 365. On the three islands here named, however, phonolite and basaltic rock are also found along with plutonic and sedimentary strata. But these rocks may have made their appearance above the surface of the sea on the first volcanic up-heaval of the island from the bed of the ocean. No traces are said to have been found of fiery eruptions or of extinct craters.

99 Dana, pp. 343—350.

100 Dana, pp. 312, 318, 320 and 323.

and crowned by a regularly rounded ash-cone. There is here no trace of any stream of lava; yet on the conical mountain of Apia (2576 feet), which is likewise on Upolu, as well as on the Peak of Fao (3197 feet) we meet with fields of scoriaceous lava (Malpais of the Spaniards), the surface of which is as it were crimped, and often twisted like a rope. The lava-fields of Apia contain narrow subterranean cavities.

Tahiti, in the centre of the Society's Islands, far more trachytic than basaltic, exhibits, strictly speaking, only the ruins of its former volcanic frame-work, and it is difficult to trace the original form of the volcano in those enormous masses looking like ramparts and chevaux-de-frise, with perpendicular precipices of several thousand feet in depth. Of its two highest summits, Aorai and Orohena, the former was first ascended and investigated by that profound geologist Dana.[1] The trachytic mountain, Orohena, is said to equal Etna in height. Thus, next to the active group of the Sandwich Islands, Tahiti contains the highest rock of eruption in the whole range of the Ocean between the Continents of America and Asia. There is a felspathic rock on the small islands of Borabora and Maurua, near Tahiti, designated by late travellers with the name of syenite, and by Ellis in his Polynesian researches described as a granitic aggregate of felspar and quartz, which, on account of the breaking out of porous, scoriaceous basalt in the immediate neighbourhood, merits a much more complete mineralogical investigation. Extinct craters and lava-streams are not now to be met with on the Society's Islands. The question occurs,—are the craters on the mountain tops destroyed,—or did the high and ancient structures, now riven and transformed, continue closed at the top like a dome, while the veins of basalt and trachyte poured immediately forth from fissures in the earth, as has probably been the case at many other points of the sea's bottom? Extremes of great viscidity or great fluidity in the matter poured out, as well as the varying width, or narrowness of the fissures through which the effusion takes place, modify the shapes of the self-forming vol-

[1] Léop. von Buch, p. 383; Darwin, *Volc. Isl.* p. 25; Darwin, *Coral Reefs*, p. 138; Dana, pp. 286—305 and 364.

canic mountain-strata, and where friction produces what is called ashes and fragmentary sub-division, give rise to small and for the most part transitory cones of ejection, which are not to be confounded with the great terminal cinder-cones of the permanent structural frames.

Close by the Society's Islands, in an easterly direction, are the Low Islands, or Paumotu. These are merely coral islands, with the remarkable exception of the small basaltic group of Gambier's and Pitcairn's Islands.[2] Volcanic rock, similar to the latter, is also found in the same parallel (between 25° and 27° south latitude), 1260 geographical miles farther to the east, in the Easter Island (Waihu), and probably also 240 miles farther east, in the rocks Sala y Gomez. On Waihu, where the loftiest conical peaks are scarcely a thousand feet high, Captain Beechey remarked a range of craters, none of which appeared, however, to be burning.

In the extreme east towards the New Continent, the range of the South Sea Island terminates with one of the most active of all island groups, the Archipelago of Galapagos, composed of five great islands. Scarcely anywhere else, on a small space of barely 120 or 140 geographical miles in diameter, has such a countless number of conical mountains and extinct craters (the traces of former communication between the interior of the earth and the atmosphere), remained visible. Darwin calculates the number of the craters at nearly two thousand. When that talented observer visited the Galapagos in the expedition of the "Beagle," under Captain Fitzroy, two of the craters were simultaneously in a state of igneous eruption. On all the islands, streams of a very fluid lava may be seen which have forked off into different channels and have often run into the sea. Almost all are rich in augite and olivine; some of which are more of a trachytic character, are said to contain albite[3] in large crystals. It

[2] Dana, p. 137.

[3] Darwin, *Volc. Isl.*, pp. 104, 110—112, and 114. When Darwin says so decidedly that there is no trachyte on the Galapagos, it is because he limits the term trachyte to the common felspar, *i.e.* to orthoklase, or orthoklase and sanidine (glassy felspar). The enigmatical fragments imbaked in the lava of the small and entirely basaltic crater of James Island contain no quartz, although they appear to rest on a plutonic rock (See above, p. 367 et seq). Several of the volcanic cone-mountains on the Galapagos Islands, have at the orifice a narrow

would be well, in the perfection to which mineralogical science is now brought, to institute investigations for the purpose of discovering whether oligoclase is not contained in these porphyritic trachytes, as at Teneriffe, Popocatepetl and Chimborazo, or else labradorite, as at Etna and Stromboli. Pumice is entirely wanting on the Galapagos, as at Vesuvius, where although it may be present, it is not produced, nor is hornblende anywhere mentioned to have been found in them; consequently the trachyte formation of Toluca, Orizaba, and some of the volcanoes of Java, from which Dr. Junghuhn has sent me some well-selected solid pieces of lava for examination by Gustav Rose, does not prevail here. On the largest and most westerly island of the Galapagos group, Albemarle, the cone-mountains are ranged in a line, and consequently on fissures. Their greatest height, however, reaches only to 4636 feet. The Western Bay, in which the Peak of Narborough, so violently inflamed in 1825, rises in the form of an island, is described by Leopold von Buch[4] as a crater of up-heaval, and compared to Santorino. Many margins of craters on the Galapagos are formed of beds of tufa, which slope off in every direction. It is a very remarkable circumstance, seeming to indicate the simultaneous operation of some great and wide-spread catastrophe, that the margins of all the craters are disrupted or entirely destroyed towards the south. A part of what in the older descriptions is called tufa, consists of palagonite beds, exactly similar to those of Iceland and Italy, as Bunsen has ascertained by an exact analysis of the tufas of Chatham Island.[5] This island, the most easterly of the whole group, and whose situation is fixed by careful astronomical observations by Captain Beechey, is, according to my determination of the longitude of the city of Quito (78° 44′ 8′), and according to Acosta's *Mapa de la Nueva Granada* of 1849, 536 geographical miles distant from the Punta de S. Francisco.

cylindrical, annular addition, exactly like what I saw on Cotopaxi;—"in some parts the ridge is surmounted by a wall or parapet perpendicular on both sides." Darwin, *Volc. Isl.* p. 83.

[4] L. von Buch, p. 376.

[5] Bunsen, *in Leonhard's Jahrb. für Mineralogie*, 1851, s. 856; also in Poggend, *Annalen der Physik*, Bd. lxxxiii, s. 223.

IX. Mexico.

The six Mexican Volcanoes, Tuxtla,* Orizaba, Popocatepetl,* Toluca, Jorullo* and Colima,* four of which have been in a state of igneous activity within the historical era, were enumerated in a former place,[6] and described in their geognostically remarkable relative position. According to recent investigations by Gustav Rose, the formation of Chimborazo is repeated in the rock of Popocatepetl, or Great volcano of Mexico. This rock also consists of oligoclase and augite. Even in the almost black beds of trachyte, resembling pitch-stone, the oligoclase is recognisable in very small acute-angled crystals. To this same Chimborazo and Teneriffe formation belongs the volcano of Colima, which lies far to the west, near the shore of the South Sea. I have not myself seen this volcano, but we are indebted to Herr Pieschel [7] (since the spring of 1855) for a very instructive view of the different kinds of rocks collected by

[6] See above, pp. 279—281.

[7] See Pieschel, *Ueber die Vulkane von Mexico, in the Geitschrift für allgem. Erdkunde,* Bd. vi, 1856, s. 86 and 489—532. The assertion there made (p. 86) "that never mortal has ascended the steep summit of the Pico del Fraile," that is to say, the highest Peak of the Volcano of Toluca, has been confuted by my barometrical measurement made upon that very summit, (which is, by the way, scarcely 10 feet in width,) on the 29th September, 1803, and published first in 1807, and again recently by Dr. Gumprecht in the same volume of the journal above referred to (p. 489). The doubt raised on this point was the more singular as it was from this very summit of the Pico del Fraile, whose tower-like sides are certainly not very easy to climb, and at a height scarcely 600 feet less than that of Mont Blanc, that I struck off the masses of trachyte which are hollowed out by the lightning, and which are glazed on the inside like vitreous tubes. An essay was inserted so early as 1819 by Gilbert in volume lx of his *Annalen der Physik,* (s. 261) on the specimens placed by me in the Berlin Museum as well as in several Parisian collections (see also *Annales de Chimie et de Physique,* t. xix, 1822, p. 298). In some places the lightning has bored such regular cylindrical tubes (as much as 3 inches in length,) that they can be looked through from end to end, and in those cases the rock surrounding the openings is likewise vitrified. I have also brought with me pieces of trachyte in my collections, in which the whole surface is vitrified without any tube-like perforation, as is the case at the little Ararat and at Mont Blanc. Herr Pieschel first ascended the double-peaked volcano of Colima, in October, 1852, and reached the

him, as well as for his interesting geological notices on the volcanoes of the whole Mexican highlands, all of which he has personally visited. The volcano of Toluca, whose highest summit (the Pico del Frayle), though narrow and difficult to climb, I ascended on the 29th September, 1803, and found barometrically to be 15,166 feet high, has a totally different mineralogical composition from the still active Popocatepetl and the igneous mountain of Colima; this must not, however, be confounded with another, still higher summit, called the Snow-mountain. The volcano of Toluca consists, like the Peak of Orizaba, the Puy de Chaumont in the Auvergne and Ægina, of a combination of oligoclase and hornblende. From this brief sketch it will be seen, and it is well deserving of notice, that in the long range of volcanoes which extend from ocean to ocean, there are not two immediately succeeding each other which are of similar mineralogical composition.

X. The North-western Districts of America (northward of the parallel of Rio Gila).

In the section which treats of the volcanic action on the eastern Asiatic Islands,[8] particular notice has been drawn to the bow-like curve in the direction of the fissure of upheaval from which the Aleutian Islands have risen, and which manifests an immediate connection between the Asiatic and American continents,—between the two volcanic peninsulas Kamtschatka and Aliaska. At this point is the outlet, or rather the northern boundary, of a mighty gulf of the Pacific Ocean, which from the 150 degrees of longitude embraced by it under the equator, narrows itself down between the terminal points of these two peninsulas to 37°

crater, from which he then saw nothing but sulphuretted-hydrogen vapour rising in a cloud; but Sonneschmid, who vainly attempted to ascend Colima, in February, 1796, gives an account of an immense ejection of ashes in the year 1770. In the month of March 1795, on the other hand, red-hot scoriæ were visibly thrown out in a column of fire at night.—"To the north-west of the volcano of Colima, a volcanic branch-fissure runs along the shore of the South Sea. Extinct craters and ancient lava-streams are recognised in what are called the Volcanoes of Ahuacatlan (on the road from Guadalaxara to San Blas) and Tepic." (Pieschel, *ibid.* p. 529).

[8] See above, pp. 367—372.

of longitude. On the American continent, near the sea-shore, a number of more or less active volcanoes has become known to mariners within the last seventy or eighty years, but this group lay hitherto as it were isolated, and unconnected with the volcanic range of the Mexican tropical region, or with the volcanoes which were believed to exist on the peninsula of California. If we include the range of extinct trachytic cones as intermediate links, we may be said to have obtained insight into their important geological connection over a gap of more than 28° of latitude, between Durango and the new Washington territory, northward of West Oregon. The study of the physical condition of the earth owes this important step in advance to the scientifically well-prepared expeditions, which the government of the United States has fitted out for the discovery of the best road from the plains of the Mississippi to the shores of the South Sea. All the departments of natural history have derived advantage from those undertakings. Great tracts of country have been found, in the now explored terra-incognita of this intermediate space, from very near the Rocky Mountains on their eastern slope, to a great distance beyond their western descent, covered with evidences of extinct or still active volcanoes (as for instance in the Cascade Mountains). Thus, setting out from New Zealand and ascending first a long way to the north-west through New Guinea, the Sunda Islands, the Philippines and Eastern Asia, to the Aleutians, and then descending towards the south through the north-western, the Mexican, the Central American, and South American territories to the terminating point of Chili, we find the *entire circuit of the basin of the Pacific Ocean*, throughout an extent of 26,400 geographical miles, surrounded by a range of recognisable memorials of volcanic action. Without entering into the details of exact geographical bearings and of the perfected nomenclature, a cosmical view such as this could never have been obtained.

Of the circuit of the great oceanic[9] basin here indicated (or, as there is but one united mass of water over the

[9] The term "Grand Ocean," used to designate the basin of the South Sea by that learned geographer, my friend Contre-Amiral de Fleurieu, the editor of the *Introduction Historique au Voyage de*

whole earth, we ought rather to say the circumference of the largest of those portions of it which penetrate between continents) it remains for us now to describe the tract of country which extends from Rio Gila to Norton's and Kotzebue's Sounds. Analogies drawn in Europe from the Pyrenees or the Alpine chain, and in South America from the Cordilleras of the Andes, from South Chili to the fifth degree of north latitude in New Grenada, supported by fanciful delineations in maps, have propagated the erroneous opinion that the Mexican mountains, or at least their highest ridge, can be traced along like a wall, under the name of the Sierra Madre, from south-east to north-west. But though the mountainous part of Mexico is a mighty swelling of the land running connectedly in the direction above stated between two seas to the height of from 5000 to 7000 feet, yet on the top of this, in the same way as in the Caucasus and in Central Asia, still loftier ranges of mountains, running in partial and very various directions, rise to about 15,000 and 17,800 feet. The arrangement of these partial groups, erupted from fissures not parallel to each other, is in its bearings for the most part independent of the ideal axis which may be drawn through the entire swell of the undulating flattened ridge. These remarkable features in the formation of the soil give rise to a deception which is strengthened by the pictorial effect of the beautiful country. The colossal mountains covered with perpetual snow seem as it were, to rise out of a plain. The spectator confounds the ridge of the soft swelling land, the elevated plain, with the plain of the low lands, and it is only from the change of climate, the lowering of the temperature, under the same degree of latitude, that he is reminded of the height to which he has ascended. The fissure of upheaval, frequently before mentioned, of the volcano of Anahuac (running in a direction from east to west between 19° and 19¼° lat.) intersects[10] the general axis of the swelling land almost at right angles.

Marchand, confounds the whole with a part, and consequently leads to misapprehension.

[10] On the axes of the greatest elevations and of the volcanoes in the tropical zone of Mexico, see above pp. 279 and 319. Compare also *Essai Pol. sur la Nouv.-Esp.* t. i, pp. 257—268, t. ii, p. 173; *Views of Nature,* p. 37.

The conformation here described of a considerable portion of the surface of the earth, which only began to be established by careful measurements since the year 1803, must not be confounded with those swellings of the soil which are met with enclosed between two mountain-chains which bound them as it were like walls, as in Bolivia at the Lake of Titicaca, and in Central Asia, between the Himalaya and Kuen-lün. The former of these, the South American elevation, which at the same time forms the bottom of a valley, is on an average according to Pentland, 12,847 feet above the level of the sea,—the latter, or Thibetian, according to Captain Henry Strachey, Joseph Hooker, and Thomas Thomson, is upwards of 14,996. The wish expressed by me half a century since in my circumstantial "*Analyse de l'Atlas Géographique et Physique du Royaume de la Nouvelle-Espagne* (§ xiv), that my profile of the elevated plain between Mexico and Guanaxuato might be continued by measurements over Durango and Chihuahua as far as Santa Fé del Nuevo Mexico, is now completely realized. The length of way, reckoning only one-fourth for the inflections, amounts to far more than 1200 geographical miles, and the characteristic feature of this so long unobserved configuration of the earth (the soft undulation of the swelling, and its breadth in a transverse section, amounting sometimes to 240 or 280 geographical miles) is manifested by the fact that the distance (from Mexico to Santa Fé), comprising a difference of parallels of fully 16° 20′ about the same as that from Stockholm to Florence, is travelled over in four-wheeled carriages, on the ridge of the table-land, without the advantage of artificially prepared roads. The possibility of such a medium of intercourse was known to the Spaniards so early as the end of the 16th century, when the Viceroy, the Conde de Monterey,[11] planned the first settlements from Zacatecas.

In confirmation of what has been stated in a general way

[11] By Juan de Oñate, 1594. *Memoir of a Tour to Northern Mexico in 1846 and 1847* by Dr. Wislizenus. On the influence of the configuration of the soil (the wonderful extent of the table-land) on the internal commerce and the intercourse of the tropical zone with the north, when once civic order, legal freedom and industry increase in these parts, see *Essai Pol.*, t. iv., p. 38, and Dana, p. 612.

respecting the relative heights between the capital of Mexico and Sante Fé del Nuevo Mexico, I here insert the chief elements of the barometrical levellings, which have been completed from 1803 to 1847. I take them in the direction from north to south, so that the most northerly, placed at the top of the list, may correspond more readily with the bearings of our charts :[12]

[12] In this survey of the elevations of the soil between Mexico and Sante Fé del Nuevo Mexico, as well as in the similar, but more imperfect table which I have given in the *Views of Nature*, p. 208, the letters Ws, Bt, and Ht, attached to the numerals, denote the names of the observer. Thus, Ws stands for Dr. Wislizenus, editor of the very instructive and scientific *Memoir of a Tour to Northern Mexico*, connected with Col. Doniphan's Expedition, in 1846 and 1847 (Washington, 1848), Bt the Chief Counsellor of Mines, Burkart, and Ht for myself. At the time when I was occupied from March 1803 to February 1804 with the astronomical determinations of places in the tropical part of New Spain, and ventured, from the materials I could discover and examine, to design a map of that country, of which my respected friend, Thomas Jefferson, then President of the United States, during my residence in Washington, caused a copy to be made, there existed as yet in the interior of the country on the road to Santa Fé, no determinations of latitude north of Durango (lat. 24° 25′). According to the two manuscript journals of the engineers Rivera, Lafora and Mascaró, of the years 1724 and 1765, discovered by me in the archives of Mexico, and which contained directions of the compass and computed partial distances, a careful calculation showed for the important station of Santa Fé, according to Don Pedro de Rivera, lat. 36° 12′ and long. 105° 52′ 30″. (See my *Atlas Géogr. et Phys. du Mexique*, Tab. 6, and *Essai Pol.* t. i, pp. 75—82). I took the precaution in the analysis of my map, to note this result as a very uncertain one seeing that in the valuations of the distances as well as in the directions of the compass, uncorrected for the magnetic variation, and unaided by objects in treeless plains, destitute of human habitations, over an extent of more than 1200 geographical miles, all the errors cannot be compensated (t. i, pp. 127—131). It happens that the result here given, as compared with the most recent astronomical observations, turns out to be much more erroneous in the latitude than in the longitude,—being in the former about thirty-one and in the latter scarcely twenty-three minutes. I was likewise fortunate enough to determine, nearly correctly, the geographical position of the Lake Timpanogos, now generally called the Great Salt Lake, while the name of Timpanogos is now only applied to the river which falls into the little Utah-lake, a fresh water lake. In the language of the Utah Indians a river is called *og-wahbe*, and by contraction *ogo* alone; *timpan* means rock, so that Timpan-ogo signifies rock-river (Frémont, *Expl. Exped.* 1845, p. 273). Buschmann explains the word *timpa* as

Santa Fé del Nuevo Mexico (lat. 35° 41′), height 7047 feet, Ws.

Albuquerque[13] (lat. 35° 8′), height 4849 feet, Ws.

Paso del Norte[14] on the Rio Grande del Norte (lat. 29° 48′), height 3790 feet, Ws.

Chihuahua (lat. 28° 32′), 4638 feet, Ws.

Cosiquiriachi, 6273 feet, Ws.

Mapimi, in the Bolson de Mapimi (lat 25° 54′), 4782 feet, Ws.

Parras (lat. 25° 32′), 4986 feet, Ws.

Saltillo (lat. 25° 10′), 5240 feet, Ws.

Durango (lat. 24° 25′), 6849 feet, according to Oteiza.

Fresnillo (lat. 23° 10′), 7244 feet, Bt.

Zacatecas (lat. 22° 50′), 9012 feet, Bt.

San Luis Potosi (lat. 22° 8′), 6090 feet, Bt.

Aguas calientes (lat. 21° 53′), 6261 feet, Bt.

derived from the Mexican *tetl*, stone, while in *pa* he finds a substantive termination of the native North-Mexican languages; to *ogo* he attributes the general signification of water; see his work,—*Die Spuren der Aztekischen Sprache im nördlichen Mexico*, s. 354—356 and 351 Compare *Expedition to the Valley of the Great Salt Lake of Utah*, by Captain Howard Stansbury, 1852, p. 300, and Humboldt, *Views of Nature*, p. 206. My map gives to the *Montagnes de Sel gemme*, somewhat to the east of the Laguna de Timpanogos, lat. 40° 7′, long. 111° 48′ 30″; consequently my first conjecture differs 39 minutes in latitude, and 17 in longitude. The most recent determinations of the position of Santa Fé, the Capital of New Mexico, with which I am acquainted, are 1st, by Lieutenant Emory (1846) from numerous astronomical observations, lat. 35° 44′ 6″, and 2nd, by Gregg and Dr. Wislizenus (1848), perhaps in another locality, 35° 41′ 6″. The longitude, according to Emory, is 7^h 4′ 18″, in time from Greenwich, and therefore 106° 5′ in the equatorial circle; according to Wislizenus, 108° 22′ from Paris (*New Mexico and California*, by Emory, Docum. No. 41, p. 36; Wisl. p, 29). Most maps err in making the latitudes of places in the neighbourhood of Santa Fé too far to the north. The height of the city of Santa Fé above the level of the sea, according to Emory, is 6844, according to Wislizenus fully 7046 feet (mean measurement 6950); it therefore resembles that of the Splügen and Gotthard passes in the Swiss Alps.

[13] The latitude of Albuquerque is taken from the beautiful special map entitled, *Map of the Territory of New Mexico* by Kern, 1851. Its height, according to Emory (p. 166), is 4749 feet; according to Wislizenus (p. 122), 4858.

[14] For the latitude of the *Paso del Norte* compare Wisliz. p. 125 Met. Tables 8—12, Aug. 1846.

Lagos (lat. 21° 20′), 6376 feet, Bt.
Villa de Leon (lat. 21° 7′), 6134 feet, Bt.
Silao, 5911 feet, Bt.
Guanaxuato (lat. 21° 0′ 15″), 6836 feet, Ht.
Salamanca (lat. 20° 40°), 5762 feet, Ht.
Celaya (lat. 20° 38′), 6017 feet, Ht.
Queretaro (lat. 20° 36′ 39″), 6363 feet, Ht.
San Juan del Rio, in the State of Queretaro (lat. 20° 30′), 6490 feet, Ht.
Tula (lat. 19° 57′), 6733 feet, Ht.
Pachuca, 8140 feet, Ht.
Moran, near Real del Monte, 8511 feet, Ht.
Huehuetoca, at the northern extremity of the great plain of Mexico (lat. 19° 48′), 7533 feet, Ht.
Mexico (lat. 19° 25′ 45″), 7469 feet, Ht.
Toluca (lat. 19° 16′), 8825 feet, Ht.
Venta de Chalco, at the south-eastern extremity of the great plain of Puebla, 7712 feet, Ht.
San Francisco Ocotlan, at the western extremity of the great plain of Puebla, 7680 feet, Ht.
Cholula, at the foot of the ancient graduated Pyramid (lat. 19° 2′), 6906 feet, Ht.
La Puebla de los Angeles (lat. 19° 0′ 15″), 7201 feet, Ht.
(The village of las Vigas marks the eastern extremity of the elevated plain of Anahuac, lat. 19° 37′; the height of the village is 7814 feet, Ht).

Thus, though previous to the commencement of the 19th century not a single altitude had been barometrically taken in the whole of New Spain, the hypsometrical and in most cases also astronomical observations for thirty-two places in the direction from north to south, in a zone of nearly 16½° of latitude, between the town of Santa Fé and the capital of Mexico, have been accomplished. We thus see that the surface of the wide elevated plain of Mexico assumes an undulating form varying in the centre from 5850 to 7500 feet in height. The lowest portion of the road from Parras to Albuquerque is even 1066 feet higher than the highest point of Vesuvius.

The great, though gentle,[15] swelling of the soil, whose

[15] Compare Frémont, *Report of the Exploring Exped. in* 1842, p. 60; Dana, *Geology of the United States Expl. Exped.* pp. 611—613; and for

highest portion we have just surveyed, and which from south to north, from the tropical part to the parallels of 42° and 44°, so increases in extent from east to west that the Great Basin, westward of the great Salt Lake of the Mormons, has a diameter of upwards of 340 geographical miles, with a mean elevation of nearly 5800 feet, differs very considerably from the rampart-like mountain-chains by which it is surmounted. Our knowledge of this configuration is one of the chief poinits of Frémont's great hypsometrical investigations in the years 1842 and 1844. This swelling of the soil belongs to a different epoch from that late upheaval which we call mountain-chains and systems of varied direction. At the point where, about 32° lat., the mountain-mass of Chihuahua, according to the present settlement of the boundaries, enters the western territory of the United States (in the provinces taken from Mexico), it begins to bear the not very definite title of the Sierra Madre. A decided bifurcation,[16] however, occurs in the neighbourhood of Albuquerque, and at this bifurcation the western chain still maintains the general

South America, Alcide D'Orbigny, *Voy. dans l'Amérique mérid. Atlas,* pl. viii. *de Géologie spéciale,* fig. i.

[16] For this bifurcation and the correct denomination of the east and west chains see the large special map of the *Territory of New Mexico,* by Parke and Kern, 1851: Edwin Johnson's *Map of Railroads,* 1854; John Bartlett's *Map of the Boundary Commission,* 1854: *Explorations and Surveys from the Mississippi to the Pacific in* 1853 *and* 1854, vol. i, p. 15; and, above all, the admirable and comprehensive work of Jules Marcou, Geologist of the Southern Pacific R. R. Survey, under the command of Lieutenant Whipple, entitled *Résumé explicatif d'une Cartc géologique des Etats Unis et d'un Profil géologiquc allant de la vallée du Mississippi aux côtcs de l'Océan Pacifique,* pp. 113—116; also in the *Bulletin de la Société géologique de la France,* 2e Série, t. xii, p. 813. In the elongated valley closed by the Sierra Madre, or Rocky Mountains, lat. 35°—38½°, the separate groups of which the western chain of the Sierra Madre and the eastern chain of the Rocky Mountains (Sierra de Sandia) consist bear different names. To the first chain belong, reckoning from south to north, the Sierra de las Grullas, the S. de los Mimbres (Wislizenus, pp. 22 and 54), Mount Taylor (lat. 35° 15′), the S. de Jemez and the S. de San Juan; in the eastern chain the Moro Peaks, or Sierra de la Sangre de Cristo, are distinguished from the Spanish Peaks (lat. 37° 32′) and the north westerly tending White Mountains, which close the elongated valley of Taos and Santa Fé. Professor Julius Fröbel, whose examination of the volcanoes of Central America I have already noticed (*Cosmos,* above, p. 274), has with muuh

title of the Sierra Madre, while the eastern branch has received from lat. 36° 10′ forward (a little to the north of Santa Fé) from American and English travellers the equally ill-chosen, but now universally accepted title of the Rocky Mountains. The two chains form a lengthened valley, in which Albuquerque, Santa Fé and Taos lie, and through which the Rio Grande del Norte flows. In lat. 38½° this valley is closed by a chain running east and west for the space of 88 geographical miles, while the rocky mountains extend undivided in a meridional direction as far as lat. 41°. In this intermediate space rise somewhat to the east the Spanish Peaks, Pike's Peak (5800 feet), which has been

ability elucidated the indefinite geographical appellation of Sierra Madre on the older maps, but he has at the same time, in a treatise entitled *Remarks contributing to the Physical Geography of the North American Continent* (9th *Annual Report of the Smithsonian Institution*, 1855, pp. 272—281), given expression to a conjecture which, after having examined all the materials within my reach, I am unable to assent to, namely, that the Rocky Mountains are not to be regarded as a continuation of the Mexican Mountain range in the tropical zone of Anahuac. Uninterrupted mountain chains, like those of the Apennines, the Swiss Jura, the Pyrenees, and a great part of the German Alps, certainly do not exist from the 19th to the 44th degrees of latitude. from Popocatepetl in Anahuac as far as to the north of Frémont's Peak in the Rocky Mountains, in the direction from SS.E. to NN.W., but the immense swelling of the surface of the land which goes on increasing in breadth towards the north and north-west, is continuous from tropical Mexico to Oregon, and on this swelling (or elevated plain), which is itself the great geognostic phenomenon, separate groups of mountains, running in often varying directions, rise over fissures which have been formed more recently and at different periods. These *superimposed* groups of mountains, which, however, in the Rocky Mountains are for an extent of 8 degrees of latitude connected together almost like a rampart, and rendered visible to a great distance by conical mountains, chiefly trachytic, from 10,000 to 12,000 feet high, produce an impression on the mind of the traveller which is only the more profound from the circumstance that the elevated plateau which stretches far and wide around him assumes in his eyes the appearance of a plain of the level country. Though in reference to the Cordilleras of South America, a considerable part of which is known to me by personal inspection, we speak of double and triple ranges (in fact the Spanish expression las Cordilleras de los Andes refers to such a disposition and partition of the chain), we must not forget that even here the directions of the separate ranges of mountain groups, whether in long ridges or in consecutive domes, are by no means parallel, either to one another, or to the direction of the entire swell of the land.

beautifully delineated by Frémont, James' Peak (11,434 feet), and the three Park Mountains, all of which enclose three deep valleys, the lateral walls of which rise up, along with the eastern Long's Peak, or Big Horn, to a height of 9060 and 11,191 feet.[17] On the eastern boundary, between Middle and North Park, the mountain chain all at once changes its direction and runs from lat. $40\frac{1}{4}°$ to 44° for a distance of about 260 geographical miles from south-east to north-west. In this intermediate space lie the south Pass (7490 feet), and the famous Wind River Mountains, so singularly sharp pointed, together with Frémont's Peak (lat. 43° 8′), which reaches the height of 13,567 feet. In the parallel of 44,° in the neighbourhood of the Three Tetons, where the north-westerly direction ceases, the meridian direction of the Rocky Mountains begins again, and continues about as far as Lewis and Clarke's Pass, which lies in lat. 47° 2′ and long. 112° 9′ 30.″ Even at this point, the chain of the Rocky Mountains maintains a considerable height (5977 feet), but from the many deep river-beds in the direction of Flathead River (Clarke's Fork), it soon

[17] Frémont, *Explor. Exped.* pp. 281—288. Pike's Peak, lat. 38° 50′, delineated, at p. 114; Long's Peak, 40° 15′; ascent of Frémont's Peak (13,570 feet) p. 70. The Wind River Mountains take their name from the source of a tributary to the Big Horn River, whose waters unite with those of the Yellow Stone River, which falls into the Upper Missouri (lat. 47° 58′, long. 103° 6′ 30″). See the delineations of the Alpine range, rich in mica-slate and granite, pp. 66 and 70. I have in all cases retained the English names given by the North American Geographers, as their translation into a pure German nomenclature has often proved a rich source of confusion. To help the comparison of the direction and length of the meridian-chain of the Ural, which, according to the careful investigations of my friend and travelling companion, Colonel Ernst Hofmann, takes a curve at the northern extremity towards the east, and which, from the Truchmenian Mountain Airuk-Tagh ($48\frac{3}{4}°$) to the Sablja Mountains (65°), is fully 1020 geographical miles in length, with those of the Rocky Mountains, I would here remind the reader that the latter chain runs, between the parallels of Pike's Peak and Lewis and Clarke's Pass, from 105° 9′ 30″ into 112° 9′ 30″ of longitude. The chain of the Ural which, within the same space of 17 degrees of latitude, deviates little from the meridian of 59° 0′ 30″, likewise changes its direction under the parallel of 65°, and attains, under lat, $67\frac{1}{2}°$ the meridian of 66° 5′ 30″. Compare Ernst Hofmann, *der nördliche Ural und das Küstengebirge Pac-Choi*, 1856, s. 191 and 297—305, with Humboldt, *Asie centrale* (1843) t. i. p. 447.

decreases to a more regular level. Clarke's Fork and Lewis or Snake River unite in forming the great Columbia River, which will one day prove an important channel for commerce. (*Explorations for a railroad from the Mississippi River to the Pacific Ocean, made in* 1853—1854, vol. i, p. 107.)

As in Bolivia, the eastern chain of the Andes furthest removed from the sea, that of Sorata (21,287 feet) and Illimani (21,148 feet), furnish no volcano now in a state of ignition, so also in the western parts of the United States, the volcanic action on the coast-chain of California and Oregon is at present very limited. The long chain of the Rocky Mountains, at a distance from the shores of the South Sea varying from 480 to 800 geographical miles, without any trace of still existing volcanic action, nevertheless shows, like the eastern chain of Bolivia in the vale of Yucay,[18] on both of its slopes volcanic rock, extinct craters, and even lavas inclosing obsidian, and beds of scoriæ. In the chain of the Rocky Mountains which we have here geographically described in accordance with the admirable observations of Frémont, Emory, Abbot, Wislizenus, Dana, and Jules Marcou, the latter, a distinguished geologist, reckons three groups of old volcanic rock on the two slopes. For the earliest notices of the vulcanicity of this district we are also indebted to the investigations made by Frémont since the years 1842 and 1843 (*Report of the Exploring Expedition to the Rocky Mountains in* 1842, *and to Oregon and North California in* 1843–44, pp. 164, 184–187, and 193).

On the eastern slope of the Rocky Mountains, on the south-western road from Bent's Fort, on the Arkansas River to Santa Fé del Nuevo Mexico, lie two extinct volcanoes, the Raton Mountains[19] with Fisher's Peak, and the hill of El Cerrito between Galisteo and Pera Blanca. The lavas of the former cover the whole district between the Upper Arkansas and the Canadian River. The Peperino and the volcanic scoriæ, which are first met with even in the prairies, on

[18] See above p. 295.

[19] According to the road-map of 1855, attached to the general report of the Secretary of State, Jefferson Davis, the Raton Pass rises to an elevation of as much as 7180 feet above the level of the sea. Compare, also, Marcou, *Résumé explicatif d'une Carte Géol.*, 1855, p. 113.

approaching the Rocky Mountains from the east, belong perhaps to old eruptions of the Cerrito, or of the stupendous Spanish Peaks (37° 32′). This easterly volcanic district of the isolated Raton Mountains forms an area of 80 geographical miles in diameter; its centre lies nearly in latitude 36° 50′.

On the western slope most unmistakeable evidences of ancient volcanic action are discernible over a wider space, which has been traversed by the important expedition of Lieutenant Whipple throughout its whole breadth from east to west. This variously shaped district, though interrupted for fully 120 geographical miles to the north of the Sierra de Mogoyon, is comprised (always on the authority of Marcou's geological chart) between latitude 33° 48′ and 35° 40′, so that instances of eruption occur further south than those of the Raton Mountains. Its centre falls nearly in the parallel of Albuquerque. The area here designated divides into two sections, that of the crest of the Rocky Mountains nearer Mount Taylor, which terminates at the Sierra de Zuñi,[20] and the western section, called the Sierra de San Francisco. The conical mountain of Mount Taylor, 12,256 feet high, is surrounded by radiating lava-streams, which, like Malpays still destitute of all vegetation, covered over with scoriæ and pumice-stone, wind along to a distance of several miles, precisely as in the district around Hecla. About 72 geographical miles to the west of the present Pueblo de Zuñi rises the lofty volcanic mountain of San Francisco itself. It has a peak which has been calculated at more than 16,000 feet high, and stretches away southward from the Rio Colorado Chiquito, where, farther to the west, the

[20] We must be careful to distinguish, to the west of the mountain-ridge of Zuñi, where the Paso de Zuñi attains an elevation of as much as 7943 feet, between Zuñi viejo, the old dilapidated town delineated by Möllhausen on Whipple's expedition, and the still inhabited Pueblo de Zuñi. Forty geographical miles north of the latter, near Fort Defiance, there still exists a very small and isolated volcanic district. Between the village of Zuñi and the descent to the Rio Colorado chiquito (Little Colorado) lies exposed the petrified forest which Möllhausen admirably delineated in 1853, and described in a treatise which he sent to the Geographical Society of Berlin. According to Marcou (*Résumé explic. d'une Carte Géol.*, p. 59), fossil trees and ferns are mingled with the silicified coniferæ.

Bill William Mountain, the Aztec Pass (6279 feet), and the Aquarius Mountains (8526 feet) follow. The volcanic rock does not terminate at the confluence of the Bill William Fork with the great Colorado, near the village of the Mohave Indians (lat. 34°, long. 114°), for, on the other side of the Rio Colorado at the Soda Lake, several extinct, but still open craters of eruption, may be recognized.[21]

Thus we find here in the present New Mexico, in the volcanic group commencing at the Sierra de San Francisco, and ending a little to the westward of the Rio Colorado Grande, or del Occidente (into which the Gila falls), over a distance of 180 geographical miles, the old volcanic district of the Auvergne and the Vivarais repeated, and a new and wide field opened up for geological investigation.

Likewise on the western slope, but 540 geographical miles more to the north, lies the third ancient volcanic group of the Rocky Mountains, that of Frémont's Peak, and the two triple-mountains, whose names, the Trois Tétons and the Three Buttes,[22] correspond well with their conical forms. The former lie more to the west than the latter, and consequently farther from the mountain chain. They exhibit wide-spread, black banks of lava, very much rent, and with a scorified surface.[23]

Parallel with the chain of the Rocky Mountains, sometimes single and sometimes double, run several ranges in which their northern portion from lat. 46° 12′, are still the seat of volcanic action. First, from San Diego to Monterey ($32\frac{1}{4}$° to $36\frac{3}{4}$°), there is the coast-range, specially so-called, a continuation of the ridge of land on the peninsula of Old, or Lower, California; then, for the most part 80 geographical

[21] All on the authority of the profiles of Marcou and the above-cited road-map of 1855.

[22] The French appellations, introduced by the Canadian fur-hunters, are generally used in the country and on English maps. According to the most recent calculations, the relative positions of the extinct volcanoes are as follows:—Frémont's Peak, lat. 43° 5′, long. 110° 9′ 30″; Trois Tétons, lat. 43° 38′, long. 110° 49′ 30″; Three Buttes, lat. 43° 20′, long. 112° 41′ 30″; Fort Hall, lat. 43° 0′, long. 111° 24′ 30″.

[23] Lieut. Mullan, on Volcanic Formation, in the *Reports of Explor. and Surveys*, vol. i (1855), pp. 330 and 348; see also Lambert's and Tinkham's Reports on the Three Buttes, *ibid.* pp. 167 and 226—230, and Jules Marcou, p. 115.

miles distant from the shore of the South Sea, the Sierra Nevada (de Alta California) from 36° to $40\frac{3}{4}$°; then again, commencing from the lofty Shasty Mountains in the parallel of Trinidad Bay (lat. 41° 10′), the Cascade range, which contains the highest still ignited peak, and which, at a distance of 104 miles from the coast, extends from south to north far beyond the parallel of the Fuca Strait. Similar in their course to this latter chain (lat. 43°—46°), but 280 miles distant from the shore, are the Blue Mountains,[24] which rise in their centre to a height of from 7000 to 8000 feet. In the central portion of Old California, a little farther to the north, near the eastern coast or bay in the neighbourhood of the former Mission of San Ignacio, in about 28° north latitude, stands the extinct volcano, known as the "Volcanes de las Virgenes," which I have given on my chart of Mexico. This volcano had its last eruption in 1746; but we possess no reliable information either regarding it or any of the surrounding districts; (See Venegas, *Noticia de la California*, 1757, t. i, p. 27; and Duflot de Moras, *Exploration de l'Orégon et de la Californie*, 1844, t. i, pp. 218 and 239).

Ancient volcanic rock has already been found in the coast-range near the harbour of San Francisco, in the Monte del Diablo, which Dr. Trask investigated (3673 feet), and in the auriferous elongated valley of the Rio del Sacramento in a trachytic crater now fallen in, called the Sacramento Butt, which Dana has delineated. Farther to the north, the Shasty, or Tshashtl Mountains, contain basaltic lavas, obsidian, of which the natives make arrow-heads, and the talc-like serpentine which makes its appearance on many points of the earth's surface, and appears to be closely allied to the volcanic formations. But the true seat of the still existing igneous action is the Cascade Mountain range, in which, covered with eternal snow, several of the peaks rise to the height of 16,000 feet. I shall here give a list of these, proceeding from south to north. The now ignited, and more or less active volcanoes, will be (on the plan heretofore adopted)

[24] Dana, p. 616—620; Blue Mountains, p. 649—651; Sacramento Butt, p. 630—643; Shasty Mountains, p. 614; Cascade range. On the Monte Diablo range, perforated by volcanic rock, see also John Trask, on the *Geology of the Coast Mountains and the Sierra Nevada*, 1854, pp. 13—18.

(see above, p. 61, note 71) distinguished by a star. The high conical mountains not so distinguished, are probably partly extinct volcanoes, and partly unopened trachytic domes.

Mount Pitt, or M'Laughlin ; lat. 42° 30′, a little to the west of Lake Tlamat ; height 9548 feet.

Mount Jefferson, or Vancouver (lat. 44° 35′), a conical mountain.

Mount Hood (lat. 45° 10′), decidedly an extinct volcano, covered with cellular lava. According to Dana this mountain, as well as Mount St. Helen's, which lies more northerly in the volcano range, is between 15,000 and 16,000 feet high, though somewhat lower[25] than the latter. Mount Hood was ascended in August, 1853, by Lake, Travaillot, and Heller.

Mount Swalahos, or Saddle Hill, S.S.E. of Astoria[26], with a fallen in, extinct crater.

Mount St. Helen's,* north of the Columbia river (lat. 46° 12′). According to Dana, not less than 15,000 feet high[27]. Still burning and always smoking from the summit-crater. A volcano of very beautiful, regular, conical form and covered with perpetual snow. There was a great eruption on the 23rd November, 1842 ; which, according to Frémont, covered everything to a great distance round with ashes and pumice.

Mount Adams (lat. 46° 18′), almost exactly east of the volcano of St. Helen's, more than 112 geographical miles distant from the coast, if it be true that the last-named and still active mountain, is only 76 of those miles inland.

[25] Dana (pp. 615 and 640) estimated the volcano of St. Helen's at 16,000 feet, and Mount Hood of course under that height, while according to others Mount Hood is said to attain the great height of 18,316 feet, which is 2521 feet higher than the summit of Mont Blanc, and 4730 feet higher than Frémont's Peak in the Rocky Mountains. According to this estimate, (Langrebe, *Naturgeschichte der Vulkane*, Bd. i, s. 497), Mount Hood would be only 571 feet lower than the volcano Cotopaxi ; on the other hand Mount Hood, according to Dana, exceeds the highest summit of the Rocky Mountains by 2586 feet at the utmost. I am always desirous of drawing attention to *variantes lectiones* such as these.

[26] Dana, *Geol. of the U.S. Expl. Exped.*, pp. 640 and 643—645.

[27] Variously estimated previously at 10,178 feet by Wilkes, and 13,535 feet by Simpson.

Mount Regnier,* also written Mount Rainier (lat. 46° 48′) E S.E. of Fort Nisqually, on Puget's Sound, which is connected with the Fuca Strait. A burning volcano; according to Edwin Johnson's road-map of 1854, 12,330 feet high. It experienced severe eruptions in 1841 and 1843.

Mount Olympus (lat. 47° 50′). Only 24 geographical miles south of the strait of San Juan de Fuca, long so famous in the history of the South Sea discoveries.

Mount Baker,* a large and still active volcano, situated in the territory of Washington (lat. 48° 48′), of great (unmeasured?) height (not yet determined), and regular conical form.

Mount Brown (16,000 feet?) and, a little more to the east, Mount Hooker (16,750 feet?), are cited by Johnson as lofty, old-volcanic trachytic mountains, under lat. 52¼°, and long. 117° 40′ and 119° 40′. They are therefore remarkable as being more than 300 geographical miles distant from the coast.

Mount Edgecombe,* on the small Lazarus Island, near Sitka (lat. 57° 3′). Its violent igneous eruption in 1796, has already been mentioned by me (see above, p. 269). Captain Lisiansky, who ascended it in the first years of the present century, found the volcano then unignited. Its height[28] reaches, according to Ernst Hofmann, 3039 feet, according to Lisiansky, 2801 feet. Near it are hot springs which issue from granite, as on the road from the Valles de Aragua to Portocabello.

Mount Fairweather, or Cerro de Buen Tiempo; according to Malaspina, 4489 mètres, or 14,710 feet high[29]. In lat. 58° 45′. Covered with pumice-stone, and probably ignited up to a short time back, like Mount Elias.

The volcano of Cook's Inlet (lat. 60° 8′). According to Admiral Wrangel 12,065 feet high, and considered by that intelligent mariner, as well as by Vancouver, to be an active volcano[30].

[28] Karsten's *Archiv. für Mineralogie*, Bd. i, 1829, s. 243.

[29] Humboldt, *Essai Polit. sur la Nouv. Esp.*, t. i, p. 266. tom. ii, p. 310.

[30] According to a manuscript which I was permitted to examine in the year 1803, in the Archives of Mexico, the whole coast of Nutka, as far as what was afterwards called "Cook's Inlet," was visited during the expedition of Juan Perez, and Estevan José Martinez, in the year 1774.

Mount Elias, lat. 60° 17′; long. 136° 10 30″. According to Malaspina's manuscripts, which I found in the Archives of Mexico, 5441 mètres, or 17,854 feet. According to Captain Denham's chart, from 1853 to 1856, the height is only 14,970 feet.

What M'Clure, in his account of the North-West Passage, calls the Volcano of Franklin's Bay (lat. 69° 57′; long 127°) eastward of the mouth of the Mackenzie river, seems to be a kind of *earth-fire*, or salses, throwing out hot, sulphurous vapours. An eye-witness, the Missionary Miertsching, interpreter to the expedition on board the ship "Investigator," found from thirty to forty columns of smoke rising from fissures in the earth, or from small conical mounds of clays of various colours. The sulphurous odour was so strong that it was scarcely possible to approach the columns of smoke within a distance of twelve paces. No rock or other solid masses could be discovered in the immediate vicinity. Lights were seen from the ship at night, no ejections of mud, but great heat of the bed of the sea, and small pools of water containing sulphuric acid were observed. The district merits a careful investigation, and the phenomenon stands quite unconnected there, like the volcanic action of the Cerro de Buen Tiempo, or of Mount Elias in the Californian Cascade range (M'Clure, *Discovery of the N.W. Passage*, p. 99; *Papers relative to the Arctic Expedition*, 1854, p. 34; Miertsching's *Reise-Tagebuch*; Gnadau, 1855, s. 46).

I have hitherto treated the volcanic vital activities of our planet in their intimate connections, as if forming an ascending scale of the great and mysterious phenomenon of a reaction of its fused interior upon its surface, clothed with animal and vegetable organisms. I have considered next in order to the almost purely dynamic effects of the *earthquake* (the wave of concussion) the *thermal springs and salses*, that is to say, phenomena produced, with or without spontaneous ignition, by the permanent elevation of temperature communicated to the water-springs and streams of gas, as well as by diversity of chemical mixture. The highest, and in its expressions, the most complicated grade of the scale, is presented by the volcanoes, which call into action the great and varied processes of crystalline rock-formation by the dry method, and which consequently do not simply reduce and destroy, but appear in the character of creative powers, and form the materials for new combinations. A considerable portion of very recent, if not of the most recent, mountain-strata, is the work of volcanic action, whether effected, as in the present day, by the pouring forth of molten masses at many points of the earth from peculiar conical, or dome-shaped elevated stages, or, as in the early years of our planet's existence, by the immediate issuing forth of basaltic and trachytic rock by the side of the sedimentary strata, from a net-work of open fissures, without the intervention of any such structures.

In the preceding pages I have most carefully endeavoured to determine the locality of the points at which a communication has long continued open between the fluid interior of the earth and the atmosphere. It now remains to sum up the number of these points, to separate out of the rich abundance of the volcanoes which have been active in very remote historical periods, those which are still ignited at the present day, and to consider these according to their division into Continental and Insular Volcanoes. If all those which, in this enumeration, I think I may venture to consider the lowest limit of the number, were simultaneously in action, their influence on the condition of the atmosphere, and its climatic, and especially its electric relations, would certainly be extremely perceptible ; but as the eruptions do not take place simultaneously, but at different times, their effect is diminished and is confined within very narrow and chiefly mere local limits. In great eruptions there occur around the crater, as a consequence of the exhalation, volcanic storms, which being accompanied by lightning and torrents of rain, often occasion great ravages ; but these atmospheric phenomena have no generally extended results. For that the remarkable obscurity (known by the name of the *dry fog*) which for the space of several months, from May to August of the year 1783, overspread a very considerable part of Europe and Asia, as well as the North of Africa—while the sky was seen pure and untroubled at the top of the lofty mountains of Switzerland—could have been occasioned by the unusual activity of the Icelandic volcanicity, and the earthquakes of Calabria, as is even now sometimes maintained, seems to me very improbable on account of the magnitude of the effect produced.* Yet a certain apparent influence of earthquakes, in cases where they occupy much space in changing the commencement of the rainy season, as in the highland of Quito and Riobamba (in February, 1797), or in the south-eastern countries of Europe and Asia Minor (in the Autumn of 1856), might indeed be viewed as the isolated influence of a volcanic eruption.

In the following table the first figures denote the number of the volcanoes cited in the preceding pages, while the second figures, inclosed in parentheses, denote the number of those which in recent times have given evidence of their igneous activity.

Number of Volcanoes on the Earth.

I	Europe (above, p. 349, 350)	7	(4)
II	Islands of the Atlantic Ocean (p. 351—354) ...	14	(8)
III	Africa (p. 354, 355)	3	(1)
IV	Asia—Continental	25	(15)
	(1) Western and Central (p. 356—362) ...	11	(6)
	(2) The Peninsula of Kamtschatka (p. 362—367)	14	(9)
V	Eastern Asiatic Islands (p. 367—377)	69	(54)
VI	South Asiatic Islands (p. 297—308, 377—382) ...	120	(56)
VII	Indian Ocean (p. 382—388, and note 79 at p. 385, 386)	9	(5)
VIII	South Sea (p. 388—401, notes 83—85 at p. 389—391)	40	(26)
IX	America—Continental	115	(53)
	(1) South America	56	(26)
	(*a*) Chili (p. 285, note 75 at p. 287—290) ...	24	(13)
	(*b*) Peru and Bolivia (p. 285—291, note 74 at p. 286, 287)	14	(3)
	(*c*) Quito and New Granada (p. 285, note 73 at p. 286)	18	(10)
	(2) Central America (p. 258, 268—279, 285, 328, notes 66—68 at p. 271—278)	29	(18)
	(3) Mexico, south of the Rio Gila (p. 279, 281, 285, 308—328, and notes 6—13 at p. 310—322, 401—429, notes 7—14 at p. 402—408)	6	(4)
	(4) North-Western America, north of the Gila (p. 409—419)	24	(5)
	The Antilles[31]	5	(3)
	Total	407	(225)

* [A similar fog overspread the Tyrol and Switzerland in 1755, just before the great earthquake which destroyed Lisbon. It appeared to be composed of earthy particles reduced to an extreme degree of fineness.]—Tr.

[31] In the Antilles the volcanic activity is confined to what are called the "Little Antilles," three or four still active volcanoes having

The result of this laborious work, on which I have long

broken out on a somewhat curvilinear fissure running from south to north, nearly parallel to the volcanic fissure of Central America. In the course of the considerations induced by the simultaneousness of the earthquakes in the valleys of the rivers Ohio, Mississippi, and Arkansas, with those of the Orinoco, and of the shore of Venezuela, I have already described the little sea of the Antilles, in its connection with the Gulf of Mexico and the great plain of Louisiana, between the Alleghanys and the Rocky Mountains, on geognostic views, as a single ancient basin (*Voyage aux Régions Equinoxiales*, t. ii, pp. 5 and 19; see also above, p. 6). This basin is intersected in its centre, between 18° and 22° lat. by a plutonic mountain-range from Cape Catoche of the peninsula of Yucatan to Tortola and Virgen gorda. Cuba, Haiti, and Porto Rico, form a range running from west to east, parallel with the granite and gneiss chain of Caraccas. On the other hand, the Little Antilles, which are for the most part volcanic, unite together the plutonic chain just alluded to (that of the Great Antilles) and that of the shore of Venezuela, closing the southern portion of the basin on the east. The still active volcanoes of the Little Antilles lie between the parallels of 13° to $16\frac{1}{2}$°, in the following order, reckoning from south to north :—

The volcano of the island of St. Vincent, stated sometimes at 3197 and sometimes at 5052 feet high. Since the eruption of 1718 all remained quiet, until an immense ejection of lava took place on the 27th April, 1812. The first commotions commenced as early as May, 1811, near the Crater, three months after the island of Sabrina in the Azores had risen from the sea. They began faintly in the mountain-valley of Caraccas, 3496 feet above the surface of the sea, in December of the same year. The complete destruction of the great city took place on the 26th March, 1812. As the earthquake which destroyed Cumana on the 14th December, 1796, was with justice ascribed to the eruption of the volcano of Guadaloupe (the end of September, 1796), in like manner the destruction of Caraccas appears to have been the effect of the reaction of a southerly volcano of the Antilles,—that of St. Vincent. The frightful subterranean noise, like the thundering of cannon, produced by a violent eruption of the latter volcano on the 30th April, 1812, was heard on the distant grass-plains (Llanos) of Calabozo, and on the shores of the Rio Apure, 192 geographical miles farther to the west than its junction with the Orinoco (*Humboldt, Voy.* t. ii, p. 14). The volcano of St. Vincent had thrown out no lava since 1718, but on the 30th April, a stream of lava flowed from the summit crater, and in four hours reached the sea shore. It was a very striking circumstance, and one which has been confirmed to me by very intelligent coasting mariners, that the noise was very much stronger on the open sea, far from the island, than near the shore.

The volcano of the island S. Lucia, commonly called only a solfatara, is scarcely 1200 to 1800 feet high. In the crater are several small basins periodically filled with boiling water. In the year 1766, an ejection of scoriæ and cinders is said to have been observed, which is been occupied, having in all cases consulted the original

certainly an unusual phenomenon in a solfatara, for although the careful investigations of James Forbes and Poulett Scrope, leave no room to doubt that an eruption took place from the Solfatara of Pozzuoli in the year 1198, yet one might be inclined to consider that event as a collateral effect produced by the great neighbouring volcano, Vesuvius (See Forbes in the *Edinb. Journal of Science*, vol. i, p. 128, and Poulett Scrope in the *Transact.* of the Geol. Soc. 2nd Ser. vol. ii, p. 346). Lancerote, Hawaii and the Sunda Islands furnish us with analogous examples of eruptions at exceedingly great distances from the summit craters, the peculiar seat of action. It is true the solfatara of Pozzuoli was not disturbed on the occasion of great eruptions of Vesuvius in the years 1794, 1822, 1850 and 1855, (Julius Schmidt, *Ueber die Eruption des Vesuvs. in Mai*, 1855, p. 156), though Strabo (lib. v, p. 245), long before the eruption of Vesuvius, speaks of fire, somewhat vaguely it is true, in the scorched plains of Dicäarchia, near Cumœa and Phlegra. Dicäarchia in Hannibal's time received the name of Puteoli from the Romans who colonised it. "Some are of opinion," continues Strabo, "on account of the bad smell of the water that the whole of that district as far as Baiæ and Cumœa is so called, because it is full of sulphur, fire and warm water. Some think that on this account Cumœa (Cumanus ager) is called also Phlegra . . . ." and then again Strabo mentions discharges of fire and water, "προχοὰς τοῦ πυρὸς καὶ τοῦ ὕδατος)."

The recent volcanic action of the island of Martinique in the Montagne Pelée (according to Dupuget, 4706 feet high), the Vauclin and the Pitons du Carbet is still more doubtful. The great eruption of vapour on the 22nd January, 1792, described by Chisholm, and the shower of ashes of the 5th August, 1851, deserve to be more thoroughly inquired into.

The Soufrière de la Guadeloupe, according to the older measurements of Amic and Le Boucher, 5435 and 5109 feet high, but according to the latest and very correct calculations of Charles Sainte-Claire Deville, only 4867 feet high, exhibited itself on the 28th September, 1797, 78 days before the great earthquake and the destruction of the town of Cumana, as a volcano ejecting pumice (Rapport fait au Général Victor Hugues par Amic et Hapel sur le Volcan de la Basse Terre, dans la nuit du 7 au 8 Vendimiaire, an 6, pag. 46; Humboldt, *Voyage*, t. i, p. 316). The lower part of the mountain is dioritic rock, the volcanic cone, the summit of which is open, is trachyte, containing labradorite. Lava does not appear even to have flowed in streams from the mountain called on account of its usual condition, the *Soufrière*, either from the summit crater, or from the lateral fissures, but the ashes of the eruptions of Sept. 1797, Dec. 1836, and Feb. 1837, examined by the excellent and much lamented Dufrénoy, with his peculiar accuracy, were found to be finely pulverised fragments of lava, in which felspathic minerals (labradorite, rhyakolite and sanidine) were recognisable together with pyroxene. (See Lherminier, Daver, Elie de Beaumont and Dufrénoy, in the *Comptes rendus de l'Acad. des Sc.* t. iv, 1837, pp. 294; 651 and 743—749). Small fragments of quartz have also sources of information (the geological and geographical

been recognised by Deville in the trachytes of the soufrière, together with the crystals of labradorite (*Comptes rendus*, t. xxxii, p. 675), while Gustav Rose even found hexagonal-dodecahedra of quartz in the trachytes of the volcano of Arequipa (Meyen, *Reise um die Erde*, Bd. ii, s. 23).

The phenomena here described, of the temporary ejection of very various mineral productions from the fissure-openings of a soufrière, remind us very forcibly that what we are accustomed to denominate a solfatara, soufrière or fumarole, denotes properly speaking only certain conditions of volcanic action. Volcanoes which have once emitted lava; or, when that failed, have ejected loose scoriæ of considerable volume, or finally the same scoriæ pulverised by trituration, pass on a diminution of their activity, into a state in which they yield only sulphur sublimates of sulphurous acid and aqueous vapour. If as such we were to call them semi-volcanoes, it would readily convey the idea that they are a peculiar class of volcanoes. Bunsen, to whom along with Boussingault, Senarmont, Charles Deville and Danbrée science is indebted for such important advances for their ingenious and happy application of chemistry to geology, and especially to the volcanic processes, shows "how, when in sulphur sublimations, which almost always accompany volcanic eruptions, the masses of sulphur in the form of vapour come in contact with the glowing pyroxene rocks, the sulphurous acid is generated by the partial decomposition of the oxyde of iron contained in those rocks. If the volcanic action then sinks to a lower temperature, the chemical action of that zone then enters into a new phase. The sulphurous combinations of iron and perhaps of metals of the earths and alkalies there produced, commence their operation on the aqueous vapour, and the result of the alternate action is the generation of sulphuretted hydrogen and the products of its decomposition, disengaged hydrogen and sulphur vapour."—The sulphur fumaroles outlive the great volcanic eruptions for centuries. The muriatic acid fumaroles belong to a different and later period. They seldom assume the character of permanent phenomena. The muriatic acid in the gases of craters is generated in this way; the common salt which so often occurs as a product of sublimation in volcanoes, particularly in Vesuvius, is decomposed in higher temperatures, under the co-operation of aqueous vapour and silicates, and forms muriatic acid and soda, the latter combining with the silicates present. Muriatic acid fumaroles which, in Italian volcanoes, are not unfrequently on the most extensive scale, and are then generally accompanied by immense sublimations of common salt, seem to be of a very unimportant character in Iceland. The concluding stages in the chronological series of all these phenomena consist in mere emanations of carbonic acid. The hydrogen contained in the volcanic gases has hitherto been almost entirely overlooked. It is present in the vapour-springs of the great solfataras of Krisuvik and Reykjalidh in Iceland, and is indeed at both those places combined with sulphuretted hydrogen. When the latter come in contact with sulphuric acid, they are both mutually decomposed by the separation of the sulphur, so that accounts of travels), is that, out of 407 volcanoes cited by

they can never occur together. They are however not unfrequently met with on one and the same field of fumaroles in close proximity to each other. Unrecognisable as was the sulphuretted hydrogen gas in the Icelandic solfataras just mentioned, it failed on the other hand entirely in the solfataric condition assumed by the crater of Hecla shortly after the eruption of the year 1845,—that is to say, in the first phase of the volcanic secondary action. Not the smallest trace of sulphuretted hydrogen could be detected, either by the smell or by re-agents, while the copious sublimation of sulphur, the smell of which extended to a great distance, afforded indisputable evidence of the presence of sulphurous acid. In fact, on the approach of a lighted cigar to one of these fumaroles those thick clouds of smoke were produced which Melloni and Piria have noticed as a test of the smallest trace of sulphuretted hydrogen (*Comptes rendus*, t. xi, 1840, p. 352, and Poggendorff's *Annalen*, Ergänzungsband, 1842, s. 511). As it may however be easily seen by experiment that even sulphur itself, when sublimated with aqueous vapour, produces the same phenomenon, it remains doubtful whether any trace whatever of sulphuretted hydrogen accompanied the emanations from the crater of Hecla in 1845, and of Vesuvius in 1843 (compare Robert Bunsen's admirable and geologically important treatise on the processes of formation of the volcanic rock of Iceland, in Poggend. *Annal.* Bd. lxxxiii, 1851. s. 241, 244, 246, 248, 254 and 256; serving as an extension and rectification of the treatises of 1847 in Wöhler's and Liebig's *Annalen der Chemie und Pharmacie*, Bd. lxii, s. 19). That the emanations from the solfatara of Pozzuoli are not sulphuretted hydrogen, and that no sulphur is deposited from them by contact with the atmosphere, as Breislak has conjectured (*Essai Minéralogique sur la Soufrière de Pozzuoli*, 1792, p. 128—130), was remarked by Gay-Lussac when I visited the Phlegræan Fields with him at the time of the great eruption of lava in the year 1805. That acute observer, Archangelo Scacchi likewise decidedly denies the existence of sulphuretted hydrogen (*Memorie geologiche sulla Campania*, 1849, p. 49—121), Piria's test seeming to him only to prove the presence of aqueous vapour; — "Son di avviso che lo solfo emane mescolato a i vapori acquei senza essere in chimica combinazione con altre sostanze,"—"I am of opinion that the sulphur emanates mixed with aqueous vapours without being in combination with other substances." An actual analysis, however, long looked for by me, of the gases ejected by the solfatara of Pozzuoli, has been very recently published by Charles Sainte-Claire Deville and Leblanc, and has completely established the absence of sulphuretted hydrogen (*Comptes rendus de l'Acad. d. Sc.* t. xliii, 1856, p. 746). Sartorius von Waltershausen, on the other hand, observed on cones of eruption of Etna, in 1811, a strong smell of sulphuretted hydrogen, where in other years sulphurous acid only was perceived. Nor did Charles Deville discover any sulphuretted hydrogen at Girgenti, or in the Macalube, but a small portion of it on the eastern declivity of Etna, in the spring of Santa Venerina. It is remarkable, that throughout the important series of me, 225 have exhibited proofs of activity in modern times. Previous statements of the number[32] of active volcanoes have given sometimes about 30 and sometimes about 50 less, because they were prepared on different principles. In the division made by me, I have confined myself to those volcanoes which still emit vapours, or which have had historically certain eruptions in the 19th or in the latter half of the 18th century. There are doubtless instances of the intermission of eruptions which extend over four centuries and more, but these phenomena are of very rare occurrence. We are acquainted with the lengthened series of the eruptions of Vesuvius in the years 79, 203, 512, 652, 983, 1138, and 1500. Previous to the great eruption of Epomeo on Ischia in the year 1302, we are acquainted only with those which occurred in the 36th and 45th years before our era, that is to say, 55 years before the eruption of Vesuvius.

Strabo, who died at the age of 90 under Tiberius (99 years after the occupation of Vesuvius by Spartacus), and whom no historical account of any former eruption had ever reached, describes Vesuvius notwithstanding as an ancient and long extinct volcano. "Above the places" (Herculaneum and Pompeii), he says, "lies the Mount Vesuios, covered round by the most beautiful farms, except on the summit. This is indeed for the most part pretty smooth, but on the whole

chemical analyses made by Boussingault on gas-exhaling volcanoes of the Andes (from Puracé and Tolima to the elevated plains of las Pastos and Quito), both muriatic acid and sulphuretted hydrogen (hydrogène sulfureux) are wanting.

[32] The following numbers are given in older works as those of the volcanoes still in a state of activity:—by Werner, 193; by Cæsar von Leonhard, 187; by Arago, 175 (*Astronomie Populaire,* t. iii, p. 170); variations which, as compared with my results, all show a difference ranging from $\frac{1}{8}$ to $\frac{1}{45}$ in a downward direction, occasioned partly by diversity of principle in judging of the igneous state of a volcano, and partly by a deficiency of materials for forming a correct judgment. It is well known, as I have previously remarked, and as we learn from historical experience, that volcanoes which have been held to be extinct have, after the lapse of very long periods, again become active, and therefore the result which I have obtained must be considered as rather too low than too high. Leopold von Buch, in the supplement to his masterly description of the Canary Isles, and Landgrebe, in his Geography of Volcanoes, have not attempted to give any general numerical result.

unfruitful, and having an ashy appearance. It exhibits fissured hollows of red-coloured rock, as if it were corroded by fire, so that it might be supposed that this place had formerly burned and had gulphs of fire, which, however, had died away when the fuel became consumed." (Strabo, lib. v. page 247, Casaub.) This description of the primitive form of Vesuvius indicates neither a cone of cinders nor a crater-like hollowing[33] of the ancient summit, such as, being walled in, could have served Spartacus[34] and his gladiators for a defensive stronghold.

[33] This description is therefore totally at variance with the often repeated representation of Vesuvius, according to Strabo, given in Poggendorff's *Annalen der Physik*, Bd. xxxvii, s. 190, Tafel 1. It is a very late writer, Dio Cassius, under Septimius Severus, who first speaks, not (as is frequently supposed) of the production of several summits, but of the changes of form which the summits have undergone in the course of time. He records (quite in confirmation of Strabo) that the mountain formerly had everywhere a flat summit. His words are as follows (lib. lxvi, cap. 21, ed. Sturz, vol. iv, 1824, p. 240):—"For Vesuvius is situated by the sea near Naples, and has numerous sources of fire. The whole mountain was formerly of uniform height, and the fire arose from its centre, for at this part only is it in a state of combustion. Outwardly, however, the whole of it is still down to our times devoid of fire. But, while the exterior is always without conflagration, and the centre is dried up (heated) and converted into cinders, the peaks round about it have still their ancient height. But the whole of the igneous part, being consumed by length of time, has become hollow by sinking in, so that the whole mountain (if we may compare a small thing with a great) resembles an amphitheatre." (*Comp. Sturz*, vol. vi, *Annot*, ii, p. 568). This is a clear description of those mountain-masses which, since the year 79, have formed the margins of the crater. The explanation of this passage, by referring it to the Atrio del Cavallo, appears to me erroneous. According to the large and excellent hypsometrical work of that distinguished Olmutz astronomer, Julius Schmidt, for the year 1855, the Punta Nasone of the Somma is 3771 feet, the Atrio del Cavallo, at the foot of the Punta Nasone, 2661, and the Punta or Rocca del Palo (the highest edge of the crater of Vesuvius to the north, pp. 112—116) 3992 feet high. My barometrical measurements of 1822 (*Views of Nature*, pp. 376—377) gave for the same three points 3747 feet, 2577 feet, and 4022 feet—showing a difference of 24, 84, and 30 feet respectively. The floor of the Atrio del Cavallo has, according to Julius Schmidt (*Eruption des Vesuvs im Mai* 1855, p. 95), undergone great alterations of level since the eruption of Feb. 1850.

[34] Velleius Paterculus, who died under Tiberius, mentions Vesuvius, it is true, as the mountain which Spartacus occupied with his gladiators (ii. 30), while Plutarch, in his *Biography of Crassus*, cap. ii, speaks only

Diodorus Siculus, likewise (lib. iv. cap. 21, 5), who lived under Cæsar and Augustus, in his account of the progress of Hercules and his battles with the giants in the Phlegræan Fields, describes "what is now called Vesuvius as a λόφος, which, like Etna in Sicily, once emitted a great deal of fire, and (still) shows traces of its former ignition." He calls the whole space between Cumæ and Naples the Phlegræan Fields, as Polybius does the still greater space between Capua and Nola (lib. ii, cap. 17), while Strabo (lib. v, page 246) describes with much local truth the neighbourhood of Puteoli (Dicæarchia), where the great Solfatara lies, and calls it Ἡφαίστου ἀγορά. In later times the name of τὰ φλεγραῖα πεδία is ordinarily confined to this district, as at this day geologists place the mineralogical composition of the lavas of the Phlegræan Fields in opposition to those from the neighbourhood of Vesuvius. The same opinion that in ancient times there was fire burning within Vesuvius, and that that mountain had formerly had eruptions, is most distinctly expressed in the architectural work of Vitruvius (lib. ii, cap. 6), in a passage which has hitherto not been sufficiently regarded:—"Non minus etiam memoratur, antiquitus crevisse ardores et abundavisse sub Vesuvio monte, et inde evomuisse circa agros flammam. Ideoque nunc qui spongia sive *pumex Pompejanus* vocatur, excoctus ex alio genere lapidis, in hanc redactus esse videtur generis qualitatem. Id autem genus spongiæ, quod inde eximitur, non in omnibus locis nascitur, nisi circum Ætnam, et collibus Mysiæ, qui à Græcis κατακεκαυμένοι nominantur." It is also related that in ancient times the fire increased and abounded beneath Mount Vesuvius, and vomited out flame from thence on the fields around. So that now what is called spongia, or Pompeian pumex, baked out of some other kind of stone, seems to have been reduced to this kind of snbstance. But that kind of spongia which is got out of there is not produced in all

of a rocky district, having a single narrow entrance. The servile war of Spartacus took place in the 681st year of Rome, or 152 years before the eruption of Vesuvius described by Pliny (24th August, 79, A.D.). The circumstance that Florus, a writer who lived in the time of Trajan, and who, being acquainted with the eruption just referred to, knew what was hidden in the interior of the mountain, calls it "cavus," proves nothing, as others have already observed, for its earlier configuration (*Florus*, lib. i, cap. 16, "Vesuvius mons, Ætnæi ignis imitator;" lib. iii, cap. 20, "fauces cavi montis)."

places, only around Ætna and on the hills of Mysia, which are called by the Greeks κατακεκαυμένοι.) Now, it can no longer be doubted, since the investigations of Böckh and Hirt, that Vitruvius lived in the time of Augustus,[35] and consequently a full century before the eruption of Vesuvius, at which the elder Pliny met his death. The passage thus quoted, therefore, and the expression *pumex Pompeianus* (thus connecting pumice-stone with Pompeii), present a special geological interest in relation to the question raised as to whether, according to the acute conjecture of Leopold von Buch,[36] Pompeii was overwhelmed only by the pumiceous tufa-beds thrown up on the first formation of Mount Somma; these beds, which are of submarine formation, covering in horizontal layers the whole level between the Apennine range and the west coast of Capua as far as Sorento, and from Nola to the other side of Naples,—or whether Vesuvius itself, entirely contrary to its present habit, ejected the pumice from its interior.

Both Carmine Lippi,[37] who (1816) describes the tufa covering of Pompeii as an aqueous deposit, and his ingenious opponent Archangelo Scacchi,[38] in the letter addressed to the Cavaliere Francesco Avellino (1843), have directed attention to the remarkable phenomenon that a portion of the pumice of Pompeii and Mount Somma contains small fragments of chalk which have not lost their carbonic acid, a circumstance which, on the supposition that they have been exposed to a great pressure during their igneous formation, can excite but little surprise. I have myself had the opportunity

[35] At all events Vitruvius wrote earlier than the elder Pliny, as is evident, not merely because he is three separate times cited by Pliny in his list of authorities, so unjustly attacked by the English translator Newton (lib. xvi, xxxv, and xxxvi), but because in book xxxv, cap. 14, s. 170—172, as has been distinctly proved by Sillig (vol. v, 1851, p. 277) and Brunn (*Diss. de auctorum indicibus Plinianis*, Bonnæ, 1856, pp. 55—60), a passage has actually been extracted from Vitruvius by Pliny himself. See also Sillig's edition of Pliny, vol. v, p. 272. Hirt, in his *Essay on the Pantheon*, places the date of Vitruvius's writings on Architecture between the years 16 and 14 of our era.

[36] Poggendorff's *Annalen*, Bd. xxxvii, s. 175—180.

[37] Carmine Lippi: *Fu il fuoco o l'acqua che sotterò Pompei ed Ercolano?* (1816) p. 10.

[38] Scacchi, *Osservazioni critiche sulla maniera come fu seppellita l'Antica Pompei*, 1843, pp. 8—10.

of seeing specimens of this pumice-stone in the interesting geological collections of my learned friend and academical colleague, Dr. Ewald. The similarity of the mineralogical constitution at two opposite points naturally gives rise to the question,—whether that which covers Pompeii has been thrown down, as Leopold von Buch supposes, during the eruption of the year 79, from the declivities of Somma,—or whether, as Scacchi maintains, the newly-opened crater of Vesuvius has ejected pumice simultaneously on Pompeii and on Somma? What was known as *pumex Pompejanus* in the time of Vitruvius, under Augustus ,carries us back to eruptions before the time of Pliny, and from the experience we have respecting the variable nature of the formations in different ages and different circumstances of volcanic activity, we should be as little warranted in absolutely denying that, since its first existence, Vesuvius could have ejected pumice, as we should be in absolutely taking it for granted that pumice—that is to say, the fibrous or porous condition of a pyrogenous mineral—could only be formed where obsidian or trachyte with vitreous felspar (sanidine) were present.

Although, from the examples which have been cited of the length of the periods at which the revival of a slumbering volcano may take place, it is evident that much uncertainty must still remain, yet it is of great importance to verify the geographical distribution of burning volcanoes for a determinate period. Of the 225 open craters through which, in the middle of the 19th century, the molten interior of the earth maintains a volcanic communication with the atmosphere, 70, that is to say, one-third, are situated on the continents, and 155, or two-thirds, on the islands of our globe. Of the 70 continental volcanoes, 53, or three-fourths, belong to America, 15 to Asia, 1 to Europe, and 1 or 2 to that portion of the continent of Africa hitherto known to us. In the South-Asiatic islands (the Sundas and Moluccas), as well as in the Aleutian and Kurile Islands, the greatest number of the island volcanoes are situated in a very limited space. The Aleutian Isles contain, perhaps, more volcanoes active in late historical times than the whole continent of South-America. On the whole surface of the earth, the tract containing the greatest number of volcanoes is that which ranges between 73° west and 127° east longitude, and between 47° south and 66° north latitude, in a direction from south-east to north-west.

If we suppose the great gulph of the sea, known under the name of the South Sea, or South Pacific Ocean, to be cosmically bounded by the parallel of Behring's Straits, and that of New Zealand, which is also the parallel of South Chili and North Patagonia, we shall find—and this result is very remarkable—in the interior of the basin, as well as around it (on its Asiatic and American continental boundaries), 198, or nearly seven-eighths of the 225 still active volcanoes of the whole earth. The volcanoes nearest the poles are, so far as our present geographical knowledge goes, in the northern hemisphere the volcano Esk, on the small island of Jan Meyen, in lat. 71° 1′, and west long. 7° 30′ 30″, and in the southern hemisphere Mount Erebus, whose red flames are visible even by day, and which Sir James Ross,[39] on his great southern voyage of discovery in 1841, found to be 12,400 feet high, or about 240 feet higher than the Peak of Teneriffe, in lat. 77° 33′, and long. 166° 58′ 30″ east.

The great number of volcanoes on the islands and on the shores of continents must have early led to the investigation by geologists of the causes of this phenomenon. I have already, in another place (*Cosmos*, vol. i, p. 242), mentioned the confused theory of Trogus Pompeius under Augustus, who supposed that the sea-water excited the volcanic fire. Chemical and mechanical reasons for this supposed effect of the sea have been adduced to the latest times. The old hypothesis of the sea-water penetrating into the volcanic focus seemed to acquire a firmer foundation at the time of the discovery of the metals of the earth by Davy, but the great discoverer himself soon abandoned the theory to which even Gay-Lussac inclined,[40] in spite of the rare occurrence, or total absence of hydrogen gas. Mechanical, or rather dynamical causes, whether sought for in the contraction of the upper crust of the earth and the rising of continents, or in the locally diminished thickness of the inflexible portion of the

[39] Sir James Ross, *Voyage to the Antartic Regions*, vol. i, pp. 217, 220, and 364.

[40] Gay-Lussac, *Réflexions sur les Volcans* in the *Annales de Chimie et de Physique*, t. xxii, 1823, p. 429; see above, p. 169; Arago, *Œuvres complètes*, t. iii, p. 47.

earth's crust, might, in my opinion, offer a greater appearance of probability. It is not difficult to imagine that at the margins of the up-heaving continents which now form the more or less precipitous littoral boundary visible over the surface of the sea, fissures have been produced by the simultaneous sinking of the adjoining bottom of the sea, through which the communication with the molten interior is promoted. On the ridge of the elevations, far from that area of depression in the oceanic basin, the same occasion for the existence of such rents does not exist. Volcanoes follow the present sea-shore in single, sometimes double, and sometimes even triple parallel rows. These are connected by short chains of mountains, raised on transverse fissures, and forming mountain-nodes. The range nearest to the shore is frequently (but by no means always) the most active, while the more distant, those more in the interior of the country, appear to be extinct or approaching extinction. It is sometimes thought that, in a particular direction in one and the same range of volcanoes, an increase or diminution in the frequency of the eruptions may be perceived, but the phenomena of renewed activity after long intervals of rest render this perception very uncertain.

As many incorrect statements of the distance of volcanic activity from the sea are circulated, either through ignorance of, or inattention to, the exact localities both of the volcanoes and of the nearest points of the coast, I shall here give the following distances in geographical miles (each being equal to about 2030 yards, or 60 to a degree):—In the Cordilleras of Quito, the volcano of Sangay, which discharges uninterruptedly, is situated in the most easterly direction, but its distance from the sea is still 112 miles. Some very intelligent monks attached to the mission of the Indios Andaquies at the Alto Putumayo have assured me that on the upper Rio de la Fragua,[41] a tributary of the Caqueta, to the eastward of the Ceja, they had seen smoke issue from a conical moun-

[41] The position of the Volcan de la Fragua, as reduced at Timana, is N. L. 1° 48′, long. 75° 30′ nearly. Compare the *Carte Hypsométrique des Nœuds de Montagnes dans les Cordillères,* in the large atlas of my travels, 1831, pl. 5, see also pl. 22 and 24. This mountain, lying isolated and so far to the east, ought to be visited by a geologist capable of determining the longitude and latitude astronomically.

tain of no great height, and whose distance from the coast must have been 160 miles. The Mexican volcano of Jorullo, which was elevated above the surface in September, 1759, is 84 miles from the nearest point of the sea-shore (see above, pp. 314–321); the volcano of Popocatepetl is 132 miles; an extinct volcano in the eastern Cordilleras of Bolivia, near S. Pedro de Cacha, in the vale of Yucay (see above, p. 295), is upwards of 180 miles; the volcanoes of the Siebengebirge, near Bonn, and of the Eifel (see above, p. 231—238), are from 132 to 152 miles; those of Auvergne, Velay, and Vivarais,[42] distributing them into three separate groups (the group of the Puy de Dôme, near Clermont, with the Mont Dore, the group of the Cantal, and the group of the Puy and Mezenc), are severally 148, 116, and 84 miles distant from the sea. The extinct volcanoes of Olot, south of the Pyrenees, west of Gerona, with their distinct and sometimes divided lava-streams, are distant only 28 miles from the Catalonian shores of the Mediterranean, while, on the other hand, the undoubted, and to all appearances very lately extinct, volcanoes in the long chain of the Rocky Mountains, in the north-west of America, are situated at a distance of from 600 to 680 miles from the shore of the Pacific.

A very abnormal phenomenon in the geographical distribution of volcanoes is the existence in historical times of active, and partially, perhaps, even of burning volcanoes in the mountain-chain of the Thian-shan (the Celestial Mountains), between the two parallel chains of the Altai and the Kuen-lün. The existence of these volcanoes was first made known by Abel-Rémusat and Klaproth, and I have been enabled, by the aid of the able and laborious investigations of

[42] In these three groups which, according to the old geographical nomenclature, belong to Auvergne, the Vivarais, and the Velay, the distances given in the text are those of the northernmost parts of each group as taken from the Mediterranean Sea (between the Golfe d'Aigues Mortes and Cette). In the first group, that of the Puy de Dôme, a crater erupted in the granite near Manzat, called Le Gour de Tazena, is taken as the most northerly point (Rozet, in the *Mém. de la Société Géol. de France*, t. i, 1844, p. 119). Farther south than the group of the Cantal, and therefore nearest the sea-shore, lies the small volcanic district of la Guiolle near the Monts d'Aubrac, north-west of Chirac, and distant scarcely 72 geographical miles from the sea. Compare the *Carte Géologique de la France*, 1841.

Stanislas Julien, to treat of them fully in my work on Central Asia.[43] The relative distances of the volcano of Pe-shan

[43] Humboldt, *Asie Centrale,* t. ii, pp. 7—61, 216, and 335—364; *Cosmos,* vol. i, p. 244. The mountain-lake of Issikul, on the northern slope of the Thian-shan, which was lately visited for the first time by Russian travellers, I found marked on the famous Catalonian map of 1374,* which is preserved as a treasure among the manuscripts of the Paris library. Strahlenberg, in his work entitled *Der nördliche und östliche Theil von Europa und Asien* (Stockholm, 1730, s. 327), has the merit of having first represented the Thian-shan as a peculiar and independent chain, without however being aware of its volcanic action. He gives it the very indefinite name of Mousart, which,—as the Bolor was designated by the general title of Mustag, which particularizes nothing, and merely indicates snow,—has for a whole century occasioned an erroneous representation, and an absurd and confused nomenclature of the mountain-ranges to the north of the Himalaya, confounding meridian and parallel-chains with each other. Mousart is a corruption of the Tartaric word *Muztag,* synonymous with our expression *snowy chain,* the Sierra Nevada of the Spaniards, the Himalaya in the Institutes of Menu,—signifying the habitation (*alaya*) of snow (*hima*), and the Sineshan of the Chinese. Eleven hundred years before Strahlenberg wrote, under the dynasty of Sui, in the time of Dagobert, king of the Franks, the Chinese possessed maps, constructed by order of the Government, of the countries lying between the Yellow River and the Caspian Sea, on which the Kuen-lün and the Thian-shan were marked. It was undoubtedly these two chains, but especially the first, as I think I have shown in another place (*Asie Centr.* t. i, pp. 118—129, 194—203, and t. ii, p. 413—425), which, when the march of the Macedonian army had brought the Greeks into closer acquaintance with the interior of Asia, spread among their geographers the knowledge of a belt of mountains extending from Asia Minor to the eastern sea, from India and Scythia to Thinæ, thus cutting the whole continent into two halves (Strabo, lib. i, p. 68, lib. xi, p. 490). Dicæarchus, and after him Eratosthenes, denominated this chain the *elongated Taurus;* the Himalaya chain is included under this appellation. "That which bounds India on the north," we are expressly told by Strabo (lib. xv, p. 689), "from Ariane to the eastern sea, is the extremest portions of the Taurus, which are separately called by the natives Paropamisos, Emodon, Imaon, and other names, but which the Macedonians call the Caucasus." In a previous part of the book, in describing Bactriana and Sogdiana (lib. xi, p. 519), he says, "the last portion of the Taurus, which is called Imaon, touches the Indian (eastern) Sea." The terms "on this side and on that side the Taurus," had reference to what was

[* This curious Spanish map was the result of the great commercial relations which existed at that time between Majorca and Italy, Egypt and India. See a more full notice of it in *Asie Centrale, loc. cit.*—Tr.]

(Mont Blanc) with its lava-streams, and the still burning

believed to be a single range running east and west; that is to say, a parallel-chain. Strabo was aware of this, for he says, "the Greeks call the half of the region of Asia looking to the north *this side the Taurus*, and the half towards the south *that side*" (lib. ii, p. 129). In the later times of Ptolemy, however, when commerce in general, and particularly the silk-trade, became animated, the appellation of Imaus was transferred to a meridian chain, the Bolor, as many passages of the 6th book show (*Asie Centr.* t. i, pp. 146—162). The line in which, parallel to the equator, the Taurus range intersects the whole region, according to Hellenic ideas, was first called by Dicæarchus, a pupil of the Stagirite, a Diaphragma (partition-wall), because, by means of perpendicular lines drawn from it, the geographical width of other points could be measured. The diaphragma was the parallel of Rhodes, extended on the west to the pillars of Hercules, and on the east to the coast of Thinæ (*Agathemeros* in Hudson's *Geogr. Gr. Min.*, vol. ii, p. 4). The divisional line of Dicæarchus, equally interesting in a geological and an orographical point of view, passed into the work of Eratosthenes, who mentions it in the 3rd book of his description of the earth, in illustration of his table of the inhabited world. Strabo places so much importance on this direction and partition line of Eratosthenes that he (lib. i, p. 65) thinks it possible "that on its eastern extension, which at Thinæ passes through the Atlantic Sea, there might be the site of another inhabited world, or even of several worlds;" although he does not exactly predict that they will be found to exist. The expression "Atlantic Sea" may seem remarkable as used instead of the "eastern sea," as the south sea (the Pacific) is usually called, but as our Indian Ocean, south of Bengal, is called in Strabo the Atlantic South Sea, so were both seas to the south-east of India considered to be connected, and were frequently confounded together. Thus, we read, lib. ii, p. 130, "India, the largest and most favoured country, which terminates at the eastern sea and at the Atlantic South Sea," and again, lib. xv, p. 689, "the southern and eastern sides of India, which are much larger than the other sides, run into the Atlantic Sea," in which passage, as well as in the one above quoted regarding Thinæ (lib. i, p. 65), the expression "eastern sea" is even avoided. Having been uninterruptedly occupied since the year 1792 with the strike and inclination of the mountain-strata, and their relation to the bearings of the ranges of mountains, I have thought it right to point attention to the fact that, taken in the mean, the equatorial distance of the Kuen-lün, throughout its whole extent, as well as in its western prolongation by the Hindu-Kho, points towards the basin of the Mediterranean Sea and the Straits of Gibraltar (*Asie Centr.*, t. i, pp. 118—127, and t. ii, pp. 115—118), and that the sinking of the bed of the sea in a great basin which is volcanic, especially on the northern margin, may very possibly be connected with this upheaval and folding in. My friend, Elie de Beaumont, so thoroughly acquainted with all that relates to geological bearings, is opposed to these views on loxodromical principles (*Notice sur les Systèmes de Montagnes*, 1852, t. ii, p. 667).

igneous mountain (Hotschen) of Turfan, from the shores of the Polar Sea and the Indian Ocean, are almost equally great, about 1480 and 1520 miles. On the other hand, the distance of Pe-shan, whose eruptions of lava are separately recorded, from the year 89 of our era up to the 7th century, in Chinese works, from the great mountain-lake of Issikul to the descent of the Temurtutagh (a western portion of the Thian-shan) is only 172 miles, while from the more northerly situated lake of Balkasch, 148 miles in length, it is 208 miles distant.[44] The great Dsaisang lake, in the neigbourhood of which I was during my stay in the Chinese Dsungarei in 1829, is 360 miles distant from the volcanoes of Thian-shan. Inland waters are therefore not wanting, but they are certainly not in such propinquity as that which the Caspian Sea bears to the still active volcano of Demavend in the Persian Mazenderan.

While, however, basins of water, whether oceanic or inland, may not be requisite for the maintenance of volcanic activity,—yet, if islands and coasts, as I am inclined to believe, abound more in volcanoes only because the elevation of the latter, produced by internal elastic forces, is accompanied by a neighbouring depression in the basin of the sea,[45] so that an area of elevation borders on an area of depression, and that at this bordering-line large and deeply penetrating fissures and rents are produced,—it may be supposed that in the central Asiatic zone, between the parallels of 41° and 48,° the great Aralo-Caspian area of depression, as well as the large number of lakes, whether disposed in ranges or otherwise, between the Thian-shan and the Altai-Kurtschum, may have given rise to littoral phenomena. We know from tradition that many small basins now ranged in a row like a string of beads (*lacs à chapelet*) once upon a time formed a single large basin. Many large lakes are seen to divide and form smaller ones from the disproportion between precipitation and evaporation. A very experienced observer of the Kirghis Steppe, General Genz of Orenburg, has conjectured that there formerly existed a water-

[44] See above, p. 358.

[45] See Arago, Sur la cause de la dépression d'une grande partie de l'Asie et sur le phénomène que les pentes les plus rapides des chaînes de montagnes sont (généralement) tournées vers la mer la plus voisine, in his *Astronomie Populaire*, t. iii. pp. 1266—1274.

communication between the Sea of Aral, the Aksakal, the Sary-Kupa and the Tschagli. A great furrow is observed, running from south-west to north-east, which may be traced by the way of Omsk, between Irtisch and Obi, through the steppe of Barabinsk, which abounds in lakes, towards the moory plains of the Samoiedes, towards Beresow and the shore of the Arctic Ocean. With this furrow is probably connected the ancient and wide-spread tradition of a *Bitter Lake* (called also the Dried Lake, Hanhai) which extended eastward and southward from Hami, and in which a portion of the Gobi, whose salt and reedy centre was found by Dr. von Bunge's careful barometrical measurement to be only 2558 feet above the level of the sea, rose in the form of an island.[46] It is a geological fact, which has not hitherto received its due share of attention, that seals, exactly similar to those which inhabit the Caspian Sea and the Baikal in shoals, are found upwards of 400 miles to the east of the Baikal in the small fresh-water lake of Oron, only a few miles in circumference. The lake is connected with the Witim, a tributary of the Lena, in which there are no seals.[47] The present isolation of these animals and their distance form the mouth of the Volga (fully 3600 geographical miles) form a remarkable geological phenomenon, indicative of an ancient and extensive connection of waters. Can it be that the numerous depressions to which, throughout a large tract of country, this central part of Asia has been exposed, have called forth exceptionally, on the convexity of the continental swelling, conditions similar to those produced on the littoral borders of the fissures of elevation?

From reliable accounts rendered to the Emperor Kanghi, we are acquainted with the existence of an extinct volcano far to the east, in the north-western Mantschurei, in the neighbourhood of Mergen (probably in lat. $48\frac{1}{2}°$ and long. 122° 20′ east). The eruption of scoriæ and lava from the mountain of Bo-shan or Ujun-Holdongi (the Nine Hills)

[46] Klaproth, *Asia Polyglotta,* p. 232, and *Mémoires relatifs à l'Asie* (from the Chinese Encyclopedia, published by command of the Emperor Kang-hi, in 1711), t. ii. p. 342; Humboldt, *Asie Centrale,* t. ii, pp. 125 and 135—143.

[47] Pallas, *Zoographia Rosso-Asiatica,* 1811, p. 115.

from 12 to 16 miles in a south-westerly direction from Margen, took place in January 1721. The mounds of scoriæ thrown out on that occasion, according to the report of the persons sent by the Emperor Kanghi to investigate the circumstances, were 24 geographical miles in circumference ; it was likewise mentioned that a stream of lava, damming up the water of the river Udelin, had formed a lake. In the 7th century of our era the Bo-shan is said to have had a previous igneous eruption. Its distance from the sea is about 420 geographical miles, similar to that of the Himálaya,[48] so that it is upwards of three times more distant than

[48] It is not in the Himalaya range, near the sea (some portions of it between the colossal Kunchinjinga and Shamalari, approach the shore of the Bay of Bengal within 428 and 376 geographical miles), that the volcanic action has first burst forth, but in the *third,* or interior, parallel chain, the Thian-shan, nearly four times as far removed from the same shore, and that under very special circumstances, the subsidence of ground in the neighbourhood deranging strata and causing fissures. We learn from the study of the geographical works of the Chinese, first instigated by me and afterwards continued by my friend Stanislas Julien, that the Kuen-lün, the northern boundary range of Tibet, the Tsi-shi-shan of the Mongols, also possesses in the hill of Shin-Khieu a cavern emitting uninterrupted flames (*Asie Centrale,* t. ii, pp. 427—467 and 483). The phenomenon seems to be quite analogous to the Chimæra in Lycia, which has now been burning for several thousands of years (see above, p. 256—7, and note 51) ; it is not a volcano, but a fire-spring, diffusing to a great distance an agreeable odour (probably from containing naphtha ?). The Kuen-lün which, like me in the *Asie Centrale* (t. i, p. 127 and t. ii, p. 431), Dr. Thomas Thomson, the learned botanist of Western Tibet (*Flora Indica,* 1855, p. 253), describes as a continuation of the Hindu-Kho, which is joined from the south-east by the Himalaya chain, approaches this chain at its western extremity to such a degree that my excellent friend, Adolph Schlagintweit, designates "the Kuen-lün and the Himalaya on the west side of the Indus, not as separate chains, but as one mass of mountains." (Report No. ix of the *Magnetic Survey in India by* Ad. Schlagintweit, 1856, p. 61). In the whole extent towards the east, however, as far as 92° 20′ east longitude, in the direction of the starry lake, the Kuen-lün forms, as was shown so early as the 7th century of our era by minute descriptions given under the Dynasty of Sai (Klaproth, *Tableaux Historiques de l'Asie,* p. 204), an independent chain running east and west parallel to the Himalaya at a distance of about 7½ degrees of latitude. The brothers Hermann and Robert Schlagintweit are the first who have had the courage and the good fortune to traverse the chain of the Kuen-lün, setting out from Ladak and reaching the territory of Khotan in the months of July and September, 1856. According to their observations, which are always

the volcano of Jorullo. We are indebted for these remarkable geognostic accounts from the Mantschurei to the industry of W. P. Wassiljew (*Geog. Bote*, 1855, Heft. v, s. 31) and to an essay by M. Semenow (the learned translator of Carl Ritter's great work on Geology) in the 17th vol. of the Proceedings of the Imperial Russian Geographical Society.

In the course of the investigations into the geographical distribution of volcanoes, and their frequent occurrence on islands and sea-coasts, that is to say, on the margins of continental elevations, the probable great inequality in the depth to which the crust of the earth has hitherto been penetrated has also been frequently brought under consideration. One is disposed to believe that the surface of the internal molten mass of the earth's body lies nearest to those points at which the volcanoes have burst forth. But as it may be conceived that there are many intermediate degrees of consistency in the solidifying mass, it is difficult to form a clear idea of any such surface of the molten matter; if a change in the comprehensive capacity of the external firm and already solidified *shell*, be supposed to be the chief cause of all the subversions, fissures, upheavals and basin-like depressions. If we might be allowed to determine what is called the thickness of the earth's crust in an arithmetical ratio deduced from experiments drawn from Artesian wells, and from the fusion-point of granite, that is to say, by taking equal geothermal degrees of depth,[49] we should find it to be 20 $\frac{8}{10}$ geographical miles or $\frac{1}{329}$th of the Polar diameter.[50] But the influences of

extremely careful, the highest water-shedding mountain-chain is that on which is situated the Karakorum pass (18,304 feet) which, stretching from south-east to north-west, lies parallel to the opposite southerly portion of the Himalaya (to the west of Dhawalagiri). The rivers Yarkland and Karakasch, which form a part of the great water system of the Tarim and Lake Lop, rise on the north-eastern slope of the Karakorum chain. From this region of water-springs the travellers arrived by way of Kissilkorum and the hot springs (120° F.) at the small mountain lake of Kiuk-kiul, on the chain of the Kuen-lün which stretches east and west (Report No. viii, *Agra*, 1857, p. 6).

49 *Cosmos*, vol. i, pp. 26, 167; see above, pp. 34—38.

50 Arago (*Astron. Populaire*, t. iii, p. 248) adopts nearly the same thickness of the earth's crust, namely, 40,000 metres, or about 22 miles; Elie de Beaumont (*Systèmes de Montagnes*, t. iii, p. 1237), calculates the thickness at about $\frac{1}{4}$ more. The oldest calculation is that

the pressure and of the power of conducting heat exercised by various kinds of rock, render it likely that the geothermal degrees of depth increase in value in proportion as the depth itself increases.

Notwithstanding the very limited number of points at which the fused interior of our planet now maintains an active communication with the atmosphere, it is still not unimportant to inquire in what manner and to what extent the volcanic exhalations of gas operate on the chemical composition of the atmosphere, and through it, on the organic life developed on the earth's surface. We must, in the first place, bear in mind that it is not so much the summit-craters themselves as the small cones of ejection and the fumaroles, which occupy large spaces and surround so many volcanoes, that exhale gases,—and that even whole tracts of country in Iceland, in the Caucasus, in the high land of Armenia, on Java, the Galapagos, the Sandwich Islands and New Zealand, exhibit a constant state of activity through solfataras, naphtha-springs, and salses. Volcanic districts, which are now reckoned among those which are extinct, are likewise to be regarded as sources of gas, and the silent working of the subterranean forces, whether destructive or formative, within them is, with regard to quantity, probably more productive than the great, noisy, and more rare eruptions of volcanoes, although their lava-fields continue to smoke either visibly or invisibly for years at a time. If it be said that the effects of these small chemical processes can be but little regarded, for that the immense volume of the atmosphere, constantly kept in motion by currents of air, could only be affected in its primitive mixture to a very small extent through means of such apparently unimportant additions,[51] it will be necessary to bear in mind the powerful

of Cordier, in mean value 56 geographical miles, an amount which, according to Hopkins's mathematical theory of stability, would have to be multiplied fourteen times, and would give between 688 and 860 geographical miles. I quite concur on geological grounds in the doubts raised by Naumann in his admirable *Lehrbuch der Geognosie* (vol. i, p. 62—64, 73—76 and 289), against this enormous distance of the fluid interior from the craters of the active volcanoes.

[51] A remarkable example of the way in which perceptible changes of mixture are produced in nature by very minute, but continuous, accumulation is afforded by the presence of silver in sea-water, which was discovered by Malaguti and confirmed by Field. Not-

influence exerted, according to the admirable investigations of Percival, Saussure, Boussingault and Liebig, by three or four ten-thousandth parts of carbonic acid in our atmosphere on the existence of the vegetable organism. From Bunsen's excellent work on the different kinds of volcanic gas, it appears that among the fumaroles of different stages of activity and local diversity, some (as for example at Hecla) yield from 0.81 to 0.83 of nitrogen, and in the lava-streams of the mountain 0.78, with mere traces (0.01 to 0.02) of carbonic acid, while others in Iceland, as for instance near Krisuvik, on the contrary, yield from 0.86 to 0.87 of carbonic acid, with scarcely 0.01 of nitrogen.[52] We find likewise in the important work on the emanations of gas in Southern Italy and Sicily by Charles Sainte-Claire Deville and Bornemann, that there is an immense proportion of nitrogen gas (0.98) in the exhalations of a fissure situated low down in the crater of Vulcano, while the sulphuric acid vapours show a mixture of 74.7 nitrogen gas and 18.5 oxygen, a proportion which approaches pretty nearly to the composition of the atmospheric air. On the other hand the gas which rises from the spring of Acqua Santa[53] in Catania is pure nitrogen gas, as was also the gas of the Volcancitos de Turbaco at the time of my American journey.[54]

Are we to conclude that the great quantity of nitrogen dispersed through the medium of volcanic action consists of that alone which is imparted to the volcanoes by meteoric water?—or are there internal and deeply-seated sources of nitrogen? It must also be borne in mind that the air dissolved in rain-water does not contain, like the atmosphere, 0.79 of nitrogen, but according to my own experiments, only

withstanding the immense extent of the ocean and the trifling amount of surface presented to it by the ships which traverse it, yet the trace of silver in the sea-water has in recent times become observable on the copper-sheeting of ships.

[52] Bunsen, *Ueber die chemischen Prozesse der vulkanischen Gesteinsbildungen* in Poggend. *Annalen*, Bd. lxxxiii, s. 242 and 246.

[53] *Comptes rendus de l'Acad. des Sciences*, t. xliii, 1856, pp. 366 and 689. The first correct analysis of the gas which rushes with noise from the great solfatara of Pozzuoli, and which was collected with great difficulty by M. Ch. St.-Claire Deville, gave the following results: —sulphurous acid (*acide sulfureux*) 24.5,—oxygen 14.5,—and nitrogen 61.4.

[54] See above, pp. 211- 218.

0.69. Nitrogen is a source of increased fertility,[55] by the formation of ammonia, through the medium of the almost daily electrical explosions in tropical countries. The influence of nitrogen on vegetation is similar to that of the substratum of atmospheric carbonic acid.

In analysing the different gases of the volcanoes which lie nearest to the equator (Tolima, Puracé, Pasto, Tuqueres and Cumbal) Boussingault has discovered, along with a great deal of aqueous vapour, carbonic acid and sulphuretted hydrogen gas, but no muriatic acid, no nitrogen and no free hydrogen.[56] The influence still exercised by the interior of our planet on the chemical composition of the atmósphere in withdrawing this matter in order to give it out again under other forms, is certainly but an insignificant part of the chemical revolutions which the atmosphere must have undergone in remote ages on the eruption of great masses of rock from open fissures. The conjecture as to the probability of a very large portion of carbonic acid gas in the ancient

[55] Boussingault, *Economie rurale* (1851), t. ii, p. 724—726;—"The permanency of storms in the interior of the atmosphere (within the tropics) is an interesting fact, being connected with one of the most important questions in the physical history of the globe, namely, that of the fixation of the nitrogen of the air in organised beings. Whenever a series of electric sparks passes through the humid atmosphere, the production and combination of nitric acid and ammonia take place. The nitrate of ammonia uniformly accompanies the rain during a storm, and being by nature fixed, it cannot maintain itself in the state of vapour; carbonate of ammonia is found in the air, and the ammonia of the nitrate is carried to the earth by the rain. Thus it appears, in fact, to be an electric action which disposes the nitrogen of the atmosphere to become assimilated by organised beings. In the equinoxial zone, throughout the whole year, every day, and probably even every moment, there is a continual succession of electric discharges going on. An observer, stationed at the equator, if he were endowed with organs sufficiently sensitive, would hear without intermission the noise of thunder." Sal ammoniac, however, together with common salt, are from time to time found as products of sublimation, even in lava-streams,—on Hecla, Vesuvius, and Etna, in the volcanic chain of Guatemala (the volcano of Izalco), and above all in Asia in the volcanic chain of the Thian-shan. The inhabitants of the country between Kutsch, Turfan, and Hami pay their tribute to the Emperor of China in certain years in sal ammoniac (in Chinese *nao-sha*, in Persian *nushaden*), which is an important article of internal trade. (*Asie Centrale*, t. ii, pp. 33, 38, 45, and 428.)

[56] *Viajes de Boussingault* (1849) p. 78.

aëriform envelope is strengthened by a comparison of the thickness of the present seams of coals with that of the thin coal-strata (seven lines in thickness) which, according to Chevandier's calculations, our thickest woods in the temperate zone would yield to the soil in the course of 100 years.[57]

In the infancy of geognosy, previous to Dolomieu's ingenious conjectures, the source of volcanic action was not placed below the most ancient rock-formations, which were then generally supposed to be granite and gneiss. Resting on some feeble analogies of inflammability, it was long believed that the source of volcanic eruptions, and the emanations of gas to which they for many centuries give rise, was to be sought for in the later, upper-silurian floetz-strata, containing combustible matter. A more general acquaintance with the earth's surface, profounder and more strictly conducted geological investigations, together with the beneficial influence which the great advances made by modern chemistry have exercised on the study of geology, have taught us that the three great groups of volcanic or eruptive rock (trachyte, phonolite, and basalt), when viewed as large masses, appear when compared together to be of different ages, and for the most part widely separated from each other. All three, however, have come later to the surface than the Plutonic granite, the diorite, and the quartz-porphyry,—later than all the silurian, secondary, tertiary, and quartary (pleistocene) formations,—and that they frequently traverse the loose strata of the diluvial formations and bone-breccias. A striking variety[58] of these intersections, compressed into a small space, is exhibited, as we learn from Rozet's observations, in Auvergne. While the great trachytic mountain-masses of the Cantal, Mont-Dore, and Puy de Dôme, penetrate the granite

[57] *Cosmos,* vol. i, pp. 283—5.

[58] Rozet, *Mémoire sur les Volcans d'Auvergne,* in the *Mémoires de la Soc. Géol. de France, 2me Série,* t. i, 1844, pp. 64 and 120—130 :—"The basalts (like the trachytes) have penetrated through the gneiss, the granite, the coal formations, the tertiary formations, and the oldest diluvian beds. The basalts are even frequently seen overlying masses of basaltic boulders; they have issued from an infinite number of openings, several of which are still perfectly recognisable. Many of them exhibit cones of scoriæ more or less considerable, but nowhere do we find craters similar to those which have given out streams of lava."

itself, and at the same time enclose in some parts (for example, between Vic and Aurillac, and at the Giou de Mamon) large fragments of gneiss[59] and limestone, we find also the trachyte and basalt intersecting as dykes the gneiss, and the coal-beds of the tertiary and diluvial strata. Basalt and phonolite, closely allied to each other, as the Auvergne and the central mountains of Bohemia prove, are both of more recent formation than the trachytes, which are frequently traversed in layers by basalts.[60] The phonolites are, on the other hand, more ancient than the basalts; where they probably never form dykes, but on the contrary dykes of basalt frequently intersect the porphyritic-schist (phonolite). In the chain of the Andes belonging to Quito, I have found the basalt-formation a great distance apart from the prevailing trachytes; almost solely at the Rio Pisque and in the valley of Guaillabamba.[61]

As in the volcanic elevated plain of Quito everything is covered with trachytes, trachytic-conglomerates, and tufas, it was my most earnest endeavour to discover, if possible, some point at which it might be clearly seen on which of the older rocks the mighty cone and bell-shaped mountains are placed, or, to speak more precisely, through which of them they had broken forth. Such a point I was so fortunate as to discover in the month of June 1802, on my way from Riobamba Nuevo (9483 feet above the surface of the South Pacific) when I attempted to ascend the Tunguragua on the

[59] Resembling the granitic fragments imbedded in the trachyte of Jorullo. See above, p. 321.

[60] Also in the Eifel, according to the important testimony of the mine-director, Von Dechen. See above, p. 237.

[61] See above, p. 333. The Rio de Guaillabamba flows into the Rio de las Esmeraldas. The village of Guaillabamba, near which I found the isolated oliviniferous basalt, is only 6430 feet above the level of the sea. An intolerable heat prevails in the valley, which is still more intense in the Valle de Chota, between Tusa and the Villa de Ibarra, the sole of which sinks to 5288 feet, and which is rather a chasm than a valley, being scarcely 9600 feet wide and 4800 feet deep (Humboldt, *Rec. d'Observations Astronomiques*, vol. i, p. 307). The rubbish-ejecting Volcan de Ansango, on the descent of the Antisana, does not belong to the basalt-formation at all; it is an oligoclase-trachyte resembling basalt (compare, for the distances, *Antagonisme des Basaltes et des Trachytes*, my *Essai Géognostique sur le gisement des Roches*, 1823, pp. 348 and 359, and generally, pp. 327—336).

side of the Cuchilla de Guandisava. I proceeded from the delightful village of Penipe over the swinging rope-bridge (*puente de maroma*) of the Rio Puela to the isolated Hacienda de Guansce (7929 feet), where to the south-east, opposite the point at which the Rio Blanco falls into the Rio Chambo, rises a splendid colonnade of black trachyte resembling pitch-stone. It looks at a distance like the basalt-quarry at Unkel. At Chimborazo, a little higher than the basin of Yana-Cocha, I saw a similar group of trachytic columns of greater height but less regularity. The columns to the south-east of Penipe are mostly pentagonal, only 14 inches in diameter, and frequently bent and diverging. At the foot of this black trachyte of Penipe, not far from the mouth of the Rio Blanco, a very unexpected phenomenon presents itself in this part of the Cordilleras;—greenish-white mica-slate with garnets interspersed in it, and farther on, beyond the shallow stream of Bascaguan, at the hacienda of Guansce, near the shore of the Rio Puela, and probably dipping below the mica-slate granite of a middling-sized grain, with light reddish felspar, a small quantity of blackish green mica and a great deal of greyish white quartz. There is no hornblend, nor is there any syenite. Thus it appears that the trachytes of the volcano of Tungurahua, resembling those of Chimborazo in their mineralogical condition, that is to say, consisting of a mixture of oligoclase and augite, have here penetrated granite and mica-slate. Farther towards the south, and a little to the east of the road leading from Riobamba Nuevo to Guamote and Ticsan, in that part of the Cordilleras which recedes from the sea-shore, the rocks formerly called primitive, mica-slate and gneiss, make their appearance everywhere, towards the foot of the colossal altar de los Collanes, the Cuvillan, and the Paramo del Hatillo. Previous to the arrival of the Spaniards; and even before the dominion of the Incas extended so far to the north, the natives are said to have worked metalliferous beds in the neighbourhood of the volcanoes. A little to the south of San Luis numerous dykes of quartz are observed running through a greenish clay-slate. At Guamote, at the entrance to the grassy-plain of Tiocaxa, we found large masses of rock consisting of quartzites very poor in mica, of a distinct linear parallel structure, running regularly at an angle of 70 degrees to the north. Farther to the south at Ticsan, not far from Alausi, the Cerro Cuello de Ticsan shows large masses of sulphur imbedded in a layer of quartz, subordinate to the neighbouring mica-slate. So great a diffusion of quartz in the neighbourhood of trachytic volcanoes appears at first sight somewhat strange. The observations which I made, however, of the overlying, or rather of the breaking forth of trachyte from mica-slate and granite at the foot of the Tungurahua (a phenomenon which is as rare in the Cordilleras as in Auvergne) have been confirmed, after an interval of 47 years, by the admirable investigations of the French geologist Sebastian Wisse at the Sangay.

That colossal volcano, 1343 feet higher than Mont-Blanc, entirely destitute of lava-streams (which Charles Deville declares are also wanting in the equally active Stromboli) but ejecting uninterruptedly, at least since the year 1728, a black, and frequently brightly glowing rock, forms a trachytic-island of scarcely 8 geographical miles in diameter[62] in the midst of beds of granite and gneiss. A totally opposite condition of stratification is exhibited in the volcanic district

[62] Sébastien Wisse, Exploration du Volcan de Sangay, in the *Comptes rendus de l'Acad. des Sciences*, t. xxxvi, 1853, p. 721; comp. also above, p. 251.

According to Boussingault, the ejected fragments of trachyte brought home by Wisse and collected on the upper descent of the cone (the traveller reached an elevation of 960 feet below the summit, which is itself 485 feet in diameter), consist of a black, pitch-like fundamental mass, in which are imbedded crystals of glassy (?) felspar. It is a very remarkable phenomenon, and one which up to the present time seems to stand alone in the history of volcanic ejections that, along with these large black pieces of trachyte, small sharp-edged fragments of pure quartz are thrown out. According to a letter from my friend Boussingault, dated January 1851, these fragments are no longer than 4 cubic centimètres in bulk. No quartz is found disseminated in the trachytic mass itself. All the volcanic trachytes which I have examined in the cordilleras of South America and Mexico, and even the trachytic porphyries in which the rich silver veins of Real del Monte, Moran and Regla are contained, to the north of the elevated valley of Mexico, are entirely destitute of quartz. Notwithstanding this seeming antagonism, however, of quartz and trachyte in still-active volcanoes, I am by no means inclined to deny the volcanic origin of the "*trachytes et porphyres meulières* (mill-stone trachytes)" to which Beudant first drew attention. The mode, however, in which these are formed, being erupted from fissures, is entirely different from the formation of the conical and dome-like trachyte structures.

of Eifel, as I have already observed, both from the activity which once manifested itself in the Maars (or mine-funnels) sunk in the Devonian-schist, and that shown in the raised structures from which lava-streams flow, as on the long ridge of the Mosenberg and Gerolstein. The surface does not here indicate what is hidden in the interior. The absence of trachyte in volcanoes which were so active thousands of years ago, is a still more striking phenomenon. The augitiferous scoriæ of the Mosenberg, which partly accompany the basaltic lava-stream, contain small burnt pieces of schist, but no fragments of trachyte, and in the neighbourhood the trachytes are absent. This species of rock is only to be seen in the Eifel in a state of entire isolation[63] far from the Maars and lava-yielding volcanoes, as in the Sellberg at Quiddelbach, and in the mountain-chain of Reimerath. The different nature of the formations through which the volcanoes force their way so as to operate with power on the outer crust of the earth is geologically as important as the material which they throw out.

The conditions of configuration in those rocky structures through which volcanic action manifests itself, or has endeavoured to do so, have at length been in modern times far more completely investigated and described in their often very complicated variations in the most distant quarters of the globe than in the previous century, when the entire morphology of volcanoes was limited to conical and bell-shaped mountains. There are many volcanoes whose configuration, altitude and range (what the talented Carl Friedrich Naumann calls the geotectonics),[64] we now know in the most satisfactory manner, while we continue in the greatest ignorance regarding the composition of their different rocks and the association of the mineral species which characterise their trachytes, and which are recognisable

[63] See above, pp. 232—6.

[64] The fullest information we possess on any volcanic district, founded on actual measurements of altitudes, angles of inclination, and profile views, is contained in the beautiful work of the Astronomer of Olmütz, Julius Schmidt, on Vesuvius, the solfatara, Monte Nuovo, the Astroni, Rocca Monfina and the old volcanoes of the Papal territory (in the Albanian Mountains, Lago Bracciano, and Lago di Bolsena). See his hypsometrical work, *Die Eruption des Vesuvs im Mai*, 1855, with *Atlas*, plates iii, iv, ix.

apart from the principal mass. Both kinds of knowledge, however,—the morphology of the rocky piles and the oryctognosy of their composition,—are equally necessary to the perfect understanding of volcanic action; nay, the latter, founded on crystallisation and chemical analysis, on account of the connection with plutonic rocks (porphyritic quartz, greenstone and serpentine) is of even greater geognostic importance. The little we believe we know of what is called the volcanicity of the Moon depends too, from the very nature of the knowledge, on configuration alone[65].

65 The progressive perfection of our acquaintance with the formation of the surface of the Moon as derived from numerous observers, from Tobias Mayer down to Lohrmann, Mädler and Julius Schmidt, has tended on the whole rather to diminish than to strengthen our belief in great analogies between the volcanic structures of the earth and those of the moon; not so much on account of the conditions of dimension and the early recognised ranging of so many ring-shaped mountains, as on account of the nature of the *rills* and of the system of rays which cast no shadows (radiations of light) of more than 400 miles in length and from 2 to 16 miles in breadth, as in Tycho, Copernicus, Kepler and Aristarchus. It is remarkable, however, that Galileo, in his letter to Father Christoph Grienberger, *Sulle montuosita della Luna*, should have thought of comparing annular mountains, whose diameter he considered greater than they actually are, to the circumvallated district of Bohemia, and that the ingenious Robert Hooke in his "Micrography" attributes the type of circular formation almost universally prevalent on the moon to the reaction of the interior of its body on the exterior (vol. ii, p. 701, and vol. iv, p. 496). With respect to the annular mountain ranges of the moon, I have been of late much interested with the relation between the height of the central mountain and that of the circumvallation or margins of the crater, as well as by the existence of parasitic craters on the circumvallation itself. The result of all the careful observations of Julius Schmidt, who is occupied with the continuation and completion of Lohrmann's Topography of the Moon, establishes "that no single central-mountain attains the height of the wall of its crater, but that in all cases it probably even lies together with its summit considerably below that surface of the moon from which the crater is erupted. While the cone of ashes in the crater of Vesuvius which rose on the 22nd of October 1822, according to Brioschi's trigonometrical measurement, exceeds in height the Punta del Palo, the highest edge of the crater on the north (618 toises above the sea), by about 30 feet, and was visible at Naples, many of the central mountains of the moon, measured by Mädler and the Olmütz Astronomer, lie fully 6400 feet lower than the mean margin of circumvallation, nay, even 100 toises below what may be taken as the mean surface-level in that part of the moon to which they respectively belong (Mädler, in *Schumacher's Jahrbuch für* 1841, pp. 272 and

If, as I would fain hope, what I here propound regarding the classification of the volcanic rocks; or, to speak more precisely, on the arrangement of the trachytes according to their composition, excites any particular interest, the merit of this classification is entirely due to my friend and Siberian fellow-traveller, Gustav Rose. His accurate observation of nature, and the happy combination which he possesses

274, and Jul. Schmidt; *Der Mond*, 1856, s. 62). In general, the central mountains, or central mountain-masses of the moon have several summits, as in Theophilus, Petavius and Bulliald. In Copernicus there are 6 central mountains, and Alphonsus alone exhibits a true central sharp pointed peak. This state of things recalls to mind the Astroni in the Phlegræan fields, on whose dome-formed central masses Leopold von Buch justly lays much stress. "These masses," he says, "like those in the centre of the annular mountains of the moon, did not break forth. There existed no permanent connection with the interior,—no volcano, but they rather appeared like models of the great trachytic unopened domes so abundantly dispersed over the earth's crust, such as the Puy de Dôme and Chimborazo." (Poggendorff's *Annalen*, Bd. xxxvii, 1836, p. 183.) The circumvallation of the Astroni is of an elliptic form, closed all round, and rises in no part higher than 830 feet above the level of the sea. The tops of the central summits lie more than 660 feet lower than the maximum of the south-western wall of the crater. The summits form two parallel ridges, covered with thick bushes (Julius Schmidt, *Eruption des Vesuvs*. s. 147, and *Der Mond*, s. 70 and 103). One of the most remarkable objects, however, on the whole surface of the moon is the annular mountain-range of Petavius, in which the whole internal floor of the crater expands convexly in the form of a tumour or cupola, and is crowned besides with a central mountain. The convexity here is a permanent form. In our terrestrial volcanoes the flooring of the crater is only temporarily raised by the force of internal vapours sometimes almost to the height of the margin of the crater, but as soon as the vapours force their way through, the floor sinks down again. The largest diameters of craters on the earth are,—the Caldeira de Fogo, according to Charles Deville 4100 toises (4·32 geographical miles) and the Caldeira de Palma, according to Leop. v. Buch 3100 toises, while on the moon, Theophilus is 50,000 toises, and Tycho 45,000 toises, or respectively, 52 and 45 geogr. miles in diameter. Parasitic craters, erupted from a marginal wall of the great crater, are of very frequent occurrence on the moon. The base of these parasitic craters is usually empty, as on the great rent margin of the Maurolycus; sometimes, but more rarely, a smaller central mountain, perhaps a cone of eruption, is seen in them, as in Logomontanus. In a beautiful sketch of the crater-system of Etna, which my friend Christian Peters the Astronomer (now in Albany, North-America) sent me from Flensburg in August 1854, the parasitic marginal crater, called the Pozzo di Fuoco, which was formed in January 1833, on the east-south-east side, and which had several violent eruptions of lava, is distinctly recognisable.

of chemical, crystallo-mineralogical and geological knowledge, have rendered him peculiarly well qualified to promulgate new views on that set of minerals whose varied, but frequently recurring association is the product of volcanic action. This great geologist, partly at my instigation, has with the greatest kindness, especially since the year 1834, repeatedly examined the fragments which I brought from the slopes of the volcanoes of New Granada, los Pastos, Quito, and the high land of Mexico, and compared them with the specimens from other parts of the globe contained in the rich mineral-collection of the Berlin Cabinet. Before my collections were separated from those of my companion Aimé Bonpland, Leopold von Buch had examined them microscopically with persevering diligence (in Paris, 1810—1811, between his return from Norway and his voyage to Teneriffe). He had also, at an earlier period, during my residence with Gay Lussac at Rome (in the Summer of 1805) as well as afterwards in France, made himself acquainted with what I had noted down in my travelling journal on the spot, in the month of July 1802, respecting certain volcanoes, and in general on the affinity between volcanoes and certain porphyries destitute of quartz[66]. I preserve as a memorial which I

66 The unspecific and indefinite term "trachyte" (Rauhstein), which is now so generally applied to the rock in which the volcanoes break out, was first given to a rock of Auvergne, in the year 1822 by Hauy in the second edition of his *Traité de Minéralogie*, vol. iv, p. 579, with a mere notice of the derivation of the word and a short description in which the older appellations of *granite chauffé en place* of Desmarets), trap-porphyry and domite are not even mentioned. It was only by oral communication, originating in Hauy's Lectures in the Jardin des Plantes, that the term " trachyte " was propagated previous to 1822, for example, in Leopold von Buch's treatise on basaltic islands and craters of upheaval, published in 1818, in Daubuisson's *Traité de Minéralogie*, 1819, and in Beudant's important work, *Voyage en Hongrie*. From letters lately received by me from M. Elie de Beaumont, I find that the recollections of M. Delafosse, formerly Aide-Naturaliste to Hauy, and now Member of the Institute, fix the application of the term "trachyte" between the years 1813 and 1816. The publication of the term "domite" by Leop. v. Buch, seems according to Ewald, to have occurred in the year 1809; it is first mentioned in the third letter to Karsten (*Geognost. Beobacht. auf Reisen durch Deutschl. und Italien*, Bd. ii, 1809, s. 244). "The porphyry of the Puy de Dôme," it is there stated, "is a peculiar, and hitherto nameless rock, consisting of crystals of felspar with a glassy lustre, hornblende and small laminæ of black mica. In the clefts of this kind of rock, which I provisionally term domite,

consider invaluable, some sheets with remarks on the volcanic products of the elevated plateaux of Quito and Mexico, which the great geologist communicated to me for my information more than 46 years ago. Travellers, as I have elsewhere[67] said, being merely the bearers of the imperfect knowledge of

I find beautiful drusic cavities, the walls of which are covered with crystals of iron-glance. Through the whole length of the Puy, cones of domite alternate with cones of cinders." The second volume of the Travels, containing the letters from Auvergne, was printed in 1806, but not published till 1809, so that the publication of the name of domite properly belongs to the latter year. It is singular that four years later, in Leopold von Buch's treatise on the trap-porphyry, domite is not even mentioned.—In referring to a drawing of the profile of the Cordilleras, contained in the journal of my travels in the month of July 1802, and included between the 4th degree north and 4th degree south latitude under the inscription "Affinité entre le feu volcanique et les porphyres," my only object was to mention that this profile, which represents the three breakings through of the volcanic groups of Popayan, Los Pastos and Quito, as well as the eruption of the trap-porphyry in the granite and mica-slate of the Paramo de Assuay (on the great road from Cadlud, at a height of 15,526 feet), led Leopold von Buch, too kindly and too distinctly, to ascribe to me the merit of having first noticed "that all the volcanoes of the chain of the Andes have their foundation in a porphyry which is a peculiar kind of rock and belongs essentially to the volcanic formations" (*Abhandlungen der Akhademie der Wissensch. zu Berlin,* aus den Jahren, 1812—1813, s. 131, 151 and 153). I may indeed have noticed the phenomenon in a general way, but it had already, as early as 1789, been remarked by Nose, whose merits have long been too little appreciated, in his Orographical Letters, that the volcanic rock of the Siebengebirge is "a peculiarly Rhenish kind of porphyry, closely allied to basalt and porphyritic schist." He says "that this formation is especially characterised by glassy felspar," which he proposes should be called sanidine, and that it belongs, judging from the age of its formation, to the middle floetz-rocks (*Niederrheinische Reise,* Th. i, s. 26, 28 and 47; Th. ii, s. 428). I do not find any grounds for Leopold von Buch's conjecture that Nose considered this porphyry-formation, which he not very happily terms granite-porphyry, as well as the basalts, to be of later date than the most recent floetz-rocks. "The whole of this rock," says the great geologist, so early removed from among us, "should be named after the glassy felspars (therefore sanidine-porphyry) had it not already received the name of trap-porphyry" (*Abh. der Berl. Akad.* aus den J. 1812—13, s. 134). The history of the systematic nomenclature of a science is so far of importance as the succession of prevalent opinions is found reflected in it.

67 Humboldt, *Kleinere Schriften,* Bd. i, *Vorrede,* s. iii.—v.

their age, and their observations being deficient in many of the leading ideas, that is to say, those discriminating marks which are the fruits of an advancing knowledge, the materials which have been carefully collected and geographically arranged, will almost alone maintain an enduring value.

To confine the term trachyte, as is frequently done (on account of its earliest application to the rocks of Auvergne and of the Siebengebirge, near Bonn) to a volcanic rock containing felspar, especially Werner's vitreous felspar, Nose's and Abich's sanidine, is fruitlessly to break asunder that intimate concatenation of volcanic rock which leads to higher geological views. Such a limitation might justify the expression "that in Etna, so rich in labradorite, no trachyte occurs." Indeed my own collections are said to prove that "no single individual of the countless volcanoes of the Andes consists of trachyte; that in fact the subtance of which they are composed is albite, and that therefore, as oligoclase was at that time (1835) always erroneously considered to be albite, all kinds of volcanic rock should be designated andesite (consisting of albite with a small quantity of hornblende)".[68] Gustav Rose has taken the same view that I myself adopted, from the impressions which I brought back with me from my journeys, on the common nature of all volcanoes, notwithstanding a mineralogical variation in their internal composition; on the principle developed in his admirable essay on the felspar groups,[69] in his classification of the trachytes, he generalizes orthoclase, sanidine, the anorthite of Mount Somma, albite, labradorite and oligoclase, as forming the felspathic ingredient of the volcanic rocks. Brief appellations which are supposed to contain definitions lead to many obscurities in orology as well as in chemistry. I was myself for a long time inclined to adopt the expressions orthoclase-trachytes, or labrador-trachytes, or oligoclase-tra-

[68] Léop. v. Buch in Poggend, *Annalen*, Bd. xxxvii, 1836, s. 188, 190.

[69] Gustav Rose in Gilbert's *Annalen*, Bd. lxxiii, 1823, s. 173, and *Annales de Chimie et de Physique*, t. xxiv, 1823, p. 16. Oligoclase was first held by Breithaupt as a new mineral species (Poggendorff's *Annalen*, Bd. viii, 1826, s. 238). It afterwards appeared that oligoclase was identical with a mineral which Berzelius had observed in a granite dyke resting upon gneiss near Stockholm, and which, on account of the resemblance in its chemical composition he had called "Natron Spodumen." (Poggendorff's *Annal.* Bd. ix, 1827, s. 281).

chytes, thus comprehending the glassy felspar (sanidine), on account of its chemical composition, under the species orthoclase (common felspar). The terms were at least well-sounding and simple, but their very simplicity must have induced error, for though labrador-trachyte points to Etna and to Stromboli, yet oligoclase-trachyte, in its important twofold combination with augite and hornblende, would erroneously connect the widely diffused and very dissimilar formations of Chimborazo and the volcano of Toluca. It is the association of a felspathic element with one or two others which here forms the characteristic feature, as it does in the formation of some mineral-dykes.

The following is a view of the divisions into which Gustav Rose, subsequently to the winter of 1852, distributes the trachytes, in reference to the crystals enclosed in them, and separately recognisable. The chief results of this work, in which there is no confounding of oligoclase with albite, were obtained ten years earlier; when my friend discovered, in the course of his geognostic investigations in the Riesengebirge, that the oligoclase there formed an essential ingredient of the granite, and his attention being thus directed to the importance of oligoclase as an ingredient of that rock, he was induced to look for it likewise in other rocks.[70] This examination led to the important result (Poggend. *Ann.* Bd. lxvi, 1845, s. 109) that albite never forms a part in the mixed composition of any rock.

First division. "The principal mass contains only crystals of glassy felspar, which are laminar, and in general large. Hornblende and mica either do not occur in it at all, or in extremely small quantity, and as an entirely unessential admixture. To this division belongs the trachyte of the Phle-

[70] See Gustav Rose on the granite of the Riesengebirge, in Poggendorff's *Ann.* Bd. lvi, 1842, s. 617. Berzelius had found the oligoclase, his "Natron Spodumen," only in a dyke of granite; in the treatise just cited it is for the first time spoken of as an ingredient in the composition of granite (the mineral itself). Gustav Rose here determined the oligoclase according to its specific gravity, the greater proportion of lime contained in it as compared with albite, and its greater fusibility. The same compound with which he had found the specific gravity to be 2.682 was analysed by Rammelsberg (*Handwörterbuch der Mineralog.* supplem. i, s. 104, and G. Rose *Ueber die zur Granitgruppe gehörenden Gebirgsarten*, in the *Zeitschr. der Deutschen geol. Gesellschaft*, Bd. i, 1849, s. 364).

græan Fields (Monte Olibano near Pozzuoli), that of Ischia and of La Tolfa, as also a part of the Mont-Dore (the Grande Cascade). Augite is but very rarely found in small crystals in trachytes of the Mont-Dore[71]—never, in the Phlegræan Fields together with hornblende; nor is leucite, of which last however, Hoffmann collected some pieces on the Lago Averno (on the road to Cumæ), while I found some on the slope of the Monte Nuovo[72] (in the autumn of 1822). Leucite-ophyr in loose fragments is more frequent in the island of Procida and the adjoining Scoglio di S. Martino."

Second Division. "The ground-mass contains some detached crystals of glassy felspar, and a profusion of small snow-white crystals of oligoclase. The latter are frequently overspread with the glassy felspar in regular order, and form a covering about the felspar, as is so frequently seen in G. Rose's granitite (the principal mass of the Riesengebirge and Iser-gebirge, consisting of granite with red felspar, particularly rich in oligoclase and magnesian-mica, but without any white potash-mica). Hornblende and mica, and in some modifications augite, occasionally appear in small quantity. To this division belong the trachytes of the Drachenfels and of the Perlenhardt in the Siebengebirge[73] near Bonn, and many modifications of the Mont-Dore and Cantal; some trachytes also of Asia Minor (for which we are indebted to that industrious traveller Peter von Tschi-

[71] Rozet, Sur les montagnes de l'Auvergne, in the *Mém. de la Soc. Géol. de France,* 2me Série, t. i, partie i, 1844, p. 69.

[72] Fragments of Leucite-ophyr, collected by me at the Monte Nuovo, are described by Gustav Rose in Fried. Hoffmann's *Geognostichen Beobachtungen,* 1839, s. 219. On the trachyte of the Monte di Procida of the island of the same name, and the rock of San Martino, see Roth, *Monographie des Vesuvs.* 1857, s. 519—522, tab. viii.—The trachyte of the island of Ischia contains in the Arso, or stream of Cremate (1301) vitreous felspar, brown mica, green augite, magnetic iron and olivine (s. 528), but no leucite.

[73] The geologico-topographical conditions of the Siebengebirge near Bonn, have been developed with comprehensive talent and great exactness by my friend H. von Dechen, director of mines, in the 9th annual volume of the *Verhandlungen des Naturhistorischen Vereines der Preuss, Rheinlande und Westphalens,* 1852, s. 289—567. All the chemical analyses of the trachytes of the Siebengebirge which have hitherto appeared are there collected (p. 323—356); mention is also made of the trachytes of the Drachenfels and Röttchen, in which, besides the large crystals of sanidine, several small crystalline particles may be distin-

chatscheff), of Afiun Karahissar (famous for the culture of the poppy) and Mehammed-kyöe in Phrygia, and of Kayadschyk and Donanlar in Mysia, in which glassy felspar, with a great deal of oligoclase, some hornblende, and brown mica are mingled."

guished in the fundamental mass. "These portions have been found by Dr. Bothe, on chemical analysis in Mitscherlich's Laboratory, to be oligoclase, corresponding exactly with the oligoclase of Danvikszoll (near Stockholm) noticed by Berzelius." (Dechen, s. 340—346). The Wolkenburg and the Stenzelberg are destitute of glassy felspar (s. 357 and 363), and belong, not to the second division, but to the third ; they contain a Toluca-rock. That section of the geological description of the Siebengebirge which treats of the relative age of trachyte-conglomerate and basalt conglomerate contains many new views (p. 405—461). "With the more rare dykes of trachyte in the trachyte-conglomerates, which prove that the formation of trachyte has still continued after the deposit of the conglomerate (s. 413), are associated a great number of basalt courses (s. 416). The basalt-formation extends decidedly into a later basalt than the trachyte-formation, and the principal mass of the basalt is here more recent than the trachyte. On the other hand a portion of this basalt only, and not of all basalts (s. 323) is more recent than the great mass of the brown-coal rocks. Both formations, the basalt and the brown-coal rocks, run into each other in the Siebengebirge as well as in many other places, and must be considered in the aggregate as contemporaneous." Where very small crystals of quartz occur by way of rarity in the trachytes of the Siebengebirge, as (according to Nöggerath and Bischof) in the Drachenfels and in the valley of Rhöndorf, they fill up cavities and seem to be of later formation (p. 361 and 370); caused perhaps by efflorescence of the sanidine. On Chimborazo I have on one solitary occasion seen similar deposits of quartz, though very thin, on the internal surfaces of the cavities of some very porous, brick-red masses of trachyte at an elevation of about 17,000 feet (Humboldt, *Gisement des Roches*, 1823, p. 336). These fragments, which are frequently mentioned in my journal, are not deposited in the Berlin collections. Efflorescence of oligoclase, or of the whole fundamental mass of the rock may also yield such traces of disengaged silicic acid. Some points of the Siebengebirge still merit renewed and persevering investigation. The highest summit, the Löwenburg, represented as basalt, seems, from the analysis of Bischof and Kjerulf, to be a doleritic rock (H. v. Dechen, s. 383, 386, 393). The rock of the little Rosenau, which has sometimes been called Sanido-phyre, belongs, according to G. Rose, to the first division of his trachytes, and is very closely allied to many of the trachytes of the Ponga Islands. The trachyte of the Drachenfels with large crystals of glassy felspar seems, according to Abich's yet unpublished investigations, most nearly to resemble the Dsyndserly-dagh which rises to a height of 8526 feet, to the north of the great Ararat, from a formation of nummulites underdipped by Devonian strata.

Third Division. "The ground-mass of this dioritic trachyte contains many small crystals of oligoclase with black hornblende and brown magnesian-mica. To this belong the trachytes of Ægina,[74] of the valley of Kozelnik near Schemnitz[75], of Nagyag in Transylvania, of Montabaur in the Duchy of Nassau, of the Stenzelberg and the Wolkenburg in the Siebengebirge near Bonn, of the Puy de Chaumont, near Clermont in Auvergne, and of the Liorant in Cantal; also the Kasbegk in the Caucasus, the Mexican volcanoes of Toluca[76] and Orizaba, the volcano of Puracé and the splendid columns of Pisoje[77] near Popayan, though whether the latter are trachytes is very uncertain. The domites of Leopold von Buch belong likewise to this third division. In the white, fine-grained fundamental mass of the trachytes of the Puy de Dôme are found glassy crystals, which were constantly taken for felspar, but which are always streaked on the most distinct cleavage surface, and are oligoclase; hornblende and some mica are also present. Judging from the volcanic specimens for which the royal

[74] From the close propinquity of Cape Perdica of the island of Ægina to the long famous red-brown Trözen-trachytes (*Cosmos*, see above, p. 229) of the peninsula of Methana, and from the sulphur-springs of Bromolimni, it is probable that the trachytes of Methana, as well as those of the island of Kalauria, near the small town of Poros, belong to the same third division of Gustav Rose (oligoclase with hornblende and mica) (Curtius, *Peloponnesos*, Bd. ii, s. 439, 446, tab. xiv).

[75] See the admirable geological map of the district of Schemnitz by Bergrath, Johann von Peltko, 1852, and the *Abhandlungen der k. k. geologischen Reichsanstalt*, Bd. ii, 1855, Abth. i, s. 3.

[76] *Cosmos*, see above, pp. 401—2.

[77] The basaltic columns of Pisoje, the felspathic part of which has been analysed by Francis (Poggend. *Annal.* Bd. lii, 1841, s. 471), near the banks of the Cauca, in the plain of Amolanga (not far from the Pueblos of Sta. Barbara and Marmato), consist of a somewhat modified oligoclase in large beautiful crystals, and small crystals of hornblende. Nearly allied to this mixture are, the quartz, containing dioritic-porphyry of Marmato, brought home by Degenhardt, the felspathic part of which was named by Abich Andesine,—the rock, destitute of quartz, of Cucurusape, near Marmato, in Boussingault's collection (Charles Ste.-Cl. Deville, *Etudes de Lithologie*, p. 29), the rock which I found 12 geographical miles eastward of Chimborazo, below the ruins of old Riobamba (Humboldt, *Kleinere Schriften*, Bd. i, s. 161), and lastly, the rock of the Esterel Mountains in the department of the Var (Elie de Beaumont, *Explic. de la Carte Géol. de France*, t. i, p. 473).

collection is indebted to Herr Mollhausen, the draughtsman and topographist of Lieut. Whipple's exploring expedition, the third division, or that of the dioritic Toluca-trachytes, also includes those of Mount Taylor, between Santa Fé del Nuevo Mexico and Albuquerque, as well as those of Cieneguilla on the western slope of the Rocky Mountains, where, according to the able observations of Jules Marcou, black lava-streams overflow the Jura-formation." The same mixture of oligoclase and hornblende which I saw in the Azteck highlands, in Anahuac proper, but not in the Cordilleras of South America, are also found far to the west of the Rocky Mountains and of Zuñi, near the Mohave river, a tributary of the Rio Colorado (see Marcou, *Résumé of a geological reconnaissance from the Arkansas to California*, July, 1854, pp. 46—48. See also two important French treatises,—*Résumé explicatif d'une Carte Géologique des Etats-Unis*, 1855, pp. 113—116, and *Exquisse d'une Classification des Chaînes de Montagnes de l'Amérique du Nord*, 1855; *Sierra de S. Francisco et Mount Taylor*, p. 23). Among the trachytes of Java, for specimens of which I am indebted to my friend Dr. Junghuhn, we have likewise recognised those of the third division in three volcanic districts, namely, Burung-agung, Tyinas and Gurung Parang (in the Batugangi district).

Fourth division. "The leading mass contains augite with oligoclase:—the Peak of Teneriffe,[78] the Mexican volcanoes

[78] The felspar in the trachytes of Teneriffe was first recognised in 1842 by Charles Deville, who visited the Canary Islands in the autumn of that year; see that distinguished geologist's *Voyage Géologique aux Antilles et aux Iles de Ténériffe et de Fogo*, 1848, pp. 14, 74, and 169; also Analyse du Feldspath de Ténériffe, in the *Comptes rendus de l'Acad. des Sciences*, t. xix, 1844, p. 46. "The labours of Messrs. Gustav Rose and H. Abich," he says, "have contributed in no small degree, both crystallographically and chemically, to throw light on the numerous varieties of minerals which were comprised under the vague denomination of felspar. I have succeeded in submitting to analysis *carefully isolated* crystals whose density in different specimens was very uniformly 2·593, 2·594, and 2·586. This is the first time that the oligoclase felspar has been indicated in volcanic regions, with the exception perhaps of some of the great masses of the Cordillera of the Andes. It was not detected, at least with any certainty, except in the ancient eruptive rocks (plutonic, granite, syenite, syenitic porphyry . . . .), but in the trachytes of the Peak of Teneriffe it plays a part analogous to that of the labrador in the doleritic masses of

Popocatepetl[79] and Colima, the South American volcanoes, Tolima (with the Paramo de Ruiz), Puracé near Popayan,

Etna." Compare also Rammelsberg, in the *Zeitschr. der Deutschen geol. Gesellschaft,* Bd. v, 1853, s. 691, and the 4th Supplement of his *Handwörterbuchs der chem. Mineralogie*, s. 245.

79 The first determination of height of the great volcano of Mexico, Popocatepetl is, so far as I am aware, the trigonometrical measurement already mentioned (see above, p. 41, note 42), executed by me on 24th January, 1804, in the Llano de Tetimba. The summit was found to be 1536 toises above the Llano, and as the latter lies barometrically 1234 toises above the coast of Vera Cruz, we obtain 2770 toises, or 17,728 English feet, as the absolute height of the volcano. The barometrical measurements which have succeeded my trigonometrical calculation lead me to conjecture that the volcano is still higher than I have made it in the *Essai sur la Géographie des Plantes,* 1807, p. 148, and in the *Essai Politique sur la Nouv. Espagne,* t. i, 1825, p. 185. William Glennie, who first reached the margin of the crater on the 20th April, 1827, found it, according to his own calculation (*Gazeta del Sol,* published in Mexico, No. 1432), 17,884 feet, equal to 2796 toises, but, as corrected by the mining director, Burkart, who has acquired so high a reputation in the department of American hypsometry, and who compared the calculation in Vera Cruz with barometrical observations taken nearly at the same time, it comes out fully 18,017 feet. On the other hand, a barometrical measurement by Samuel Birbeck (10th Nov. 1827), calculated according to the tables of Oltmanns, gave only 17,854 feet, and the measurement of Alex. Doignon (Gumprecht, *Zeitschrift für Allg. Erdkunde,* Bd. iv, 1855, s. 390); coinciding almost too precisely with the trigonometrical measurement of Tetimba, gives 5403 metres, equal to 17,726 feet. The talented Herr von Gerolt, the present Prussian ambassador in Washington, accompanied by Baron Gros, likewise visited the summit of Popocatepetl (28th May, 1833), and found, by an exact barometrical measurement, the Roca del Fraile, below the crater, 16,896 feet above the sea. Singularly contrasted with these chronologically-stated hypsometrical results appears a carefully-conducted barometrical measurement by M. Craveri, published by Petermann in his valuable *Mittheilungen über wichtige neue Erforschungen der Geographie,* 1856 (Heft x), s. 358—361. That traveller found, in September, 1855, the height of the highest margin of the crater, the north-west, compared with what he considered the mean height of the atmospheric pressure in Vera Cruz, only 5230 metres, or 17,159 feet, which is 555 feet ($\frac{1}{32}$ of the whole height under measurement) less than I found it by trigonometrical measurement half a century previous. Craveri likewise makes the height of the city of Mexico above the sea 196 feet less than Burkart and I have found it to be at very different times; he reckons it at only 2217 metres, or 7274 feet, instead of 2277 metres, or 7471 feet. In Dr. Petermann's periodical above referred to, p. 479—481, I have explained myself more particularly on

Pasto and Cumbal (according to specimens collected by

the subject of these variations plus or minus, as compared with the result of my trigonometrical measurement, which unfortunately has never been repeated. The 453 determinations of height which I made from September, 1799, to February, 1804, in Venezuela, on the woody shores of the Orinoco, the Rio de la Magdalena, and the river Amazon; in the Cordilleras of New Granada, Quito, and Peru, and in the tropical region of Mexico, all of which, re-calculated by Professor Oltmanns, uniformly according to the formula of Laplace and the co-efficients of Ramond, have been published in my *Nivellement Barométrique et Géologique*, 1810 (*Recueil d'Observ. Astronom.* t. i, pp. 295—334) were performed without exception with Ramsden's cistern-barometers "à niveau constant," and not with apparatus in which several fresh-filled Torricellian tubes may be inserted one after another, nor by the instrument, projected by myself, described in Lamétherie's *Journal de Physique*, t. iv, p. 468, and occasionally used in Germany and France during the years 1796 and 1797. Gay-Lussac and I made use, to our mutual satisfaction, of a portable Ramsden cistern-barometer exactly similar in construction, in the year 1805, during our journey through Italy and Switzerland. The admirable observations of the Olmutz astronomer, Julius Schmidt, on the margins of the crater of Vesuvius (*Beschreibung der Eruption im Mai*, 1855, s. 114—116) furnish from their similarity additional motives of satisfaction. As I never have ascended the summit of Popocatepetl, but measured it trigonometrically, there is no foundation whatever for the extraordinary criticism (Craveri, in Petermann's *Geogr. Mittheilungen*, Heft x, s. 359), "that the height of the mountain as described by me is unsatisfactory, because, as I myself stated, I had made use of fresh-filled Torricellian tubes." The apparatus with several tubes ought never to be used in the open air, more especially on the summit of a mountain. It is one of those means which, from the conveniences furnished by large towns, may be employed at long intervals, when the operator feels anxious as to the state of his barometer. For my own part, I have had recourse to it only on very rare occasions, but I would nevertheless still recommend it to travellers, accompanied by a comparison with the boiling point, as warmly as I did in my *Observations Astronomiques* (vol. i, pp. 363—373):—"As it is better not to observe at all than to make bad observations, we ought to be less afraid of breaking the barometer than of putting it out of order. M. Bonpland and I having four different times traversed the Cordilleras of the Andes, the determinations which chiefly interested us were repeated at different times, as we returned to the places which seemed doubtful. We occasionally employed the *apparatus of Mutis*, in which Torricelli's primary experiment is performed, by applying successively three or four strongly heated tubes, filled with mercury recently boiled in a stoneware crucible. When there is no possibility of replacing the tubes, it is perhaps prudent not to boil the mercury in the tubes themselves. In this way I have found, in experiments made in conjunction with Lindner, Boussingault), Rucu-Pichincha, Antisana, Cotopaxi, Chim·

Professor of Chemistry at the School of Mines in Mexico, the height of the column of mercury at Mexico in six tubes, as follows :—

259.7 lines (old Paris foot)
259.5
259.9
259.9
260.0
259.9

"The two last tubes alone had, by means of heat, been deprived of air by Bellardoni, the instrument maker at Mexico. As the exactness of the experiment depends partly on the perfect cleanliness of the inside of the empty tubes, which are so easily carried, it is a good plan to seal them hermetically over a lamp." As the angles of altitude cannot, in mountainous districts, be taken from the sea-shore, and the trigonometrical measurements are of a mixed nature and to a considerable extent (frequently as much as $\frac{1}{2}$ or $\frac{1}{2.7}$ of the whole height) barometrical, the determination of the height of the elevated plain in which the base line may be measured is of great importance. As corresponding barometrical observations at sea are seldom obtained, or for the most part only at too great a distance, travellers are too often induced to take the results they have obtained from a few days' observations, conducted by them at different seasons of the year, as the mean height of the pressure of the atmosphere on the elevated plain and at the seashore. "In wishing to know whether a measurement made by means of the barometer possesses the exactness of trigonometrical operations, it is only necessary to ascertain whether, in a given case, the two kinds of measurement have been taken under equally favourable circumstances, that is to say, by fulfilling those conditions which both theory and long experience have prescribed. The mathematical experimenter dreads the effect of terrestrial refractions, while the physical experimenter has reason to fear the unequal and far from simultaneous distribution of the temperature in the column of air at the extremities of which the two barometers are placed. It is probable enough that near the surface of the earth the decrease of caloric is slower than at greater elevations, and in order to ascertain with precision the mean density of the whole column of air, it would be necessary to ascend in a balloon so as to examine the temperature of each successive stratum or layer of the superimposed air" (Humboldt, *Recueil d' Observ. Astron.* vol. i, p. 138; see also 371, in the appendix on refraction and barometrical measurements). While the barometrical measurement of M. M. Truqui and Craveri gives only 17,159 feet to the summit of Popocatepetl, whereas Glennie gives 17,889 feet, I find that the lately published measurement of Professor Carl Heller of Olmütz, who has thoroughly investigated the district surrounding Mexico, as well as the provinces of Yucatan and Chiapa.

borazo,[80] Tunguragua, and trachyte rocks which are covered by the ruins of Old Riobamba. In the Tunguragua, besides the augites there occur also separate blackish green

corresponds to within 32 feet of my own. (Compare my *Essay on the Height of the Mexican Volcano Popocatepetl,* in Dr. Petermann's *Mittheilungen aus Justus Perthes Geographischer Anstalt,* 1856, s. 479—481).

[80] In the Chimborazo rock it is not possible, as in the Etna rock, to separate mechanically the felspathic crystals from the ground-mass in which they lie, but the large proportion of silicic acid which it contains, along with the fact connected therewith of the small specific gravity of the rock, make it apparent that the felspathic constituent is oligoclase. The quantity of silicic acid which a mineral contains and its specific gravity are generally in an inverse ratio; in oligoclase and labradorite the former is 64 and 53 per cent. while the latter is 2.66 and 2.71. Anorthite, with only 44 per cent. of silicic acid, has the great specific gravity of 2.76. This inverse proportion between the quantity of silicic acid and the specific gravity does not occur, as Gustav Rose remarks, in the felspathic minerals, which are also isomorphous, but with a different crystalline form. Thus felspar and leucite, for instance, have the same component parts,—potash, alumina, and silicic acid. The felspar, however, contains 65 and the leucite only 56 per cent. of silicic acid, yet the former has a higher specific gravity, namely, 2.56, than the latter, whose specific gravity is only 2.48.

Being desirous in the spring of 1854 to obtain a fresh analysis of the trachyte of Chimborazo, Professor Rammelsberg kindly undertook the task, and performed it with his usual accuracy. I here give the results of this analysis, as they were communicated to me by Gustav Rose, in a letter in the month of June, 1854. He says: "The Chimborazo rock, submitted to a careful analysis by Professor Rammelsberg, was broken from a specimen belonging to your collection, which you had brought home from the narrow rocky ridge at a height of more than 19,000 feet above the sea."

Rammelsberg's Analysis.

(Height 19,194 English feet; spec. grav. 2.806.)

			Oxygen.	
Silicic acid	59.12	...	30.70	2.33
Alumina	13.48	...	6.30	...
Protoxide of iron	7.27	1.61	...	1
Lime	6.50	1.85	...	
Magnesia	5.41	2.13	6.93	...
Soda	3.46	0.89	...	...
Potash	2.64	0.45	...	...
	97.88			

crystals of uralite, of from half a line to five lines in length, with a perfect augite form and the cleavage of hornblende (see Rose, *Reise nach dem Ural*, Bd. ii, s. 353)." I brought

Abich's Analysis.

(Height 16,179 English feet; spec. grav. 2.685.)

			Oxygen.	
Silicic acid	65.09	...	33.81	2.68
Alumina	15.58	...	7.27	...
Oxide of iron	3.83	...	1.16	...
Protoxide	1.73	...	0.39	...
Lime	2.61	...	0.73	1
Magnesia	4.10	...	1.58	...
Soda	4.46	...	1.14	...
Potash	1.99	...	0.33	...
Chlorine, and loss by heat	0.41	...	...	...
	99.80			

In explanation of these figures it must be observed, that the first series gives the ingredients in a per centage, the second and third give the oxygen contained in them. The second space shows only the oxygen of the stronger oxides (those which contain 1 atom of oxygen). In the third space this is recapitulated, so as to offer a comparison with that of the alumina earth (which is a weak oxide) and of the silicic acid. The fourth space gives the proportion of the oxygen of the silicic acid to the oxygen of the aggregate bases, which latter are fixed = 1. In the trachyte of Chimborazo this proportion is – 2.33 : 1.

"The differences between the analyses of Rammelsberg and of Abich are certainly important. Both analysed minerals from Chimborazo, from the relative heights of 19,194 and 16,179 feet, which were broken off by you and were taken from your geological collection in the Royal Mineral Cabinet at Berlin. The mineral from the lower elevation (scarcely 400 feet higher than the summit of Mont Blanc) which Abich has analysed, possesess a smaller specific gravity, and in correspondence therewith a greater quantity of silicic acid, than the mineral taken from a point 2918 feet higher, analysed by Rammelsberg. Assuming that the argillaceous earth belongs only to the felspathic ingredient, we may reckon in the analysis of Rammelsberg :—

Oligoclase	58.66
Augite	34.14
Silicic acid	4.08

As thus, by the assumption of oligoclase, a portion of silicic acid remains over uncombined, it is probable that the felspathic ingredient is oligoclase and not labradorite. The latter does not occur with a similar fragment, with distinct uralite crystals, from the slope of the Tunguragua at an elevation of 13,260 feet. Gustav Rose considers this specimen strikingly different

uncombined silicic acid, and if we were to suppose labradorite in the rock, a greater quantity of silicic acid would remain over."

A careful comparison of several analyses for which I am indebted to the friendship of M. Charles Sainte-Claire Deville, to whom the valuable geological collections of our mutual friend Boussingault are accessible for chemical experiment, shows that the quantity of silicic acid contained in the fundamental mass of the trachytic rocks is generally greater than in the felspars which they contain. The table kindly communicated to me by the compiler himself in the month of June, 1857, contains only five of the great volcanoes of the chain of the Andes :—

Names of the Volcanoes.	Structure and Colour of the Mass.	Silicic Acid in the whole Mass.	Silicic Acid in the Feld-spar alone.
Chimborazo	semi-vitrified, brownish grey	65.09 Abich	58.26
	semi-vitreous, and black	63.19 Deville	
	crystalline, compact, grey......	62.66 Deville	
Antisana	grey-black	64.26 Abich	58.26
	....	63.23 Abich	
Cotopaxi	vitreous and brownish	69.28 Abich	....
	granulated	63.98 Abich	
Pichincha	black, vitreous	67.07 Abich	....
Puracé	nearly bottle green...............	68.80 Deville	55.40
Guadaloupe	grey, granulated, and cellular	57.95 Deville	54.25
Bourbon	crystalline, grey, porous	50.90 Deville	49.06

"These differences, as far as regards the relative richness in silica of the ground-mass (and the felspar)," continues Charles Deville, "will appear still more striking when it is considered that, in analysing a rock *en masse*, there are included in the analysis, along with the basis properly so called, not only fragments of felspar similar to those which have been extracted, but even such minerals as amphibole, pyroxene, and especially peridote, which are less rich in silica than the felspar. This excess of silica manifests itself *sometimes* by the presence of isolated grains of quartz, which M. Abich has detected in the trachytes of the Drachenfels (Siebengebirge, near Bonn), and which I have myself observed with some surprise in the trachytic dolerite of Guadaloupe."

"If," observes Gustav Rose, "we add to this remarkable synopsis of the silicic acid contained in Chimborazo the result of the latest analysis, from the seven fragments of trachyte from the same volcano which are contained in my cabinet. It recalls to mind the formation of green slate (schistose augitic-porphyry) which we

that of Rammelsberg in May, 1854, we shall find that the result obtained by Deville occupies exactly the mean between those of Abich and Rammelsberg. Thus:—

Chimborazo-rock.

Silicic acid	65.09	Abich (spec. grav. 2.685)
	63.19	Deville
	62.66	do.
	59.12	Rammelsberg (spec. grav. 2.806)"

In the *Echo du Pacifique* of the 5th January, 1857, published at San Francisco in California, an account is given of a French traveller, named M. Jules Rémy, having succeeded, on the 3rd November, 1856, in company with an Englishman, Mr. Brencklay, in reaching the summit of Chimborazo, which was "however, enveloped in a cloud, so that we ascended without perceiving it." He observed, it is stated, the boiling point of water at 171°.5 F., with the temperature of the air at 31°.9 F., on calculating upon these data, the height he had attained by a hypsometrical rule tested by him in repeated journeys in the Haway Archipelago, he was astonished at the result brought out. He found, in fact, that he was at an elevation of 21,467 feet, that is to say, at a height differing by only 40 feet from that given by my trigonometrical measurement at Riobamba Nuevo in the elevated plain of Tapia, in June, 1803, as the height of the summit of Chimborazo,—namely, 21,426 feet. This correspondence of a trigonometrical measurement of the summit with one founded on the boiling point is the more surprising, as my trigonometrical measurement, like all measurements of mountains in the Cordilleras, involves a barometrical portion, and from the want of corresponding observations on the shore of the South Sea, my barometrical determination of the height of the Llano de Tapia, 9484 feet, cannot possess all the exactness that could be desired. (For the details of my trigonometrical measurement, see my *Recueil d'Observations Astron.*, vol. i, pp. 72 and 74). Professor Poggendorff kindly undertook to ascertain what result under the most probable hypotheses a rational mode of calculation would produce. He found, reckoning under both hypotheses, that the prevailing temperature of the atmosphere at the sea being 81°.5 F., or 79°.7 F., and the barometer marking 29.922 inches, with the thermometer at the freezing point, the following result is obtained by Regnault's table:—the boiling point at the summit at 171°.5 F. answers to 12,677 inches of the barometer at 32° temperature; the temperature of the air may therefore be taken at 35°.3 F. = 34°.7 F. According to these data, Oltmanns' tables give, for the height ascended, under the first hypothesis (81°.5), = 7328^{m}.2, or 24,043 feet, and under the second (79°.7), = 7314^{m}.5, or 23,998 English feet, showing an have found so diffused on the Asiatic side of the Ural (*Ibid.* s. 544).

Fifth division. "A mixture of labradorite[81] and augite,[82] a doleritic trachyte: Etna, Stromboli; and, according to the admirable works on the trachytes of the Antilles by Charles Sainte-Claire Deville, the Soufrière de la Guadeloupe, as well as the three great *cirques* which surround the Pic de Salazu, on Bourbon."

Sixth division. "The ground-mass, often of a grey colour, in which crystals of leucite and augite lie imbedded, with very little olivine:—Vesuvius and Somma; also the extinct volcanoes of Vultur, Rocca Monfina, the Albanian hills and Borghetto. In the older mass (for example, in the wall and paving-stones of Pompeii) the crystals of leucite are more considerable in size and more numerous than the augite.

average of 777m., or 2549 English feet, more than my barometrical measurement. To have corresponded with this, the boiling point, should have been found about 2°.25 cent. higher, if the summit of Chimborazo had actually been reached. *Poggendorff's Annalen*, Bd. c, 1857, s. 479.

81 That the trachytic rocks of Etna contain labradorite was demonstrated by Gustav Rose in 1833, when he exhibited to his friends the rich Sicilian collections of Friedrich Hoffmann in the Berlin Mineralogical cabinet. In his treatise on the minerals known by the names of green-stone and green-stone porphyry (*Poggend. Annal.*, Bd. xxxiv, 1835, p. 29), Gustav Rose mentions the lavas of Etna, which contain augite and labradorite (compare Abich in his interesting treatise on the whole felspathic-family, (*Poggend. Annal.*, 1840, Bd. l, s. 347). Leopold von Buch describes the rock of Etna as analogous to the dolerite of the basalt-formation (*Poggend. Annal.*, Bd. xxxvii, 1836, s. 188).

82 Sartorius von Waltershausen, who has for many years carefully investigated the trachytes of Etna, makes the following important observations:—"the hornblende there belongs especially to the older masses,—the green-stone veins in the Val del Bove, as well as the white and red trachytes, which form the ground mass of Etna in the *Serra Giannicola*. Black hornblende and bright yellowish-green augite are there found side by side. The more recent lava-streams from 1669 (especially those of 1787, 1809, 1811, 1819, 1832, 1838, and 1842), show augite, but no hornblende. The latter seems to be generated only after a longer period of cooling" (Waltershausen, *Ueber die vulkainschen Gesteine von Sicilien und Island*, 1853, s. 111—114). In the augitiferous trachytes of the fourth division in the chain of the Andes, along with the abundant augites, I have indeed sometimes found none, but sometimes, as at Cotopaxi (at an elevation of 14,068 feet) and at Rucu-Pichincha, at a height of 15,304 feet, distinct black hornblende-crystals in small quantities.

In the present lavas, on the contrary, the augites predominate and the leucites are on the whole very scarce, although the lava-stream of the 22nd April, 1845, has furnished them in abundance.[83] Fragments of trachytes of the first division, containing glassy felspar (Leopold von Buch's *trachyte proper*), are imbedded in the tufas of Monte Somma; they also occur detached in the layer of pumice which covers Pompeii. The leucite-ophyr-trachytes of the sixth division must be carefully distinguished from the trachytes of the first division, although leucites occur in the westernmost part of the Phlegræan Fields and on the island of Procida, as has been already mentioned."

The talented originator of the above classification of volcanoes, according to the association of the simple minerals which they present, does not by any means suppose that he has completed the grouping of all that are found on the surface of the earth, which is still on the whole so very

[83] See Pilla, in the *Comptes rendus de l'Acad. des Sc.*, t. xx, 1845, p. 324. In the leucite-crystals of the Rocca Monfina, Pilla has found the surface covered with worm-tubes (*serpulæ*), indicating a submarine volcanic formation. On the leucite of the Eifel, in the trachyte of the Burgberg near Rieden, and that of Albano, Lago Bracciano, and Borghetto, to the north of Rome, see above, page 32, note 93. In the centre of large crystals of leucite, Leop. v. Buch has generally found the fragment of a crystal of augite, round which the leucite-crystallisation has formed, "a circumstance which, considering the ready fusibility of the augite, and the infusibility of the leucite, is somewhat singular. More frequently still are fragments of the fundamental mass itself enclosed like a nucleus in leucite-porphyry." Olivine is likewise found in lavas, as in the cavities of the obsidian, which I brought from the Cerro del Jacal in Mexico (*Cosmos*, vol. i, p. 268, note ‡), and yet, strange to say, also in the hypersthene rock of Elfdal (Berzelius, *Sechster Jahresbericht*, 1827, s. 302), which was long considered to be syenite. A similar contrast in the nature of the places where it is found is exhibited by oligoclase, which occurs in the trachytes of still burning volcanoes (the Peak of Teneriffe and Cotopaxi), and yet at the same time also in the granite and granitite of Schreibersau and Warmbrunn in the Silesian Riesengebirge (Gustav Rose, in the minerals belonging to the granite-group, in the *Zeitschriften d. Deutsch. geol. Gesellsch.*, zu *Berlin*, Bd. i, s. 364). This is not the case with the leucite in the Plutonic rocks, for the statement that leucite has been found disseminated in the mica-slate and gneiss of the Pyrenees near Gavarnie (an assertion which even Hauy has repeated) has been found erroneous, after many years' investigation, by Dufrénoy (*Traité de Minéralogie*, t. iii, p. 399).

imperfectly investigated in a scientifically geological and chemical sense. Modifications in the nomenclature of the associated minerals, as well as additions to the trachyte-formations themselves, are to be expected in two ways, both from the progressive improvement of mineralogy itself (in a more exact specific distinction both with regard to form and chemical composition), and from the increased number of collections, which are for the most part so incomplete and so aimless. Here, as in all other cases where the governing law in cosmical investigations can only be discovered by a widely-extended comparison of individual cases, we must proceed on the principle that everything which, in the present condition of science, we think we know, is but a small portion of what the next century will bring to light. The means of early acquiring this advantage lie in profusion before us, but the investigation of the trachytic portion of the dry surface of the earth, whether raised, depressed, or opened up by fissures, has hitherto been very deficient in the employment of thoroughly exhaustive methods.

Though similar in form, in the construction of their framework and their geotectonic relations, volcanoes situated very near each other have frequently a very different individual character in regard to the composition and association of their mineral aggregate. On the great transverse fissure which, extending from sea to sea, almost entirely in a direction from west to east, intersects a chain of mountains, or, more properly speaking, an uninterrupted mountainous swell, running from south-east to north-west, the volcanoes occur in the following order:—Colima (13,003 feet), Jorullo (4265 feet), Toluca (15168 feet), Popocatepetl (17,726 feet), and Orizaba (17,884 feet). Those situated nearest to each other are dissimilar in the composition which characterizes them, a similarity of trachyte occurring only alternately. Colima and Popocatepetl consist of oligoclase with augite, and consequently have the trachyte of Chimborazo or Teneriffe; Toluca and Orizaba consist of oligoclase with hornblende, and consequently have the rock of Ægina and Kozelnik. The recently formed volcano of Jorullo, which is scarcely more than a large eruptive hill, consists almost alone of scoriaceous lavas, resembling basalt and pitchstone, and seems more like the trachyte of Toluca than that of Colima.

In these considerations on the individual diversity of the mineralogical constitution of neighbouring volcanoes, we find a condemnation of the mischievous attempt to introduce a name for a species of trachyte, derived from a mountain-chain, chiefly volcanic, of more than 7200 geographical miles in length. The name of Jura limestone, which I was the first to introduce,[84] is unobjectionable, because it is taken from a simple unmixed rock; from a chain of mountains whose antiquity is characterised by its containing organic remains. It would in like manner be unobjectionable to designate trachyte-formations after particular mountains,—to make use of the expression Teneriffe-trachyte or Etna-trachyte for decided oligoclase or labradorite formations. So long as there was an inclination among geologists to find albite everywhere among the very different kinds of felspar which are peculiar to the chain of the Andes, every rock in which albite was supposed to exist was called andesite. I first meet with the name of this mineral, with the distinct definition that "andesite is composed of a preponderating quantity of albite and a small quantity of hornblende," in the important treatise written in the beginning of the year 1835 by my friend Leopold von Buch on "*Craters of upheaval and volcanoes*."[85] This tendency to find albite every where

[84] In the course of a geological tour which I made, in 1795, through the south of France, western Switzerland, and the north of Italy, I had satisfied myself that the Jura limestone, which Werner reckoned among his Muschel-kalk, constituted a peculiar formation. In my treatise on subterranean gases, published by my brother, Wilhelm von Humboldt, in 1799, during my residence in South America, this formation, which I provisionally designated as Jura limestone, was for the first time mentioned (s. 39). This account of the new formation was immediately transferred to the Oberbergrath Karsten's mineralogical tables, at that time so generally read (1800, p. 64, and preface, p. vii). I named none of the petrifactions which characterise the Jura formation, and in relation to which Leopold von Buch has acquired so much credit (1839); I erred likewise in the age ascribed by me to the Jura formation, supposing it to be older than muschel-kalk, on account of its propinquity to the Alps, which were considered older than Zechstein. In the earliest tables of Buckland, on the *Superposition of strata in the British Islands*, the Jura limestone of Humboldt is reckoned as belonging to the upper oolite. Compare my *Essai Géogn. sur le Gisement des Roches*, 1823, p. 281.

[85] The name of Andesite first occurrs in print in Leopold von Buch's treatise, read on the 26th March, 1835, at the Berlin Academy. That

lasted for five or six years, until renewed investigations of a great geologist limits the appellation of trachyte to those cases in which glassy felspar is contained, and thus speaks in the above treatise, which was not printed till 1836 (*Poggend. Annal.*, Bd. xxxvii, s. 188—190):—"The discoveries of Gustav Rose, relating to felspar, have shed a new light on volcanoes and geology in general, and the minerals of volcanoes have in consequence presented a new and totally unexpected aspect. After many careful investigations in the neighbourhood of Catanea and at Etna, Elie de Beaumont and I have convinced ourselves that felspar is not to be met with on Etna, and consequently there is no trachyte either. All the lava-streams, as well as all the strata in the interior of the mountain, consist of a mixture of augite and labradorite. Another important difference in the minerals of volcanoes is manifested when albite takes the place of felspar, in which case a new mineral is formed, which can no longer be denominated trachyte. According to G. Rose's (present) investigations, it may be considered tolerably certain that not one of the almost innumerable volcanoes of the Andes consists of trachyte, but that they all contain albite in their constituent mass. This conjecture seems a very bold one, but it loses that appearance when we consider that we have become acquainted, through Humboldt's journeys alone, with one-half of these volcanoes and their products in both hemispheres. Through Meyen we are acquainted with these albitiferous minerals in Bolivia and the northern part of Chili; through Pöppig, as far as the southernmost limit of the same country; through Erman, in the volcanoes of Kamtschatka. Their presence being so widely diffused and so distinctly marked, seems sufficiently to justify the name of andesite, under which this mineral, composed of a preponderance of albite and a small quantity of hornblende, has already been sometimes noticed." Almost at the same time that this appeared, Leopold von Buch enters more into the detail of the subject in the addenda with which, in 1836, he so greatly enriched the French edition of his work on the Canary Islands. The volcanoes Pichincha, Cotopaxi, Tungurahua, and Chimborazo, are all said to consist of andesite, while the Mexican volcanoes were called genuine (sanidiniferous) trachytes (*Description physique des Iles Canaries*, 1836, pp. 486, 487, 490, and 515). This lithological classification of the volcanoes of the Andes and those of Mexico shows that, in a scientific point of view, such a similarity of mineralogical constitution and the possibility of a general denomination derived from a large extent of country, cannot be thought of. A year later, when Leopold von Buch first made mention, in *Poggendorff's Annalen*, of the name of *Andesite*, which has been the occasion of so much confusion, I committed the mistake myself of making use of it on two occasions;—once, in 1836, in the account of my attempt to ascend Chimborazo, in Schumacher's *Jahrbuch*, 1837, s. 204, 205 (reprinted in my *Kleinere Schriften*, Bd. i, s. 160, 161), and again, in 1837, in the treatise on the highland of Quito (in *Poggend. Ann.*, Bd. xl, s. 165). "Recent times have taught us," I observed, already strongly opposing my friend's conjecture as to the similar constitution of all the Andes-volcanoes, "that the more profound and less prejudiced character led to the recog-

different zones do not always present the same (mineralogical) composition, or the same component parts. Sometimes we find trachytes, properly so called, characterised by the glassy felspar, as at the Peak of Teneriffe and in the Siebengebirge near Bonn, where a little albite is associated with the felspar, — felspathic trachytes, which, as active volcanoes, exhibit abundance of obsidian and pumice; sometimes melaphyre, and doleritic mixtures of labradorite and augite, more nearly resembling the basalt formation, as at Etna, Stromboli, and Chimborazo; sometimes albite with hornblende prevails, as in the lately so-called andesites of Chili and the splendid columns, described as dioritic-porphyry, at Pisoje near Popayan, at the foot of the volcano of Puracé, or in the Mexican volcano of Jorullo; finally, they are sometimes leucite-ophyrs, a mixture of leucite and augite, as in the Somma, the ancient wall of the crater of elevation of Vesuvius." By an accidental misinterpretation of this passage, which shows many traces of the then imperfect state of geological knowledge (felspar being still ascribed to the Peak of Teneriffe instead of oligoclase, labradorite to Chimborazo, and albite to the volcano of Toluca), that talented investigator Abich, who is both a chemist and a geologist, has erroneously attributed to myself the invention of the term andesite as applied to a trachytic, widely-dispersed rock, rich in albite (*Poggend. Ann.*, Bd. li, 1840, s. 523), and has given the name of *andesine* to a new species of felspar, first analysed by him, but still somewhat enigmatical in its nature, "with reference to the mineral (from Marmato, near Popayan) in which it was first observed." The andesine (pseudo-albite in andesite) is supposed to occupy a middle position between labradorite and oligoclase; at the temperature of 55°.7 its specific gravity is 2.733, while that of the andesite in which the andesine occurred is 3.593. Gustav Rose doubts, as did subsequently Charles Deville (*Etudes de Lithologie*, p. 30), the individuality of andesine, as it rests only on a single analysis of Abich, and because the analysis of the felspathic ingredient in the beautiful dioritic-porphyry of Pisoje near Popayan, brought by me from South America, which was performed by Francis (*Poggend.*, Bd. lii, 1841, s. 472) in the laboratory of Heinrich Rose, while it certainly shows a great resemblance to the andesine of Marmato, as analysed by Abich, is, notwithstanding, of a different composition. Still more uncertain is the andesine in the syenite of the Vosges (from the Ballon de Servance, and Coravillers, which Delesse has analysed). Compare G. Rose, in the already often-cited *Zeitschrift der Deutschen geologischen Gesellschaft*, Bd. i, for the year 1849, s. 369. It is not unimportant to remark here that the name andesine, introduced by Abich as that of a simple mineral, appears for the first time in his valuable treatise entitled, *Beitrag zur Zenntniss des Feldspaths* (in *Poggend. Ann.*, Bd. l, s. 125, 341, Bd. li, s. 519), in the year 1840, which is at least five years after the adoption of the name andesite, instead of being prior to the designation of the mineral from which it is taken, as has been sometimes erroneously supposed. In the formations of Chili which Darwin so frequently calls andesitic granite nition of the trachytic albites as oligoclase.[85] Gustav Rose has come to the general conclusion that it is very doubtful whether albite occurs at all among the minerals as a real and essential element of commixture; consequently, according to the old conception of andesite, this mineral would actually be wanting in the chain of the Andes.

The mineralogical condition of the trachytes is imperfectly recognised if the porphyritically enclosed crystals cannot be separately examined and measured, in which case, the investigator must have recourse to the numerical proportions of the earths, alkalies and metallic oxides, which the result of the analysis furnishes, as well as to the specific gravity of

and andesitic porphry rich in albite (*Geological Observations on South America*, 1846, p. 174), oligoclase may also very likely be obtained. Gustav Rose, whose treatise on the nomenclature of the minerals allied to greenstone and greenstone-porphyry (in *Poggendorff's Ann.*, Bd. xxxiv, s. 1—30) appeared in the same year, 1835, in which Leopold von Buch employed the name of andesite, has not, either in the treatise just mentioned, or in any later work, made use of this term, the true definition of which is, not albite with hornblende, but in the Cordilleras of South America, oligoclase with augite. The now obsolete account of the designation of andesite, of which I have perhaps treated too circumstantially, helps to show, like many other examples in the history of the development of our physical knowledge, that erroneous or insufficiently grounded conjectures (as, for instance, the tendency to enumerate varieties as species) frequently turn out advantageous to science, by inducing more exact observations.

[86] So early as 1840, Abich described oligoclase-trachyte from the summit-rock of the Kasbegk and a part of the Ararat (*Ueber die Natur und die Zusammensetzung der Vulkan-Bildungen*, s. 46), and even in 1835, Gustav Rose had the foresight to say that though "he had not hitherto in his definitions taken notice of oligoclase and pericline, yet that they *probably* also occur as ingredients of admixture." The belief formerly so generally entertained that a decided preponderance of augite or of hornblende might be taken to denote a distinct species of the felspar family, such as glassy orthoclase (sanidine), labradorite or oligoclase, appears to be very much shaken by a comparison of the trachytes of the Chimborazo and Toluca rocks, belonging to the fourth and third division. In the basalt-formation, hornblende and augite often occur in equal abundance, which is by no means the case in the trachytes; but I have met with augite crystals, quite isolated, in Toluca rock, and a few hornblende crystals in portions of the Chimborazo, Pichincha, Puracé, and Teneriffe rocks. Olivines, which are so very rarely absent in the basalts, are as great a rarity in trachytes as they are in phonolites; yet we sometimes find, in certain lava-streams, olivines formed in great abundance by the side of augites. Mica is on the

the seemingly amorphous mass to be analysed. The result is obtained in a more convincing and more certain manner if the principal mass, as well as the chief elements of the mixture, can be singly investigated both mineralogically and chemically. This is the case with the trachytes of the Peak of Teneriffe and those of Etna. The supposition that the principal mass consists of the same small, inseparable, component parts which we recognise in the large crystals appears to be by no means well grounded, for, as we have already noticed, as shown in Charles Deville's work, the apparently amorphous principal mass generally furnishes more silicic acid than would be expected from the nature of the felspar and the other visible commixed elements. Among the leucite-ophyrs, as Gustav Rose observes, a striking contrast is exhibited, even in the specific difference of the prevailing alkalies (of the potash containing interspersed leucites) and the almost exclusively natroniferous principal mass.[87]

But along with these associations of augite with oligoclase, augite with labradorite, and hornblende with oligoclase, which are referred to in our classification of the trachytes, and which especially characterise them, there exist likewise in each vol-

whole very unusual in basalt, and yet some of the basaltic summits of the Bohemian central mountains, first described by Reuss, Freiesleben, and myself, contain plenty of it. The unusual isolation of certain mineral bodies, and the causes of their legitimate specific association, probably depend on many still undiscovered causes of pressure, temperature, fluidity, and rapidity in cooling. The specific differences of the association are, however, of great importance, both in the mixed rocks and in the masses of mineral veins; and in geological descriptions, noted down in the open air, in sight of the object described, the observer should be careful not to make any mistake as to what may be a prevailing, or at least a rarely absent member of the association, and what may be sparingly or only accidentally combined. The diversity which prevails in the elements of a mixture,—for instance, in the trachytes,—is repeated, as I have already noticed, in the rocks themselves. In both continents there exist large tracts of country in which trachyte formations and basalt formations as it were repel each other, as basalts and phonolites; and there are other countries in which trachytes and basalts alternate with each other in tolerably close proximity (see Gustav Jenzsch, *Monographie der böhmischen Phonolithe,* 1856, s. 1—7).

[87] See Bischof, *Chemische und physikalische Geologie,* Bd. ii, 1851, s. 2288, 2297; Roth, *Monographie des Vesuvs.* 1857, s. 305.

cano other easily recognisable, unessential elements of commixture, whose presence in large quantities or total absence in different volcanoes, often situated very near to each other, is very striking. Their occurrence, either in frequent abundance, or else at long and separate intervals, depends probably in one and the same natural laboratory on various conditions of the depth from which the matter originally came, the temperature, the pressure, the fluidity, or the quicker or slower process of cooling. The fact of the specific occurrence or the absence of certain ingredients is opposed to certain theories, such as the derivation of pumice from glassy felspar or from obsidian. These views, which have not been altogether lately adopted, but originated as early as the end of the 18th century from a comparison of the trachytes of Hungary and of Teneriffe, engaged my attention for several years in Mexico and the Cordilleras, as my journals will testify. From the great advancement which lithology has undeniably made in modern times, the more imperfect definitions of the mineral species made by me during my journey have, through Gustav Rose's careful mineralogical elaboration of my collections, been improved and accurately certified.

Mica.

Black or dark-green magnesian mica is very abundant in the trachytes of the Cotopaxi, at an elevation of 14,470 feet between Suniguaicu and Quelendaña, as also in the subterranean pumice-beds of Guapulo and Zumbalica at the foot of Cotopaxi,[88] but 16 miles distant from the same. The trachytes of the volcano of Toluca are likewise rich in magnesian mica, which is wanting in the Chimborazo.[89] In the Continent of Europe micas have shown themselves in abundance: at Vesuvius (for example in the eruptions of 1821—1823, according to Monticelli and Covelli); in the Eifel in the old volcanic Bombs of the Lacher Lake;[90] in the basalt

[88] *Cosmos*, see above, p. 343.

[89] It is almost superfluous to mention that the term *wanting* signifies only that, in the investigation of a not inconsiderable portion of volcanoes of large extent, a particular sort of mineral has hitherto been vainly sought for. I wish to distinguish between what is wanting (not being found), being of very rare admixture, and what, though more abundant, is still not normally characteristic.

[90] Carl von Oeynhausen, *Erkl. der geogn. Karte des Lacher Sees.* 1847, s. 38.

of the Meronitz, of the marly Kausawer Mountain and especially of the Gamayer summit[91] of the central Bohemian chain; more rarely in the phonolite,[92] as well as in the dolerite of the Kaiserstuhl near Freiburg. It is remarkable that in the trachytes and lavas of both continents not only no white (chiefly bi-axal) potash-mica is observable, but that it is entirely dark-coloured (chiefly uni-axal) magnesian-mica, and that this exceptional occurrence of the magnesia-mica is extended to many other rocks of eruption and plutonic rocks, such as basalt, phonolite, syenite, syenitic-slate, and even granitite, while the granite proper contains at one and the same time, white alkaline-mica and black or brown magnesia-mica.[93]

Glassy Felspar.

This kind of felspar, which plays so important a part in the action of European volcanoes; in the trachytes of the first and second division (for example, on Ischia, in the Phlegræan Fields, or the Siebengebirge near Bonn), is probably entirely wanting in the New Continent, in the trachytes of active volcanoes. This circumstance is the more striking as sanidine (glassy felspar) belongs essentially to the argentiferous, non-quartzose Mexican porphyries of Moran, Pachuca, Villalpando and Acaquisotla, the first of which are connected with the obsidians of Jacal.[94]

[91] See the *Bergmännisches Journal*, von Köhler und Hofmann, 5ter Jahrgang, Bd. i, 1792, s. 244, 251, 265. Basalt rich in mica, as on the Gamayer summit in the Bohemian centre mountains, is a rarity. I visited this part of the Bohemian central range in the summer of 1792, in company with Carl Freiesleben, afterwards my companion in my Swiss tour, who has exercised so great an influence over my geological and mining education. Bischof doubts all production of mica by the igneous method, and considers it a metamorphic product by the moist method. See his *Lehrbuch der chem. und physikal. Geologie*, Bd. ii, s. 1426, 1439.

[92] Jenzsch, *Beiträge zur Kenntniss der Phonolithe, in der Zeitschrift der Deutschen Geologischen Gesellschaft*, Bd. viii, 1856, s. 36.

[93] Gustav Rose, *Ueber die zur Granitgruppe gehörigen Gebirgsarten, in derselben Zeitschrift*, Bd. i, 1849, s. 359.

[94] The porphyries of Moran, Real del Monte and Regla (the latter celebrated for the rich silver mines of the Veta Biscayna, and the vicinity of the obsidians and pearlstones of the Cerro del Jacal and the Messerberg, Cerro de las Navajas), like almost all the metalliferous porphyries of America, are quite destitute of quartz (on these and other analogous phenomena in Hungary, see Humboldt,

Hornblende and Augite.

In this account of the characteristics of six different divisions of the trachytes, it has been already observed how the same minerals which occur as essential elements of commixture (for example, hornblende in the third division, or the Toluca rock), appear in other divisions in a separate or sporadic condition (as in the fourth and fifth divisions, in the rock of Pichincha and of Etna). I have found hornblende,

Essai géognostique sur le Gisement des Roches, pp. 179—188 and 190—193). The porphyries of Acaquisotla, however, on the road from Acapulco to Chilpanzingo, as well as those of Villalpando to the North of Guanaxuato, which are penetrated by auriferous veins, along with the sanidine contain also grains of brownish quartz.— The small inclosures of grains of obsidian and glassy felspar being on the whole rare in the volcanic rocks at the Cerro de las Navajas, and in the Valle de Santiago, so rich in basalt and pearl-stone, which is traversed in going from Valladolid to the volcano of Jorullo, I was the more astonished at finding at Capula and Pazcuaro, and especially near Yurisapundaro, all the ant-hills filled with beautifully shining grains of obsidian and sanidine. This was in the month of September, 1803 (*Nivellement barométr.* p. 327, No. 366, and *Essai géognost. sur le Gisement des Roches*, p. 356). I was amazed that such small insects should be able to drag the minerals to such a distance. It has given me great pleasure to find that an active investigator, M. Jules Marcou, has observed something exactly similar. "There exists," he says, "on the high plateaux of the Rocky Mountains, and particularly in the neighbourhood of Fort Defiance (to the west of Mount Taylor), a species of ant which, instead of using fragments of wood and vegetable remains for the purpose of building its dwelling, employs only small stones of the size of a grain of maize. Its instinct leads it to select the most brilliant fragments of stones, and thus the ant-hill is frequently filled with magnificent transparent garnets and very pure grains of quartz." (Jules Marcou, *Résumé explicatif d'une Carte géogn. des Etats-unis*, 1855, p. 3.)

Glassy felspar is very rare in the present lavas of Vesuvius, but this is not the case in the old lavas, for instance in those of the eruption of 1631, where it occurs along with crystals of leucite. Sanidine is also found in abundance in the Arso lava-stream, from Cremate towards Ischia, of the year 1301, without any leucite; but this must not be confounded with the older stream, described by Strabo, near Montagnone and Rotaro (*Cosmos*, see above, pp. 265, 427). Glassy felspar is not only rare in the trachytes of Cotopaxi and other volcanoes of the Cordilleras generally, but is equally so in the subterranean pumice-quarries at the foot of the Cotopaxi. What was formerly described as sanidine are crystals of oligoclase.

though not in large quantities, in the trachytes of the volcanoes of Cotopaxi, Rucu-Pichincha, Tungurahua and Antisana, along with augite and oligoclase, but scarcely ever along with these two minerals on the slope of the Chimborazo up to a height of more than 19,000 feet. Among the many specimens which I brought from Chimborazo, hornblende is recognized only in two, and even then in small quantity. In the eruptions of Vesuvius in the years 1822 and 1850, augite and crystals of hornblende (these nearly 9 Parisian lines in length) were contemporaneously formed by exhalations of vapours on fissures.[95] The hornblende of Etna, as Sartorius von Waltershausen observes, belongs especially to the older lavas. That remarkable mineral, so widely diffused in Western Asia and at several points of Europe, which Gustav Rose has denominated Uralite, being allied in structure and crystalline form to hornblende and augite,[96] I here once more gladly point attention to the first occurrence of uralite crystals in the New Continent;—they were recognised by Rose in a piece of trachyte which I abstracted from the slope of the Tungurahua, 3200 feet below the summit.

Leucite.

Leucites, which in Europe belong exclusively to Vesuvius, the Rocca Monfina, the Albanian Mountains near Rome, the Kaiserstuhl in the Breisgau, and the Eifel (in the western environs of the Lachar Lake in blocks, and not in the contiguous rock, as in the Burgberge near Rieden), have never yet been found in volcanic rocks of the New Continent, or the Asiatic portion of the old. Leopold von Buch discovered them round an augite-crystal as early as the year 1798, and described in an admirable treatise their frequent formation.[97] The augite-crystal round which, according to this great geologist, the leucite is formed, is seldom wanting, but appears to me to be sometimes replaced by a small grain or morsel of trachyte. The unequal degrees of fusibility, between the grain of trachyte and the surrounding mass of

[95] Roth, *Monographie des Vesuvs.* s. 267, 382.

[96] See above, note 82; Rose, *Reise nach dem Ural.*, Bd. ii, s. 369; Bischof, *Chem. und Physik. Geologie*, Bd. ii, s. 528—571.

[97] Gilbert's *Annalen der Physik.*, Bd. vi, 1800, s. 53;—Bischof, *Geologie*, Bd. ii, s. 2265—2303.

leucite raise some chemical difficulties to the explanation of the mode in which the integumental covering is formed. Leucites, partly detached, acc ording to Scacchi, and partly mixed with lava, were extremely abundant in the recent eruptions of Vesuvius in 1822, 1828, 1832, 1845 and 1847.

Olivine.

Olivine being very abundant in the old lavas of Vesuvius[98] (especially in the leucite-ophyrs of the Somma) in the Arso of Ischia, in the eruption of 1301, mixed with glassy felspar, brown mica, green augite and magnetic iron, in the volcanoes of the Eifel which emit lava-streams (for example, in the Mosenberge westward of Manderscheid),[99] and in the south-eastern portion of Teneriffe in the lava-eruption of Guimar in the year 1704, I have also searched for it very diligently, but in vain, in the trachytes of the volcanoes of Mexico, New Granada and Quito. Our Berlin collections contain sixty-eight specimens of trachyte of the four volcanoes, Tungurahua, Antisana, Chimborazo and Pichincha alone, 48 of

[98] The recent lavas of Vesuvius contain neither olivine, nor glassy felspar; Roth. *Mon. des Vesuvs.* s. 139. According to Léopold von Buch, the lava-stream of the Peak of Teneriffe of 1704, described by Viera and Glas, is the only one which contains olivine (*Descr. des Iles Canaries*, p. 207). The supposition that the eruption of 1704 was the first which had taken place since the conquest of the Canary Islands at the end of the 15th Century, has been shown by me in another place (*Examen Critique de l'Histoire de la Géographie*, t. iii, pp. 143—146) to be erroneous. Columbus saw the eruption of fire on Teneriffe, at the time of his first voyage of discovery, on the nights from the 21st to the 25th August, when he went in search of Doña Beatriz de Bobadilla, on the Gran Canaria. It is thus noticed in the Admiral's journal, under the Rubric of "Jueves, 9 de Agosto," which contains notices up to the 2d September,—"Vieron salir gran fuego de la Sierra de la Isla de Tenerife, que es muy alta en gran manera,"—"they saw a great deal of fire rising with a grand appearance out of the mountain of the Island of Teneriffe, which is very high;" Navarrete, *Col. de los Viages de los Españoles*, t. i, p. 5. The lady above named must not be confounded with Doña Beatriz Henriquez of Cordova,—the mother of his illegitimate son, the learned Don Fernando Colon, the historian of his father,—whose pregnancy in the year 1488 so materially contributed to detain Columbus in Spain, and to lead to the discovery of the New World being made on account of Castille and Leon, and not for Portugal, France, or England (see my *Examen Critique*, t. iii, pp. 350 and 367).

[99] *Cosmos*, see above, p. 232.

which were contributed by me and 20 by Boussingault.[100] In the basalt formations of the New World, olivine along with augite is as abundant as in Europe; but the black, basaltic trachyte of Yana Urcu, near Calpi at the foot of the Chimborazo,[1] as well as those enigmatical trachytes called *la reventazon del volcan de Anzango*,[2] contain no olivine. It was only in the great, brown-black lava-stream, with a crisp, scoriaceous surface raised like a cauliflower, whose track we followed in order to reach the crater of the volcano of Jorullo, that we met with small grains of olivine imbedded.[3] The prevailing scarcity of olivine in the modern lavas and the greater part of the trachytes seems less striking when we recollect that, essential as olivine appears to be for basalt in general, yet (according to Krug von Nidda and Sartorius von Waltershausen) in Iceland and in the German Rhone Mountains the basalt destitute of olivine is not distinguishable from that which abounds in it. The former it has been the custom from the earliest times to call *trap* and *wacke*, the latter we have in modern times denominated *Anemasite*.[4] Olivines, which sometimes occur as large as a man's head in the basalts of Rentières in the Auvergne, attain also in the Unkler quarries, which were the object of my first youthful researches to the size of 6 inches in diameter. The beautiful hypersthene rock of Elfdalen in Sweden, much employed

[100] A considerable portion of the minerals collected during my American Expedition, has been sent to the Spanish Mineral Cabinet, to the King of Etruria, to England and to France. I do not refer to the geological and botanical collections which my worthy friend and fellow-labourer Bonpland possesses, with the twofold right of self-collection and self-discovery. This extensive dispersion of the materials, (which, from the very exact account given of the places in which they originated, does not prevent the maintenance of the groups in their geographical relations,) has this advantage that it facilitates the most comprehensive and exact definition of those minerals whose substantial and habitual association characterises the different kinds of rocks.

[1] Humboldt, *Kleinere Schriften*, Bd. i, s. 139.

[2] *Ibid*, s. 202, and *Cosmos*, see above, p. 232.

[3] Humboldt, *Kl. Schr.* vol. i, p. 344. I have also found a great deal of olivine in the Tezontle (cellular lava, or basaltic amygdaloid?—in Mexican, tetzontli, *i.e.*, stone-hair, from *tetl*, stone, and *tzontli*, hair) belonging to the Cerro de Axusco in Mexico.

[4] Sartorius von Waltershausen, *Physisch-geographische Skizze von Island*, s. 64.

for ornamental purposes,* a granulated mixture of hypersthene and labradorite, which Berzelius has described as syenite, likewise contains olivine,[5] as does also (though more rarely) the phonolite of the *Pic de Griou*, in the Cantal.[6] While, according to Stromeyer, nickel is a very constant accompaniment of olivine, Rumler has on the other hand discovered arsenic in it,[7] a metal which has been found in the most recent times widely diffused in so many mineral springs, and even in sea-water. The occurrence of olivine in meteoric stones[8] and in artificial scoriæ, as investigated by Sefstrom,[9] I have already mentioned.

Obsidian.

As early as in the spring and summer of 1799, while I was preparing in Spain for my voyage to the Canary Isles, there prevailed generally among the mineralogists in Madrid,—Hergen, Don José Clavijo, and others,—the opinion that pumice was entirely derived from obsidian. This opinion had been founded on the study of some fine geological collections from the Peak of Teneriffe, and a comparison of them with the phenomena which Hungary furnishes, although the latter were at that time explained chiefly in accordance with the Neptunian views of the Freiberg school. Doubts of the correctness of this theory of formation, awakened at an early period in my mind by my observations in the Canary Isles, the Cordilleras of Quito, and in the range of Mexican volcanoes,[10] impelled me to direct my most earnest attention

[* It is there cut into vases, sometimes of a considerable size, and other ornamental objects. From the high polish it takes, and the contrast of its colours, it is one of the most beautiful stones in existence.—Tr.]

5 Berzelius, *Sechster Jahresbericht*, 1827, p. 392; Gustav Rose, in Poggend. *Ann.* vol. xxxiv, 1835, p. 14 (*Cosmos*, vol. i, p. 464).

6 Jenzsch, *Phonolithe*, 1856, p. 37, and Senft, in his important work, *Classification der Felsarten*, 1857, p. 187. According to Scacchi olivine occurs also, along with mica and augite, in the lime-blocks of the Somma. I call these remarkable masses *erupted blocks*, not lavas, for the Somma appears never to have ejected the latter.

7 Poggend. *Annal.* Bd. xlix, 1840, s. 591, and Bd. lxxxiv, s. 302; Daubrée in the *Annales des Mines*, 4me Série, t. xix, 1851, p. 669.

8 *Cosmos*, vol. i, p. 119, and vol. iv, p. 595.

9 *Ibid.* vol. i, p. 269, note*.

10 Humboldt, *Personal Narative*, vol. i, p. 113 (Bohn's Edition).

to two groups of facts;—first, the different nature of the *enclosures* of obsidians and pumice in general, and secondly, the frequency of the association or entire separation of them in well investigated, active volcanic structures. My journals are filled with notices on this subject, and the specific definition of the imbedded minerals has been ascertained by the most varied and most recent investigations of my ever ready and obliging friend, Gustav Rose.

Both glassy felspar and oligoclase occur in obsidian as well as in pumice, and frequently both of them together. As examples may be cited,—the Mexican obsidians of the Cerro de las Navajas on the eastern slope of the Jacal, collected by me,—those of Chico, with many crystals of mica,—those of Zimapan to the S. S. W. of the capital of Mexico, mixed with small distinct crystals of quartz, and the pumice of the Rio Mayo (on the mountain-road from Popayan to Pasto) as well as those of the extinct volcano of Sorata, near Popayan. The subterranean pumice quarries near Llactagunga[11] contain a large quantity of mica, oligoclase, and (which is very rare in pumice and obsidian), hornblende also; the latter, however, is also found in the pumice of the volcano of Arequipa. Common felspar (orthoclase) never occurs in pumice along with sanidine, nor is augite ever present. The Somma, not the cone of Vesuvius itself, contains pumice, enclosing earthy masses of carbonate of lime. It is by this remarkable variety of a calcareous pumice that Pompeii was overwhelmed.[12] Obsidians are rare in genuine lava-like streams; they belong almost solely to the Peak of Teneriffe, Lipari, and Volcano.

Passing now to the association of obsidian and pumice in one and the same volcano, the following facts appear. Pichincha possesses large pumice-fields and no obsidian. Chimborazo, like Etna, whose trachytes, however, have a

[11] See above, p. 342.

[12] Scacchi, *Osservazioni critiche sulla maniera come fu sepellita l'antica Pompei*, 1843, p. 10, in opposition to the theory proposed by Carmine Lippi, and afterwards shared by Tondi, Tenore, Pilla, and Dufrénoy, that Pompeii and Herculaneum were not overwhelmed by rapilli and ashes direct from the Somma, but that they were conveyed there by water. Roth, *Monogr. des Vesuvs.* 1857, s. 458, see above, p. 429.

totally different composition (containing labradorite instead of oligoclase), shows neither obsidian nor pumice; this same deficiency I observed on my ascent of the Tungurahua. The volcano Puracé, near Popayan, has a great deal of obsidian mixed in its trachytes, but has never yielded any pumice. The immense plains out of which rise the Ilinissa, Carguairazo, and Altar are covered with pumice. The subterranean pumice-quarries near Llactacunga, as well as those of Huichapa south-east of Queretaro; and the accumulations of pumice at the Rio Mayo,[13] those near Tschegem in the Caucasus,[14] and near Tollo[15] in Chili, at a distance from active volcanic structures, appear to me to belong to the phenomena of eruption from the numerous fissures in the level surface (of the earth. Another Chilian volcano, that of Antuco,[16] of which Pöppig has given a description as scientifically important as it is agreeably written) produces, like Vesuvius, ashes, triturated *rapilli* (sand), but gives out no pumice, no vitrified or obsidian-like mineral. Without the presence of either obsidian or glassy felspar, we sometimes meet with pumice in trachytes of very dissimilar composition, although in many cases it is not present. Pumice, as Charles Darwin observes, is entirely wanting in those of the Archipelago of the Galapagos. We have already remarked in another place that cones of cinders are wanting in the mighty volcano of Mauna Loa in the Sandwich Islands, as well as in the volcanoes of the Eifel[17] which once emitted lava-streams. Though the island of Java contains a series of more than forty volcanoes, of which as many as twenty-three are still active, yet Junghuhn was only able to discover two points in the volcano of Gunung Guntur, near Bandong and the great Tengger Mountains,[18] in which masses of obsidian have been formed. These do not appear to have given occasion

[13] *Nivellement Barométrique*, in Humboldt, *Observat. Astron.*, vol. i, p. 305, No. 149.

[14] See above, p. 345.

[15] For an account of the pumice-hill of Tollo, at a distance of two days' journey from the active volcano of Maypu, which has itself never ejected a fragment of such pumice, see Meyen, *Reise um die Erde*, Th. i, s. 338 and 358.

[16] Pöppig, *Reise in Chile und Peru*, Bd. i, s. 426.

[17] See above, p. 392, and notes, pp. 320—3.

[18] Franz Junghuhn, *Java*, Bd. ii, s. 388, 592.

to the formation of pumice. The sand-lakes of Dasar, which lie about 6828 feet above the mean level of the sea, are not covered with pumice, but with a layer of rapilli, described as being obsidian-like, semi-vitrified fragments of basalt. The cone of Vesuvius, which never emits pumice, gave out from the 24th to the 28th October, 1822, a layer 18 inches thick of sand-like ashes, consisting of pulverised trachytic-rapilli, which has never been mistaken for pumice.

The cavities and air-holes of obsidian in which crystals of olivine, probably precipitated from vapours, have formed, as, for example, in the Mexican Cerro del Jacal, are sometimes found in both hemispheres to contain another kind of enclosures, which seem to indicate the manner of their origin and formation. In the wider portions of these long-extended, and for the most part very regularly parallel cavities, fragments of half-decomposed earthy trachyte are found embedded. Beyond these the cavity runs on in the form of a tail, as if a gas-like elastic fluid had been developed by volcanic heat in the still soft mass. This phenomenon particularly attracted the attention of Leopold von Buch when he visited the Thomson collection of minerals at Naples in company with Gay-Lussac and myself in the year 1805.[19] The inflation of obsidian by the operation of fire, which did not escape attention in the early period of Grecian antiquity,[20] is certainly caused by some such development of gas. According to Abich, obsidians pass the more easily into cellular (not parallel-porous) pumice, the poorer they are in silicic acid and the richer they are in alkalies. It remains, however, very uncertain, according to Rammelsberg's researches,[21] whether the tumefaction is to be ascribed to the volatilisation of potash or hydrochloric acid. It is probable that similar phenomena of inflation in trachytes rich in obsidian and sanidine, in porous basalts and amygdaloids in pitch-stone, tourmaline, and that dark-brown flint which loses its colour, may have very different causes in the different materials

19 Leopold von Buch, in the *Abbandl. der Akademie der Wiss. zu Berlin*, for the years 1812—1813 (Berlin, 1816), s. 128.

20 *Theophrastus de lapidibus*, s. 14 and 15 (*Opera ed. Schneider*, t. i, 1818, p. 689, t. ii, p. 426, and t. iv, p. 551), says this of the "liparian stone" (λιπαραῖος).

21 Rammelsberg, in *Poggend. Annal.*, Bd. lxxx, 1850, s. 464, and fourth supplement to his *Chemische Handwörterbuch*, s. 169; compare also *Bischof. Geol.*, Bd. ii, s. 2224, 2232, 2280.

themselves. An investigation which has now been long looked for in vain, founded on accurate experiments, exclusively directed to these escaping gaseous fluids, would lead to an invaluable extension of our knowledge of the geology of volcanoes, if at the same time attention were paid to the operation of the sea-water in subterranean formations, and to the great quantity of carburetted hydrogen belonging to the commingled organic substances.

The facts which I have brought together at the end of this section, the enumeration of those volcanoes which produce pumice without obsidian, and those which yield a great deal of obsidian and no pumice,—the remarkable, not constant, but very diversified association of obsidian and pumice with certain other minerals, early led me, during my residence in the Cordilleras of Quito, to the conclusion that the formation of pumice is the result of a chemical process, which may be verified in trachytes of very heterogeneous composition, without the necessity of a previous intervention of obsidian (that is to say, without its pre-existence in large masses). The conditions under which such a process is performed on a large scale, are perhaps founded (I would here repeat) less on the diversity of the material than on the gradation of heat, the pressure determined by the depth, the fluidity, and the length of time occupied in solidification The striking, though rare, phenomena presented by the isolation of immense subterraneous pumice-quarries, far from any volcanic structures (conical and bell-shaped mountains), lead me at the same time to conjecture[22] that a not inconsiderable—perhaps even, in regard to volume—the greater, number of the volcanic rocks have been erupted, not from upraised volcanic structures, but from a net-work of fissures on the surface of the earth frequently covering over in the form of strata a space of many square miles. To these probably belong those masses of trap of the lower silurian formation of the south-west of England, by the chronometric determination of which my worthy friend, Sir Roderic Murchison, has so greatly increased and heightened our acquaintance with the geological construction of the globe.

[22] See above, pp. 308, 330 332—336, 344—346, 354. For particulars respecting the geographical distribution of pumice and obsidian in the tropical zone of the New Continent, see Humboldt, *Essai Géognostique sur le gisement des Roches, &c.*, 1823, pp. 340—342, and 344—347.

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