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II. Second Annual Report of the United States Geological Survey, 1880–'81, by J. W. Powell. 1882. 8°. lv, 588 pp. 61 pl. 1 map.

III. Third Annual Report of the United States Geological Survey, 1881–'82, by J. W. Powell. 1883. 8°. xviii, 564 pp. 67 pl. and maps.

IV. Fourth Annual Report of the United States Geological Survey, 1882–'83, by J. W. Powell. 1884. 8°. xxxii, 473 pp. 85 pl. and maps.

V. Fifth Annual Report of the United States Geological Survey, 1883–'84, by J. W. Powell. 1885. 8°. xxxvi, 469 pp. 58 pl. and maps.

VI. Sixth Annual Report of the United States Geological Survey, 1884–'85, by J. W. Powell. 1886. 8°. xxix, 570 pp. 65 pl. and maps.

VII. Seventh Annual Report of the United States Geological Survey, 1885–'86, by J. W. Powell. 1888. 8°. xx, 656 pp. 72 pl. and maps.

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MONOGRAPHS.

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XIV. Fossil Fishes and Fossil Plants of the Triassic Rocks of New Jersey and the Connecticut Valley, by John S. Newberry. 1888. 4°. xiv, 152 pp. 26 pl. Price $1.00.

In preparation:

XV. Younger Mesozoic Flora of Virginia, by William M. Fontaine.

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50. Formulas and Tables to facilitate the construction and use of Maps, by R. S. Woodward.

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Mineral Resources of the United States, 1883 and 1884, by Albert Williams, jr. 1885. 8°. xiv, 1016 pp. Price 60 cents.

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Washington | government printing office | 1888

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Washington | government printing office | 1888

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Author title.

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United States geological survey | J. W. Powell, director | — | Geology | of the | quicksilver deposits | of the | Pacific slope | with an atlas | by | George F. Becker | [Vignette] |

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VOLUME XIII

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UNITED STATES GEOLOGICAL SURVEY

J. W. POWELL, DIRECTOR

GEOLOGY

OF THE

QUICKSILVER DEPOSITS

OF THE

PACIFIC SLOPE

WITH AN ATLAS

BY

GEORGE F. BECKER

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LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
U. S. GEOLOGICAL SURVEY,
CALIFORNIA DIVISION OF GEOLOGY,
Washington, D. C., July 19, 1887.

SIR: I have the honor to transmit herewith a report on the geology of the quicksilver deposits of the Pacific slope, prepared in accordance with your instructions.

Very respectfully, your obedient servant,

GEORGE F. BECKER,
Geologist in Charge.

HON. J. W. POWELL,
Director U. S. Geological Survey.

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PREFACE.

The field work of the investigations recorded in this volume occupied nearly the whole of three seasons, beginning in 1883. All the mines might have been examined and the maps colored in a much shorter time, but it was found soon after the examinations were begun that they could not be completed satisfactorily without also solving some important general problems affecting the whole region, and much of the time spent was devoted to these questions.

The examinations of the Knoxville and New Idria districts furnished me with strong paleontological and structural grounds for believing that an important and previously undetermined non-conformity existed in the Coast Ranges. On my application, Dr. C. A. White devoted one season to examining my collections of fossils and their field occurrence with me. He indorsed my conclusions in all respects. The paleontological statements of this report are all on his authority, excepting where otherwise accredited.

It was found that the quicksilver districts of California afforded a remarkable opportunity for the investigation of the metamorphism of Mesozoic rocks and that it was highly desirable to determine what connection, if any, existed between the formation of ore deposits and this metamorphism. The investigation occupied much time and was most laborious.

It was known before these investigations were undertaken that the deposition of cinnabar was probably still taking place at Sulphur Bank and Steamboat Springs. It was of course necessary to make an effort to discover whether such was really the case, and, if so, under what conditions the solution and precipitation of cinnabar and the accompanying minerals occurred. The problems presented by this inquiry were far from being simple or readily solved.

Dr. W. H. Melville has had charge of my laboratory throughout the period covered by these investigations. He has made all the analyses recorded in this report, as well as a large part of the experiments. A portion of his time has been occupied in investigations which are not recorded here, but which I hope to publish soon. His work has been very difficult, but entirely satisfactory to me.

Mr. H. W. Turner has assisted me in all the field work, and Chapter XII is written from his notes. His accuracy and powers of observation have been very valuable to me. Mr. Waldemar Lindgren joined me only in time for the last season's field work. His assistance in the microscopical lithology has been very efficient and important. I could not without aid have accomplished in a reasonable time so trying an investigation as that of the metamorphic rocks of the Coast Ranges.

For myself, I may say that I have studied with care in the field every portion of the areas surveyed in detail; I spent months at the microscope and made many important chemical experiments on the solubility of ores. It has been my endeavor to do justice to all sides of a very fine subject and to draw only legitimate conclusions from the facts observed by my assistants and myself. I approached the problems mentioned above entirely without preconceived ideas of the solutions to be reached, and have expressed my conclusions as to the geology of California or of other regions without regard to the opinions of others; but, while entertaining some confidence in the correctness of my results for the region surveyed, I do not even incline to the hypothesis that all crystalline sedimentary rocks have a history similar to that of those which I have described or that ore deposits are all formed in a similar way.

The superintendents of the mines examined have afforded me every facility, often at inconvenience to themselves, and I have much to thank them for. Mr. Louis Janin has supplied me with many valuable notes gathered in his large experience as a mining expert. Mr. Frank Reade, who assisted me in examining the Comstock lode, was surveyor of the New Almaden mine during the period covered by the present investigation, and he prepared for me the excellent plans and sections of that mine.

In addition to those who took part in the present investigation I am indebted to numerous previous observers, to whom I have endeavored to assign due credit in the proper places.

Readers will perhaps notice the absence of illustrations of magnified thin sections in this volume. After having presented in a former report illustrations of this kind which are generally acknowledged to be unsurpassed by any yet published, I have come to the conclusion that the lessons which they teach do not repay their cost in time and money.

I have thought it best to make each chapter in this volume as far as possible independent of the rest. In doing so I am sure that I meet the wishes of many readers who will care to consult only certain portions of the book. This plan, however, involves some repetition, which may prove wearisome to continuous readers. I crave their indulgence in this respect for the sake of the larger class. Personally, I should prefer never to restate a fact or an opinion.

After the manuscript of this report was substantially completed I was authorized to visit the great Almaden mine in Spain and the Tuscan deposits. Such a visit was almost essential to the purposes of the investigation; for the results which I had reached from study of the American deposits differed in important respects from the conclusions of some geologists respecting the great Spanish deposit. If they were right, it became necessary to warn American miners that cinnabar might be looked for under very different conditions from those described in this volume. If the greatest quicksilver deposit of the world proved similar in its mode of occurrence to those of California, the conclusions drawn from the latter would gain greatly in strength. I had the satisfaction of finding that the deposit of Almaden showed an association with eruptive phenomena, a structure, and a mineral association similar to those which are typical of the Pacific slope. Such statements as that the Almaden ore bodies are not veins, that the cinnabar is free from other sulphides, that it is accompanied by no gangue minerals, that it was deposited with the inclosing rocks, that it is deposited by substitution for sandstone, and that there is no evidence of a connection between the deposition and eruptive phenomena—these allegations are, in my judgment, erroneous. The Tuscan deposits, too, I found similar to some in California. Only a few notes concerning my studies of these mines are included in this volume. I exuect to write more fully of them hereafter.

JULY, 1887.

BRIEF OUTLINE OF RESULTS.

Quicksilver appears to be rather more than three times as abundant in nature as silver. The quicksilver produced in the world from 1850 to 1885, inclusive, weighed 1.74 times as much as the silver produced, but the value of the silver was about 16.4 times that of the quicksilver. The great quicksilver-producing localities of the world have been Almaden in Spain, Idria in Austria, Huancavelica in Peru, California, and the province of Kwei-Chau in China. No statistics are known to exist of the Chinese product. The total known products of the other regions take rank in the order in which they are named above, but of late years Peru has produced nothing and from 1850 to 1885 California yielded about half the total product. The production of Italy is more important than it is usually assumed to be. In 1886 the yield was 7,478 flasks. The production of California, which was nearly 80,000 flasks in 1877, was only about 30,000 in 1886.

A chain of quicksilver deposits of very greatly varying commercial importance almost girdles the world. Beginning in Spain, these deposits are distributed along the great chain, including the Alps, Caucasus, and Himalayas to China; thence through Japan along the eastern edge of the Asiatic continent to the Arctic circle. Beginning again in Alaska, the deposits follow the western Cordilleras down to Chili. Brief descriptions of the more important or more interesting of these deposits are given in Chapter II and serve as an introduction to the discussions of the deposits of the Pacific slope.

The sedimentary rocks of the Coast Ranges of California are almost all composed of granitic detritus. A portion of these have been subjected to very intense metamorphism and have been converted into thoroughly crystalline rocks, in part schistose. These rocks are of Cretaceous age and are grouped as pseudodiabase, pseudodiorite, glaucophane-schists, phthanites, and serpentine. Very elaborate field studies, microscopical examinations, and chemical analyses of these rocks are given in Chapter III, which is mainly devoted to the investigation of their origin and the processes by which they have become recrystalline. The conclusion reached is that dynamical action, together with warm waters carrying magnesian salts and silica in solution, effected the metamorphism at the epoch of an exceedingly violent upheaval. This chapter also includes an investigation of concretions in sandstone, which are referred to the action of organic matter, and an analysis of the conditions under which decomposition will produce rounded nodules, like pebbles.

The massive rocks of the quicksilver areas include granite, ancient porphyries, andesites, rhyolite, and basalt. A new group of andesites is discussed, for which the name *asperites* is suggested. It is shown that these rocks are of variable mineralogical composition, even in the same eruptions, while all of them share a trachytic habitus. The name is simply a latinized equivalent of trachyte. Very remarkable andesitic and basaltic glasses occur near Clear Lake in areas of unusual size. These glasses are extremely acid, but contain also a very high percentage of alkalis, and it is because of this peculiar chemical composition that they have failed to crystallize, not because they have cooled more rapidly or under less pressure than the accompanying crystalline rocks. An attempt is also made to show that the original crust of the earth was granitic and reasons are given for believing that the primeval rock is exposed in California. The lavas burst through the granite, and the conclusion is reached that they cannot possibly consist of remelted sediments.

The historical and structural geology of the quicksilver belt is discussed in Chapter V. It is shown that the metamorphosed rocks pass over into early Cretaceous beds containing a very characteristic fossil of the genus *Aucella*. Soon after the era in which this mollusk lived—the Neocomian—occurred the great upheaval which induced the metamorphism. The next strata in point of age comprise a hitherto undetected group of the middle Cretaceous called the Wallala beds. They were laid down unconformably on the already metamorphosed Neocomian. At the very end of the Cretaceous the Chico series were deposited for the most part on the metamorphic rocks and unconformably with them. Following the Chico are the Téjon beds, which are here regarded as Eocene; but there was continuity of life and of sedimentation from the Chico to the Téjon, or from the Cretaceous to the Tertiary—a state of things detected nowhere else in the northern hemisphere. Upon the Téjon lie the Miocene rocks with no notable non-conformity. The close of the Miocene was marked by an important upheaval, which was recognized by earlier observers. The volcanic period seems to have begun nearly at this time. The end of the Pliocene was also marked by disturbances, and most of the asperites seem to have been erupted at this epoch. The ore deposits stand in close relation to the volcanic phenomena and are probably nearly or quite all Post-Pliocene.

The gold belt of California contains *Aucella*-bearing beds in Mariposa and Tuolumne Counties. This shell is of the same species as that in the Coast Ranges, and the first known upheaval of these mountains was contemporaneous with an important addition to the Sierra Nevada. A description of various forms of *Aucella* from different portions of the world, by Dr. C. A. White, with plates, forms an appendix to this chapter.

Descriptive chapters follow dealing with the various districts of which detailed surveys were made. Each of these districts affords special facilities for the study of some special topic. The Clear Lake region contains fresh-water Pliocene beds, and in it the age of the andesites can be determined. It also contains remarkable areas of volcanic glass. At Sulphur Bank cinnabar is being precipitated from heated waters largely by the action of ammonia. At Knoxville, besides the ore deposits, there are admirable opportunities for determining the age of the metamorphic rocks and for studying the process of alteration. At New Idria the non-conformity between the metamorphic rocks and the Chico and the continuity between the Chico and Téjon appear. The New Almaden mine is particularly well adapted for the study of the structure of the ore deposits. At Steamboat Springs cinnabar is being deposited without the complications introduced by the presence of ammonia.

In Chapter XII the Great Western, Great Eastern, and Napa Consolidated mines are described, and in the next chapter more or less information is given concerning each of over fifty minor deposits on the Pacific slope. Some of these have been productive mines, while others are mere prospects or possess only a geological interest.

A general discussion of the deposits described follows, including the enumeration of the gangue minerals, the microscopical character of ores, etc. It appears that the cinnabar has been deposited solely in pre-existing openings, and never by substitution for rock. The fissure systems, which are always present, are very irregular, and deposits cannot be conveniently classified according to existing systems. A new descriptive term, "chambered vein," is suggested, which would include nearly all the deposits. A chambered vein is defined as a deposit consisting of an ore-bearing fissure and of ore bodies contiguous with the fissure which extend into the country rock. It appears that all of the deposits described have probably been deposited in the same way from hot sulphur springs.

Chapter XV deals with the processes by which the ore has been dissolved and precipitated in nature. It is shown by experiment and analysis that cinnabar unites with sodium sulphide in various proportions, forming soluble double sulphides, and that these compounds can exist in such waters as flow from Sulphur Bank and Steamboat Springs either at ordinary temperatures or above the boiling-point. Metallic gold, iron pyrite, copper pyrite, and other minerals found with cinnabar are also soluble in the same solutions.

A discussion of the origin of the ore concludes the investigation. It is shown that the quicksilver is probably derived from granitic rocks by the action of heated sulphur waters which rise through the granite from the foci of volcanic activity below that rock.

For the convenience of those who consult the report the separate chapters are made as far as possible independent of one another, a plan involving a certain amount of repetition. Further to facilitate the use of the volume, the last chapter presents a summary of those which precede it.

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GEOLOGY OF THE QUICKSILVER DEPOSITS OF THE PACIFIC SLOPE.

By George F. Becker.

CHAPTER I.

STATISTICS AND HISTORY.

Relative value of quicksilver.—The exceptional physical and chemical properties of quicksilver give this metal a peculiar position in the markets of the world, which it is desirable to illustrate by comparison with that of other metals. The normal price of a metal is slightly, and only slightly, greater than the average cost of production; for competition forces prices towards a minimum and in every industry there are individual establishments which, through errors in judgment or want of foresight, work at an actual loss. For purposes of comparison it is fair to assume that the average cost of production is not far from 90 per cent. of the average price. From January, 1850, to January, 1886, the average price of quicksilver may be taken at about $50 a flask, though the fluctuations have been so great and so frequent that a precise mean could not possibly be reached. The average total cost has probably been about $45, or say $1.30 a kilogram. It costs about twenty-nine times as much to produce a kilogram of silver and four hundred and sixty times as much to produce a kilogram of gold. These facts afford sufficient proof that quicksilver is a far more abundant metal than is silver. Were quicksilver and silver produced in exactly equal quantities and were the extraction equally expensive, the cost of production would be substantially proportional to the abundance of the metals in nature. The weight of quicksilver produced is considerably in excess of the weight of silver. Were the quicksilver product about three-fifths of the actual amount and were the richer deposits only worked as a consequence of this restriction, the metal could be produced still more cheaply. The cost of reduction per kilogram, however, is trifling for quicksilver, but very considerable for silver. Making due allowance for this fact, it appears that quicksilver must be three or more times as abundant in nature as silver.

The quantity of metal produced bears an intimate but not a simple relation to the selling price. Higher prices would stimulate the production of quicksilver, but restrict consumption for certain purposes and to a certain extent. With some metals decrease of price brings with it a greatly increased consumption, but this has not hitherto proved to be the case with quicksilver, which is employed for very few purposes in large quantities. The consequence is that, in comparison with the quantity produced, quicksilver is the cheapest of metals; or, in other words, the value of the total product is very small. The total weight of quicksilver produced in the past thirty-six years is less than twice as great as that of silver, but the total value of the quicksilver is only one-sixteenth that of the silver. The world has yielded nearly one-sixteenth as much gold as quicksilver during the past thirty-six years, but the total gold product is worth thirty times as much as that of quicksilver. Tin is a metal sharing some properties with quicksilver, and, if one compares frozen quicksilver with tin, the likeness is much stronger. The tin produced in thirty-six years weighs about six times as much as the quicksilver; but, because the demand for tin is insatiable, the price remains sufficiently high to make the total value of the tin more than twice as great as that of quicksilver.

These relations may be succinctly expressed in a table such as the following, which gives the total weights and values, the value of a kilogram of each metal, and the relative quantities when gold, silver, and quicksilver are each regarded as unity. Silver is now worth much less than the mint value; but, for a great part of the period which has elapsed since 1850, this metal has been at a slight premium. The mint value is thus sufficiently close to the average for the present purpose. The data as to the gold and silver products are compiled from figures given by Dr Soetbeer and Dr. Kimball.[1] The figures for tin are only approximations, but are close enough for the purpose.[2] In estimating the total quicksilver I have supposed, with Mr. Randol, that the average yearly product, besides that of Almaden, Idria, and California, is 2,000 flasks.[3] The mean value is assumed at $50 a flask.

The world's product of four metals from January, 1850, *to January,* 1886.

	Total product.				Total value.				Value per kilogram.			
	Kilograms.	Approximate ratios.			Dollars.	Approximate ratios.			Dollars.	Approximate ratios.		
Gold	6,484,922	1.	0.11	0.064	4,309,879,161	1.	1.79	29.3	664.60	1.	16.	458.
Silver..........	58,054,906	8.9	1.	0.57	2,413,203,111	0.56	1.	16.4	41.5676	0.063	1.	28.7
Quicksilver ...	101,300,000	15.6	1.74	1.	146,800,000	0.03	0.06	1.	1.45	0.002	0.035	1.
Tin	620,000,000	95.6	10.7	6.12	322,400,000	0.07	0.13	2.2	0.52	0.0008	0.013	0.36

Uses for quicksilver.—The low value of quicksilver, which is abnormally small considering the comparative rarity of the metal, is due to its restricted use. It is true that the number of purposes to which quicksilver is applied is very great; but most of these applications imply the consumption of trifling quantities of the metal. A single flask of quicksilver in the form of mirror-backs, thermometers, or medicines goes a long way. The great mass of the metal is employed in the amalgamation of ores and in the manufacture of vermilion. As only certain silver ores can be economically amalgamated, the demand for this purpose fluctuates greatly. The bullion of the Comstock was all extracted by this process, but amalgamation is not applicable to any of the ores of Leadville. The demand for vermilion also is limited by the competition of other red pigments. A few years since, Mr. J. A. Baur, of San Francisco, devised a means for the extirpation of phylloxera, which consists in intimately mixing clay with quicksilver (or "ex-

[1] Report of the Director of the Mint, 1885, pp. 169 and 171.

[2] They are estimated from data contained in Mr. J. A. Phillips's Ore Deposits and statistics which I gathered at the Paris Exposition of 1878 (Reports of the United States Commissioners, vol. 4).

[3] This for the later years is much too small. The Tuscan mines are said to be producing about six hundred flasks a month.

tinguishing" quicksilver with clay) and adding this material, which is substantially blue mass, to the soil in which the vines are planted. The process seemed at first successful, but subsequently failed to give the desired result. Prof. E. W. Hilgard[1] has experimented on the process and found it entirely successful when properly carried out. No lead or oil should be added to the quicksilver, and the soil either must be sandy or, after impregnation with mercury, must be warmed in a hot sun or by artificial means, to saturate it with mercurial vapor. Should this process be widely introduced it would greatly enlarge the market for quicksilver and would correspondingly benefit the mining industry.

Comparison between various mining regions.—Quicksilver has been produced in large quantities in but few localities. The principal productive regions have been Almaden in Spain, Idria in Austria, Kwei-Chau in China, Huancavelica in Peru, and California. Italy has yielded a little quicksilver for a long time and a considerable number of localities elsewhere have had a temporary or local importance, but none is to be compared with those enumerated in the last sentence. Peru is now producing no quicksilver and the Chinese production is small, but it is certain that the Chinese deposits are not exhausted and Huancavelica may possibly resume production when the conditions for intelligent exploitation are better.

Such geological interest as attaches to the occurrence of exceptionally large quantities of cinnabar is independent of the question of future productiveness, and a few historical notes on the past yield may be welcome to the reader.

The great quicksilver mine of the world is Almaden, which has been worked since at least 415 years before the Christian era, and perhaps still longer. What quantity of ore was extracted from it in ancient times and in the Middle Ages there is no means of knowing, further than that Pliny reports 10,000 pounds of cinnabar a year as brought to Rome from Almaden (Sisapo). The product was certainly never large until the amalgamation process was invented in 1557. Since that time the product has increased pretty steadily, and the output since 1850 is nearly equal to that of the entire eighteenth century. The deposit is said to grow richer in depth

[1] Science, vol. 6, 1885, p. 497, and vol. 7, 1886, p. 462.

and is certainly far from being exhausted; on the contrary, in the method of exploitation followed, large pillars of ore are left as reserves. The contents of these reserves would be sufficient to yield the usual product for very many years to come, but no authoritative statement of the total amount of metal contained in them has been made. The total recorded yield is nearly four million flasks.

The deposits of Idria were discovered, according to some authorities, in 1490; according to others, in 1497. Since 1580 they have been worked by government officials for public account. The mines and reduction works are extremely well managed, and the greatest additions which have been made to the technology and geology of quicksilver have come from this establishment. The mine is worked at a large profit, and in 1880 the director, that eminent mining geologist, the late M. V. Lipold, stated with evident and justifiable pride that the average clear profit to the state for the preceding sixty-five years had been 365,000 florins[1] per annum. The profit in 1874 lacked but a few thousand of 2,000,000 florins, and in only three of the sixty-five years was there a deficit. As at Almaden, the deposit grows stronger in depth, and in 1880 the reserves were known to contain no less than 30,142,000 kilograms, or 873,504 flasks of 75 Spanish pounds. The total known product up to January, 1886, is over a million and a half of flasks; but no data were preserved for some forty years during the term which had elapsed since work began. The product of Idria has been about three-eighths of that of Almaden.

In northern Italy, at no great distance from Idria, are several deposits, of which the principal is the Vallalta. There is also a series of mines in Tuscany stretching along the western coast of Italy. Some of the deposits are of considerable commercial importance. The product is given by Mr. A. d'Achiardi as follows, in kilograms:

	1860.	1870.	1878.	1879.	1880.
Tuscan mines	3,500	15,000	120,563	129,600	115,940
Venetian mines	30,256	31,192	3,080	2,464	(?)

[1] Austrian paper money. A florin, silver, is $0.4878. The value of paper fluctuates. At 45 cents the above yearly profit would be $164,250.

This table serves to show how the quicksilver mining industry has been transferred from Vallalta to Tuscany. The sum of the products here given for five years is 13,087 flasks, Spanish standard, or an average of 2,617 flasks a year. From 1850 to 1860 the average was probably considerably lower. Since 1880 it has been greater.[1]

The ore deposits of Huancavelica, in Peru, were discovered soon after the invention of the amalgamation process. There are over forty deposits in the district, but the principal mine was the Santa Barbara. This mine was sometimes worked by the state and was sometimes leased to private parties on condition that the metal obtained should be made over to the state at a fixed price. Stealing, however, was prevalent to such an extent that merchants flocked to Huancavelica with no inconsiderable sums of money to buy from miners and foremen the metal which it was their duty to turn into the treasury. The technical management seems to have been as bad as the business administration of this property, and there can be little doubt that skillful and honest work would have secured a far larger total output. With all disadvantages, the Santa Barbara mine alone yielded to the state about as much quicksilver as has thus far been produced in California.

Of the mines of Kwei-Chau, in China, very little is known. Baron von Richthofen, however, a most excellent judge, believed this district to be the richest quicksilver region in the world.

Table of products.—I have thought it worth while to bring the figures representing the known production of the more important quicksilver regions together for comparison in the following table. The figures for Almaden are taken from a memoir by Mr. H. Kuss[2] and data furnished by Mr. J. B. Randol.[3] In Mr. Kuss's table of product for 1800 to 1875, there is a misprint amounting to 1,000,000 kilograms. Mr. Randol's data prove that the total for this period given by Mr. Kuss is correct and that the misprint is between 1800 and 1850. The product of Almaden for 1885 was 47,026 flasks. The

[1] According to data furnished to me by the superintendents of the Siele and the Cornachino mines (the only ones at work, so far as I can ascertain, in Tuscany), the average product for the five years 1881 to 1885 was 5,789 flasks. The product for 1886 was 7,478 flasks.

[2] Annales des mines, vol. 13, 1878, p. 150.

[3] Mineral Resources U. S. 1883 and 1884, p. 492.

data for Idria up to January 1, 1880, are from an official publication.[1] The amount of quicksilver definitely known to have been produced in the sixteenth century is 2,934,000 kilograms. "At the beginning of the seventeenth century the production rose, and, beginning with 1612, the product was for some years 1,680 metrical centals annually. During the later years the average yearly product was 1,120 centals." I shall assume that this latter and smaller output extended over seventy years. This assumption, in combination with the figures just given, leads to the total product prior to 1800 which appears in the table. The production of Idria from 1800 onwards is from exact official figures.[2] The data for Huancavelica are taken from Mr. M. E. de Rivero's memoir on the district.[3]

The data from 1571 to 1790 are for the Santa Barbara mine alone, from which the state received 1,040,469 quintals 30 pounds 15 ounces during this period. The known product subsequent to 1790 includes other mines as well as the Santa Barbara.

Product of the principal districts, in Spanish flasks of 75 Spanish pounds or 34.507 kilograms.

	First record.	Up to 1700.	1700 to 1800.	1800 to 1850.	1850 to 1886.	Total to Jan., 1886.
	Year.					
Almaden	1564	517,684	1,221,477	1,091,075	1,135,576	3,965,812
Idria	1525	399,861	608,743	242,226	301,549	1,552,379
Huancavelica	1571	881,867	543,642	75,604	....	1,501,113
California	1850	....	....	....	1,429,346	1,429,346
		1,799,412	2,373,862	1,408,905	2,866,471	8,448,650

Discovery of California deposits.—In the last century Mexico was almost entirely dependent upon Spain and Peru for the quicksilver needed for the amalgamation process. As this process was indigenous to Mexico and was also a national industry peculiarly suited to her resources, it was felt to be specially

[1] Das k. k. Quecksilberwerk zu Idria in Krain, 1881.

[2] In the memoir already referred to, Lipold gives the product of the mine from 1800 to the end of 1879 at 78,480 metrical centners, which is 227,432 flasks. The present director, Mr. Joh. Novák, has been good enough to supply me with the following figures, in flasks:

	1880.	1881.	1882.	1883.	1884.	1885.	1886.
Product of Idria	10,510	11,333	11,652	13,153	13,968	13,501	14,495

[3] Memoria sobre el rico mineral de azogue de Huancavelica, Lima, 1848.

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desirable that quicksilver mines should be developed on her own soil. Accordingly, as far back as 1783, quicksilver mining was made the subject of special legislation. A quicksilver fund was established out of the public revenues for the purpose of promoting the discovery and development of quicksilver mines. On every hundred weight of the metal produced a bounty was paid, and a large sum was offered to those who should succeed in producing a specified quantity annually.[1]

Not only are there many skillful miners and prospectors in Mexico, but so universal is the interest in the subject that a knowledge of ores has become almost instinctive among Mexicans. It would be supposed that, when their natural acuteness in mineralogy was sharpened by the promised rewards, some of the many cinnabar deposits of California would have been discovered within a few years after the promulgation of the edicts of 1783; but this did not happen for more than sixty years.

It has been asserted that the California Indians knew of the cinnabar of New Almaden and used it for paint long before the Spanish-American immigrants became acquainted with it. The evidence on this point seems to be quite inconclusive, and it is not impossible that the incident is borrowed from the history of Peru, where, as all historians are agreed, the subjects of the Incas were familiar with the use of vermilion. The same story has been related within a few years of Nevada Indians. It is hard to say whether it is more probable that the aborigines repeated the same series of discoveries in personal adornment at these three points or that the whites have forced the same characteristic anecdote into service a number of times, with changes of names and dates. It has also been asserted that the Spanish Californians excavated cinnabar at New Almaden and used it to paint the mission church at Santa Clara. The occurrence was certainly known as early as 1824, when Antonio Suñol and Luis Chaboya erected a mill on a neighboring stream and endeavored to extract silver from the cinnabar. A second attempt of the same kind was made in 1835. Late in 1845 Andreas Castillero, a Mexican officer who was on a journey to Sutter's Fort, passed through Santa Clara. The mysterious ore was shown to him, and he is

[1] The notes on the history of the discovery of quicksilver in California are derived from the testimony in the case of The United States *vs.* Andreas Castillero, decided by the Supreme Court, December term, 1862. (Black's S. C. R., vol. 2.)

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said to have visited the mines. He shortly afterwards returned, and what occurred, according to the testimony of Jacob P. Leese, is so curious and interesting as to be worth quoting:

> About the latter part of November, or first of December, 1845, I went into the mission of Santa Clara to dine with Padre Real, of the mission. Mr. Castillero was there. Our general conversation through dinner was about this mine and of experiments which Castillero had been trying to find out what the mineral was. He made a remark and said he thought he knew what it was. If it was what he supposed it was he had made his fortune. We were anxious to know what it was. He got up from the table and ordered the servant to pulverize a portion of this ore. After it was pulverized he ordered the servant to bring in a hollow tile full of lighted coals. He took some of the powdered ore and threw it on the coals. After it got perfectly hot he took a tumbler of water and sprinkled it on the coals with his fingers. He then emptied the tumbler and put it over the coals upside down; then took the tumbler off and went to the light to look at it; then made the remark that it was what he supposed it was—"quicksilver." He showed all who were there the tumbler, and we found that it was frosted with minute globules of metal, which Castillero collected with his finger and said it was quicksilver. He then said to-morrow he would test it thoroughly and find out what it was worth. He considered it very rich on account of the weight of the ore, and if it proved as rich as the quicksilver mines in Spain, that the Mexican government had offered to any one for the discovery of such a mine in the Republic of Mexico one hundred thousand dollars.

Like so many Mexican practices, this test has a very quaint and medieval character, but it was nevertheless founded upon correct principles and was calculated to afford a demonstration of the presence of quicksilver without the use of reagents which were, perhaps, inaccessible to Castillero. By the use of glowing coals and water he effected a steam-roasting of the ore, which was sure to liberate metallic mercury if cinnabar was present, and the cold wet tumbler acted as an efficient closed condenser. The test was, in fact, equivalent to the ordinary blow-pipe test in a closed tube, the action of alkaline reducing agents being replaced by that of steam.

Castillero laid claim to the property as a mine containing silver, gold, and quicksilver. He either had difficulty in thinking of a mine containing no precious metals or thought it expedient to make his claim sufficiently broad. There was nothing unnatural in the association, for the three metals are found together at almost innumerable points in America and Europe. In the opinion of the Supreme Court of the United States, indeed, this association constitutes an inconsistency which tended strongly to impair the validity of the entire claim, but judicial geology is well known to belong to a special school. Work was begun almost immediately under Castillero's direction, gun-barrels being used as retorts. These insignificant reduction works have now grown to very imposing dimensions, but the quantity of ore in sight is no longer so satisfactory.

The other deposits of California have been found in part by systematic prospecting and in part by accident. The Redington mine was discovered in making excavations for a highway. The Sulphur Bank, as its name implies, was worked for sulphur for some time before the presence of the underlying cinnabar was suspected. The very high prices which quicksilver brought in 1874 and 1875 greatly stimulated production and the discovery of deposits. None of those found grows richer as depth from the surface increases, but most of them are very imperfectly developed, and, as will be shown in subsequent chapters, this feature depends upon peculiarities of the systems of fissures connected with the ore deposits, not upon characteristics of cinnabar. It is by no means impossible that great deposits of cinnabar, comparable with those of Idria, if not with those of Almaden, still exist in California. None such, however, is now known and the amount of ore in sight is not great.

Production in California.—The following table of production of the mines of California has been compiled from year to year by Mr. J. B. Randol and is well known to those interested in the subject.

Production of quicksilver on the Pacific Slope, in flasks of 76½ pounds avoirdupois.

Years.	New Almaden.	New Idria.	Redington.	Sulphur Bank.	Guadalupe.	Great Western.	Pope Valley.	Napa Consolidated.[1]	St. John.	Altoona.
1850	7,723	Production from 1858 to 1866, 17,455 flasks—no yearly details obtainable—included in production of various mines.	....	....	Yearly production previous to 1875 not obtainable; total, estimated at 20,000 flasks, included in production of various mines.	....	....	....	....	Some was produced prior to 1875, but no record was kept; estimated production previous to 1875, 1,000 flasks, included in production of various mines.
1851	27,779		....	....		....	....	....	....	
1852	15,901		....	....		....	....	....	....	
1853	22,284		....	....		....	....	....	....	
1854	30,004		....	....		....	....	....	....	
1855	29,142		....	....		....	....	....	....	
1856	27,138		....	....		....	....	....	....	
1857	28,204		....	....		....	....	....	....	
1858	25,761		....	....		....	....	....	....	
1859	1,294		....	....		....	....	....	....	
1860	7,061		....	....		....	....	....	....	
1861	34,429		....	....		....	....	....	....	
1862	39,671		444	....		....	....	....	....	
1863	32,803		852	....		....	....	....	....	
1864	42,489		1,914	....		....	800	....	....	
1865	47,194		3,545	....		....	....	....	....	
1866	35,150	6,525	2,254	....		....	....	....	....	
1867	24,461	11,403	7,862	....		....	....	....	....	
1868	25,628	12,180	8,686	....		....	1,122	....	....	
1869	16,898	10,315	5,018	....		....	1,580	....	....	
1870	14,423	9,888	4,516	....		....	1,220	....	....	
1871	18,568	8,180	2,128	....		....	1,970	....	....	
1872	18,574	8,171	3,046	....		....	1,830	....	....	
1873	11,042	7,735	3,294	....		340	1,955	....	....	
1874	9,084	6,911	6,678	573		1,122	1,645	....	1,743	
1875	13,648	8,432	7,513	5,372	3,342	3,384	1,940	....	1,927	533
1876	20,549	7,272	9,183	8,367	7,381	4,322	300	573	1,683	1,979
1877	23,996	6,316	9,399	10,993	6,241	5,856	1,060	2,229	1,463	1,317
1878	15,852	5,138	0,686	9,465	9,072	4,963	1,075	3,049	....	1,534
1879	20,514	4,425	4,516	9,249	15,540	6,333	1,325	3,605	1,290	1,919
1880	23,465	3,209	2,139	10,706	6,670	6,442	275	4,416	492	245
1881	26,060	2,775	2,194	11,152	5,228	6,241	....	5,552	....	....
1882	28,070	1,953	2,171	5,014	1,138	5,179	....	6,842	....	....
1883	29,000	1,606	1,894	2,612	84	3,860	....	5,890	....	....
1884	20,000	1,025	881	890	1,179	3,292	....	4,307	....	....
1885	21,400	1,144	1,385	1,296	35	3,469	....	3,506	....	....
1886	18,000	1,406	409	1,449	....	1,949	....	5,247	....	....
Total	853,259	126,099	97,637	77,138	55,910	56,701	18,097	45,216	8,598	7,527

[1] Including Ætna.

Production of quicksilver on the Pacific Slope, in flasks of $76\frac{1}{2}$ *pounds avoirdupois*—Cont'd.

Years.	Oceanic.	Oakland.	California.	Great Eastern.	Sunderland.	Cloverdale.	Abbott.	Manhattan.	Various mines.[1]	Total yearly production of California mines.
1850	....	....	....	....	....	....	....	Yearly production previous to 1876 not obtainable; total, estimated at 3,594 flasks, included in production of various mines.	....	7,723
1851	....	....	....	....	....	....	....		....	27,779
1852	....	....	....	....	....	....	....		4,099	20,000
1853	....	....	....	....	....	....	....		....	22,284
1854	....	....	....	....	....	....	....		....	30,004
1855	....	....	....	....	....	....	....		3,858	33,000
1856	....	....	....	....	....	....	....		2,862	30,000
1857	....	....	....	....	....	....	....		....	28,204
1858	....	....	....	....	....	....	....		5,239	31,000
1859	....	....	....	....	....	....	....		11,706	13,000
1860	....	....	....	....	....	....	....		2,939	10,000
1861	....	....	....	....	....	....	....		571	35,000
1862	....	....	....	....	....	....	....		1,885	42,000
1863	....	....	....	....	....	....	....		6,876	40,531
1864	....	....	....	....	....	....	....		2,286	47,489
1865	....	....	....	....	....	....	....		2,261	53,000
1866	....	....	....	....	....	....	....		2,621	46,550
1867	....	....	....	....	....	....	....		3,184	47,000
1868	....	....	....	....	....	....	....		112	47,728
1869	....	....	....	....	....	....	....		....	33,811
1870	....	....	....	....	....	....	....		....	30,077
1871	....	....	....	....	....	....	....		840	31,686
1872	....	....	....	....	....	....	....		....	31,621
1873	....	....	....	....	....	....	....		3,276	27,642
1874	....	....	....	....	....	....	....		....	27,756
1875	....	....	....	412	....	....	....		3,747	50,250
1876	2,358	2,150	965	387	1,570	1,028	1,436	976	2,585	75,074
1877	2,575	1,395	1,516	505	735	1,291	836	439	1,234	79,396
1878	1,679	1,615	1,640	1,366	472	116	....	....	158	63,880
1879	779	1,505	1,110	1,455	....	18	....	....	101	73,684
1880	....	166	422	1,279	....	....	....	....	....	59,926
1881	....	....	....	1,065	....	208	....	....	376	60,851
1882	....	....	....	2,124	....	....	....	....	241	52,732
1883	....	....	....	1,669	....	....	....	....	101	46,725
1884	....	....	....	332	....	....	....	....	7	31,913
1885	....	....	....	446	....	....	....	....	392	32,073
1886	....	....	....	735	....	....	....	....	786	29,981
Total	7,391	6,831	5,653	11,775	2,777	2,661	2,272	1,415	64,353	1,451,370

[1] The column of various mines includes the product of the Buckeye, Mt. Jackson, Bacon, Bella Union, American, Porter, Wall Street, Rattlesnake, Kentuck, and other mines. This column includes, in 1882, 50 flasks produced in Oregon.

Geographical position of mines.—The following list will enable the reader to find some of the mines mentioned in the preceding table, as well as others to be referred to later, on the sketch-map of California (Pl. I) and to appreciate approximately the geographical position of others:

Distribution of quicksilver mines.

(Mines marked M are in the Mayacmas district.)

Abbott, Colusa county.
Altoona, Trinity county.
American (M), Lake county.
Bacon (M), Lake county.
Bella Union, Napa county.
Buckeye, Colusa county.
California (Reed), Yolo county.
Cerro Bonito, Fresno county.
Cloverdale (M), Sonoma county.
Enriquita, Santa Clara county.
Guadalupe, Santa Clara county.
Great Eastern, Sonoma county.
Great Eastern (M), Lake county.
Great Western (M), Lake county.
Kentucky (M), Sonoma county.
Little Panoche, Fresno county.
Los Prietos, Santa Barbara county.
Manhattan, Napa county.
Manzanita, Colusa county.
Mt. Jackson, Sonoma county.
Napa Consolidated, Napa county.
New Almaden, Santa Clara county.
New Idria, Fresno county.
Oakland (M), Sonoma county.
Oceanic, San Luis Obispo county.
Ocean View, San Luis Obispo county.
Picacho, San Benito county.
Pope Valley, Napa county.
Rattlesnake (M), Sonoma county.
Redington, Napa county.
Reed (same as California), Yolo county.
San Juan Bautista, Santa Clara county.
St. John, Solano county.
Stayton, San Benito county.
Steamboat Springs, Ormsby county, Nev.
Sunderland, San Luis Obispo county.
Wall street (M), Lake county.

Other interesting statistical information with reference to quicksilver may be found in the Mineral Resources issued by the U. S. Geological Survey.

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CHAPTER II.

NOTES ON FOREIGN OCCURRENCES OF QUICKSILVER.

There are few districts besides those of the Pacific Slope in which mercurial ores are met with in such abundance as to be of great commercial importance. The Almaden mines, in Spain, take the first rank, and those of Idria, in southern Austria, have yielded and will continue to yield a considerable product. Several thousand flasks a year are also extracted from the Tuscan mines. China now produces little quicksilver, though she formerly exported it, besides supplying the home demand. This is not due to the exhaustion of the mines, and there seems to be good reason to suppose that the deposits of Kwei-Chau are of great extent and value. Peru has yielded very large quantities of quicksilver in former times, but the mines are in part exhausted and in part have been ruined by bad mining. While the number of highly productive localities is small, the localities in which ores occur are very numerous, and many of these have been of temporary or local importance. The geological interest attaching to a locality is not dependent upon the amount of metal which it has furnished to the markets of the world, but upon the relations between cause and effect which the occurrence serves to elucidate, and a brief review of the deposits known to exist away from the Pacific Slope will form the fittest introduction to the subject of this memoir.

It will appear in the subsequent chapters that nearly every mineral association and mode of occurrence known to exist elsewhere is repeated in California and Nevada, so that the mercurial deposits of the Pacific Slope admirably represent those of the world so far as they are known.

I have made no systematic endeavor to exhaust geological literature with reference to foreign occurrences of mercurial ores, though it is certain that no very important deposits have escaped me. I have sought to compile

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notes on comparatively little-known deposits rather than on those which have been most frequently described, and I have altogether omitted a considerable number of unimportant occurrences in Germany and Austria, descriptions of which are readily accessible in standard works on mining geology. Two reviews of the quicksilver deposits of the world have been of great use to me. These are by Mr. A. Nöggerath[1] and Prof. A. d'Achiardi[2] respectively.

The sketch-map of the world (Pl. II) accompanying this chapter will be of some assistance in following the text, but its principal purpose is to illustrate the larger features of the distribution of cinnabar.

NORTH AMERICA.

Away from the Pacific Slope the United States possesses no known deposits of cinnabar. There is, indeed, a settlement named Cinnabar near the Yellowstone Park; but I am informed that no mercuric sulphide has been found there. A telluride of mercury, coloradoite, is found with tellurides of gold and silver and with free gold in some of the mines of Boulder county, Colo, but only in small quantities.[3] In notices of the distribution of quicksilver the statement has often been made that cinnabar is found in Connecticut in river sands. I have not found a citation of the original authority for this statement. Prof. J. D. Dana writes me that he knows of no such occurrence, and it is safe to assume that no discovery of cinnabar could have been made near the home of this famous mineralogist without coming to his knowledge.

Towards the beginning of the century cinnabar was reported at numerous points in the Eastern States; it was even said to be very abundant in the beach sands of the Great Lakes. Had these assertions been correct they certainly would have been confirmed. Gold amalgam has been found at Plymouth, Vt., and the native copper of one of the mines at Lake Superior is said by M. Hautefeuille to contain a little mercury.[4]

[1] Zeitschr. für Berg-, Hütten- und Salinenwesen im preuss. Staate, vol. 10, 1862, p. 386.
[2] I metalli loro minerali e miniere, vol. 1, 1883, p. 100.
[3] Emmons and Becker: Statistics and Technology of the Precious Metals, Tenth Census Repts. U. S., vol. 13, p. 66.
[4] Geological Survey of Canada, Geology of Canada, 1863, p. 518.

Nova Scotia.—In the auriferous region of Nova Scotia cinnabar and native quicksilver are said to have been found at Gay's River and globules of the metal were washed from a soft slate at Waverley.[1] There is certainly nothing improbable in these reports, for cinnabar and mercury occur in many of the gold fields of the world.

Santo Domingo.—Mr. W. S Courtney[2] quotes "an English writer about the close of the last century" as stating that there is "mercury at the head of the river Yaque." Mercury is also enumerated among the minerals of Hayti by Mr. J. D. Champlin, jr.[3] In Mr. Gabb's memoir on Santo Domingo I find no mention of this metal.

Mexico.—Ores of quicksilver occur at a great number of localities in Mexico, the number of deposits being estimated by Prof. A. del Castillo at not less than fifty. He is also of the opinion that the country is capable of yielding annually the 2,000,000 or 2,500,000 pounds necessary for home consumption.[4] Most of the mines appear to be unsatisfactory, however, for in 1882 but one quicksilver mine was in operation.[5]

Quicksilver ores occur in the following States of Mexico, arranged as nearly as may be in the order of their latitude: Chihuahua, Durango, Zacatecas, San Luis Potosi, Guanajuato, Queretaro, Hidalgo, Jalisco, Mexico, Morelos, Guerrero, Oaxaca. Those of Guadalcázar, in the State of San Luis Potosi, and of Huitzuco, in the State of Guerrero, are the most important.[6]

According to Mr. D. de Cortázar[7] quicksilver ores in Mexico occur in primary, transition, secondary, and tertiary strata, but are found everywhere near eruptive rocks.

Humboldt describes one deposit as forming a vein of considerable width and length "in veritable pitchstone porphyry." The walls of this vein were impregnated to some extent, so that traces of cinnabar and metallic

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[1] H. How: Mineralogy of Nova Scotia, 1869, p 61.

[2] The Gold Fields of St. Domingo, 1860, p. 119.

[3] Encyc. Brit., 9th ed., article Hayti.

[4] A note communicated to the Mining and Scientific Press, San Francisco, January 16, 1875. I regret not having been able to obtain a copy of this author's work, Memoria sobre las minas de azogue de America, 1872.

[5] On the authority of Mr. Lorenzo Castro: Encyc. Brit., article Mexico.

[6] S. Ramirez: Riqueza minera de Mexico, p. 91.

[7] Repts. Phila. Internat. Exh. 1876 to Parliament, vol. 3, London, 1878, p. 389.

mercury were observed in the porphyry at considerable distances from the vein.[1] At Durasno, between Tierra Nueva and San Luis de la Paz, in the State of Guanajuato, he inspected a cinnabar deposit forming a layer[2] resting on porphyry.

The cinnabar deposits in the mining district of Guadalcázar were discovered in 1840. Though they are numerous they appear to be of no great value, for in 1874 they were not yielding enough quicksilver to supply the demand in the state in which they lie.[3] This district forms the subject of a paper by Mr. Ramirez,[4] from which the following notes are taken. The country rock of the district is chiefly limestone, with a few intercalated beds of shale. The rock is compact and usually of a bluish-gray tint. No fossils are known to occur in it, nor does it stand in such relations to other strata as to render a stratigraphical determination of its age practicable. It is supposed, however, to be Cretaceous both by Mr. Ramirez and by Mr. V. d'Aoust.[5] The region also contains granites and porphyries; the latter inclose deposits of silver ores, but the quicksilver ores are confined to the limestone in the district in which this metal has been exploited. According to Nöggerath, however, cinnabar with pyrite and galena is also found in granite in this region.

Ores of quicksilver occur at numerous points along a belt nearly forty miles in length (sixty kilometers), which extends to the northwest of Guadalcázar. The deposits occur mainly as layers in the limestone, but

[1] Essai politique sur le royaume de la Nouvelle Espagne, p. 585. The vein is called the San Juan de la Chica. It traverses the mountain of the Calzones and extends to Chichindara. I have not been able to find these localities on the maps.

[2] I shall use this word to translate the term manto, which does not seem to correspond to any expression recognized in English or German mining technology and seems also to bear a somewhat variable meaning among Spanish-American miners. Humboldt (ibid., p. 584) defines manto as "une couche horizontale," but horizontality is certainly not a necessary attribute of mantos as the term is used by Spanish-American mining geologists. Rivero, in describing the deposits of Huancavelica, repeatedly uses the expression manto ó capa, and capa is the term employed for a stratum of sedimentary rock. According to F. A. Moesta (Ueber das Vork. der Chlor-, Brom- und Iodverbindungen, p. 25), the Chilian miners use this word to describe any layer or sheet of mineral, irrespective of origin, so that strata of sedimentary rock and veins crossing strata, as well as dikes, may all be called mantos. Rivero, however, makes a sharp distinction between veins and mantos, and both he and the Mexican geologists seem to me to understand by manto either an ore-bearing stratum or a deposit resembling a stratum, such as a bed-vein, irrespective of the question whether or not the ore deposition has accompanied sedimentation. No doubt the term is much more loosely used by miners.

[3] Castillo, loc. cit.

[4] Anales del ministerio de fomento, Mexico, vol. 3, 1877, p. 339.

[5] Comptes rendus Acad. sci., Paris, vol. 83, 1876, p. 289.

irregular networks of veins, or stockworks, are also found. The limestone forming the immediate walls of the layers differs from that which is more remote from the deposits, the rock at the contact tending to assume a blackish color and a compact granular structure. The deposits are ordinarily separated from the country rock by a deposit of gypsum.[1] The chief ore is cinnabar, often hepatic and sometimes accompanied by the seleno-sulphide guadalcázarite, first described by Mr. del Castillo from this locality. Calcite and fluorspar are the gangue minerals. Native sulphur occurs with the ore in the principal vein of the district, the Trinidad. This appears to me to suggest the recency of the deposit and its deposition from hot sulphur springs; for most native sulphur is certainly formed by the decomposition of hydrogen sulphide in contact with air. Mr. Ramirez supposes the sulphur formed by sublimation; but I do not find in his description any evidence of the former prevalence of very high temperatures, and the presence of calcite and fluorspar indicates deposition from solutions.

The deposits of Huitzuco, about fifty miles north of Tixtla, in the State of Guerrero, were discovered in March, 1874. The geology and the deposits of mercury, silver, lead, and other metals of this state have been described by Mr. T. L. Laguerenne.[2] Granite seems to underlie the country. Upon it rest metamorphic rocks, including serpentine and eruptive masses. In the neighborhood of Huitzuco the rocks are metamorphic slates and limestones which have been much disturbed. The cinnabar deposits are mainly pockets of various dimensions and layers, but veins also exist. The deposit of Tepozonalco is a vein (veta) between slate and limestone, both rocks being metamorphosed and disturbed. The ore is argentiferous and is distributed through the entire vein matter. The ordinary ore of the district is livingstonite, a sulphide of antimony containing mercury. Cinnabar is said also to form pseudomorphs after stibnite.[3]

Prof. F. Sandberger has given a very interesting account of specimens of ore sent to him from Huitzuco by Mr. F. Velten. They represent a series from fresh stibnite to pseudomorphs of cinnabar after stibnite, containing only

[1] I suppose this mineral to result from the reaction of iron sulphate, produced by the oxidation of pyrite, on the limestone walls.

[2] Anales del ministerio de fomento, Mexico, vol. 7, 1882, p. 605.

[3] Velten and Lehmann; Sitzungsber. k. bayer. Akad. Wiss., vol. 2, Munich, 1867, p. 202, cited by d'Achiardi.

traces of antimony. The first step is an oxidation of stibnite to stibiconite, accompanied by a more or less complete impregnation with black, amorphous metacinnabarite. The transformation of the whole mass to cinnabar follows. The change from black to red sulphide is considered as due to the probable solubility of mercuric sulphide in calcium sulphide. Quartz and gypsum are the gangue minerals.[1]

At Chilapa also, near Tixtla, cinnabar occurs in a well defined vein in metamorphic slate. Quartz and iron oxides constitute the gangue, and the vein matter incloses fragments of country rock. In places the quartz is stained with copper. Cinnabar impregnates the entire width of the vein. At San Onofre mercurial ores occur under conditions similar to those at Guadalcázar; near San Felipe are veins of cinnabar in porphyry; near Guanajuato deposits of cinnabar and mercuric iodide occur in Tertiary clays and conglomerates; at Loma de Encinal veins of cinnabar exist in decomposed porphyry; and rich mercurial deposits are said to occur at Maltrata. In 1876 Mr. Geo. T. Walker, reporting in manuscript on the Guanacevi district, in the State of Durango, calls attention to the fact that, in the La Colorada silver mine, ores containing cinnabar occur close to the hanging wall of the vein. This occurrence has a parallel in this country near Belmont, Nev.

Guatemala.—According to Nöggerath, a specimen of cinnabar from Guatemala, accompanied by barite, exists in Berlin. I have met with no other mention of quicksilver ores in Central America.

SOUTH AMERICA.

Colombia.—Mr. R. R. Hawkins, of my staff, found native quicksilver disseminated in globules in a clay soil near the town of Cruces, on the Isthmus of Panama. He also found float cinnabar near the Magdalena river, in the State of Tolima. "Near Choco," probably the bay of that name, "gold amalgam and platinum are found together."[2] Humboldt mentions cinnabar as occurring in the province of Antioquia, in the valley of the Santa Rosa, to the east of the river Cuaca, and also between the towns Ibague and Carthago.

[1] Sitzungsber. k. bayer. Akad. Wiss., Munich, July 3, 1875.
[2] Nöggerath, loc. cit.

Ecuador.—Near the town of Azogue (Spanish for quicksilver) cinnabar occurs in veins in the more ancient sandstones. Between this point and Cuenca, at which quicksilver has also been mined, fragments of cinnabar are found with gold in gravels. Deposits similar to those of Azogue are worked within the city of Loja.[1]

Peru.—Of late years Peru has yielded no considerable quantities of quicksilver, though it was formerly one of the great quicksilver-producing countries of the world. The most northerly deposit is that of Chonta,[2] in the western Andes, close to the frontier of Ecuador. Mr. Bugdoll[3] describes the deposit as a bed in early Paleozoic rocks. It is composed of clay, sand, pyrite, and cinnabar. The ore impregnates the sandstone foot-wall to some extent. In the direction of the strike the ore is replaced by pyrite. Veins of lead ore cross the cinnabar deposit nearly at right angles.

In the Santa Apolonia Mountains, near Cajamarca, globules of quicksilver occur in trachyte. Specimens were exhibited at Paris in 1878 in the fine collection of Mr. A. Raimondi.[4]

Humboldt notes the appearance of quicksilver at Vuldivui, "in the province of Pataz." There is now no such province, and I presume the locality to be near the town of that name. The same geologist states that cinnabar is found at the Baths of Jesus, to the southeast of Guacarachuco (probably another form of the name Huacrachuco). These baths are no

[1] H. A. Webster: Encyc. Brit., article Ecuador.

[2] The deposits mentioned in Peru being somewhat numerous, the following table may be convenient to readers. The latitudes are only approximate:

Localities.	Provinces.	Latitude. °	′
Chonta	Piura	4	30
Cajamarca	Cajamarca	7	
Pataz	Libertad	7	30
Huacrachuco	Huanuco	8	
Caraz	Ancachs	9	
Santa	Ancachs	9	
Huaraz	Ancachs	9	20
Cerro de Pasco	Junin	10	40
Yauli	Junin	11	40
Huancavelica	Huancavelica	13	
Ayavlri	Puno	14	40

[3] Zeitschr. für Berg-, Hütten- und Salinenwesen im preuss. Staate, vol. 10, 1862, p. 391.

[4] G. vom Rath: Naturwiss. Studien, Bonn, 1879, p. 372.

doubt hot springs. He also mentions this ore at Guaraz (Huaraz) and near Santa.

In the province of Ancachs[1] mercury occurs in only a few deposits, which appear to be of little value. It is always found as cinnabar in veins, and mixed with other sulphides, such as galena, blende, pyrite, and gray copper. One of the principal mines is the Santa Cruz, near Caraz. The large amount of carbonic anhydride evolved in this mine renders its exploitation difficult.

There is a quicksilver mine in the great silver-mining district of Cerro de Pasco, at Cuipan. The rocks of this region include granite and trachytic lavas, as well as more or less metamorphosed sedimentary beds.[2]

In the mineral district of Yauli, 75 miles northeast of Lima, close to the Punabamba ranch, in a valley of the Andes, hot sulphur springs reach the surface and deposit considerable quantities of sulphur. Above these springs are quartz veins carrying seams and pockets of cinnabar and pyrite. The inclosing rocks are schists and sandstones.[3]

For over two hundred years the district of Huancavelica (sometimes written Guancavelica) yielded almost as much, possibly quite as much, metal as the district of Almaden, and the recorded total product of Huancavelica considerably exceeds that of California. The district of Huancavelica lies on the eastern slope of the western range of the Cordilleras. The rocks, according to Mr. Crosnier,[4] are of Jurassic age and are elevated to a nearly vertical position, but have a westerly dip. They strike north and south. The sedimentary rocks are the same throughout the district, and consist of argillaceous schists, conglomerates, sandstone, and limestone, alternating in thick beds. There are also, according to Mr. Rivero,[5] porphyries and trachytic lavas in the district, and granite is exposed at least at one locality. All traces of volcanic action have not disappeared from this

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[1] Explotacion y beneficio de los minerales de Ancachs, Prof. M. du Chatenet: Anales constr. civ. y minas Peru, vol. 3, 1883, p. 3.

[2] Alijandro Babinski, State engineer: Informe sobre el Cerro de Pasco, 1876.

[3] Bugdoll, loc. cit.; Mineral de Yauli, por L. Plücker y Rico: Anales constr. civ. y minas Peru, vol. 3, 1883, p. 62.

[4] Annales des mines, Paris, 5th series, vol. 2, 1852, p. 37.

[5] Memoria sobre el rico mineral de azogue de Huancavelica, por Mariano Eduardo de Rivero, Lima, 1848.

region. In the environs of the town are hot springs still depositing sinter, and so abundant is this material that the town is built of it. The most famous mine is the Santa Barbara, close to the town of Huancavelica, but there are over forty points at which cinnabar occurs, the most remote being 18 leagues (20 to a degree) from the Santa Barbara, and sixteen of them within 2 leagues. The department of Huancavelica contains silver, copper, lead, iron, and coal, as well as quicksilver.

The deposit of Santa Barbara consists of impregnations of cinnabar, mainly in sandstone. Some observers have pronounced it a vein, but Mr. Rivero denies that this name is applicable and considers it a layer or bed running parallel with the beds of limestone, sandstone, and conglomerate. Humboldt points out that cinnabar occurs close to Huancavelica in two very different ways, in part in true veins (filons) and in part in strata (couches). In the Santa Barbara it occurs chiefly as impregnations in portions of the sandstone bed, though much of the sandstone is barren; but he states that in portions of the deposit the cinnabar forms stringers, which are sometimes reticulated, forming a true stockwork or irregular reticulated mass. According to Crosnier profound disturbance of the rocks preceded the deposition of ore, and the deposit appears to me therefore to be a tabular impregnation intimately related to a fissure system. The difference between such a deposit and a bed vein does not seem great or important. Besides pyrite the mine carries much mispickel and realgar, differing in this respect from the other great cinnabar deposits of the world, though similar associations in smaller deposits are frequent. According to Humboldt the arsenic is found almost exclusively in the lower levels. He also mentions galena among the metallic minerals. Calcite and barite are the gangue minerals.

The Santa Barbara was discovered in 1566 by Enrique Garcés, but it had long been known to the Indians, who called cinnabar llimpi and used it to paint their bodies. According to Mr. Rivero no historian has mentioned that they obtained quicksilver by the distillation of cinnabar. He states, however, that in the immediate neighborhood of the Santa Barbara there are remains of ancient, very small, retort-shaped furnaces in which the subjects of the Peruvian Incas reduced cinnabar. In this connection it is interesting to note that in the northern part of Chili, according to Mr. V.

Perez-Rosales,[1] the Indians of the present day extract quicksilver from cinnabar in small, rudely made, earthen retorts (cornues en terre) and supply the demand of the gold mines of the region. Has this industry survived among the natives from the time of the Incas? It might also be asked what connection, if any, existed between the primitive furnaces of the Indians and the aludels of the Bustamente furnace which was invented at Huancavelica in 1633 by Lope Saavedra Barba, a physician and prospector.

Native quicksilver is found in the pores of a trachyte at Ayaviri, department of Puno,[2] and this is the most southerly locality in Peru of which I have notes.

Bolivia.—It is stated that cinnabar is among the ores of Bolivia and that quicksilver is frequently found associated with silver ores.[3]

Chili.—Mr. Crosnier, in discussing the deposits of Chili and Peru (loc. cit.), remarks that deposits of mercury appear to occur indifferently in stratified rocks and in granite. The Punita mine, in Chili, is in the latter. According to Mr. Rosales (loc. cit.) cinnabar occurs in the northern provinces, especially near Andacollo, in the province of Coquimbo. Near the town of Chili[4] cinnabar is found in dendritic forms, inclosed in quartz. Amalgams are well known to be frequent in the Chilian precious metal mines, especially at Arqueras.

The Argentine Republic.—It has been asserted that traces of mercury have been found in the sandstones at La Cruz and at Santo Tomé. Professor Stelzner[5] regards this occurrence as extremely problematical. These localities lie in the northeastern part of the republic. The northwestern corner of the country, adjoining portions of Peru and Chili known to contain mercurial ores, does not appear to have been explored to any considerable extent.

Brazil.—There is no doubt that quicksilver occurs in southern Brazil, but the information concerning it is very indefinite and probably in part erroneous. In 1865 Dr. Bosquet, a resident of Paranagua, stated that at

[1] Essai sur le Chili, 1857, p. 166.

[2] G. vom Rath, loc. cit. In view of the investigations of later years on the supposed trachytes of the Pacific Slope, it is not improbable that the two mercurial lavas of Peru are really andesites.

[3] J. A. Phillips: Ore Deposits, p. 620; Keith Johnston: Encyc. Brit., article Bolivia.

[4] Nöggerath, loc. cit. I cannot find such a town on the maps.

[5] Geol. und Pal. Arg. Rep., 1885, p. 249.

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one of the extremities of the city a deposit of mercury existed so abundant that in the rainy season it flowed from a talus on the borders of the sea.[1] Mr. G. C. Broadhead states that mercury is found in rich quantities in the province of Paraná, and is also found in Santa Catherina and, in the metallic state, in São Paulo.[2] In 1886 Mr. J. C. Gomes, of the Brazilian legation at Washington, wrote: "Mercury has been discovered at the Capão d'Anta, in the province of Paraná, in quantities that will permit competition with mines of Europe, Peru, and California"[3] Prof. Orville Derby, of whom I made inquiry, writes me that the only authoritative reference known to him is by W. L. von Eschwege.[4] Cinnabar, according to this geologist, occurs sparingly in rounded grains in gold sands in the bed of a stream flowing from the itacolumite mountain of Cachoeira, near Ouro Preto (formerly Villa Rica). It is not known that this locality has been re-examined. Professor Derby has visited two localities at which it is said that native mercury was found, but could detect none and is inclined to suspect an artificial origin.[5] He is of the opinion that the Capão d'Anta locality requires further investigation. The neighboring region is one of undisturbed Devonian shales and sandstones. The occurrence was reported by Mr. Keller, who visited it in 1864 or 1865, to be native quicksilver found in loose earth in a gully, and, so far as Professor Derby knows, only a few ounces have been collected as a curiosity.

ICELAND.

The Great Geyser.—During his well-known investigation of the Great Geyser, Mr. Des Cloizeaux found metallic mercury and mercuric sulphide in the geyserite of which the basin of that remarkable spring is composed. At the time of this examination similar occurrences elsewhere were unknown or had been very imperfectly studied, and the probability that the presence of the metal was due to artificial transportation seemed so great

[1] Bull. Soc. géographic, Paris, 5th series, vol. 9, 1865, p. 528.

[2] Rept. Phila. Internat. Exh. 1876 to Parliament, vol. 3, London, 1878, p. 494.

[3] Commercial and Emigrational Guide to Brazil, Compiled and Translated from Official Publications, Washington, 1886.

[4] Beiträge zur Gebirgskunde Brasiliens, 1832, p. 283.

[5] The localities are the island of Itaparica, in front of the city of Bahia, and the fagenda de Bon Successo, on the Rio das Vellias, mentioned by R. F. Burton (The Highlands of Brazil, vol. 2, 1869, p. 69).

as to deter Mr. Des Cloizeaux from mentioning the discovery in his memoir on the Great Geyser.[1] He collected numerous specimens, however, some of which he was kind enough to show me, and noted the conditions in detail. During the last forty years quicksilver and its sulphides have repeatedly been discovered in close relations to thermal springs, and it no longer seems intrinsically improbable that this occurrence was produced by deposition from natural solutions. Indeed, it has repeatedly been referred to in the later literature, though not by its discoverer, as if it were beyond question a natural deposit.

The basin of the Great Geyser is about eighteen meters in diameter, and the point at which the quicksilver was found is within the rim exactly due east, magnetic, from the vent. Traces of the metal were detected over an area of about one square meter, and Mr. Des Cloizeaux roughly estimates the entire quantity of mercury which he collected at about half a pound. It occurred at depths from the surface of the sinter varying from one or two millimeters to about four centimeters. The specimens which I saw seem to show that the mercury was originally deposited in the metallic state, for liquid globules of the metal about two millimeters or less in diameter are often partially enveloped in crusts of black sulphide, manifestly produced by the action of soluble sulphides on the inclosed metallic drops. Portions of the sinter, at some distance from visible globules of quicksilver, were stained black by mercuric sulphide, and at some points small quantities of the red sulphide made their appearance.

The fact that cinnabar accompanies this quicksilver shows that the water of the geyser is capable of dissolving traces of mercuric sulphide; for, had not this been the case, only metacinnabarite could have resulted from the attack of metallic mercury by soluble sulphides. The investigations described in Chapter XV of this memoir also show that mercuric sulphide is soluble to a considerable extent in waters of a composition similar to that of this great spring. Such solubility is evidently a necessary condition of the hypothesis that the mercury was deposited from the water.

On the other hand, there are circumstances connected with the occurrence which seem to me to point somewhat strongly to an artificial origin.

[1] Annales de chimie, Paris, vol. 19, 1847, p. 444. The information given in the text was verbally communicated to me by Mr. Des Cloizeaux.

Judging from the specimens, it would appear, as already mentioned, that nearly or quite all of the quicksilver was originally deposited in the metallic state and that the sulphide accompanying it is of secondary origin. Now, though more or less native quicksilver often accompanies deposits of cinnabar, the metallic mercury usually forms but a small proportion of the entire ore. To this rule there are some exceptions. At the Rattlesnake mine, in California, for example, a large part of the quicksilver was native, but here, and at other points in the same State at which native quicksilver was abundant, it was also accompanied by unusual quantities of bituminous oils, which were probably not without effect upon the form in which the metal was deposited. Near Montpellier, France, also, quicksilver has been found in some quantity, so far as I know unaccompanied by cinnabar. But the deposition of quicksilver, almost exclusively in the metallic state, from waters such as that of the Great Geyser, containing soluble sulphides and little or no organic matter, is very hard to understand. It is also very difficult to account for the distribution of the metal on the supposition that it was brought to the surface in solution by the heated waters. The basin of the Great Geyser is extremely symmetrical; in other words, the deposition of mineral matter takes place with great uniformity on all sides of the vent. Now, although the quantity of quicksilver found was by no means inconsiderable at a single spot, it was detected nowhere else in the basin. It seems highly improbable that the metal should have been deposited from the water without any approach to symmetry of distribution. In the opinion of Mr. Des Cloizeaux, it is not difficult to imagine circumstances under which a barometer might have been broken at the point where the mercury was found. The water sinks periodically into the vent, leaving the point in question bare, and returns again with a rush. An observer, taking the opportunity to advance as close to the vent as possible, would have to fly for his life as the water returned, and might well drop his instruments.

Professor Bunsen, who, as is well known, was engaged in investigating the geysers at the same time with Mr. Des Cloizeaux, also examined this occurrence of quicksilver, and has informed me that in his opinion it was certainly the result of an accident and was not a natural deposit.

EUROPE.

Northwestern Europe.—Amalgams have been found at Kongsberg, in Norway,[1] and at Sala, in Sweden,[2] but no cinnabar has been discovered in Scandinavia, so far as I am aware. In the Scotch highlands, Black[3] reported an ore containing lead, copper, and a little silver, which, on distillation, yielded some mercury. Possibly this may have been a tetrahedrite. According to Prof. R. Jameson, a quantity of quicksilver was found in a peat moss on the Scotch island of Isla about the beginning of this century. Some further search was made with no result.[4] I should regard such an occurrence as almost certainly due to human agency.

Portugal.—A quicksilver mine is said to have existed in the latter part of the last century in gravels. The locality seems to be at Conna, on the Tagus, not far from Lisbon.[5]

Spain.—Near Mieres,[6] to the south of Oviedo, in Asturia, cinnabar deposits, which had been worked long ago, and probably by the Romans, were rediscovered soon after 1840. The country rock in this district is composed of carboniferous sandstones and schists. The crest of a range of hills is formed of a breccia, bounded on both sides by broken and contorted beds of sandstone and schist, and composed of fragments of these rocks. In this breccia, or belt of extreme disturbance, occur cinnabar, pyrite, mispickel, and realgar. The ore is thus similar to that of Huancavelica. The cinnabar fills cracks and interstitial cavities and sometimes appears as impregnations Some streaks of ore are four to six inches in width. My authority speaks of no gangue mineral, but mentions a deposit of ferrous carbonate in one portion of the belt with the cinnabar, and, so far as gangue minerals are present, they are perhaps carbonates. The ore-bearing belt is forty-five to sixty-five feet wide and about four miles in length. It seems manifest, as Mr. Klemm concludes, that these deposits

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[1] Reports of the American Commissioners on the Paris Exposition of 1878, Mining Industries, by J. D. Hague, vol. 4, p. 270.

[2] A. Nöggerath, loc. cit.

[3] Nöggerath, loc. cit., probably Joseph Black, who wrote various treatises towards the close of the last century.

[4] Mineralogical Travels etc., vol. 1, 1813, p. 153.

[5] V. d'Aoust, Comptes rendus Acad. sci., Paris, vol. 83, 1876, p. 289, and Nöggerath, loc. cit.

[6] J. G. Klemm: Berg- und hüttenm. Zeitung, vol. 26, 1867, p. 13.

are more recent than the shattering of the mass in which they occur. At Santander, in the same province, cinnabar forms pockets in the lead and zinc ores.[1] Casiano de Prado mentions the occurrence of cinnabar and coal together from this province, the coal being unaltered.

The mines of Almaden are not only the greatest quicksilver mines in the world, but have yielded a product exceeded in value by very few mines of any kind.[2] The name given by the Moors (al maden, the mine) was therefore not inappropriate. Cinnabar from Spain is frequently mentioned by the ancient writers, and the indications are that it came from this locality. The accounts reach back to 415 B. C., when an Athenian, Callias by name, is said to have invented and made known a method of separating cinnabar from earthy matter and to have acquired a fortune by mining in Spain. Pliny describes the locality under the name of Sisapo in such a way as to leave no doubt that the mining district of Almaden is meant. A few tons of cinnabar were extracted yearly by the Romans for use as pigment. The mines were certainly worked by the Moors, but no details are now extant. Work on a considerable scale, so far as is known, was first initiated by the German bankers, the brothers Fugger, to whom the mines were farmed in 1525 and who retained control till 1645. The demand for quicksilver did not in fact reach large proportions until the discovery of the process of extracting silver from its ores with the help of mercury by Bartolomé de Médina, a Mexican miner, in 1557. Work seems to have been prosecuted from the earliest times on portions of the deposits which are still being exploited. Various other deposits within a distance of ten miles have been

[1] G. Dewalque: Revue de géologie pour les années 1864 et 1865, vol. 4, Paris, 1866, p. 94.

[2] The principal authority on the geology of the Almaden mine is Casiano de Prado, Bull. Soc. géologique France, 2d series, vol. 12, 1855. The paleontological portion of this memoir is by Messrs. de Verneuil and Barrande. All subsequent writers owe much to this important work. Valuable papers have also been published by the following geologists and engineers: Bernaldez and Figueroa (Memoria sobre las minas de Almaden y Almadenejos, Madrid); A. Nöggerath (Zeitschr. für Berg-, Hütten- und Salinenwesen im preuss. Staate, vol. 10, 1862, p. 361); José de Monasterio y Correa (Rev. univ. mines, vol. 29, 1871, p. 1); H. Kuss (Annales des mines, Paris, vol. 13, 1878, p. 39); and Caron (Zeitschr. für Berg-, Hütten- und Salinenwesen im preuss. Staate, vol. 28, 1880, p. 126). More general is M. D. de Cortázar's Reseña físico-geologica do la provincia de Ciudad Real. Prof. R. Helmhacker has investigated the diabase and piedra frailesca of Almaden in Tschermaks mineralogische und petrographische Mittheilungen, 1877, and Prof. Salvador Calderon has studied the massive rocks of the district (Anales Soc. españ. hist. nat., vol. 13, 1884, p. 227).

The account of Almaden given in the text was compiled before my visit to the spot, and I have added to it only one or two observations which seemed necessary to obviate misunderstandings. My own results will appear separately.

discovered from time to time, but are said now to be exhausted or abandoned for other reasons.

The prevailing rocks of the Almaden district are schists, quartzites, and sandstones, together with small quantities of limestone, all of Silurian and Devonian age. Intimately associated with the deposits, though seldom in direct contact with the ores, is a rock called piedra frailesca. According to de Prado this is a metamorphosed breccia, consisting of grains of quartz, calcium carbonate, dolomite, and fragments of schist cemented by dolomitic calcite. It occurs in lenticular masses intercalated in the schists and has been found to contain Silurian fossils. Messrs. Helmhacker and Calderon regard the rock as a diabase tufa. Cracks in this rock sometimes carry cinnabar, the deposition of which is therefore later than the brecciation.

The district lies upon the northern flank of the Sierra Morena. In this range are extensive areas of granite, and a rock also called granite crops out at various points not many miles to the north of the mines. Diabase, or melaphyre, has broken through the sedimentary rocks and occupies considerable areas near the mine, and a small quantity of porphyry, regarded as trachytic by de Prado, but as Pre-Tertiary by more recent Spanish geologists, exists some six miles northeast of Almaden. The sedimentary rocks are nearly vertical and are said to be little disturbed by the diabase eruptions, which have naturally reached the surface along the planes of bedding. The strata carry enough fossils for a satisfactory determination of the age of the rocks as a whole, but the same beds seem to reappear more than once in the compressed folds, and it is often difficult to decide to which of the periods a particular stratum belongs.

The Almaden district contains many deposits of cinnabar scattered over an area of about ten miles by six, but neither these nor the ranges of hills exactly follow the strike of the strata, which is very closely east and west. There seems to be some tendency, however, both with the deposits and the ranges, to arrangement in the same direction.

The chief ore is of course cinnabar, accompanied by relatively small quantities of metallic mercury. Pyrite occurs in small quantities, and Caron detected chalcopyrite. Gangue minerals have been said to be almost entirely wanting, but Nöggerath detected a little heavy spar with the ore, and spots of bituminous matter are sometimes found. I found quartz gangue abundant both in the reserves and in the newer exposures.

The deposits of the Almaden mine consist of three tabular masses of ore, nearly 600 feet long and from 12 to 25 feet in thickness. They stand almost vertically and nearly coincide in position with the surfaces of stratification. The southernmost body is called San Pedro y San Diego; then come the San Francisco and, still farther to the north, the San Nicolas. The first of the three consists of a stratum of sandstone (or quartzite, as it is called by some authors) impregnated to a large extent with cinnabar. The impregnation differs in degree and is sometimes so complete that de Prado infers a partial replacement of the material of the rock by the metallic sulphide. Most later writers have accepted de Prado's view, but I could find no evidence to sustain it. In the two more northerly bodies the deposits consist of quartzite intersected by stringers and seams of cinnabar. The seams are sometimes parallel to one another and sometimes intersect the rock in every direction. Occasionally portions of the quartzite appear to be impregnated with cinnabar. The walls of the deposits are formed by quartzite and slate. When quartzite is the wall rock the ore dies out into it gradually, but scarcely a trace is to be found in the slate. Diabase in a highly decomposed condition is said to cut off the San Nicolas and the San Francisco to the east.

The ore does not always follow a single stratum, but, according to Kuss, sometimes passes abruptly from one stratum to another. Slickensides are noted in the schists by Caron, who also mentions small faults in the San Nicolas, which did not reappear in the San Francisco.

There has been much difference of opinion as to the classification of these deposits. Early authors regarded them as veins; de Prado, who considered that the ore was introduced from below after the formation of the beds, regarded the deposits as ore-bearing strata, but not as veins. Nöggerath assents to this opinion, pointing out that many phenomena common in veins are not found here. Caron calls them impregnations and denies that they are veins or beds. Kuss says: "So soon as one admits, with Mr. de Prado, that the mercury is derived from the earth's interior, so soon as one recognizes that the deposits of Almaden form relatively narrow belts,

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following a single direction and having a determinate dip, we do not see how one can refuse them the name of veins." For my part I am not aware that any definition of vein has been proposed which would exclude the San Francisco and the San Nicolas as they are described, nor can I see how a definition could be given which would exclude these bodies without also excluding the greater portion of known veins. The San Pedro y San Diego would also seem from the descriptions to be a vein-like impregnation, differing from the others chiefly in the size of the interstitial cavities, which, for the most part, the cinnabar has filled.

It is a very remarkable fact that the Almaden mine appears to grow richer as the depth increases. No other known quicksilver deposit exhibits this valuable peculiarity excepting the Idria. It is also interesting to note that the other deposits of the Almaden district have given out in depth, though they occupied a similar position in the same rocks. The relations of cinnabar deposition to depth are thus evidently determined by purely local causes, and not by any general principle governing precipitation. Hence it is quite possible that deposits which grow stronger as distance from the surface increases may be found in any quicksilver district Monasterio and Kuss believe the deposition of ore and the eruption of the diabase to be closely related.

The province of Granada also contains quicksilver along the southern base of the Sierra Nevada. That range is composed of micaceous and chloritic schists and serpentine. The central mass contains little ore of any kind, but gold, lead, copper, zinc, cobalt, and nickel ores are found along its edges. The quicksilver belt has been traced from Torbiscon, in Granada, to Purchena, in Almeria, and runs on a somewhat more northerly course than the Sierra. This strip of country contains numerous veins of cinnabar in talcose schists of Triassic age. The mercurial ore is accompanied by gray copper, sulphides of nickel and cobalt, and oxides of iron. The veins are small and irregular. In the soft rocks there is a tendency to the diffusion of ore.[1]

Mr. A. Heckmanns, a mining engineer of large experience in the mineral districts of Spain and Algeria, informs me that a distinct vein

[1] Guillemin-Tarayre, Comptes rendus Acad. sci., Paris, vol. 100, 1885, p. 1231.

carrying cinnabar exists in slates supposed to be Silurian in the Sierra de Montenegro, which is the eastern end of the great Sierra Nevada. Cinnabar and silver amalgam, containing 6 per cent. of quicksilver, perhaps kongsbergite, occur near Culvas de Vera, in the province of Almeria. Copper and lead ores occur in the same neighborhood. At Aquilas, on the boundary between Murcia and Almeria, quicksilver ore was found and a furnace was started, but is not now in operation. Near the famous lead-mining town of Linares, in the province of Jaen, cinnabar occurs along the partings between strata.

Cinnabar occurs at La Creu, in the province of Valencia. I have had an opportunity of examining a series of specimens from this locality in the museum of the Technical High School of Aachen. The country rock is sandstone. The gangue minerals are quartz and carbonates, with which the cinnabar is intimately mingled. Pyrite is also abundant. The ores occur in veinlets in the rock, and some of the cavities have not been completely filled. The absolute impregnation is slight.

Cinnabar is also found, according to Nöggerath, in the province of Teruel, in a cupriferous quartz vein, and the same sulphide has been recognized in the provinces of Castellon and Alicante, on the east coast of Spain. Finally it occurs, according to the same authority, in western Spain, in the province of Badajos. The Almaden district is close to the boundary of Ciudad Real and Badajos, and a small part of it lies in the latter province. Excepting at this point I could learn of no occurrence in Badajos.

France.—No important quicksilver deposit has ever been opened in France, though during the last century quicksilver ores were mined at Menildot, in the department of Manche, in northeastern France. This mine had a considerable production from 1730 to 1742.[1] A mine is said to have been worked recently at Prunières, in the department of Isère, somewhat over twenty miles from Grenoble. This statement, however, is erroneous. Mr. H. Kuss, of the French mining service, who is stationed at Grenoble, writes me that, from 1850 to 1854, explorations were made at this locality, but without success. The principal vein carried small quantities of blende, calamine, tetrahedrite, and galena, and the vein matter was

[1] Burat: Géol. appl., vol. 2, p. 130.

sometimes stained bright red with finely-disseminated cinnabar, particularly in the neighborhood of calamine. The gangue was calcite and the inclosing rock was dolomitic limestone of the Lias. The veins were very irregular and before long disappeared altogether. The proportion of cinnabar was always very small and no metal was produced. At Chalanches, in the same department, it is found with sulphides of lead and zinc in veins, inclosed by crystalline schists which contain traces of platinum. At Allemond, also in Isère, cinnabar, native quicksilver, and silver amalgam occur in a vein. In central France, at Peyrat, in the department of Haute-Vienne, native quicksilver is found in a decomposed granite. In and near the Cevennes Mountains, also in southern France, native quicksilver occurs (e. g., near Montpellier) in Tertiary or Quarternary beds. This locality was discovered in 1760.

The regions in which quicksilver has been found in France also contain other metals, as is not unusual in other countries. In Manche, blende, calamine, and galena are found; in Haute-Vienne, lead, antimony, and tin; in Isère, lead, silver, and gold; in Hérault and Aveyron, tetrahedrite and galena.[1]

On the island of Corsica cinnabar is said to occur in a state of great purity in the Balagna, in the territory of the commune Occhia and canton of Belgodère.[2] The Balagna is a district lying east of Calvi, on the north coast of Corsica, and its port is Île Rousse. Interesting deposits of cinnabar are found on Cape Corso, the northern promontory of the island. It is found with stibnite in granite (pegmatite), serpentine, euphotide, schists, and serpentiniferous limestone. With stibnite it forms crusts of a few centimeters in thickness occupying fissures in the rocks. The gangue, when there is any, is quartzose. Pyrite, a little blende, and native sulphur are found in some veins, and arsenic has been detected. Mr. Hollande states that the fissures have been filled through the action of hot springs.[3]

Italy.—Cinnabar is widely distributed in Italy and Sicily, though most of the occurrences are of very small importance. The northern part of the Venetian state is contiguous to Carniola, in which lies the Idria mine.

[1] Burat: Géol. appl., vol. 2.
[2] Nöggerath, loc. cit.
[3] D. Hollande: Bull. Soc. géologique France, 1875–1876, vol. 4, Paris, 1876, p. 31.

Both the Austrian and Italian portions of this region show many deposits of cinnabar, of which not a few have been exploited to some extent. The most famous of the Italian mines in this region is the Vallalta, near Agordo.[1] The deposit occurs at and near the contact between a mass of quartz porphyry and sedimentary rocks of Triassic age, consisting of sandstones, shales, graphitic slate, limestone, and a certain conglomerate. The deposit is irregular in width, but follows the porphyry and ends in strike with this eruptive rock. The cinnabar is found as impregnations in the porphyry and in the sandstone and as stringers in the shales, but the great mass of it is in the conglomerate, which does not seem to be found except in the deposit The matrix of the conglomerate is commonly talcose, and embedded in it are rounded pieces of gypsum, calcite, quartz, limestone, and porphyry. Small grains and stringers of cinnabar are scattered through the rock. The ordinary material of the deposit contains only two-tenths to 1 per cent. of quicksilver, but the impregnation of cinnabar increases in some places to such an extent that the greater part of the ground-mass is ore, inclosing fragments of gypsum, calcite, and quartz, as well as foils of magnesian mica. Professor vom Rath estimated the metallic contents in such a case, from the specific gravity of the mass, at no less than 24 per cent. The deposit is intersected by numerous veins of cinnabar, accompanied by seams of gypsum. The only sulphide accompanying the ore is pyrite, crystals of which are often embedded in the cinnabar. At the contact between the ore body and the graphitic slate metallic quicksilver was found. Professor vom Rath expresses no opinion as to the origin of this deposit, but in the light of what is now known of the occurrence of quicksilver I should suppose that the ore had reached its position along a fissure at or near the contact between the porphyry and the adjacent rocks. The so-called conglomerate would seem, from its constituents, to be more strictly a breccia formed by movements prior to the deposition of ore. The precipitation of gypsum and cinnabar must have been in part simultaneous, since some of the gypsum is reddened by admixture of ore. The occurrence of native quicksilver in contact with graphitic rock (and, so far as reported, there only) is suggestive of reduction. The copper depos-

[1] Described by G. vom Rath: Zeitschr. Deutsch. geol. Gesell., vol. 16, 1864, p. 121.

its near Agordo are in the same series of rocks and at no great distance. The production of the Venetian mines has never been large and of late years has become insignificant. Some data are given in Chapter I.

Traces of cinnabar are found in Lombardy in quartzite, but the quantity is nowhere considerable.[1]

In Tuscany numerous deposits of quicksilver occur in a belt about one hundred and twenty-five miles in length, running parallel to the west coast and at an average distance of about twenty miles from the ocean. The southern end of this series of deposits is at Mt. Amiata. The Levigliani mine, near Serravezza, at the northern end of the belt, was known as early as 1163. The cinnabar is accompanied by guadalcázarite, siderite, and pyrite in a quartz gangue and occurs in steatitic schists in small irregular veins. The chief mines of this belt are at its southern extremity. Amiata is a great trachytic mass resting upon rocks which are Post-Jurassic and probably Eocene. They are for the most part calcareous. All around the edge of the lava and in the Eocene rocks occur quicksilver deposits, many of which have been exploited. Mr. B. Lotti also found cinnabar in the trachyte itself, near its edge, showing that the deposits are later than the eruption. The principal mine is the Siele, about five kilometers from Selvena. This, as described by d'Achiardi, is sunk on a stratum of marl many meters in thickness, which is impregnated with cinnabar. Stringers of calcite, spotted with cinnabar, are frequent in this deposit. The same author gives geological notes on several Italian mines not mentioned here.

Cinnabar occurs at La Tolfa, not far from Civita Vecchia, associated with fluor-spar and blende.

Nöggerath writes: "At Vesuvius the occurrence of quicksilver is very doubtful. Fr. Hoffmann, in his history of geognosy, speaking of the products of Vesuvius, says that among the metallic substances Dolomieu mentions also quicksilver and stibnite, but they have never since been found, as Breislack explicitly states; hence an error seems to have been made here." On referring to Hoffmann's history[2] it does not appear to me that he intends to ascribe to Dolomieu the assertion that at Vesuvius he found quicksilver.

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[1] A. d'Achiardi, loc. cit.

[2] Geschichte der Geognosie und Schilderung der vulkanischen Erscheinungen, Berlin, 1838, p. 477.

I think Hoffmann means to deny the opinion held by Dolomieu that quicksilver and stibnite are volcanic emanations. Dolomieu, in his treatise on volcanic products,[1] does classify these minerals as products of sublimation, but I have been unable to find any passage in his writings in which he mentions having observed them at Vesuvius. In his Voyage aux îles de Lipari I find no allusion to the subject. It may be, however, that in some of his less known writings he gives the facts upon which his opinion was based.

Nöggerath, writing in 1862, makes the comment that one may assent to Hoffmann's view of the matter the more readily because, thus far, quicksilver has nowhere been found in volcanic rocks, but since 1862 cinnabar and quicksilver have been often found in volcanic rocks, and cinnabar and stibnite have frequently been discovered together. Prof. É. de Chancourtois, in his lectures at the École des Mines, has been in the habit of showing specimens of cinnabar and realgar which he found at Pozzuoli, near Naples, at the opening of the principal fumarole, and which had been deposited from the jet of aqueous and sulphurous gases.[2] Cinnabar as a product of volcanic action thus exists near Mt. Vesuvius, if not upon it.

Nöggerath records six localities in Sicily in which traces of cinnabar have been found, but without any details as to occurrence or association. One of the localities, Paterno, ten miles northwest of Catania, is at the base of Mt. Ætna. It would be very interesting to know what relation this occurrence bears to the lavas and hot springs which must exist not far from it. I have been unable to learn anything further about it.

Germany.—The quicksilver deposits of Rhenish Bavaria have lost all the commercial importance they once possessed, but not their geological interest. They have been very fully described by Prof. H. von Dechen[3] and a digest appears in von Cotta's Ore Deposits. It is therefore unnecessary to dwell upon them here. The deposits formed veins in rocks of Carboniferous age, and to some extent impregnations in sandstones. They were accompanied by a melaphyre (probably diabase), and ore was sometimes found in spots and cracks in this rock, but a connection between

[1] Journal de physique, de chimie, d'histoire naturelle et des arts, Jean Claude Lamétherie, vol. 1, 1794, p. 102.

[2] Rolland: Bull. Soc. minéralogique, vol. 1, 1878, p. 99.

[3] Archiv für Mineral., Karsten, vol. 22, 1848.

its eruption and the genesis of ore was not established. The cinnabar was accompanied by pyrite, copper ores, and lead and silver minerals, but these were for the most part rare. The gangue was composed of calcite, quartz, chalcedony, and heavy spar, and bituminous matter was not infrequent. They were richest at the top and gave out in depth. It is an interesting fact that cinnabar occurred in these mines as a fossilizing mineral, having replaced organic remains, for this seems to prove that organic matter may precipitate cinnabar from solutions.

Metacinnabarite seems to have occurred in these mines, for von Dechen[1] twice mentions among the ores Quecksilber-Mohr, though without any remark. This name is the German equivalent of *Æthiops mineralis* and means amorphous, black, mercuric sulphide, produced by grinding together metallic quicksilver and sulphur. It seems impossible that this geologist should have applied this designation without ascertaining the chemical character of the compound and very strange that he should have made no comment on the novelty of the mineral. Analyses and descriptions of this mineral, as it occurred at the Redington mine, were first published by Dr. G. E. Moore in 1870. It is curious that the Neues Jahrbuch, in reporting von Dechen's monograph, quoted his conclusions almost word for word, but omitted Quecksilber-Mohr from the list of ores.

No other quicksilver mines, so far as I am aware, have been worked in Germany, though cinnabar and quicksilver have been detected at numerous points and a little of the metal has been secured in the course of the treatment of ores of other metals. The occurrences have so often been described that no detailed notice is necessary, but a few instances may be cited. In Bavaria, near Neustadt, cinnabar was found in masses of quartz inclosed in granite. In Saxony, near Lössnitz, it has been recognized in quartz inclosed in crystalline schists. In the Harz Mountains cinnabar occurs at numerous points. The Rammelsberg mine (iron and copper pyrites and galena) contains a small quantity of mercury. At Tilkerode and Clausthal tiemanite and mercurial clausthalite (lead selenide) are found. Cinnabar has been found in veins crossing early Paleozoic rocks, with heavy spar and siderite, in the Hülfe Gottes mine. At Kreuznach and

[1] Archiv für Mineral., Karsten, pp. 430, 463.

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other points in Prussia cinnabar occurs in veins traversing eruptive and sedimentary rocks. These cases would lead one to suppose that cinnabar occurs in much the same manner as other metallic sulphides.

Austria.—The deposits of Idria were discovered during the closing years of the fifteenth century. After a number of vicissitudes they passed into the hands of the state and have been worked by the government for public account ever since the year 1580.

The geology of these mines is of great interest, for not only has it been studied with the closest attention by highly competent geologists daily for many years, but the occurrences are such as to throw much light upon the nature of the deposit and the method of genesis. Mr. M. V. Lipold, as a member of the Austrian Geological Survey, examined and mapped the country surrounding the mines in 1856. In 1867 he took charge of the mines, and in 1874 published a memoir on the geology of the deposits and of the surrounding region.[1] In 1880 he wrote another paper upon the ore deposits.[2] From these memoirs the information given below is chiefly derived. In 1878 Mr. Lipold was good enough to accompany me through the mines under his charge. My stay was far too short to enable me to add any original observations to those which the director had made; but, since his conclusions appear from the literature not even yet to find entire acceptance, I may state that, to me, the presence of a fissure system such as Mr. Lipold described, and the direct dependence of the distribution of ore upon this fissure system, seemed proved beyond question.

The region surrounding Idria is composed of Carboniferous, Triassic, and later rocks, which have been subjected to great disturbances. Of these the chief is a compressive strain, the axis of which has a northwest and southeast direction. This strain is manifested in part as a fold and partly also by a dislocation. The faulting has taken place chiefly upon a single northwest and southeast fissure, which, however, as is so usual, is accompanied by other fractures parallel to it. In the course of the faulting movement a portion of the Carboniferous beds have been driven over the Triassic strata, thus inverting the natural order. This fact formerly caused the age

[1] Jahrbuch k. k. geol. Reichsanstalt, Wien, vol. 24, 1874, p. 425.

[2] Das k. k. Quecksilberwerk zu Idria, 1881.

of the strata in which the ores are found to be greatly exaggerated, but subsequently inversion of the strata was proved both by structural evidence and by the discovery of satisfactory fossils.

The principal fissure on which dislocation took place can be traced on the surface. It is also exposed in the mines, where the crushing and crumpling of the Triassic beds which it traverses are plainly visible. The attendant parallel fissures are likewise exposed by the workings. The Triassic strata belong to various subdivisions of the Alpine Trias (Werfen, Guttenstein, Wengen, and Ikonca groups). Lithologically they consist of schists, sandstones, and more or less dolomitic limestones; in short, of all the chief varieties of sedimentary rocks. All of these stratigraphical divisions and all of the lithological varieties of rock carry more or less ore in the neighborhood of the fissures, while none of the rocks carry ore outside of the region of disturbance. Furthermore, the deposits lie along the fissures, having the same strike and dip as these. There is thus abundant evidence that the ore deposition and the fissure system are directly related.

The form of the deposits differs greatly in various parts of the ore-bearing region: To the southeast the fissures cut across the beds and the ore forms true and unmistakable veins filled with wall-rock, cinnabar, and gangue minerals. In the northern part of the mine the fissure for some distance follows the planes of bedding of the Triassic rocks and the ore is interposed between the beds somewhat as if it were a stratum. The cinnabar is found, however, not only between strata and impregnating strata, but in the cracks penetrating the sedimentary beds, showing that the deposition followed the disturbance and that the coincidence of the fissure and the planes of bedding was due only to the fact that these, when nearly vertical, were surfaces of least resistance. In short, this is a bed vein, that is, a vein which happens to coincide in direction with the stratification. In the same part of the mine a portion of the lower Triassic limestones and dolomites have been crushed, and the deposit assumes the form of an irregular reticulated deposit or stockwork. Where the rock is sandy or porous, impregnations are found.

The mineralogical character of the ore is extremely simple. Cinnabar is the prevailing mineral, of course. Native quicksilver is found in small quantities, especially at contacts with the Carboniferous beds. Pyrite is tolerably abundant, sometimes associated with metallic mercury. No other metalliferous mineral occurs. The usual gangue minerals are quartz, calcite, and dolomite, and they have been deposited simultaneously with the cinnabar. Idrialite occurs in shapeless masses and is especially associated with hepatic cinnabar. In one region a small quantity of fluor-spar has been detected with cinnabar and dolomite. Mr. Lipold regarded the association of minerals and the manner of their occurrence as conclusively proving that the ore had been deposited from fluid solutions, a conclusion which appears to me entirely justifiable.

This mine, unlike others in southern Austria and northern Italy, grows richer as its depth increases, and the known reserves in 1880 were sufficient to maintain the production at the current rate for over seventy years.

There are noteworthy analogies between this mine and that of Almaden. In the latter the ore occasionally crosses strata, though usually following the stratification. In both, reticulated deposits are found, though at Idria the reticulated mass is irregular in outline, while at Almaden it is tabular. Pyrite is the only foreign metallic mineral abundant in either deposit. In both a part of the deposits follow the stratification and in both there is evidence of disturbance preceding ore deposition. Impregnations occur in sandstone in each mine. Both deposits grow stronger as the depth increases. Thus, while the general impression produced by the two chief mines of cinnabar is different, the difference is one rather of degree in the development of particular features than of fundamental character. Cinnabar is also found at many points in Carniola, Styria, Carinthia, Salzburg, and the Tyrol. At a number of these localities small quantities of quicksilver have been produced, but none is commercially important. The mode of occurrence, so far as known to me, is in each case similar to that of other deposits more or less fully described in this review.

In Bohemia cinnabar, quicksilver, and calomel are found with iron deposits. At Horowitz the quantities obtained were so considerable that from time to time a few hundred-weight of quicksilver were produced as an incident to the production of hematite. The latter forms a bed in Silurian schists, while the cinnabar, accompanied by heavy spar and pyrite, is found in cracks in the schists at right angles to the bedding.[1] In specimens which I have examined calc-spar also is present The reader may be reminded that at Mieres, also, bodies of iron ore are found with cinnabar.

Hungary.—Though mercurial tetrahedrite is not unknown elsewhere, it seems particularly characteristic of Hungary, and it is well known to metallurgists that small quantities of quicksilver have been obtained for a very long time as an incident to the roasting of copper ores in the Hungarian Erzgebirge. In this region mercurial gray copper ore, pyrite, cinnabar, and amalgam occur in veins inclosed by crystalline schists and gabbro, usually with quartz and heavy spar as gangue minerals. Ores of antimony, lead, and iron are also found with those of quicksilver. One variety of the mercurial tetrahedrite contains no less than 16.7 per cent. of quicksilver.

Cinnabar and quicksilver also exist at many points in Transylvania, though not in deposits of much commercial value. Very interesting is a vein in the Carpathians, between Transylvania and Bakowina, at Thihuthal, which occurs at the contact between a dike of lava and much-altered argillaceous schist. The vein is sixteen inches thick and is filled with calcite, dolomite, and country rock. This vein matter contains streaks and bunches of cinnabar. Small quantities of galena and zincblende are also found in it.[2]

Servia.—An important deposit of cinnabar was discovered in Mt. Avala, near Belgrade, in 1883, or, more properly speaking, rediscovered, since the Romans seem to have opened a mine upon it. This deposit has formed the subject of an important study by Prof. A. von Groddeck.[3] Ore has been found at six points near Mt. Avala. These localities do not form a straight line, but are distributed over a triangular space. The country rock is serpentine, believed to be an alteration product of an enstatite-olivine rock. The ore is mainly cinnabar, but native quicksilver and a little calomel are found. Pyrite and millerite, finely disseminated, accompany the cinnabar, and in a single locality galena also occurs. The gangue

[1] Von Cotta: Erzlagerstätten, part 2, p. 204.

[2] Ibid., part 2, p. 269. The average annual product of quicksilver in Hungary from 1864 to 1883, twenty years, is said to have been 26.65 metric tons, or 772 flasks, Spanish standard (Mineral Resources U. S. 1885, p. 293).

[3] Zeitschr. für Berg-, Hütten- und Salinenwesen im preuss. Staate, vol. 33.

minerals are chalcedony, quartz, calcite, dolomite, barite, and iron oxides. Chrome iron is disseminated in the serpentine and the gangue. The ore is found in seams and stringers of quartz and heavy spar, which intersect the vein matter in all directions, and also in impregnations. Prof. von Groddeck regards the deposits as intimately related to a fissure system and of a vein-like character, but infers from the micro-structure of the ore that it has in part replaced serpentine. In a series of specimens from Avala, shown to me by Professor Arzruní in Aachen, this replacement is not apparent. Messrs. de Prado, Monasterio, Kuss, and others consider a portion of the ore of Almaden to have been substituted for sandstone or quartzite, and Mr. Lipold believed that ore had replaced a part of the Idrian schist (Lagerschiefer). One would expect, in all these cases, to find descriptions of rounded kernels of rock inclosed by more and more angular envelopes of ore, the outermost bounded by irregular fissure surfaces, for this structure is usually associated with pseudomorphism. I do not find such descriptions nor have I seen any such occurrences in California, where cinnabar is often met with in contact with serpentine, sandstone, and schist. Neither have I seen anything of the kind at Almaden, at Idria, or at the Tuscan mines.

Turkey in Europe.—Mr. W. Fischbach[1] examined workable deposits of cinnabar and native quicksilver in the neighborhood of Prisren, in Albania. This place I take to be identical with Prisrend or Perserin, eighty miles east-northeast of Scutari and about four miles from the river Drin. He also reports occurrences at Crescevo, in Bosnia. There is a town Kreshevo, perhaps equivalent to Crescevo, near Serajevo, in Bosnia. Mr. A. Conrad[2] examined deposits in the Inatch Mountains, near Serajevo. They are inclosed in schists and limestones and are nearly vertical, sometimes forming veins and sometimes beds. The vein matter consists of country rock, calcite, and dolomite. The cinnabar inclosed in the vein matter is accompanied by pyrite, blende, and, it would appear, by traces of gold. Some of the deposits are several meters in thickness and, Mr. Conrad believes, could be exploited with profit if operations should be intelligently conducted.

[1] Berg- und hüttenm. Zeitung, vol. 32, 1873, p. 109.
[2] Revue de géol., vol. 5, 1865-'66, p. 115.

Mr. Fischbach also mentions that a concession has been granted for mining native quicksilver at the Dardanelles.

Russia.—Besides some points in the Ural Mountains, which will be mentioned under the head of Siberia, a discovery of cinnabar was made by Mr. Minenkoff in southern European Russia in 1879. The locality is west of the Azof railway, between the stations Nikitoffka and Gavriloffka, and seems to be about eighteen miles southwesterly from the town of Bachmut. The deposits consist of a stratum of sandstone overlain by clay slate. The ore-bearing stratum is in part impregnated with cinnabar. It is also traversed by many cracks, in which well-developed crystals of cinnabar are found. The rocks underlying the principal stratum are likewise fissured, and the cracks in it also are sometimes filled with cinnabar. According to Professor Tschermak galena is intimately mingled with the cinnabar.[1] All the rocks belong to the Carboniferous. The deposit is said to be rich, and exploitation on a commercial scale was commenced in 1886, as Professor Arzruní informs me. There are ancient superficial mine workings on the metalliferous beds.[2]

AFRICA.

Algeria.—Within a few years there was a mine called the Ras-el-Ma worked fifteen miles southeast of Philippeville, province of Constantine. Mr. Tissot states that this deposit occurred in the nummulitic limestone (Eocene) immediately at the contact with argillo-talcose schists. In his opinion the metalliferous emanations were derived from the latter rock. This mine was patented in 1861 and abandoned in 1876. He also mentions a very regular mercuriferous vein at Taghit, in the valley of the Oued-Abdi. It occurs in the lower Cretaceous.[3] Mr. A. Heckmanns informs me that in the province of Algiers, near Palestro, at a locality called Douar Guerrouma, there are typical veins in upper Cretaceous limestone which carry decomposed blende and lead ores. These ores contain silver and quicksilver, the latter sometimes to the extent of 3½ per cent. The quicksilver is not recovered at present.

[1] Tschermaks mineral. Mittheil., vol. 7, 1885, p. 93.

[2] M. Hiriakoff: Geol. Föreningens Stockholm Förhandl., vol. 8, No. 6, 1886.

[3] Texte explicatif de la carte géologique de Constantine, pp. 59 and 65. Also, Notice géol. et min., Dép. de Constantine, Exp. univ. de Paris, 1878, pp. 22 and 23.

In 1876 the Bey of Tunis exhibited a collection of ores illustrative of the resources of his dominions. The chief mineral products of Tunis include lead and mercury.[1]

ASIA.

Southwestern Asia.—Near Smyrna Mr. Fischbach (loc. cit.) found a rich vein of cinnabar accompanied by antimony ore. This is the only record of quicksilver in Asia Minor in my possession. Ibn Mohelhel, an Arabian author of the ninth century, reported quicksilver as occurring in the western portion of Zendjân, in Persia. General A. Houtum Schindler, of the Persian army, found cinnabar and native quicksilver in the district indicated by Mohelhel.[2] Cinnabar occurs with gold in alluvial washings. Furthermore, cinnabar and native quicksilver are found in considerable abundance in the basalt of the district, which also carries realgar. Sulphur, too, is plentiful and lead and silver are mined near by. This locality would appear to be a solfataric one, not dissimilar to those of California.

In Afghanistan Captain Hutton[3] reports that quicksilver is mined at latitude 31° 18′, longitude 62° 18′ 30″.

Globules of the metal are also said to occur in a cellular lava at Aden.[3]

Siberia.—Cinnabar is found in various secondary deposits in the gold-mining districts of the Ural Mountains; for example, near the Beresowsk smelting works, near Miask, and near Bogoslowsk. At the last locality pieces of cinnabar weighing a pound and a half have been found, but the original deposits of ore have never been detected in this region.[4] In the auriferous sands of Olem-Trawiansk cinnabar occurs in large pieces, an examination of which is said to justify the conclusion that the original deposits were quartz veins.[5] It is hard to see how such fragments can justify any positive conclusion as to the form of the deposits, but it is something to know the nature of the gangue. Professor Arzruní informs me that to the south of the district in which Miask is situated no cinnabar has been found, while to the north it occurs in rolled fragments in most of the gold placers.

Cinnabar also occurs at the Ildekansk quicksilver mine, in the district

[1] J. M. Safford: Rept Phila. Internat. Exh. 1876 to Parliament, vol. 3, London, 1878, p. 481.
[2] Jahrbuch k. k. geol. Reichsanstalt, Wien, vol. 31, 1881, p. 183.
[3] V. Ball: Economic Geology of India, p. 170.
[4] N. von Kokscharow: Materialen zur Mineral. Russlands, vol. 6, 1870, p. 259.
[5] C. Zincken: Berg- und hüttenm. Zeitung, vol. 39, 1880, p. 360.

of Nertschinsk, in eastern Siberia, near the borders of Manchuria. The ore, which has only been found in small quantities, forms little veins and bunches in yellowish-gray limestone, the gangue being calcite and quartz. It is said that this deposit was discovered as far back as 1759, but was worked only to a depth of thirteen meters. In 1797 the mine was reopened and eleven pounds of quicksilver were obtained. In 1834, exploration in the neighborhood disclosing nothing more, it was decided to abandon the mine. In 1837 a four-inch vein was found in the hanging, but, although it was decided to work the mine, nothing was done. In 1853 prospecting was resumed, but only traces of ore were found. It has not been worked since.[1] A specimen of the ore from this mine was exhibited in Philadelphia by the School of Mines of St. Petersburg.

Some travelers in later years have regarded the existence of a quicksilver mine in Nertschinsk as altogether mythical.[2] It certainly existed, but the above data show how small an affair it was. No other mine so insignificant has probably ever been so famous. Endless fables have been circulated as to the inhuman confinement of prisoners in the poisonous atmosphere of this mine. It is highly improbable that more than half a dozen miners were ever at work in it at one time, while mercurial poisoning in quicksilver mines occurs only where native quicksilver is abundant, a very rare case excepting at Almaden. They are ordinarily as healthful as any other subterranean excavations. Native quicksilver is not mentioned as having been observed at Ildekansk. The Nertschinsk district also produced gold, tin, silver, and lead. The country seems chiefly composed of granite and crystalline schists.

Cinnabar has also been said to occur in Kamtschatka.[3] I do not know the exact locality, nor have I been able to discover on whose authority the statement was made. Mr. George Kennan informs me that while he was at Anadyrsk, on the Anadyr River, in 1867, the natives (Chukchis) assured him that native quicksilver occurs in the neighborhood. As a proof of their statements they brought him something like 100 grammes of the

[1] Von Kokscharow (loc cit.) and A. Oserskij: Abriss der Geologie, der Mineralreichthümer und des Bergbaues von Transbaikalien, St. Petersburg, 1867.

[2] Dr. Henry Lansdell (Through Siberia, 1882) could learn of no quicksilver mine at Nertschinsk and cited other authorities to the same effect.

[3] Nöggerath, loc. cit.

metal in a glove. Mr. Kennan considers it almost impossible that this quicksilver can have been obtained by the natives from Europeans, either by design or by accident, and believes that it represents an actual occurrence. He was not shown any cinnabar.

China.—Mr. R. Pumpelly discovered in Chinese literature records of the occurrence of quicksilver in ten of the eighteen provinces.[1] The only province certainly known to contain important deposits is Kwei-Chau. Of this locality Baron F. von Richthofen writes as follows:[2]

Quicksilver has been from of old the chief commercial product of Kwei-Chau. At the beginning of the present century it was still among the regular articles of export from Canton. Then it failed and became an article of import, rising gradually in quantity until it reached the figure of over 10,000 piculs [a picul being 133⅓ pounds] in 1831 and 1832. Suddenly the Chinese no longer required the foreign quicksilver, and from 1838 commenced again to export it. This state lasted until about 1849. Since then it has become again a regular article of import, but the quantity required is much less than in former years, and is about 3,000 or 4,000 piculs annually. These alternate flood and ebb tides were probably caused by the periodical disturbances in Kwei-Chau. When the last one commenced, in 1848, the mines were abandoned, and they have not been reopened since. [The minister of the Chinese Empire to the United States informs me that of late years mining has been resumed.]

The places where the quicksilver occurs appear to be limited to a well-defined belt which extends through the whole province from southwest to northeast [over 300 miles]. One of the principal mining districts, and the only one in regard to which I was able to get some information, was Kai-Chau (in Kwei-Yang-Fu). The mines there were scattered over an area of 10 li diameter [about 3½ miles] * * * I was unable to get a clear idea regarding the mode of occurrence of the ore, but it is said to exist in considerable quantity and to have been difficult to mine only on account of the presence of much water. * * * The mines have the advantage of being near Wang-Ping-Chau; the metal can therefore conveniently and cheaply be shipped to Hang-Kow [a treaty port]. * * * The number of places at which quicksilver is found and was mined is so great as to make it not improbable that in respect to the quantity of this metal awaiting extraction Kwei-Chau is far ahead of any other known quicksilver-producing country on the globe. In many places cinnabar is brought to the surface in plowing the fields.

Since Baron von Richthofen is a mining geologist of the first rank and was familiar with the quicksilver deposits of Austria and California, his opinion as to the resources of China is entitled to great weight. Kwei-Chau,

[1] Geological Researches in China etc. The provinces are Shen-Si, Kan-Su, Shan-Tung, Ngan-Hwui, Sze-Chuen, Hu-Nan, Kwei-Chau, Cheh-Kiang, Kwang-Tung, Kwang-Si.

[2] Letter VII to the Shanghai Board of Trade, 1872, p. 81. Prof. J. D. Whitney has been kind enough to furnish me with a copy of that portion of this rare publication bearing on the province of Kwei-Chau.

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at the time of his visit, had been in a state of chronic disorder since 1848; indeed, the number of unburied corpses made the country extremely unhealthful. Realgar and orpiment are exported from Kwei-Chau, and many other metallic ores are said to exist there. The neighboring province of Yun-Nan is the auriferous district of China. According to d'Achiardi, fine natural crystals of cinnabar have reached Europe from Yun-Nan.

Thibet.—Thibet lies close to Yun-Nan and is often mentioned as a locality in which cinnabar occurs. I have not met with a citation of authority for this statement and do not know the exact locality.

Corea.—Mr. Pumpelly (loc. cit.) ascertained from Chinese records that Corea contained cinnabar deposits. Mr. Ernest Oppert[1] states that the province of Hoang-Hai contains deposits of quicksilver, tin, and lead. The geology of Corea has very recently been investigated by Dr. C. Gottsche.[2] He found the province of Hwang-Haido (equivalent to Hoang-Hai) principally occupied by crystalline schists, through which older and younger eruptive rocks have burst. He notes the presence of hot springs in this province. Other portions of Corea, under similar geological conditions, are auriferous.

Japan.—At Shizu, in the neighborhood of Sendai, province of Rikuzen, very thin veins of cinnabar occur in a whitish volcanic rock.[3] It would be interesting to know whether this is a rhyolite or a solfatarically decomposed eruptive rock of a more basic type. A quicksilver mine has been worked near Ainoura, on the peninsula of Hirado, in Matsûra Kôri of Nagasaki Ken. The former superintendent, Mr. Gower, reports that the exploitation was stopped in consequence of a discouraging accident to the reducing plant. The ore consists in part of impregnations in sandstone and in part fills small fissures and seams. The country rock belongs to the Coal Measures.[4]

British India.—It is said that quicksilver mines formerly existed in Ceylon, near Colombo, and that the Dutch exported quicksilver from them to Europe.[5] In the Andaman Islands, also, it is said, quicksilver used to

[1] Voyages to Corea, 1880, p. 171.
[2] Sitzungsberichte der Berliner Akademie, vol. 36, 1886.
[3] J. G. H. Godfrey: Quart. Jour. Geol. Soc. London, vol. 34, 1878, p. 555.
[4] H. S. Munroe: Trans. Am. Inst. Min. Eng., vol. 5, 1876–'77, p. 299.
[5] J. F. Dickson: Encyc. Brit., 9th edition, article Ceylon.

be obtained. The rocks here are similar to those of California near San Francisco. Traces of native mercury are reported from Madras.

Dutch India.—In Borneo cinnabar has long been known to exist. At the gold diggings of Sarawak small rolled fragments of cinnabar are found, and the antimony ores, of which the district yields large quantities, also contain some mercury. By systematic prospecting, original deposits of cinnabar were found about 1867. The chief deposit is at a hill known as Tagora. The rock consists of partially metamorphosed, interbedded shales and sandstones. The ore is found in the slate and more rarely in the sandstone. It is a very irregular deposit, but includes vein-like developments. Calcite, heavy spar, and pyrite accompany the ore. At Gading, a few miles west of Tagora, stibnite and cinnabar occur together. Cinnabar was first mined in 1868. The product in 1872 was 1,733 flasks; in 1873, 1,505 flasks.[1] In 1880 the value of the quicksilver produced in Sarawak was $66,300.[2] Mr. S. B. J. Skertchly, formerly of the Geological Survey of Great Britain, informs me that he has examined alluvial deposits from the interior of north Borneo containing gold and cinnabar. On the island of Sumatra, in the southern part of the Pedang highlands, in the neighborhood of Sibelaboe, fine particles of cinnabar accompanied by magnetic iron occur in crystalline schists, but not in quantities sufficiently large to warrant mining operations.[3] Quicksilver is also reported from the island of Java at Samarang.[4]

Spanish India.—Unimportant quantities of quicksilver ores are reported to occur in the Philippine Islands.[5]

Australia.—Rev. W. B. Clarke, who has so greatly contributed to the elucidation of the mining geology of Australia, wrote as follows in 1875:[6]

Some years since, I reported on the occurrence of mercury in this colony, but my expectation of the discovery of a lode of cinnabar has been disappointed. The cin-

[1] A. H. Everett: Notes on the Distribution of the Useful Minerals in Sarawak, not dated, but seemingly written in 1874.

[2] Mining Journal, London, 1882, p. 415. This value corresponded, at the London prices for 1880, to about 2,000 flasks.

[3] R. D. M. Verbeek: Beschr. Sumatra's Westkust, 1883, p. 562.

[4] D'Achiardi, loc. cit.

[5] This note is derived at second hand from J. Roth: Geologische Beschaffenheit der Philippinen.

[6] Mines and Mineral Statistics of New South Wales, etc., Sydney, 1875, p. 201.

nabar occurs on the Cudgegong in drift lumps and pebbles, and is probably the result of springs, as in California. In New Zealand, and in the neighborhood of the Clarke River, north Queensland, the same ore occurs in a similar way.

About this date work was in progress on a quicksilver mine on the Cudgegong,[1] but in 1876 the official reports pass it over in silence. In 1878 specimens of cinnabar and quicksilver were exhibited in Paris,[2] but no information was afforded concerning the character of the deposits. Cinnabar has been mined at the Wilkinson mine in Kilkivan, fifty miles from Maryborough, Queensland.[3] According to the prospectus of a mining company a few tons of quicksilver were extracted in Kilkivan in 1885. Cinnabar is said to exist in West Australia also.[4]

Mr. Nöggerath reports small quantities of crystalline cinnabar in a gold vein in Bendigo County, Victoria. This very interesting occurrence is not mentioned by Mr. William Nicholas in his catalogue of localities of minerals which occur in Victoria,[5] nor by Mr. R. B. Smyth in his Mines and Mineral Statistics of Victoria.[6] The observation has probably never before been published in English. The same author mentions gold amalgam at German Reef, on the Tarrangower.

New Zealand.—As long ago as 1866 it was known that quicksilver occurs a few miles southeast of Omapere Lake, near the Bay of Islands. In 1870 Mr. F. W. Hutton[7] visited the locality, where there are numerous springs, hot and cold. He found two warm sulphur springs accompanied by mercurial deposits. The sandstone was impregnated with native mercury and cinnabar. He also detected an open vein a quarter to a half inch in width in the sandstone, lined with a black ore of mercury, accompanied by sulphur and globules of quicksilver. He ascertained that this black ore was a sulphide containing some iron. Mr. Hutton thus nearly anticipated Dr. G. E. Moore's discovery of metacinnabarite. This ore is now known to occur at several mines in California, at Huitzuco in Mexico,

[1] Annual Report of the Department of Mines, New South Wales, 1875, Sydney, 1876, p. 31.
[2] Repts. of the U. S. Commissioners Paris Univ. Exp., 1878, vol. 4, p. 246.
[3] D. de Cortázar, loc. cit.
[4] R. Acton: Encyc. Brit., 9th edition, article Australia.
[5] Geol. Survey Victoria, Rept. Prog., 1876, p. 280.
[6] Prepared for the Victorian exhibition, 1872.
[7] Trans. New Zeal. Institute, vol. 3, 1870, p. 252.

and in Rhenish Bavaria, as well as in New Zealand. A greasy hydrocarbon accompanied the deposit described by Mr. Hutton. Dr. J. Hector[1] gives an interesting account of an occurrence at Ohaeawai, on the south side of Omapere Lake, and therefore near Mr. Hutton's locality. Hot springs and steam escape from the terminal end of a scoriaceous stream of lava, which has emanated from conical hills on the south side of the lake. These springs deposit a brown "sandstone" in laminated beds. This incoherent, granular, siliciôus sinter includes fragments of the surrounding vegetation. It also contains thin layers of cinnabar-sand and globules of metallic mercury. No great amount of the ore exists in the sinter, however, and its interest is purely scientific. Prof. A. Liversidge[2] reports rolled fragments of cinnabar from Waipori, and native quicksilver, with copper and sulphur, from Tokomairiro.

CONCLUSIONS.

Incomplete as are most of the foregoing notes on deposits of quicksilver ores, they seem to point to some conclusions which are not likely to be much modified by more detailed descriptions.

Age of the inclosing rocks.—From the crystalline schists, presumably of Archæan age, to Quaternary beds, strata of all the larger groups of geological formations are known to carry cinnabar. The mere age of the inclosing rocks cannot, therefore, be a controlling factor in the distribution of mercurial ores. More deposits are found in Pre-Tertiary rocks than in those of Tertiary or Post-Tertiary age, a fact susceptible of very simple explanation Cinnabar deposits are also found in granite and in eruptive rocks, including Post-Tertiary basalts.

Lithological character of inclosing rocks.—Cinnabar occurs in conglomerates, sandstones, limestones, and shales, or in all the great lithological subdivisions of unaltered strata. It occurs also in quartzites, slates, serpentines, and crystalline schists, as well as in basic and acidic volcanic rocks. Thus the lithological character of the inclosing rock does not determine the deposition of the ore. If there is any rock for which cinnabar seems to

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[1] Rept. Geol. Explorations, 1874–1876, p. 5.

[2] Trans. New Zeal. Institute, vol. 10, 1877, p. 502.

exhibit a partiality it is sandstone, but rich deposits are common in limestone, shale or slate, and serpentine, and are not unknown in other rocks. No definite relation between the lithological character of the inclosing rocks and the richness of deposits is apparent from the descriptions.

Relations to lines of disturbance.—Comparison of the sketch-map (Pl. II) with any physical chart of the globe shows that the quicksilver deposits bear a most intimate relation to lines of disturbance. The great mountain chain of Eurasia includes the Pyrenees, the Alps, and the Himalayas. This, which might conveniently be called the Alpimalayan chain, breaks up into divergent ranges at each end, or in Spain and China. The larger part of the known occurrences of Eurasia are distributed along the Alpimalayan chain, and their frequency is very nearly proportionate to our knowledge of the regions in which they occur. There is little reason to doubt that, when Kurdistan, Afghanistan, and Thibet are better known, quicksilver localities as yet undiscovered will be found. At the western end of the chain the quicksilver deposits, like the ranges, scatter. This appears also to be the case in China, since, according to Mr. R. Pumpelly, cinnabar occurs in ten out of the eighteen provinces of China; but I have not thought the information sufficiently definite to justify me in entering the localities on the map. The chief localities not immediately in the Alpimalayan chain are those on the western coast of Italy. These deposits form a line which may manifestly be regarded as a mere offshoot from the great belt of disturbance. The outlying range of the Ural Mountains is marked by a few traces of cinnabar. The famous deposit of eastern Siberia seems quite isolated. The occurrences of Kamtschatka and Japan lie along a line of disturbance marked by a series of active and extinct volcanoes, and the deposits of the East Indian islands are associated with similar evidences of dynamic action.

The American deposits from Alaska to Chili lie near the coast, along the western ranges of the Cordillera system, and the line in which they occur is marked from one end to the other by manifold evidences of profound disturbance. The Brazilian deposits, like that of Nertschinsk, are in mountainous, metalliferous regions, but seem only remotely connected with the main line of mountains; and a similar statement is true of the traces of cinnabar found in Santo Domingo and in Nova Scotia.

The deposits of Australia, such as they are, lie along the principal mountain range of that continent, and those of New Zealand, like those of the East Indies, are accompanied by evidences of disturbance marked by volcanoes.

Relations to volcanic phenomena.—In a few cases the deposition of cinnabar has been observed at the vents of volcanic emanations, viz, at Pozzuoli in Italy, near Lake Omapere in New Zealand, and at localities on the Pacific Slope. There are other cases in which cinnabar is immediately associated with hot springs and sulphur deposits in such a way as to suggest the former existence of hot sulphur springs of volcanic origin. Such are the deposits of Guadalcázar in Mexico, the Baths of Jesus in Peru, and those of Persia. Hot springs exist close to the great deposit of Huancavelica, but whether they contain sulphur I do not know. Cinnabar and native quicksilver are found in eruptive rocks a part of which are recent, in melaphyre in Rhenish Bavaria, quartz porphyry at Vallalta, trachyte at Mt. Amiata, trachyte or basalt in Transylvania, basalt in Persia, pitchstone porphyry in Mexico, trachyte in Peru, and, I may add, in andesite and basalt in California. As has already been pointed out, cinnabar also occurs along belts marked by the presence of volcanoes, active or extinct. This is especially notable in Italy, in western Asia, New Zealand, and throughout the entire American series of deposits from Alaska to Chili.

Mineral association.—The most common metallic mineral associated with cinnabar is pyrite, and this sulphide is perhaps never entirely absent, though it is not mentioned in some of the descriptions. It is so common, however, that were it absent in any deposit mention would probably be made of the fact. Traces of copper sulphides perhaps come next in frequency, but arsenical and antimonial compounds are found abundantly in some deposits. The quantity of arsenic at Huancavelica seriously interfered with the working of the ore, and livingstonite is an important ore in Mexico. The ore of Mieres is like that of Huancavelica. Mr. de Chancourtois found realgar with quicksilver at Pozzuoli; Dolomieu is said to have found cinnabar and stibnite on Mt. Vesuvius, but there is some doubt whether this geologist made such a statement. Antimony accompanies cinnabar in Corsica and at Smyrna; realgar and cinnabar are found together in Persia. Realgar is one of the exports of the quicksilver region of China. Gold is intimately associated with quicksilver and cinnabar at a great number of points, sometimes in veins, but oftener in gravels. There is no deposit of great importance, however, from which both metals can be profitably extracted. Ores of copper and zinc are not seldom found with cinnabar; lead and silver ores are more rare; but, as in the case of gold, it is seldom that valuable deposits of any of these metals carry important quantities of quicksilver or that valuable deposits of cinnabar contain important quantities of the other metals. It is nevertheless interesting to observe that, with the exception of tin, all the chief metallic ores are sometimes deposited together with cinnabar. The gangue minerals accompanying cinnabar are nearly always either silica, often in part of hydrous varieties, or carbonates in which calcite predominates. As Mr. d'Achiardi remarks, the character of the gangue seems largely determined by the nature of the adjacent rock. Baryte and fluorspar are not infrequent and bituminous matter is found in a very large proportion of quicksilver mines.

Form of the deposits.—Except in the case of gravels, I know of no case in which it is clear that cinnabar has been deposited simultaneously with the other material of stratified rocks. It is true that observers have not infrequently asserted of cinnabar deposits that they were coeval with the inclosing rocks, but the only ground for this opinion which I have seen given is conformability between deposits of ore and the surrounding strata. This is by no means adequate to establish the point in question. In most cases it seems certain that the deposition of ore was subsequent to some disturbance of the country rock. In these cases the ore is deposited in interstitial spaces, and possibly also to some extent by substitution for rocks or other minerals. There is no doubt that true veins of cinnabar occur, sometimes cutting sedimentary rocks and sometimes following the stratification. Reticulated masses and impregnations are also common. It is often supposed that the characteristic forms of cinnabar deposits are not to be brought under any of these categories; but I cannot see sufficient evidence in the literature to prove this supposition. Selvages and comb structure are often absent, and sometimes the walls of vein-like deposits are not well defined. But veins of ideal structure, such as those upon which the diagrams of text-books are founded, are not common in all regions, even in gold, silver, or copper deposits. Small veins in hard, coherent rock often assume this simple form, but large veins in volcanic or partially metamorphosed rocks are often indistinctly bounded and are very complex in structure. In many parts of the Comstock lode, for example, there is no definite hanging wall, and the bonanzas of that great vein are masses of brecciated rock filled in with ore. So, too, the gold veins of California are in great part bed veins, a fact due to the nearly vertical position of the strata before the deposition of ore, and they are often somewhat indistinctly defined. In short, the character of the fissure which a vein fills must depend on the physical properties of the rock, and clean-cut open fissures can be formed only in appropriate material. In many cases a fracture will produce a belt of crushed country rock, instead of an open crack, and the ore deposited in the interstitial space will depart to a corresponding degree from an ideal vein. Where the strata of a region have a nearly vertical position prior to the formation of veins, bed veins must prevail. When ore is deposited in contact with porous rocks, such as many sandstones, impregnation must take place. The chief difference between an impregnation in sandstone and the injection of a breccia is that in the former case the interstitial space is due to the original structure of the rock, instead of being brought about by dynamic action accompanying the formation of the main fissure. Impregnations of other ores, as well as those of mercury, are not uncommon.

Mr. Lipold showed conclusively that the deposit of Idria consists of simple veins, reticulated masses, and impregnations. Evidence is given above which tends to show that the deposit of Almaden is similar, except that the reticulated masses are tabular and vein-like and that bed veins greatly predominate over those which cut the beds. Humboldt's description of Huancavelica shows that similar conditions there prevail. At Vallalta, also, stringers of ore pierce the shales, the porphyry is impregnated, and the main mass of the ore seems to be a somewhat tabular or vein-like stockwork. In short, all the better-known deposits are referable to the three forms of deposits described by Mr. Lipold, and I know of no sufficient evidence to justify the belief that cinnabar occurs on a large scale as deposits coeval with the inclosing rocks. Cinnabar is not known to exist as cave-fillings. Several geologists think that cinnabar has been to some extent substituted for sandstone, shale, or serpentine; but, while this may be true to some extent, this process does not seem to have been sufficiently rapid to impress upon the deposits the peculiar character seen in some lead mines. The hypothesis of the substitution of cinnabar appears to me thus far to lack sufficient proof.

Genesis and source of the ore.—The mineral associations in which cinnabar is found seem to show conclusively that it has been deposited from solutions. A very large part of the known deposits of cinnabar are extremely similar in character, a fact which seems indicative of a similar origin. It is certain that some of the deposits are due to precipitation from hot volcanic springs and it may fairly be inferred that many of them were formed in this manner. The diversity of the country rocks in which the deposits occur is evidence that only a part of them can have derived their metallic contents from their own wall rocks; the remainder must owe their cinnabar to some source between the point at which the waters acquired their heat and the surface. Between the depth at which volcanic foci lie and the surface of the earth there must be substances of world-wide distribution which frequently contain mercury in some form as an original ingredient. These substances are probably massive rocks, and the only known rock of correspondingly wide distribution is granite.

I now pass to the geology of the cinnabar deposits of the Pacific Slope. After describing them I shall return to the subjects mentioned in these conclusions.

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CHAPTER III.

THE SEDIMENTARY ROCKS.

General character.—The Coast Ranges of California present a truly remarkable opportunity for the investigation of some of the most important phenomena embraced under the general term of metamorphism. To give a clear idea of the unusual advantages afforded by this area it is necessary to anticipate some of the results reached. Field examinations were made for this memoir at numerous points from above Clear Lake to the region of New Idria, thus partially covering a belt of the Coast Ranges about 230 miles in length. Throughout this whole region there is structural and lithological evidence that granite of very uniform character underlies the entire country. Excepting the belt of schists along the coast from Santa Cruz southward, it is estimated that 90 per cent. of all the rocks of this region are sandstones, altered or unaltered. These sandstones are also extremely uniform in character, and wherever they are inconsiderably modified the slides prepared from them show that they are directly or indirectly derived from the granite, or, in other words, that they are arcose. Of this material of known origin a portion has been highly altered. The alteration processes to which it has been subjected are identical from one end of the region to the other and innumerable transitions are presented. It is difficult to estimate the areas occupied by the metamorphic rocks of the Coast Ranges, because the occurrences are extremely irregular. A moderate estimate of the exposures between Clear Lake and New Idria, which consist of holocrystalline metamorphic rocks, sandstones in which recrystallization has made considerable progress, phthanites, and serpentine, is 3,000 square miles. Large areas, covered by late Cretaceous and Tertiary strata, are also known to be underlain by metamorphics, and this series extends far to the north and to the south of the limits indicated without substantial change in character. The study is thus not one of merely local recrystallization, but of regional metamorphism, which is not of uniform intensity and is therefore the better fitted for investigation.

The age of the altered beds is known, from direct paleontological evidence at a number of localities, to be Neocomian, and there is no evidence that any considerable quantity of older rocks is included within the area. The epoch of the metamorphism is also clearly proved to be in the earlier portion of the Cretaceous period, and probably about the close of the Neocomian.

The most interesting alteration processes to which the sandstones have been subjected are closely similar to those which characterize metamorphic areas elsewhere, consisting chiefly in the metasomatic[1] recrystallization of sediments to holocrystalline feldspathic rocks carrying ferromagnesian silicates and in the formation of vast quantities of serpentine. At the same time these rocks present peculiarities distinguishing them from many highly altered rocks in other regions.

The metamorphism accompanied or followed an upheaval of unusual violence. In this uplift the granite must have been shattered as well as the overlying strata. The metamorphism was chemically of such a character as to necessitate the supposition that solutions rising to the surface from the shattered granite beneath co-operated in the process.

Thus the origin of the sedimentary rocks, their mineralogical character in an unaltered state, their age, the approximate epoch at which they were metamorphosed, and the general character of the conditions of metamorphism are all known, while the exposures illustrating the comparatively few more important problems involved are numberless. I am not aware that metamorphism has ever been studied under conditions so favorable for elucidation. It is unnecessary to say that the material is far from exhausted by a single investigation. Much remains to be done, especially from a chemical point of view; indeed, the chemical details of the greater part of the transformations are still unknown.

[1] By metasomatism I understand and desire to express a change effected by the action of mineral solutions having an extraneous origin, but not necessarily or usually involving a total replacement of the material acted upon.

Hypotheses.—Students of the extremely difficult subject of metamorphism have, no doubt, in some cases been tempted to put forward hypotheses, to account for the existence of crystalline rocks, which were warranted neither by detailed observation on the actual series of changes nor by any known chemical principles. It would be a great mistake to assume, however, that careful observations on actual transformations are valueless unless they can be accounted for by known chemical relations. Even the structural formulas of many most important minerals are still in doubt; much more so is the complete theory of their formation; while recent researches, particularly those of Dr. Wolcott Gibbs, demonstrate the extreme complexity of many inorganic chemical processes. Though there can thus be no question as to the existence of transformations in altering rock masses for which no adequate explanation can be offered, it is equally true that observed facts are frequently capable of two or more explanations and that the relations of mingled products are often susceptible of misinterpretation. In the present investigation great care has been taken to avoid errors; and several hypotheses as to relations, in support of which considerable evidence can be adduced, have not been admitted on the ground that the appearances might after all be deceptive. It is believed that by this means the errors have been reduced to a minimum and that the residual observations and inferences recorded in the following pages afford a solid foundation for future inquiry. The results also seem sufficiently definite to form an important aid in the study of more complex metamorphic areas in other parts of the world. That the conclusions reached are applicable to other portions of California is almost certain, for the metamorphosed rocks of the gold belt are in part of the same age as those of the Coast Ranges and appear to be strikingly similar in lithological character. That region is now under investigation by my party, and it is believed that further interesting results, for the same class of metamorphic rocks at least, will be obtained in the near future.[1]

[1] It is probably impossible for any one to free himself from the influence of preconceptions. It may not be superfluous, therefore, to state that in beginning the investigation of the quicksilver belt I entertained no opinions on the character of the crystalline and serpentinoid rocks. I was quite prepared to find the former either eruptive or unaltered crystalline sediments and I entertained no prejudice against regarding serpentine either as an original deposit or as an altered olivine rock. I still regard it as not improbable that crystalline schists and serpentine are sometimes original precipitates

It is well known that eruptive as well as sedimentary rocks are subject to metamorphic action, and, since sedimentary rocks are not infrequently of nearly the same composition as eruptive masses, they should yield analogous results under similar circumstances. The study of metamorphics should therefore throw light on the transformations of eruptive masses, a study most intimately connected with mining geology. It will appear in the sequel, as it does from the published investigations of other geologists, how much caution should be exercised in deciding, from slides of altered eruptive rocks, what mineral constituents are secondary. It is certain that the neglect of such caution has more than once led lithologists into grave errors, and the facility with which it appears that new mineral combinations take place, under conditions perhaps not greatly different from those usually prevailing, strengthens the probability that deceptive appearances are even more common than has hitherto been suspected.

UNMETAMORPHOSED SEDIMENTARY ROCKS.

Macroscopical character of the rocks.—Excepting the light cream-colored schists of Miocene age which occupy a narrow strip along the coast of California from the neighborhood of Santa Cruz southward, the rocks of the quicksilver belt where unaltered are mainly sandstones of Cretaceous and Tertiary age. (See Chapter V.)

The sandstone of the Coast Ranges often occurs in practically uninterrupted series of beds many thousands of feet in thickness Indeed, the observer can hardly fail to wonder under what mechanical conditions such vast accumulations of sand can have gathered. This problem, presented in many regions, though perhaps nowhere else on so large a scale, has never I believe received a satisfactory solution. From the Neocomian to the Miocene the predominant rock of this class is of medium grain and light color, usually yellowish where exposed, bluish at some depth from the surface. The Téjon rock, however, is, as a rule, much lighter in color than the others, and often almost white. Induration is much more frequent among the

and do not doubt that highly olivinitic rocks may decompose to a mass substantially composed of serpentine. For the Coast Ranges of California and in part for the gold belt, however, careful study has led me to very different conclusions; but I do not hesitate to believe that every mineral has been formed somewhere in nature by every possible method Real peridotitic serpentine occurs in the gold belt and has been carefully compared with the serpentine of the Coast Ranges.

older sandstones, but is not unknown among the Miocene beds; and of course where induration exists the tawny color due to oxidation penetrates to a much smaller depth than in the rocks of looser texture. Deep brown, highly ferruginous sandstone is frequent in the form of nodules, as are single narrow beds, particularly in the rocks of the Chico-Téjon group, but it seldom or never occurs in large masses. The sandstones of the Knoxville (Neocomian) group are in great part metamorphosed, and they give rise to the series of rocks which will be discussed in the following pages. The unaltered Knoxville sandstones, on the other hand, lithologically considered, do not materially differ from those of subsequent periods. This fact is not a source of confusion in field work, however, for the portion of the Knoxville sandstones which has entirely escaped alteration is small, and, so far as observed, these are associated with greatly disturbed and intensely metamorphosed rocks of the same period in such a way as to leave no doubt as to their age when once it is established, as will be done in a succeeding chapter, that the great epoch of upheaval and of metamorphism in the Coast Ranges preceded the Chico and Wallala periods. There is more difficulty in distinguishing the somewhat altered rocks of later periods from similar sandstones of the Knoxville group, but associated silicification and serpentinization appear to be confined to beds not younger than the Knoxville series.

Among the unaltered rocks impure limestones play an extremely subordinate but still important part, since they contain the best fossils of the Knoxville group. More widespread are shales (sometimes calcareous), which form a connecting link between the sandstones with a calcitic cement and the limestones. The shales and limestones together form but a small portion of the entire mass.

Origin of the sandstone.—It is found that the unaltered or very slightly altered sandstones of all ages may be discussed together from a lithological point of view. The first point which suggests itself for consideration is the internal evidence of their origin which these rocks present. One of the more important generalizations resulting from the field study of the quicksilver belt is that granite probably underlies the entire area of the Coast Ranges. This inference has received unexpectedly strong confirmation from the microscopical study of the sandstones, for the entire series is thus shown to be composed of granitic detritus, or, in other words, to be arcose. In many cases, indeed, it appears from structural considerations improbable that the sands were immediately derived from granite and altogether probable that they were formed by the disintegration of earlier sandstones. The microscope shows, however, that some of these rocks consist of grains of such angularity and sharpness as to lead inevitably to the conclusion that they were directly derived from granites—indeed, from granites at no great distance from the point of deposition. As a rule the grains are worn and rounded like ordinary beach sand, and in such cases the microscope fails to show whether the material was immediately or indirectly derived from the original granite. But the arcose character is persistent in all these rocks, and this points to short transportation; for the admirable experiments and observations of Mr. Daubrée prove that the feldspathic constituents of granite are rapidly triturated and decomposed in running water. I cannot recall any description in geological literature of a mass of arcose so immense as that exposed in the Coast Ranges.

All the characteristic components of granite reappear in the sandstones, often in proportions differing but little from those which prevail in the parent rock, and it is very rarely the case that the sandstones contain any clastic fragments or allothigenetic minerals not identified in the granites still exposed in the Coast Ranges. Chemical analysis is not calculated to exhibit the origin of the sandstones, for in the course of disintegration and transportation a certain amount of material must have been reduced to impalpable powder, decomposing agencies cannot have been altogether absent, and a certain amount of mechanical concentration must have taken place, although this last influence was reduced to a minimum by the close approach of orthoclase to the density of quartz. It is manifest that the chemical indifference and superior hardness of the quartz establish a tendency to greater acidity in the sandstones than in the granites.

Microscopical character.—The quartz of the fresh and of the slightly decomposed sandstones is exactly similar to that of the granite and commonly contains abundant fluid inclusions, those of small size and regular form showing active bubbles. The feldspars are often present in about the same quantities as the quartz. The predominant species is orthoclase, with characteristic cleavages, extinctions, and twinning. Oligoclase is the most abundant triclinic feldspar, but in a few cases angles of extinction between 20° and 30° on each side of the twinning plane indicate the presence of more basic species. Biotite is also a constituent frequent in many of the sandstones. When it occurs it is usually allothigenetic, and this is shown by its relation to the structure of the mass, the scales being distorted by the pressure of the unyielding grains of quartz and feldspar about it. Occasionally biotites appear to have been bruised edgewise and very finely divided clastic material has silted in between the contorted foils. The biotite when fresh is dirty brown in color and in no respect differs from that of the granites. That a white mica, probably muscovite, forms in the sandstones epigenetically from biotite is certain. It is also found in such a way as to suggest that it is allothigenetic, but it is not impossible to explain these cases by epigenesis. While it is altogether probable on general principles that the muscovite of the granite is represented in the sandstone, the nature of the case precludes absolute certainty on this point. Muscovite is a very subordinate constituent of the granite.

Hornblende, exactly like the granitic hornblende, is tolerably common in the sandstones, usually in very small grains. Titanite in rounded grains, minute zircons, and occasionally epidote have been observed. A strongly refracting, monochroitic mineral was detected, which, after separation, was proved by chemical tests to be rutile. Tourmaline in large, brown, intensely dichroitic grains was also found in the same sandstone as the rutile. Small apatites, especially included in the clastic quartz grains, are not uncommon in the sandstones. Some of the slides of granite in the collection show more apatite in the quartz grains than do any of the slides of sandstone, but apatite is rather irregularly distributed in the granite and some thin sections of this rock contain extremely little of it.

The only allothigenetic material not derivable from the granite which appears with any considerable frequency consists of occasional black scales, sparsely distributed in some localities, from the Knoxville group upwards. In many cases these scales seem referable to carbonaceous shale; in others they at least suggest plant remains, such as are found in the schists of the Knoxville series.

Alteration of the sandstones.—The sandstones have been changed, under the conditions which have prevailed in the Coast Ranges, by several distinct processes of varying interest and importance. They are, of course, subject to the ordinary decompositions known as weathering. Here the ferromagnesian silicates are in part converted into chlorite and in part also into a ferruginous cement; the feldspars become carious, while the quartz is nearly or quite unaffected. Much more interesting is the process of metasomatic recrystallization, which is in some respects the inverse of weathering. In rocks which have undergone this process the clastic grains are transformed into ferromagnesian silicates, feldspar, zoisite, apatite, etc. A third process is that of serpentinization. This sometimes occurs in sandstones in which metasomatic recrystallization has either not taken place at all or only to an insignificant extent. The recrystallized rocks, however, are also subject to serpentinization, and from them the greater part of the serpentine of the Coast Ranges appears to have been produced. A fourth process is silicification, by which shales have been converted into phthanites and sandstones into quartzites. The serpentines and crystalline metamorphics also yield to a similar process and are converted into a dark, opaline substance known in some of the quicksilver mines as quicksilver rock, but this seems to be a phenomenon attending the process of ore deposition rather than that of regional metamorphism. A further rather unimportant process manifests itself in many localities by the presence of numerous stringers of calcite or gypsum intersecting the rocks, particularly the sandstones, in all directions. This process has affected many of the younger rocks, as well as those of the Neocomian.

It is important to remark that some of these processes are inconsistent with one another. Evidently chloritization of the ferromagnesian silicates cannot go on simultaneously with the formation of ferromagnesian silicates by metasomatic recrystallization, and this process is equally inconsistent with serpentinization. So, too, since serpentine is subject to conversion to chalcedony, serpentinization and silicification must go on under different sets of conditions.

Weathering of the sandstones.—The weathering of the sandstones can be very briefly disposed of. The chlorite which forms in this process from the ferromagnesian silicates appears to be identical with that which results from the similar minerals of the recrystallized rocks. The nature of this chlorite will necessarily be discussed in connection with these rocks. Serpentine has not been identified with certainty among the results of weathering in these sandstones. It is possible, however, that it forms a very subordinate product of this process. The decomposition of the feldspars calls for no special comment, excepting that there is no considerable quantity of well marked kaolin.

CONCRETIONS.

Analysis of an example.—One of the most interesting changes which take place in the sandstones is the formation of concretions. These are very common in the Chico-Téjon and Miocene groups. That they really represent changes of composition within the rock mass is certain, for they often develop into a symmetrical, spheroidal shape, without disturbance of the stratification, which the formation of concretions does not wholly obliterate. That these concretions could not gradually be built up during sedimentation is certain. They are usually much harder than the surrounding rock, darker, and of a redder color. In a great majority of cases no nucleus can be found at the center. Under the microscope the chief peculiarity of these concretions was found to consist in a brown cement between the clastic fragments of granitic origin. This cement does not effervesce with acid and is so unusual in character as to call for investigation.

A concretion from the Chico beds of New Idria (No. 53) was selected for examination. One sample of the pulverized rock was treated with cold, dilute chlorhydric acid (1:10) and the resulting solution analyzed. Another sample was digested with stronger acid (1:1), at first at ordinary temperatures and then for twenty-four hours on the water-bath. The solution formed was analyzed and the residue was treated with a hot solution of sodic carbonate to extract soluble silica. Special determinations were made of carbonic acid, ferric oxide, etc. The following table shows the percentages soluble in weak acid and in strong acid separately.

	First sample.	Second sample.
Loss at 100°, H^2O	0.855	....
Carbonic anhydride, CO^2	8.952	....
Silica, SiO^2	0.362	0.177
Phosphoric acid, P^2O^5	0.034	0.035
Alumina, Al^2O^3	0.320	0.385
Ferric oxide, Fe^2O^3	0.607	0.783
Manganous oxide, MnO	0.195	0.162
Lime, CaO	11.152	0.139
Magnesia, MgO	0.315	0.162
Soda, Na^2O	0.031	0.122
Potassa, K^2O	0.068	0.119
Silica extracted by Na^2CO^3	....	2.865
Residue	....	72.110
Total percentage	....	99.956

When the atomic ratios of this analysis are calculated it appears that the protoxide bases found in the first sample are slightly in excess of the amount required to saturate the carbonic acid. All excess of these bases, as well as the alumina and the iron (which is wholly in the ferric state), must be combined with phosphoric and silicic acids. Assuming that the phosphorus is as usual combined as triphosphate of calcium, the remainder is a silicate or a mixture of silicates. The atomic ratio of the sum of these silicates is:

$$Si : \overline{R}^{vi} : R'' \qquad 0.22688 : 0.09385 : 0.22695$$

$$\text{or } Si : \overline{R}^{vi} : R'' \qquad 5 : 2 : 5.$$

If the water is taken into account, as it apparently should be, the ratio becomes 2 : 5 : 2 : 5, indicating some form of a hydrous subsilicate.

The cementing material of the concretion then is an intimate mixture of calcium carbonate with a hydrous subsilicate and a small but not inconsiderable amount of phosphate. The subsilicate may probably be regarded as an iron compound in which a portion of the iron is replaced by alumina and protoxide bases. How such a cement can be formed within the body of a sandstone is evidently a question of great interest, and in its answer lies the secret of the class of concretions of which the specimen investigated is an example.

Action of a nucleus.—Since it is manifestly impossible that these concretions should be built up during the deposition of the sand, they must be due to the action of some substance embedded in the rock. The spherical form which they tend to assume and to which they often closely approximate indicates that this substance either exists or once existed at the center, and this simple inference is confirmed by the fact that the concretions are often separable into spherical shells, indicating a change in composition related to the distance from the center. Such concretions are common, for example, in the Chico beds near Lower Lake. So far as my observation goes, the central substance has utterly disappeared in a great majority of cases. In three or four instances I have found fossils at the centers of these concretions, but I have broken open great numbers of them without finding any visible difference in the substance at the center and elsewhere. Such was the case in the specimen investigated, and chemical tests also failed to detect any foreign substance. Thus, while fossils are occasionally found both in California and elsewhere at the centers of concretions in sandstone, such cases are so rare that one would by no means be justified from observation in ascribing the concretions to the action of organic matter, nor am I aware that it has ever been shown how organic matter could effect such a result.

Nucleus possibly organic.—The analysis given above appears to me capable of interpretation in a manner calculated to throw light on the nature of the central substance. The cement of the concretion contains one-fourth of 1 per cent. of phosphoric acid, most of which must have come from the central substance, for the cement of the sandstone away from concretions is almost pure calcite. Taking the size of the concretions into account this indicates the existence of much phosphorus in the central substance. The possibly organic nature of the substance in question is thus strongly suggested. But is there any way in which an organic substance could give rise to the formation of hydrous ferric silicate? I think there is.

It is well known that during the decomposition of organic matter various acids are formed, and that among them the group of humus acids frequently occurs. These acids, or some of them, dissolve magnetite, and in this way sands underlying vegetable soils are frequently bleached.[1]

[1] Roth: Allg. und chem. Geol., vol. 1, p. 596; and A. A. Julien: On the geological action of the humus acids, Proc. Am. Assoc. Adv. Sci., vol. 28, 1879, pp. 311–410.

Some of these acids also combine with silica to silico-azo-humic acids. According to Mr. P. Thenard, acids of this series form spontaneously in the soil from humic acid, the ammonia of rain water, the nitrogen of the air, and the silica contained in the soil.

Modus operandi.—It is clear that a fragment of undecomposed organic matter embedded in a porous sandstone may decompose under the action of percolating surface waters and that under favorable conditions it may yield humic acid which will attack the magnetite, always present in greater or smaller quantity. With the silica of the rock silico-azo-humic acid may also be produced. Were large quantities of organic matter present together with much water the result might be a mere bleaching of the sandstone; but, if small quantities of the solutions of the humic compounds only are formed, they will be drawn into the surrounding sandstone by capillary action and a more or less nearly spherical mass will be impregnated with them. This mass may, perhaps, increase in size until the organic matter is exhausted.

The humic compounds are very unstable, and a globular mass, such as is supposed above, would soon decompose into carbonic acid, water, etc. There would then remain a spheroidal mass of carbonates and silicates of the bases which had been dissolved at an earlier stage. The latter being formed at low temperatures would not improbably be hydrous. Calcium phosphate is soluble in solutions of carbonic acid, and one would therefore expect to find the phosphorus of the organic substance also diffused through the mass. The hypothesis of a decomposing organic nucleus thus appears to account in a rational manner for all the observed facts.

Summary of evidence.—The fossils occasionally met with in sandstone concretions are so rare as only to suggest that these masses may have been indurated through the indirect action of organic matter. The presence of phosphoric acid in notable quantities in the matrix of concretions which contain no fossils greatly strengthens the hypothesis that organic matter once existed in these masses, but has since disappeared. When it is found that the chemical character of the matrix of these concretions is also such as would result from the decomposition of organic matter by processes of which the main features are well known, the weight of the concurrent evidence is very great. It is clear that the formation of concretions is due to the presence of small masses of some foreign substance in the sandstone. Were this substance composed of any other elements than carbon, hydrogen, nitrogen, and phosphorus, such elements would almost inevitably appear as components of the concretion. It thus appears to me nearly certain that the concretions are due to the action of decomposition-products arising from organic matter.

It is evident that the formation of concretions by means of organic matter, as sketched above, is a result which will take place only under somewhat special conditions. If sufficient organic matter exists in a rock, induration of the entire mass may occur. If the humic components are washed through the rock without being allowed to decompose, the rock will be bleached. Both of these last cases are considered by Professor Julien in the paper referred to above, but he does not particularly discuss the subject of concretions

NODULES RESULTING FROM EXTERNAL ATTACK.

Cases to be discussed.—Besides the concretions discussed above, rounded nodules are found in many decomposing rocks. In the present memoir such occurrences will be noted in the basalts of the Sulphur Bank mine and in the partially serpentinized rocks, especially near Knoxville, Napa County. They are also well known to occur in some decomposed granites and in andesites, those for instance near the Comstock lode. The principles on which they are formed are extremely simple, but, so far as I know, they have never been stated, and a lack of knowledge of them has often led to erroneous assumptions of a mysterious ball structure in the rocks which favors such decomposition. As will be seen below, pebbles in brooks and on beaches, as well as grains of sand, are rounded in a manner closely analogous.

Deduction of relations.—Suppose a sphere of any homogeneous substance, into which liquids can penetrate a small but finite distance, and let this distance be assumed as the unit of length. Then, if r is the radius of the sphere, the volume of the solid which can be permeated by a liquid acting on the exterior is a spherical shell, the content of which is:

$$V=\frac{4}{3}\pi r^3-\frac{4}{3}\pi (r-1)^3=\frac{4}{3}\pi (3r^2-3r+1).$$

The surface of the sphere is, say, $S = 4 \pi r^2$ and

$$S/V = \frac{3r^2}{3r^2 - 3r + 1}.$$

The surface of the material exposed to the action of the fluid per unit of volume of the shell acted upon, or S/V, may readily be seen from this equation to diminish rapidly as the radius of the sphere increases.[1] For example, if the radius is unity, or just equal to the depth to which the solid is permeable, $S/V = 3$; if $r = 2$, $S/V = 1.7$; if $r = 4$, $S/V = 1.3$, and if the radius is infinite or if the attacked surface is flat, $S/V = 1$.

Suppose a unit of volume of a thoroughly porous, solid substance in any given shape and exposed to the action of a solvent liquid: the liquid will become partially saturated near the surface of the solid and will act less vigorously upon the underlying portions. It is clear, therefore, that, if the body is given the shape of a slender rod and is acted upon by the fluid from one end only, it will dissolve less rapidly than it would if the same mass were formed into a thin sheet and were attacked over the whole of one surface of this sheet. It is easy to see that the rate at which solution will take place in this case is nearly proportional to the surface exposed to the action of the fluid.

Hence it is sufficiently accurate for the present purpose to assume that the rate at which a spherical mass will be attacked by a corrosive fluid will be proportional to the surface exposed per unit of volume of the permeable shell, or to S/V. This function (and therefore, also, the rate at which solution will take place), as has been shown above, varies in a certain inverse ratio to the radius of the sphere.[2]

If, therefore, any comparatively dense, irregular body is acted upon by solvent or decomposing solutions, the portions the radii of curvature

[1] The portion of the sphere which is not reached by the fluid is essentially a positive quantity, and when r becomes less than unity, $\frac{4}{3} \pi (r-1)^3$ disappears from the value of S/V, which thus becomes equal to $3/r$. This is a hyperbola, asymptotic to both axes, and S/V is infinite for $r = 0$. At the point at which $r = 1$ this hyperbola passes over into the curve of the third degree given in the text. The hyperbola would be asymptotic to $S/V = 0$, while the higher curve is asymptotic to $S/V = 1$.

[2] This conclusion is not affected by the uncertainty which exists as to the exact function representing the rate of solution in terms of S/V; for it is clear that in any case this function and S/V must vary directly, and that both of them, therefore, vary inversely as the radius of curvature.

of which are equal to or less than the distance to which the fluid can permeate will yield very rapidly, while those of less abrupt curvature will be more slowly decomposed or dissolved. There will thus be a constant tendency to diminish the curvature of the more salient portions and, if the mass is not too thin, to reduce it to a sphere.

Cases.—Two special cases need consideration: If the action of the fluid were strictly confined to the surface or if the mass were absolutely impermeable, the radius of curvature would always be infinite compared with the distance to which a fluid could penetrate, and, if solution took place, the mass would always retain an angular form, the surfaces of which would be parallel to those which it originally presented. On the other hand, if the fluid could permeate to the center of the body, all portions would be attacked at once and it would disintegrate almost simultaneously throughout its mass.

Nearly every American has daily opportunities for observing the relations here reduced to exact terms. Clear, solid ice is practically impermeable by water, and an angular fragment of such ice in a glass of water becomes only slightly rounded, while the surfaces at all stages of the melting process are nearly parallel to the original ones. On the other hand, a bit of ice which is clouded with small air bubbles is permeable by water to the depth of these bubbles, and consequently the edges and corners of an angular mass of such ice are quickly rounded. Again, a lump of cane sugar is very porous and fluids permeate to its center. It therefore disintegrates under the action of a solvent fluid almost without preliminary rounding of the edges and corners.

Application to decomposing rocks.—The behavior of rocks to dissolving or decomposing agencies is similar. There do not seem to be any rocks, excepting perhaps some obsidians, which are permeable only to an insensible distance by fluids; but there are many rocks so dense that fluids penetrate them with great difficulty and very slowly. In such cases the corrosive reagents which waters contain are neutralized by the time the solutions have penetrated to a very small depth, and corrosive action is limited to this thin outer layer As decomposition is completed in the outer layer, active reagents will of course permeate farther and farther into the rock. The geometrical

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results will clearly be those discussed above. An angular mass of such a rock will yield to the decomposing agencies directly as S/V, or in an inverse ratio to its radius of curvature, and, if the mass is homogeneous, it will gradually be reduced to the spherical form. It thus becomes evident that angular blocks of basalt attacked by sulphuric acid or other corrosive fluids tend to the spherical form, not because of any variation in the internal structure, but, on the contrary, because they are substantially homogeneous.

The rocks which do not weather or decompose to rounded masses are the more permeable class. Thus, in the Washoe district dense andesites and basalts tend to the spherical form, while tufaceous masses and porous rocks decompose with tolerable uniformity throughout. In terms of the mathematical discussion for the latter, $r < 1$. Just so along the quicksilver belt: dense rocks undergoing serpentinization show rounded nodules of unaltered or slightly altered material, while more permeable masses are gradually changed to serpentine throughout.

It may not be amiss to note that the depth to which a rock will be attacked by any decomposing fluid depends somewhat upon the nature of the fluid. If the reaction between the liquid and the solid is a rapid one the liquid will become substantially saturated comparatively near the surface, while, if the reaction is feeble and slow, the fluid will penetrate to a greater depth before losing its corrosive power. Complex cases sometimes result from the co existence of various reactions, each leading to a particular kind of decomposition.

Application to pebbles.—It is evident that the principles applied in the foregoing discussion are not limited to the action of fluids. Any disintegrating agency acting uniformly on the surface of an angular body or acting successively on all points of its surface will be governed by similar laws. Consider a fragment of rock in a stream bed or on a beach. It suffers frequent impacts from other bodies of similar average size and composition. Each of these impacts disintegrates the mass at the small surface of contact to a certain average depth, and these impacts are repeated in indefinite number on all portions of its surface. The result must be the same as if the rock fragment were subjected to a disintegrating action simultaneously at all points of its surface, and, just as in the case of a solvent fluid, the mass must tend to a spherical form, provided that it is of uniform composition.

If the body is permeable to different depths in different directions or if it offers more resistance to abrasion in one direction than it does in others, the surfaces which offer the least resistance will evidently be most rapidly attacked. Hence, pebbles of sedimentary rocks, which do not in general possess equal coherence in all directions, will not tend to a spherical form, but to one more or less approaching a spheroid or even an ellipsoid.

It appears from the literature of geology that rounded masses resulting from the decomposition of comparatively impermeable rocks have not infrequently been mistaken for water-worn pebbles. When one considers that in both cases the approach to the spherical form is due to similar causes this does not seem so strange as it otherwise might.

CRYSTALLINE METAMORPHIC ROCKS.

Groups of metamorphic rocks.—The metamorphosed rocks of the Coast Ranges may be divided into serpentine and a more or less crystalline series. The latter, indeed, usually contain some serpentine; but serpentinization is evidently in part a secondary process and will be discussed, together with the massive serpentines, in a succeeding section. The division of the crystalline series which appears best to satisfy both their microscopical character and their field occurrence is as follows: (1) Partially metamorphosed sandstones, in which, although a process of recrystallization has begun, the clastic structure as seen under the microscope is not obliterated, though more or less obscured. These rocks will be referred to hereafter, for the sake of brevity, as altered sandstones. (2) Granular metamorphics, in which thorough metasomatic recrystallization of the sandstones has transformed the mass into a granular, holocrystalline aggregate which, in its most complex development, consists of augite, amphibole, feldspar, zoisite, and quartz, with accessory minerals. This class cannot be sharply separated from the first or from the following, but it forms a natural group, one or several of the constituents of which may be suppressed, forming different varieties within the group. (3) Glaucophane schist of an origin similar to that of the granular rocks, usually carrying mica, quartz, and other minerals.

(4) Phthanites or schistose rocks which have been subjected to a process of silicification.

There is seldom any doubt about the macroscopical determination of the third and fourth of these groups; in a large proportion of cases also, the granular rocks can readily be distinguished from the altered sandstones with the naked eye or the loupe, but this is by no means always possible. Many rocks which to the naked eye appear to be merely considerably altered but perfectly recognizable sandstones turn out, upon microscopical examination, to be holocrystalline and to have lost entirely the characteristic clastic structure.

The granular rocks are separable, under the microscope, into several varieties, according to their mineralogical composition; but it is seldom possible to distinguish these varieties macroscopically. In dealing with eruptive rocks the eye soon accustoms itself to the perception of very minute differences of appearance which represent or are associated with microscopical peculiarities. The metamorphic rocks are physically and chemically much more heterogeneous than eruptives, and it is only in extreme cases that the habitus is characteristic of the precise mineralogical composition.

As will appear in the sequel, the altered sandstones and the granular rocks form a series which is in reality unbroken. The processes of alteration can be studied in rocks retaining as clearly as possible evidences of their clastic character. The same processes can be traced through series in which the clastic elements gradually disappear and in the extreme members of which a holocrystalline mass of authigenetic minerals is presented. In the altered sandstones various transformations begin simultaneously, and, according to the physical and chemical conditions under which the metamorphism occurred, one or other of these changes may predominate in the fully altered rock. In this way types are produced so distinct that were these alone submitted to examination little analogy would be perceived between them; but they are, in fact, connected with one another, as well as with the unaltered sedimentary rocks, by very gradual transitions.

In describing the various types more or less repetition is unavoidable. For the sake of brevity it seems expedient to begin the discussion of the rocks by noting the minerals which result from the metamorphic processes one by one, leaving for subsequent discussion the various combinations in which they occur.

Biotite.—When foils of biotite are compressed into zigzag outlines by the pressure of adjacent clastic grains the mineral is evidently allothigenetic. In some other cases there is a lack of decisive proof as to the origin of the biotite, but there are also occurrences which can only be interpreted as authigenetic. The authigenetic biotite scales are sharper in outline than the allothigenetic foils, and are usually of a light, clear, chestnut-brown color. In cross-section they are often seen to be undulous, but do not form broken lines like clastic foils. They are frequently embedded in recrystallizing feldspar grains. The quantity of this mica detected is small, and it seems probable that when formed it readily passes over into white mica by epigenesis. In one glaucophane schist from New Idria there is a great abundance of fine, nearly uniaxial biotite.

Muscovite.—The epigenetic formation of white mica from biotite and from feldspar has long been recognized. In the recrystallizing sandstones of the Coast Ranges white mica is rather rare as an indubitably allothigenetic component, but is very common as an alteration product of brown mica. It also appears to form in the cementing mass of fine detritus and deposits between the clastic grains of sandstones; but, while the occurrences and the analogies are such as to warrant an opinion that such foils of white mica are authigenetic or epigenetic on authigenetic biotite, it can hardly be demonstrated that this material is not allothigenetic. In the more altered rocks it is seen forming in disintegrating feldspar grains and it is an important constituent of the glaucophane schists. Where it can be separated in foils it is found that the angle of the optical axes is large.

Augite.—Though a careful watch has been kept for rhombic pyroxene, none has thus far been detected in any of the metamorphic rocks. In the rocks which retain an unmistakably clastic structure augite is rare, a fact which appears to be due to the tendency of the mineral to decomposition when the structure of the rock in which it exists is sufficiently open to permit of the free percolation of solutions. There are a few examples, however, which leave no doubt as to the fact of the formation of augite in sandstones undergoing the process of metasomatic recrystallization, and which thus form a link between typical sandstones and the more highly altered rocks in which the clastic origin is not evident on mere inspection. In these rocks minute bacillar augites make their appearance in newly formed aggregates limited by the outlines of the original clastic grains. There is clearly a tendency to parallelism and to grouping of these augite crystallites, and the evidence points irresistibly to the conclusion that under favorable circumstances large solid crystals of augite form by the union of these smaller masses. In a considerable number of instances these microlites are actually united in close groups bounded by crystallographic outlines. The usual occurrence of garnet in metamorphic rocks indicates an entirely similar process of aggregation. It is quite impossible to ascribe any but an authigenetic origin to these characteristic occurrences of augite in newly formed aggregates arising from the alteration of clastic grains, nor is such a formation surprising, since the artificial reproduction of augite by the action of heated water under pressure upon appropriate mineral mixtures is a well known phenomenon. A fine example of a partially formed augite crystal in an altered sandstone is shown in Fig. 2, page 88.

In the more fully crystallized metamorphic rocks augite is often very abundant. It is of lighter tint under the microscope than the ordinary bamboo-colored augites of eruptive rocks, is monochroitic, and extinguishes at high angles. It readily passes over into uralite, chlorite, epidote, and serpentine. The uralite often has a bluish tint approaching that of glaucophane. There is a marked tendency in the larger augite crystals to the development of the orthopinacoidal cleavage, and in a few of the rocks the pyroxene is well developed diallage.

Hornblende.—This mineral occurs in the recrystallized and recrystallizing rocks in two forms. Brown hornblende forms much in the same way as augite and is observed sometimes in the same slides with it. Groups of hornblende microlites also show common crystallographic outlines; a case of this kind is shown in Fig. 3, page 89.

Either minute chemical differences or certain physical conditions seem to regulate the preponderance of the one mineral over the other, so that the fully recrystallized rocks are divisible with some sharpness into hornblendic and augitic groups. No clear indication has been detected that the mode of occurrence differs for the two classes. This may nevertheless be the case, for the amphibolic and pyroxenic rocks are macroscopically indistinguishable, excepting in a few cases, and differences in occurrence would thus readily escape detection. At present it seems more likely that the controlling factor is an unknown and certainly very slight difference of chemical composition. Observation has shown me that it is absolutely necessary in some eruptive rocks to resort to a chemical explanation of the replacement of one of these minerals by the other without affecting the probability, in another class of instances, that the same replacement is due to differences of physical condition.[1]

Green hornblende is also very abundant. Much of this is certainly uralitic and some of it appears probably due to the alteration of brown hornblende. There are also cases in which the green hornblende, so far as can be judged, is a direct product of metasomatic action, but none in which every other explanation is excluded. There are further instances which suggest the existence of a brown uralite, but these cases are believed to be better explained by envelopment.

The authigenetic hornblendes are readily distinguished from allothigenetic fragments, the latter being commonly of a dark, dirty-green color and much more pleochroitic than the newly formed mineral. The outline of clastic fragments is usually characteristic. In extreme cases there is some difficulty in distinguishing green hornblende from chlorite, but where the particles are not excessively minute the oblique extinction of the former is generally perceptible.

Glaucophane.—This is a prominent component of the micaceous schists[2] and occurs also in the more composite granular rocks and in the amphibolite. Cross-sections frequently show the amphibolic outline and cleavage. The pleochroism and absorption are strong. The pleochroic colors are *a*, brownish yellow to colorless; *b*, violet; *c*, ultramarine blue. The absorp-

[1] For some curious evidence bearing on this point, see my Geology of the Comstock Lode and the Washoe District, Mon. U. S. Geol. Survey No. 3, p. 60.

[2] According to Mr. H. G. Hanks, glaucophane was detected by Mr. Michel-Lévy, in 1878, in specimens of micaceous schist from the Wall Street quicksilver mine, Lake County, exhibited at the Paris exposition in 1878. (Fourth Annual Report of the State Mineralogist of California, 1883–'84, p. 182.)

tion is $c > b > a$. The angle of extinction is that of amphibole, but the interference colors are of lower order. The specific gravity is 3.10 to 3.11,[1] but the mineral is usually so intimately associated with others as to make a perfect separation difficult.

The genetic relations of the glaucophane are not entirely clear. In the greater number of cases it is closely associated with ordinary actinolite, and there appear to be unquestionable transitions between the two. Thus, one portion of an area of entirely undecomposed amphibole of uniform orientation is often bright blue, another green, and these pronounced tints shade off into each other by imperceptible gradations. Had only these occurrences been observed, the conclusion would have been almost inevitable that the two varieties of amphibole had been produced simultaneously and by the same methods. There are other cases, however, in which narrow streaks of the blue mineral appear along the junction of actinolite crystals, which suggest the possibility of epigenesis of glaucophane upon actinolite. I am inclined to consider this suggestion misleading, however, because fibration and sensible difference of orientation would almost inevitably result from such a process.

Zoisite.—Much the most interesting mineral yet detected in the rocks undergoing metasomatic recrystallization is zoisite, which as an important rock-forming mineral has hitherto been observed only in the saussuritic crystalline schists and gabbros. In the rocks of the Coast Ranges this mineral is one of the first indications of recrystallization; it is found in slides of every group of the recrystallized rocks and is often present in large quantities, especially in the schists.

The zoisite presents no good cleavage, but traces of fissility parallel to the main axis are sometimes visible. The prisms are usually jointed and terminal faces are often distinct. Measurements of the projection of the interfacial angle between the brachydome and brachypinacoid agree with the real value of this angle as well as could be expected. Square cross-sections are not uncommon and often only a single corner appears to be truncated. This irregular development of faces in the vertical zone is characteristic of zoisite.[2]

[1] Lüdecke found the specific gravity of glaucophane from Syra, 3.101 (Roth: Allg. und chem. Geol., p. 21).

[2] Dana's System of Mineralogy, p. 290.

The color of the zoisite, as seen by the naked eye, varies from gray to deep green. In the former case it is of course colorless in thin section, and this is usually the case in the augitic and hornblendic rocks, though a faint greenish yellow may sometimes be observed. In the glaucophane rocks the color is usually deeper, and the pleochroism is then distinct in thin section, *c* being yellowish green to light grass green and *a* and *b* almost colorless. The absorption is hardly perceptible. The pleochroism increases with the thickness of the section. The axes of elasticity, when their position can be determined, are always strictly parallel to the vertical crystallographic axis and to the pinacoidal faces. The angle of the optical axes is large and the plane of the axes is parallel to one of the pinacoidal faces. The colors of interference usually range between a bluish gray and a pale yellow, but are occasionally more vivid. The intensity of the colors often seems to vary considerably with the state of aggregation.

Zoisite occurs in the phthanites as well as in the other metamorphic rocks, but usually in much longer needles than in the other metamorphic rocks. Fig. 1 shows both types of crystals, between which there are plenty of intermediate forms.

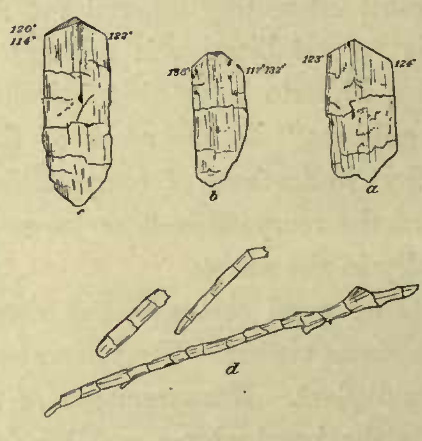

FIG. 1. Zoisite microlites, *a*, *b*, and *c*, from a glaucophane rock, No. 31, Sulphur Bank. *a* and *b* are magnified 175 diameters; *c*, 136 diameters; *d* is from minute quartz veins in phthanite (No. 51, Mt. Diablo) and is magnified 185 diameters.

For the purpose of checking the microscopical determination of this mineral, two separations and analyses were made. Though great care was taken in the separation and purification, the character of the rocks showed that only approximate results were to be expected. No. 98, Sulphur Bank, which will be described on a future page, consists mainly of glaucophane and zoisite; but fine needles of the former penetrate the latter. The purest lot of zoisite had a specific gravity of 3.21, which is less than that of unmixed zoisite, but greater than that of glaucophane. Its composition was found to be as follows:

Water at above 100°, H^2O	5.25
Silica, SiO^2	39.80
Titanic acid, TiO^2	Trace
Alumina, Al^2O^3	22.72
Ferric oxide, Fe^2O^3	4.85
Ferrous oxide, FeO	1.49
Manganous oxide, MnO	0.26
Lime, CaO	17.55
Magnesia, MgO	3.89
Soda, Na^2O	4.09
Potassa, K^2O	0.12
Total	100.02

The atomic ratio $H^2 : R'' : R^{vi} : Si$ is represented by 2.62 : 4.54 : 6.82 : 12. This clearly does not correspond to pure zoisite, of which the ratio is 1 : 4 : 9 : 12, and the question arises whether it may represent any other lime-alumina silicate. A glance at the minerals of similar composition, the density of which lies between 2.90 and 3.50, shows that the choice is small, and in fact, among known minerals, is limited to zoisite and prehnite. The specimen analyzed was more acid than zoisite, but more basic than prehnite. Considering that the maximum density of prehnite is 2.95 and that the known impurity of the specimen is acid, the tendency is all to the supposition that the mineral is zoisite. If one supposes the admixture to be simply a bisilicate of a protoxide base and that this impurity contained about one-fourth of the silica, the above atomic ratio reduces almost exactly to 3 : 4 : 9 : 12. It is true that glaucophane is an aluminous amphibole and that if sesquioxides are subtracted from the analysis the ratio 4 : 9 : 12 cannot be exactly preserved; but the rock also contains quartz and the atomic ratio of zoisite is known to vary to some extent. The figures discussed, in connection with the known impurities, are thus sufficient to show that the mineral is not prehnite and is far more closely allied to zoisite than to any other known mineral. There is an excess of water shown by the analysis, which seems to have arisen from imperfect desiccation.

A second separation was undertaken with No. 219, Sulphur Bank, a rock composed chiefly of greenish zoisite and actinolite, the former embedded in the latter. It was impossible wholly to separate the two minerals and the purest sample had a specific gravity of no less than 3.37, showing that much actinolite remained. The analysis gave the following results:

Loss above 100°, H^2O	1.119
Silica, SiO^2	39.196
Phosphoric acid, P^2O^5	Trace
Titanic acid (rutile), TiO^2	1.169
Alumina, Al^2O^3	22.760
Ferric oxide, Fe^2O^3	6.487
Ferrous oxide, FeO	1.783
Nickel oxide, NiO	Trace
Manganous oxide, MnO	0.090
Lime, CaO	22.023
Maguesia, MgO	1.643
Soda, Na^2O	3.382
Potassa, K^2O	0.575
Total	100.227

This analysis gives the atomic ratio $H^2 : R'' : \text{R}^{vi} : Si = 0.57 : 4.56 : 7.22 : 12$. Here, also, if the admixed silicate has a protoxide base and if it contains about one-sixth of the silica, the ratio is reduced to one resembling that of zoisite, viz, $\frac{2}{3} : 4 : 9 : 12$. In this case there is too little water instead of too much, but in performing the analysis the sample was accidentally dried at somewhat above 100°.

Although zoisite is extremely abundant in the metamorphic rocks of California, there were no specimens which seemed so well adapted to a separation as the two discussed above. The manner in which the components of these rocks are intergrown renders separations almost impracticable. Impure as the materials analyzed were, however, the results show that the substance in question was really a zoisite.

Under different conditions zoisite possesses a considerable similarity to other minerals. Especially when granular, it might at first sight be confounded with epidote; but it is distinguished by its color, its monochroism or slight dichroism, by the colors of interference, and, when seen in cross-section, by the angle of extinction. The more highly colored zoisite in prisms bears a superficial resemblance to augite, which needs only to be pointed out to avoid confusion. The mineral in the form of small prisms and needles may readily be confounded with apatite. The latter, however, does not give the yellow interference tints of zoisite and seldom shows the light-green tint in natural light which is frequent in zoisite. The index of refraction of zoisite seems to be higher than that of apatite, so that its crystals stand out in relief from the slide similarly to those of zircon, though not to the same extent. Cross-sections of zoisite are also usually square, and by careful use of the micrometer screw zoisite prisms may usually be seen to be fluted or furrowed in the direction of the principal axis, while apatite prisms display, so far as I know, no such irregularity of surface. The distinction between these minerals can be drawn by one or more of these means in almost all cases, but the discrimination requires watchfulness. Microlites of zoisite sometimes present an appearance somewhat resembling that of a rhombic pyroxene, but hypersthene is as a rule strongly dichroitic, while enstatite is usually fibrous and seldom if ever forms crystals. Prehnite is a mineral which might readily be confounded with zoisite, from which it is distinguished by specific gravity and by behavior to acids. These are not very satisfactory distinctions, because it is hardly practicable to test every slide with acids or to obtain the specific gravity of the mineral in every specimen. A considerable number of such tests have been made, however, and in no case did either test indicate the presence of prehnite, nor has prehnite been detected macroscopically.

Zoisite in the recrystallizing sandstones not only forms in aggregates of recrystallizing minerals, but also results from the attack of quartz grains. Well developed crystals of zoisite, with somewhat rounded terminal faces, may often be seen growing into quartz grains from the outside almost exactly as they might develop in a limpid fluid. It must of course be supposed in such cases that there is a space between the ingrowing crystal and the surrounding quartz which admits of the penetration of fluids, though under the microscope no such opening is visible. If there is one, the parasitic crystal must enlarge in diameter as well as in length, and such appears to be the fact, for the longer crystals are as a rule also the larger ones.

Zoisite is unknown in eruptive rocks, except as an epigenetic constituent. In the Coast Ranges the relations of the zoisite to the disintegrating clastic elements of the altered sandstones are such as to forbid any supposition except that it is authigenetic. The granites contain none.

Saussurite.—In 1859 Dr. T. Sterry Hunt[1] showed that the saussurite of the euphotide of Monte Rosa corresponded in chemical composition and physical character to zoisite. After the application of the microscope to the study of lithology, saussurite was recognized as (ordinarily, at all events) a mixture. In 1883 Mr. A. Cathrein[2] showed that many saussurites were mixtures of zoisite and feldspar. Many of the metamorphic rocks of the Coast Ranges might be described as saussuritic, but it appears unadvisable to retain distinct names for mixtures of this description after their real composition is established.

In the California rocks this mixture is not a product of decomposition under ordinary conditions, but of a process of recrystallization inconsistent with ordinary decomposition. In Switzerland and elsewhere eruptive diabasic rocks are supposed in some instances to have been converted into saussuritic masses, while in others decomposition has yielded no zoisite In any case the result of a chemical process must be that group of compounds the formation of which liberates heat most rapidly. It is consequently to be supposed that the saussuritic gabbros have been subjected to influences different from those to which such gabbros as have undergone ordinary decomposition have been exposed. Judging from the analogy of the rocks of the Coast Ranges, it may be conjectured that the saussuritic gabbros stand to ordinary rocks of the same species in the same relation as the zoisitic altered rocks of the Coast Ranges do to those which have merely weathered, or, in other words, that the saussuritic rocks are the result of a process of metamorphism acting upon rocks some of which are eruptive.

Feldspars.—The formation of feldspars is an almost invariable accompaniment of the metasomatic changes of the rocks of the quicksilver belt,

[1] Am. Jour. Sci., 2d series, vol. 27, 1859, p. 336.
[2] Zeitschr. für Kryst. und Mineral., Groth, vol. 7, 1883, p. 234.

and the only exception appears to be in the case of the amphibolites, which seem most rationally regarded as extreme cases of the dioritic group. The genesis of feldspar in the metamorphic rocks is certainly one of the most important changes, and it is also one which is very fully illustrated by the collections. The unquestionable authigenesis of minerals of this group is excellently seen in No. 11, Knoxville, an augitic rock intersected by minute, almost microscopic, veins. Portions of these veins are filled with well developed, striated feldspar prisms and irregular grains of plagioclase, seemingly oligoclase. In some portions carbonates are mixed with these crystals and appear to have crystallized at the same time with the feldspar. These crystals are more recent than the rock in which they are embedded, but they demonstrate that conditions necessary and sufficient to the formation of feldspar in the wet way have existed in this region. The whole occurrence is such as to exclude the possibility that these veins are of eruptive origin. There is also abundant evidence of the presence of authigenetic feldspar in the altered sandstones. The process usually commences in the fine detritus which often composes the cement of the sandstones. Here form slender, polysynthetic, plagioclase microlites, of such shapes and in such grouping that it is impossible to suppose them to be clastic constituents. The larger grains are attacked later than the cement, and both quartz and feldspar grains appear to be resolved into plagioclase, secondary quartz not infrequently forming at the same time. The corroded grains are often to be seen surrounded by a fringe of authigenetic plagioclase microlites, the nucleus remaining clear. The allothigenetic feldspar grains are also often recrystallized without any change in the external outline. In such cases an aggregate results which is usually microcrystalline, but often also includes or may be almost entirely composed of lath-like, hemitropic lamellæ.

There appears clear evidence of the process by which tolerably large plagioclases may be formed in the rocks which have undergone metasomatic recrystallization. In some rocks which still retain an indubitably clastic character, plagioclase microlites may be seen forming in groups of almost identical orientation, but still separated by thin layers of minerals not belonging to the feldspar series. Even rough, crystalline outlines may be traced surrounding such groups. The hemitropic lamellæ in such cases

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usually have frequent offsets, and the crystallographic orientation, though nearly the same for the whole group, is not absolutely uniform. It is extremely difficult to understand this building up of crystals from microlites; yet perhaps in no other way could the formation of garnets, tourmalines, and a long list of other minerals be explained in strata which can never have been reduced to a plastic state.

The commonest feldspar species in the altered sandstones and the granular rocks is oligoclase, but andesine is probably also common. Many angles of extinction, referable to andesine, have been observed, and in one case a separation and chemical analysis showed the presence of this feldspar. Labradorite is found in the gabbroitic rocks and in at least one pyroxene rock where the bisilicate is not diallage. Orthoclase has been proved chemically to exist in one glaucophane rock, and albite in a feldspar-augite-hornblende rock. There may be more albite than has been detected, since it cannot be recognized with ease by optical means in the presence of oligoclase.

Rutile.—In some of the schists and amphibolites numerous masses of a bright-brown, anisotropic mineral were observed. Many of these masses are prismatically developed, though the edges and corners are somewhat rounded. They are monochroitic and extinguish light when parallel to the principal sections of the nicols. The interference colors are scarcely distinguishable from those observed in ordinary light. A small amount of this mineral separated from an amphibolite proved on chemical examination to be titanic acid. The absence of dichroism and of brilliant colors of interference shows that it is not brookite. The prismatic development excludes anatase,[1] while its characteristics correspond exactly to those of rutile. Some of the masses of rutile are partially decomposed to a light-colored, clouded substance similar to leucoxene.

Ilmenite.—Titanic iron is very abundant in some of the groups of granular, metamorphic rocks, and the associations are such as to lead to the supposition that it has been formed at the same time with the bisilicates. The characteristic triangular grating of the ilmenite is much more common in these rocks than it usually is in eruptive masses. The ilmenite is frequently

[1] See a report of an investigation by Thürach: Neues Jahrbuch für Mineral., vol. 2, 1885, p. 398.

accompanied by clouds of leucoxene. The appearance of this material is entirely accordant with the supposition that it is granular titanite.

Titanite.—Besides the clastic grains of this mineral in the sandstones, it appears in the glaucophane schists in characteristic rhomboid forms, the corners being wholly unabraded. In the same rocks it appears as more or less regular grains, embedded in zoisite and in entirely undecomposed glaucophane. It is thus to be considered as an authigenetic component of these rocks, apparently replacing the ilmenite of the granular group. The colors in ordinary and in polarized light and the other optical properties, as well as the form, are entirely characteristic and require no comment.

Apatite.—This mineral having been detected by optical and chemical means as an authigenetic constituent in one slide, a special examination of the collection was made for fear that it might have been mistaken for zoisite. It was found in abundance in some of the pyroxene granular rocks and in two glaucophane schists. Minute prisms of this mineral appear also to be present in a few of the altered sandstones. Apatite is tolerably frequent as an inclusion in clastic grains.

Chlorites.—Chlorites are abundant both in the sandstones and in the recrystallized rocks which are undergoing weathering. As usual, it is difficult to determine the particular species of chlorite; indeed, the specific distinctions between these minerals are far from satisfactory. All of the chlorite met with possesses the usual grass-green tint and is strongly dichroitic. It is usually fibrous, but in a few cases shows irregular scales. The fibers always extinguish light when sensibly parallel to the principal section of the polarizing apparatus, while some of the scales appear to remain absolutely dark between crossed nicols. The interference colors of the fibrous aggregates vary greatly. When the mass is composed of felted fibers of minute size the colors of polarization are very feeble. In other cases dark-blue tints appear, and in some instances, which appear to be distinguished by unusually large quantities of parallel individuals, yellow interference colors make their appearance. By treatment through a perforated cover with moderately strong, warm chlorhydric acid, it was found that the ordinary fibrous chlorite of these rocks is not attacked. Portions of the same specimens, however (e. g , No. 26, Sulphur Bank), treated with boiling, concentrated chlorhydric acid, yielded a solution containing both alumina and magnesia. Clinochlor is thus absent. None of the specimens affords an opportunity of isolating the chlorite in sufficient quantities for quantitative analysis. Pennine is stated to occur characteristically in hexagonal scales, which are readily attacked by chlorhydric acid.[1] It is possible that the rather rare irregular foils mentioned above belong to this species; but the fibrous variety is certainly not easily attacked by the acid. Of the ordinary chlorites there remains only the ripidolite of Rose, which is Werner's chlorite and Dana's prochlorite. It is to be hoped that the researches of Professor Tschermak will make future determinations more satisfactory than this.

Epidote.—Epidote is not very abundant in the metamorphic rocks. In a single specimen, however (No. 119, Knoxville), it is developed in large crystalline grains with two cleavages, and in this case greatly resembles augite. The optical reference of this specimen was confirmed by a silica determination, which was 38.98 per cent. The usual occurrence of this mineral is in crystalline aggregates in association with chlorite, to which it often stands in relations strongly suggesting epigenesis from chlorite. No cases so fine as those described and figured in my memoir on the Comstock lode were met with. Professor Rosenbusch[2] doubts my explanation of those occurrences, believing that they are not of such a nature as to preclude the simultaneous formation of the two minerals. It is difficult to prove absolutely that they were not formed at the same time, because of the lack of persistent structure in the chlorite; yet, from the inspection of almost numberless cases, it certainly appears that epidote needles pierce aggregates of chlorite fibers freely, while the arrangement of these fibers does not bear any visible relation to the epidote crystals such as is familiar in cases of simultaneous formation. When I first expressed my opinion on this subject I was unaware that other lithologists had reached the same conclusion. Both Dr. H. Francke and Prof. A. Renard anticipated me in what I still regard as the most probable explanation.[3]

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[1] Fouqué and Michel-Lévy: Min. micrographique, p. 438.

[2] Neues Jahrbuch für Mineral., vol. 2, 1884, p. 187.

[3] Dr. Francke's paper, Studien über Cordillerengesteine, Inaug. Diss., Leipzig, 1875, I have not seen. The following is an extract from Mr. Renard's paper on the diabase of Challes (Bull. Acad. roy. Belgique, vol. 46, No. 8, 1878, p. 239[2]): "Francke admits that the epidote is formed by the decomposition of the viridite included in the feldspars, the viridite itself arising from the decomposition of horn-

Garnet.—In the glaucophane schists garnets are not infrequent, though nowhere very abundant, in crystals measuring from 0.3^{mm} to 2^{mm}. The garnet is of a pale reddish-brown tint, perfectly isotropic, and includes zoisite, titanite, and glaucophane. It decomposes to a coarsely foliated chlorite. Nothing answering to the kelyphite of Mr. A. Schrauf[1] has been observed, and it can only be supposed that the decomposition has been effected by the action of magnesian waters. Serpentine is also associated with the decomposing garnets, but not under conditions sufficiently pronounced in the material at hand to justify any positive assertions as to the relations of the two minerals.

Other minerals.—Zircon is common as an inclusion in clastic grains and is also probably present in some of the glaucophane schists. A careful watch has been kept for other minerals, such as andalusite, dipyre, prehnite, allanite, and zeolites. The last occur macroscopically in the New Almaden mine, but have not been observed in the slides.

ALTERED SANDSTONES.

In various specimens of altered sandstone one or other process of transformation may be lacking or insensible, but in a number of cases a single slide furnishes an almost complete epitome of the entire series. I do not think it possible to convey to the reader a better idea of the metamorphism of the sandstones than by describing a few typical instances.

Examples.—A good example of an altered sandstone is afforded by a rock from near Knoxville.[2] Macroscopically it is a dark-green, fine-grained sandstone, evidently somewhat altered. Seen under the microscope with a low power it appears to be a typical sandstone, with only insignificant changes. With a No. 4 Hartnack it is seen to contain numerous unaltered

blende. The statements applicable to the viridite of the hornblende from Francke's point of view are true also of the chloritic material derived from augite and which, as we have seen, so often fills feldspathic sections, for these two substances, so imperfectly determined from a chemical point of view, present fundamental analogies in composition. We have been led to regard the epidote inclosed in feldspar sections not as pseudomorphic after feldspar, but as a result of the transformation of chloritic matter. There are, furthermore, numerous instances of this transformation."

[1] Zeitschr. für Krys. und Mineral., Groth, vol. 6, p. 321.

[2] No. 8, Coast Range collection, bed of Jericho Creek.

grains of granitic quartz and feldspars, but it also becomes apparent that a great proportion of the allothigenetic minerals have been converted into aggregates of new minerals. Especially important is the presence in this slide of unquestionably authigenetic augite and hornblende. Augite occurs in several places under circumstances which place its authigenetic character beyond doubt. Of these the best is illustrated in the accompanying Fig. 2. It is a slightly greenish prism with terminal faces forming angles on the right and left sides, respectively, of 125° and 128°, and an angle of extinction of about 30°. It occurs in a crystalline aggregate filling the position of a clastic grain of which the outlines are traceable. The portion not occupied by the augite is composed of microcrystalline feldspar and quartz. There are also films of serpentine among the grains. The upper right-hand corner of the augite is changed to uralite.

FIG. 2. Anthigenetic augite in altered sandstone, No. 8, Coast Ranges. *A*, augite; *u*, uralite; *f*, microcrystalline feldspar; *q*, quartz grain; *s*, serpentine. Magnified 117 diameters.

Authigenetic hornblende of light-brown color is also present, and the best example appears in the following Fig. 3. It is surrounded on two sides by microcrystalline, authigenetic feldspar and lies against a clastic orthoclase grain. As appears from the cut, a large part of the outline is as sharp as possible. The unabraded corners, the color and character of the mineral, and the association all forbid its being regarded as allothigenetic. On the left side are a number of hornblende microlites in parallel position, apparently representing the incomplete portion of the crystal.

Various other phenomena can be studied in this slide: Zoisite, in prisms and granular masses, is developing in some of the clastic grains; triclinic feldspar, in grains and in polysynthetic microlites, is forming in others; and the resolution of quartz as well as of feldspar can be observed. White mica is forming authigenetically, and perhaps also apatite. Decomposition has also set in and the slide contains some serpentine. These phenomena are better observed, however, in other cases.

FIG. 3. Anthigenetic hornblende in altered sandstone, No. 8, Coast Ranges. *a*, clastic quartz; *b*, clastic feldspar; *c*, anthigenetic hornblende; *d*, authigenetic feldspar aggregate; *e*, clear isotropic mass; *s*, serpentine. Magnified 170 diameters.

No. 86, New Idria, is a coarse, bedded, dark greenish-gray sandstone, evidently altered, but manifestly a sandstone. Under the microscope the clastic character is clearly visible, the original limits of the grains being defined by irregular streaks of brown or greenish color. Some of these streaks represent decomposed mica foils. In the clear masses separated by the colored streaks are embedded angular and rounded grains, many of which are quartz carrying abundant fluid inclusions, while others are feldspar. Surrounding these nuclei are aggregates, chiefly feldspathic, and these aggregates are so related to the nuclei that it is impossible to doubt that they are composed of authigenetic minerals formed at the expense of clastic grains, only the central portions of which remain. Many of the residual grains are almost entirely surrounded by elongated microlites in positions nearly normal to the surface of the nucleus. The ends of the microlites do not merely abut against the nucleus, but penetrate it for a sensible distance, so that the edge of the grain seen in section is full of indentations, each the bed of a microlite. This relation is more clearly seen by revolving the analyzer. In positions where the colors of the host are strong while those of the parasites are weak, the original mineral is seen to extend out among the microlites, while, when the relations of the colors are reversed, the nucleus appears limited nearly to the inner ends of the microlites. As the polarizer revolves, the visible limits of the parent mineral dilate and contract in a very striking manner.

In many cases the nuclei are quartz and the microlites are polysynthetic twins, which in favorable cases give the angles of extinction of oligoclase. In other cases the nuclei are feldspar, sometimes orthoclase and again plagioclase; the parasitic microlites, however, again appear to be chiefly oligoclase. That oligoclase should result under the same conditions from the attack of quartz and of feldspar is in the highest degree remarkable; but the observations made on this slide and confirmed by comparison with other thin sections admit of no other simple explanation. The process of alteration does not go on only at the surface of the quartz grains. In the granites quartz grains are frequently composite, the separate crystalline individuals sometimes exhibiting a barely perceptible difference in crystallographic orientation. The lines dividing the individuals must also be lines of weakness, and when the fractures which take place in the disintegration of the parent rock do not follow these lines they may often be seen to have afforded opportunities for the attack of the solutions and to be marked by narrow bands of microlites nearly perpendicular to the line of division.

It is not always that the microlites resulting from the attack of quartz and feldspar in this rock are lath-like. In many cases they take the form of irregular grains indenting one another and assuming the granophyr-like structure mentioned in the slide from Jericho Creek. These grains are not polysynthetic, but evidently feldspathic, and are so associated with the elongated microlites as to make it probable that they are of the same or a closely allied species.

This slide also contains small quantities of zoisite and some undeformed foils of white mica embedded in aggregates which have replaced clastic grains. Both of these minerals are authigenetic. There are also decomposition products, including a little serpentine.

No. 134, Sulphur Bank, is manifestly a much altered, arenaceous rock, of a strong green tinge, intersected by minute veins of a feldspar-like mineral. Under the microscope the clastic character is perfectly distinct, the clear or somewhat milky grains being divided by a net-work of thoroughly characteristic conformation. The net is composed of green and brownish-green matter. The original clastic minerals have entirely disappeared. The thin section shows half a dozen minute veins, more or less continuous, and these are filled with feldspar, which is for the most part granular, but occasionally shows irregular, hemitropic lamellæ. On the course of one of the veins, at a point at which the vein pinches, is a very remarkable feldspar aggregate of lath-like microlites extending over an area several times as wide as the adjacent vein. This aggregate has replaced, wholly or in part, several clastic grains the shape of which is faintly traceable by brownish streaks. Three-fourths of the periphery of the aggregate is nevertheless bounded by straight lines. The aggregate is composed of polysynthetic, lath-shaped microlites almost exactly parallel to one another and giving low angles of extinction on each side of the twinning plane. The position of these microlites corresponds to the straight outlines and the entire aggregate appears to represent a porphyritic, authigenetic feldspar cut nearly perpendicular to the brachypinacoid and showing two distinct terminal outlines at one end. The chief distinction between this and porphyritic feldspar in eruptive rocks is the frequent interruption of the hemitropic lamellæ. The traces of the original outlines of the clastic fragments still visible in the feldspar forbid the supposition that it is an allothigenetic mineral; neither is it possible that such a crystal should have been transported and redeposited without abrasion of its corners. The slide shows several other feldspars of similar character, but less perfectly developed. The greenish-brown net-work between the altered grains in this slide is chiefly composed of a non-dichroitic, fibrous mineral showing dull-yellow interference colors and thus corresponding to serpentine. There are no patches of it large enough to show the characteristic grate structure.

No. 212*a*, Sulphur Bank, is a dull-green sandstone intersected by quartz veins. Under the microscope it is seen to be a partially decomposed sandstone, containing numerous fragments of quartz, orthoclase, and plagioclase, the interstices being in part filled with serpentine. The slide is chiefly remarkable for the presence of zoisite in considerable quantities, growing into the quartz grains. The zoisite shows the characteristic extinctions, interference colors, refraction, and cross-section.

No. 15, Sulphur Bank, an ordinary gray, indurated sandstone, shows phenomena similar to those described in No. 86, New Idria. It also contains a great deal of zoisite, both in the granular and the prismatic form. The zoisite in this slide was tested with nitric acid to make sure that apatite had not been mistaken for it.

An especially significant rock is No. 13, New Almaden, which is both macroscopically and microscopically unquestionably an altered sandstone. In the slide, however, it is seen that the progress of the metasomatic recrystallization has been somewhat irregular and that there are fields in the slide which could not be distinguished from an ordinary eruptive diabase. As the slide is moved, however, the structure and mineral composition change gradually and by insensible degrees until the eruptive habitus is lost and the clastic character is clearly revealed. There is no suggestion of included fragments or dikes of eruptive rock in the specimen or slide.

No. 13, Sulphur Bank, a slightly altered sandstone from the metamorphic series, was selected for chemical analysis. Under the microscope the rock appears to be arcose, the grains being quartz similar to those of the granites, plagioclase, and unstriated feldspars, with the optical properties of orthoclase. The grains are cemented by newly formed aggregates which seem to consist in great part of triclinic feldspar. From inspection one would expect to find in this rock about equal quantities of soda and potash. The following analysis, however, shows a very different and unexpected relation:

Loss at 100°, H^2O	0.276
Loss above 100°, H^2O	2.113
Silica, SiO^2	68.500
Phosphoric acid, P^2O^5	0.163
Titanic acid, TiO^2	0.600

Alumina, Al^2O^3	12.816
Ferric oxide, Fe^2O^3	1.293
Ferrous oxide, FeO	3.373
Manganous oxide, MnO	0.023
Lime, CaO	1.823
Magnesia, MgO	2.206
Soda, Na^2O	6.033
Potassa, K^2O	1.259
	100.478

The atomic ratio represented by this analysis is $H^2 : R'' : \bar{R}^{vi} : Si = 0.266 : 0.490 : 0.801 : 4.567$. How the soda can be so greatly in excess of the potash in such a rock I cannot explain. The cementing feldspathic mass may be very rich in soda and possibly some of the unstriated feldspars are triclinic. It is also possible that the orthoclase is abnormally sodic.

These examples show that nearly all of the most important metasomatic processes can be traced in rocks the clastic character of which could be questioned by no one for a single moment. It is only necessary to suppose the same processes carried further to obtain a product in which the clastic character is obscured or obliterated, and the altered sandstones, under the microscope no less than in the field, thus form transitions from the clastic series to the holocrystalline rocks. The enlargement of clastic grains by crystallization from infiltrating solutions, which has been shown by several geologists[1] to be not infrequent in some regions, and of which I too have studied fine examples, has not been observed in the rocks here described. The general nature of the changes here consists in the attack of clastic constituents, not in the addition of mineral matter of the same kind.

GRANULAR METAMORPHICS.

Nomenclature.—There are in many parts of the world metamorphic rocks very closely resembling diabase and diorite in mineral composition. These rocks have sometimes been called, by myself as well as by others, metamorphic diabases and metamorphic diorites; but there are serious objections to these terms. A diabase would be defined by most geologists as a Pre-Tertiary eruptive rock, mainly composed of plagioclase and pyroxene. This is also the historical meaning of the term. To those who have

[1] See Hunt, Origin of Crystalline Rocks, § 116.

this definition in mind the name metamorphic diabase would not convey the idea of a metamorphic rock resembling a diabase, but of an eruptive rock changed by metamorphic processes. Even if diabase were usually understood to signify a rock of a certain age and a particular mineral composition, irrespective of origin, the term metamorphic diabase would be inconvenient on account of its length. If it were in frequent use, it would often be contracted to diabase, and this term would lead to misunderstandings. It seems eminently desirable to retain for diabase and diorite the meanings which they have long conveyed to geological readers and to limit their application to eruptive masses. Metamorphic rocks which resemble them in mineral composition may then fitly be called *pseudodiabase* and *pseudodiorite*, and these terms will be employed in the remainder of this report.

Groups of granular metamorphic rocks.—The granular crystalline rocks of the Coast Ranges are divisible according to their mineralogical composition into several more or less well-defined groups, between which, however, there are transitions, as there also are between the granular and the schistose rocks. The chief divisions are pseudodiabase and pseudodiorite. The pseudodiabase is sometimes met in gabbroitic modifications and in a few cases contains so much zoisite that it might without impropriety be denominated a zoisite pseudodiabase; for, since it has been shown that saussurite is either mere zoisite or a mixture of zoisite and plagioclase, there appears to be no reason for retaining that name. The pseudodiorite passes by gradations into a mass so highly hornblendic as to deserve the name of amphibolite. There are also a few rocks in which no augite or amphibole appears, and which are thus composed of feldspar, quartz, zoisite, etc. These appear to represent pseudodiabase or pseudodiorite in extreme forms, since they are locally associated with these rocks, as are also the slightly altered sandstones.

The schistose rocks are all characterized by the presence of glaucophane and zoisite. They are usually micaceous, but sometimes not.

PSEUDODIABASE.

Pseudodiabase is much the commonest of the crystalline metamorphic rocks of the Coast Ranges. When sufficiently coarse in texture it is readily

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seen with the naked eye to be a crystalline mass, though it could rarely be mistaken for an eruptive rock. It then shows dark-green bisilicates and sometimes, also, feldspar grains. The absence of visible feldspar grains corresponds to a microcrystalline groundmass. Very frequently the rock is fine grained, and then it sometimes retains the appearance of an altered sandstone so perfectly that it is impossible to discriminate between this and pseudodiabase without the aid of the microscope.

Under the microscope it is found that at least a portion of the augite exists in comparatively large grains or crystals, while the feldspar may be granular or microcrystalline. In other words, as sometimes happens among eruptive rocks, both granular and somewhat porphyritic forms of pseudodiabase are common and are intimately associated. Under the circumstances a difference in chemical composition appears to be a necessary inference from this difference in structure.

Orthoclase has not been detected in the pseudodiabase. Plagioclase usually forms the greater portion of the rock. In those rocks in which the feldspathic mass is microcrystalline it forms a mass of minute interlocking grains, sometimes resembling granophyre. These minute grains seldom exhibit polysynthetic structure and cannot be referred to their proper species by optical methods. A separation and partial analysis of a typical occurrence of this material, No. 105, Knoxville, showed that it approaches andesine in specific gravity and composition. In the rocks in which the plagioclase grains reach 0.1^{mm} and upwards in length, twin structure is usual and lath-shaped individuals are common. The hemitropic lamellæ are often irregular, showing breaks and offsets. The extinctions refer them to oligoclase or andesine. Porphyritic feldspars are uncommon, but not wholly wanting. Altogether the most ordinary inclusion in the feldspar consists of grains and prisms of zoisite. These are not products of the decomposition of the feldspar, but of contemporaneous development, both minerals being often perfectly fresh. When the pseudodiabase has not been subjected to serpentinization the feldspars are often affected by a decomposition process resulting in the formation of irregular grains of a colorless substance which gives orange tints between crossed nicols. Its nature is uncertain. Distinctly developed nacrite has been detected in only one of the rocks.

Much of the quartz in the pseudodiabases is secondary, but in a few cases quartz grains appear to have formed contemporaneously with the feldspars. They carry a few fluid inclusions.

No rhombic pyroxene has been detected. In the extremely rare cases in which crystals of pyroxene extinguish light when parallel to the principal nicol sections, there appears no difference between their dichroism or other properties and those of the other pyroxenes in the same slide. The proportion of cases in which the extinction of the pyroxene crystals sensibly coincides with the principal axis is very small and not greater than might be expected in the case of a monoclinic mineral. Both augite and diallage occur, but no sharp line can be drawn between them. In nearly all cases the clinopinacoidal cleavage of the larger crystals seems well developed. Pyroxene evidently develops early and vigorously in the rocks undergoing recrystallization and tends to the formation of porphyritic crystals. Well-developed crystals are not very common.

Amphibole occurs as brownish-green crystals, formed contemporaneously with the augite and more abundantly as unmistakable uralite. A few of the pseudodiabases also carry glaucophane.

Examples.—No. 21, Coast Ranges, from near Mt. St. Helena, is a gray, rather fine-grained rock, which, on close inspection, appears crystalline. Under the microscope it is seen to contain much augite and hornblende, together with feldspar, both polysynthetic and monosynthetic, and an unusually large quantity of zoisite. It is also unusually free from decomposition products. This rock represents both the pseudodiabase and pseudodiorite, between which there is no sharp division.

The hornblende is in part of a clear, light, but not vivid, brown color, with very moderate dichroism. This variety occurs in well developed crystals, giving normal extinctions and cross-sections. Curiously associated with it is a light-green variety. Many of the crystals are in part brown and in part green, the division being a sharp, straight line. The different portions of such composite crystals extinguish simultaneously, but usually give very different interference colors. The cleavages are continuous from one portion to the other, nor does the green mineral exhibit greater fibration or any other structural peculiarity. In somo cases the line of demarkation is curvilinear, but nowhere does the green color follow cleavages or cracks or penetrate the brown by sharp indentation, as products of alteration usually do. There seems nothing to indicate that the two varieties have not formed simultaneously, and even on this supposition the sharpness of demarkation and the character of the limits are difficult to understand. There is a little ordinary chlorite in the slide, produced by decomposition of hornblende.

The augite possesses no peculiarity excepting its relations to the hornblende. There is some ordinary uralite, but there are also augite masses partly surrounded by brown hornblende in such a way as to suggest a brown uralite. The relation of the brown hornblende to the augite, however, is similar to that which the green hornblende bears to the brown, and I cannot satisfy myself that it is really epigenetic.

The feldspar is for the most part clear and fresh, and a large portion of it shows polysynthetic structure. The extinctions observed indicate the presence of oligoclase. To test the character of the feldspar, a separation was made by the Thoulet method. At a density of 2.85 a large precipitate of bisilicates and zoisite fell, carrying a portion of the feldspars with it. On reducing the specific gravity of the solution gradually, 5 per cent. fell at 2.65, which appeared under the microscope to be pure feldspar. Between 2.65 and 2.58 there was no precipitate. From 2.58 to 2.56, 7 per cent. of pure feldspar fell. This was found to contain 11 per cent. of soda, and the rock, therefore, contains both oligoclase and albite. The zoisite occurs in part in prisms with characteristic properties, but mainly as granular masses, which are nearly colorless and monochroitic, but otherwise not unlike epidote in appearance. Exactly such zoisite was isolated from a Mt. Diablo specimen and chemically tested. The greater part of the zoisite is embedded in the clear feldspar, but it also fills interstices between feldspars, so that the formation of the two minerals must have gone on simultaneously.

Ilmenite in part converted to leucoxene is abundant in this as in most of the pseudodiabases and pseudodiorites. A complete analysis of this rock gave the following result:

Loss at 100°, H^2O	0.275
Loss above 100°, H^2O	1.179
Silica, SiO^2	49.080
Phosphoric acid, P^2O^5	0.232
Titanic acid, TiO^2	1.721
Alumina, Al^2O^3	14.683
Ferric oxide, Fe^2O^3	1.946
Ferrous oxide, FeO	9.632
Manganous oxide, MnO	0.154
Lime, CaO	10.091
Magnesia, MgO	6.693
Soda, Na^2O	4.597
Potassa, K^2O	0.199
Total	100.482

The atomic ratio deduced from this analysis is $H^2 : R'' : \mathrm{R}^{vi} : Si =$ 0.162 : 1.116 : 0.935 : 3.272.

No. 11, Knoxville, appears macroscopically a green, much-altered sandstone, intersected by numerous minute veins of white mineral. Under the microscope it is found to be a holocrystalline pseudodiabase considerably decomposed. The feldspars are in part granular, but chiefly lath-shaped crystals from 0.1^{mm} to 0.4^{mm} in length. They are mostly clouded by very small interpositions. The greater part show polysynthetic structure, and the highest angles of extinction found were from 16° to 18° on each side of the twinning plane. The fine grain of the rock and the presence of much epigenetic chlorite make separation difficult. It was found, however, that the last precipitate fell at a density of 2.63, and there is therefore little orthoclase, if any, in the rock. The feldspar must be chiefly, if not wholly, oligoclase.

The veins in this slide are filled for the most part with beautiful prismatic crystals of plagioclase mixed with calcite. The augite occurs as imperfect prismatic crystals and grains, either included in the feldspars or between the crystals of the latter. Its color is very faint; it is not dichroitic and gives characteristic extinctions. The large amount of chlorite appears due to the decomposition of the augite. Zoisite is not very abundant in this slide, but is present in characteristic prisms. Ilmenite and leucoxene are frequent.

No. 36, Sulphur Bank, is a dark-green, fine-grained, crystalline rock, in which feldspars and bisilicates can be seen with the naked eye. Under the microscope all the feldspars appear to be twinned and those which are favorably placed for examination give angles of extinction appropriate to oligoclase. The slide contains a little quartz. The pyroxene is mostly in the form of small grains, but there are some larger crystals giving the angle of extinction of augite. The mineral is almost colorless. The slide also contains one hornblende prism. Titanic iron and unquestionable transitions from this to titanite are common.

This slide shows notable secondary changes. Uralitization, which is so common in the pseudodiabases, is here entirely absent. The augite decomposes directly into serpentine and chlorite, both of which are abundant.

A complete analysis of this rock was made. The composition is extremely similar to that of No. 21, Coast Ranges, given above:

Loss at 100°, H^2O	0.389
Loss above 100°, H^2O	2.965
Silica, SiO^2	51.278
Phosphoric acid, P^2O^5	0.131
Titanic acid, TiO^2	1.330
Alumina, Al^2O^3	15.048
Ferric oxide, Fe^2O^3	2.415
Ferrous oxide, FeO	8.014
Nickel oxide, NiO	0.098
Manganous oxide, MnO	0.251
Lime, CaO	7.079
Magnesia, MgO	6.069
Soda, Na^2O	4.433
Potassa, K^2O	0.123
Total	99.623

The atomic ratio deduced from this is $H^2 : R'' : R^{vi} : Si = 0.373 : 0.931 : 0.974 : 3.419$.

PSEUDODIORITE.

The pseudodiabase passes by transition into gabbroitic modifications on the one hand and into pseudodiorite on the other. There is no general and characteristic distinction between pseudodiorite and pseudodiabase, as seen under the microscope, excepting the character of the bisilicate, and it is only when the bisilicate is unusually abundant that the two rocks can be told apart without the microscope.

An interesting pseudodiorite is No. 179, Knoxville. This is a fine-grained, crystalline, dark-green rock, in which amphibole is visible macroscopically. Under the microscope it is seen that the rock is a porphyry, containing large grains of hornblende in a fine-grained, colorless groundmass. When well exposed this groundmass shows a faint net-work of greenish lines, which, judging from the form of the net, represents the outlines of the original clastic structure. Cracks also intersect the groundmass, and these often radiate from the porphyritic hornblendes in a very peculiar manner, as if the hornblendes had expanded forcibly while forming. The groundmass is very fine-grained, the individuals ranging from 0.01^{mm} downwards.

Polysynthetic microlites were not detected, but the material precisely resembles that in another rock from the same district (No. 105, Knoxville), which was isolated and found to have a specific gravity of 2.64, to contain 59.14 per cent. of silica, and to correspond qualitatively to andesine in composition.

The hornblende is of a brownish-green color and forms grains reaching half a millimeter in length. In the hornblendes are small shreds and patches of glaucophane. In other pseudodiorites (for example, No. 183, Knoxville), there is more glaucophane and single crystals of amphibole may be seen, blue at one end, green at the other, and of intermediate tints in the middle. The glaucophanic pseudodiorites form a link between the granular, crystalline rocks and the glaucophane schists. This slide shows ilmenite and leucoxene, but no zoisite was detected. There runs through the slide a vein which is filled with chlorite and a colorless mineral of uncertain character.

The hornblende in the pseudodiorites is sometimes so abundant as to form much the greater part of the rock, which may then be considered as an amphibolite. One of the best examples of this kind is No. 56, Knoxville. It is composed almost exclusively of long, slender, greenish crystals of actinolite in nearly parallel arrangement, giving the mass a schistose character. The microscope shows a little white mica, chlorite, and serpentine in the rock. Included in the actinolite are also grains of titanite, brown, somewhat pleochroitic prisms of rutile, and small zircons. Long, thin, dark inclusions, arranged parallel to the cleavage of the amphibole, are perhaps also rutile. The following analysis shows the composition of this rock:

Loss at 100°, H^2O	0.068
Loss above 100°, H^2O	0.916
Silica, SiO^2	50.437
Alumina, Al^2O^3	8.183
Chromic oxide, Cr^2O^3	0.480
Ferric oxide, Fe^2O^3	1.059
Ferrous oxide, FeO	6.285
Manganous oxide, MnO	0.213
Lime, CaO	11.550
Magnesia, MgO	17.628
Soda, Na^2O	2.982
Potassa, K^2O	0.503
Total	100.304

The atomic ratio deducible from this analysis is $H^2 : R'' : R^{vi} : Si =$ 0.109 : 1.573 : 0.539 : 3.362.

GABBROITIC PSEUDODIABASE.

While a tendency to the development of the clinopinacoidal cleavage of the pyroxenes of the pseudodiabase has been already noted, characteristic diallage is somewhat rare. One occurrence is known on Bagley Creek, at Mt. Diablo, the great mass of which is composed of zoisite-pseudodiabase and phthanites. It is a dark-green rock, composed of granules of from one to two millimeters in diameter. Fresh feldspar and the grayish-green, almost metallic luster of the diallage cleavage surfaces are visible with the naked eye.

Under the microscope the diallage is monochroitic, nearly colorless, and carries inclusions in the direction of the best cleavage. The slide contains a little uralitic hornblende. In a few places a decomposition-product, similar in appearance to the ferruginous cement of the sandstones, appears to have formed from the diallage. The feldspars are clear and give extinctions as high as 30° on each side of the twinning plane, indicating the presence of labradorite.

The hand specimens of this rock do not greatly resemble eruptive masses and the nature of the occurrence clearly indicates their metamorphic character, but the slide is indistinguishable from thin sections of eruptive gabbros.

There appears to be no reason to consider the above-described rock as anything more than a variety of the pseudodiabase. A similar rock is found at the Great Western, and at New Almaden a gabbro occurs as pebbles, apparently derived from the mountains to the south.

GLAUCOPHANE SCHISTS.

Character.—Accompanying the granular, holocrystalline metamorphics, in much smaller quantities than these, are somewhat schistose rocks, which are sometimes evidently micaceous and sometimes appear to the naked eye chloritic. All of these are found to carry glaucophane, usually accompanied by zoisite and mica. Some of them are macroscopically indistinguishable from specimens from Syra. They are so related structurally to the granular rocks as to show them to be members of the same series, and, as has been shown, glaucophane and zoisite both occur in the granular rocks. It is worthy of note that the plagioclase of the granular rocks and the glaucophane of the schists each imply the presence of sodium in the solutions, by which metasomatosis of the sandstone series was effected. The zoisites also, at least in part, contain alkalis. Though glaucophane rocks are not infrequent in the Coast Ranges they usually occur only in small patches, and it is seldom possible to trace them to their unaltered form. At Mt. Diablo, however, they certainly pass over into slightly altered shales, and there is also evidence elsewhere that the schistose structure is an original feature, not a result of metamorphism. The predominant cleavage in these schists is marked by a prevailing similarity of direction of the glaucophane prisms and mica foils, although by no means all of the crystals of either mineral are similarly placed. The structure and association of minerals will best be described by examples.

Examples.—No. 31, Sulphur Bank, is a schistose, gneiss-like rock, in which layers of greenish mica, in small foils, traverse a fine-grained, reddish or greenish gray, granular mass. Bluish-gray grains of glaucophane are also macroscopically visible. Under the microscope a great portion of the rock is seen to be made up of interlocking grains of quartz and unstriated feldspar. In the Thoulet solution a considerable amount of feldspathic material floats at 3.59, and this gives a strong potash reaction, showing that the material is at least in part orthoclase. Higher specific gravities and chemical tests show that plagioclase is also present. The slide contains a number of large glaucophane crystals, some of them, which are cut across the principal axis, exhibiting the characteristic amphibole prism and cleavage. The optical properties are as described on a previous page. There are few microlites of glaucophane.

Embedded in the mass of feldspar and quartz are numerous green hexagonal foils, which give the optical reactions of mica and are soluble with difficulty in hot sulphuric acid. The mineral is probably a biotite. White mica is also present. The scales of this mineral cannot well be separated, but in a similar rock (No. 117, Coast Ranges) white mica is present in foils of considerable size, which can be separated. They show a large angle between the optical axes, and are therefore probably muscovite. Zoisite is abundant in No. 31, in well developed, pointed prisms with terminal faces. It is greenish and slightly dichroitic, which is unusual. The slide contains a few garnets and much titanite. Some well developed rhombs of the latter mineral include ilmenite grains. Apatites, zircons, and a little chlorite connected with the biotite were observed. In the groundmass are groups of long, colorless, radiating fibers, which appear to extinguish light in the direction of the main axis and when densely massed give very vivid interference colors. These properties correspond to fibrolite, and, did these needles occur in a true gneiss, instead of in a Cretaceous, metamorphic rock, no hesitation would be felt in identifying them as such. Under the circumstances and in the absence of opportunity for determining their specific gravity, it is not safe to pronounce on their composition.

No. 147 corresponds in some particulars to the rock just described; brilliant, brown biotite, however, with characteristic interference figure, replaces the muscovite, and a small portion of the feldspar shows striations. The glaucophane is in all respects similar. Apatite is present, but zoisite could not be identified with certainty.

No. 98, Sulphur Bank, is a greenish-gray, schistose rock, consisting chiefly of glaucophane and zoisite. The latter occurs in imperfect prismatic crystals, with a maximum length of from 0.1^{mm} to 0.2^{mm}. The prisms show longitudinal furrows. The zoisite is distinctly dichroitic and has a faint olive-green tint when the prisms are parallel to the principal section of the nicols. Sections perpendicular to the main axis are square, often with one truncated corner. The extinctions are normal and the colors of interference are gray to yellow in the prisms, but more vivid in granular aggregates. The angle of the optical axes appears to be large.

Glaucophane, in needles and long, imperfect, nearly parallel prisms, gives the rock its cleavage. Quartz, albite, muscovite, and titanite are present.

The rock was reduced to a grain of one-third of a millimeter, and separated by the Thoulet method with the following result:

Specific gravity of solution.	Character of precipitate.
3.22	Small quantities of opacite and titanite.
3.21	Tolerably pure zoisite, which was repeatedly purified. For analysis, see p. 79.
3.10	No precipitate. Glaucophane suspended.
3.05	Glaucophane, with some zoisite and muscovite.
2.64	Nearly pure quartz.
2.56	A small quantity of feldspar, probably albite.
2.68	A very few grains of a colorless, indeterminable mineral.

A complete analysis of the rock gave the following result:

Loss at 100°, H^2O	0.000
Loss above 100°, H^2O	3.842
Silica, SiO^2	49.680
Phosphoric acid, P^2O^5	0.206
Titanic acid, TiO^2	1.305
Alumina, Al^2O^3	13.603
Ferric oxide, Fe^2O^3	1.862
Ferrous oxide, FeO	8.606
Manganous oxide, MnO	0.038
Lime, CaO	10.967
Magnesia, MgO	6.265
Soda, Na^2O	3.091
Potassa, K^2O	0.119
Total	99.584

The atomic ratio deducible from this analysis is $H^2 : R'' : \overset{vi}{R} : Si = 0.427 : 1.044 : 0.868 : 3.312$.

DECOMPOSITION OF THE CRYSTALLINE ROCKS.

Character.—All the crystalline rocks are often found in a more or less advanced stage of decomposition. Besides serpentinization, which will be treated in a separate section of this chapter, there have been other processes at work, particularly the epigenetic formation of uralite, chlorite, and nacrite. Though it is difficult to make out the precise relation of these transformations to serpentinization, reasons are given elsewhere for believing them to belong substantially to a different period from the serpentinization.

The conversion of augite to uralite is common in the augitic metamorphics and ordinarily presents no peculiarity. As has already been mentioned, however, brown hornblende and augite are in one case so associated as to suggest epigenesis, though it is believed that the phenomenon is really one of envelopment. Chlorite forms directly from brown hornblende, uralite, augite, and garnet. It is also not infrequently found in needles in feldspar in such a way as to suggest the supposition that it may be a result of the attack of feldspar by solutions. Epidote is found much less abundantly than it often is in eruptive rocks. Its relations to chlorite are referred to under the description of epidote. In a single pseudodiabase from New Almaden somewhat irregular, six-sided scales, showing radial striation and remaining sensibly dark between crossed nicols, occur in the feldspars and are supposed to be nacrite. Less well developed flakes of a similar substance are common in other rocks, but no considerable quantity of anything corresponding to the descriptions of kaolin has been detected. Iron oxides, carbonates, and leucoxene (probably titanite) are abundant.

PHTHANITES.

Character.—Associated with the sandstones of every group in the Coast Ranges is more or less shale, which, however, seldom forms any large portion of the exposures. Some of these shales do not effervesce with acid, and analysis shows that these contain extremely little lime or magnesia; others are composed to a large extent of carbonates. The shales of the

Knoxville group are sometimes unaltered, but more frequently silicified to chert-like masses of green, brown, red, or black colors, intersected by innumerable veins of silica. These highly altered shales, when very thin-bedded, break into parallelopipedic fragments, but where the beds reach a thickness of half an inch or more there is a decided tendency to conchoidal fracture. The green varieties are infusible before the blow-pipe, while the brown specimens are more or less fusible. The only essential difference appears to be in the state of oxidation of the iron, which is partially soluble in the reddish rocks. The most convenient name for these rocks is phthanite, introduced by Haüy to designate quartzose, argillaceous rocks with a compactly schistose structure. This term has sometimes been employed in a more special sense to denote siliceous beds intercalated in limestone, but this limitation will not be adopted here.[1]

Phthanites occur in all the metamorphic districts of the Coast Ranges, and, though the quantitative proportion which they bear to the other rocks is not great, the marked contrast between them and the surrounding masses gives them prominence. Geologically it is impossible to dissociate the phthanites from the altered sandstones, holocrystalline, metamorphic rocks, and serpentine. All of these rocks, with transitional varieties, are found together and are often mingled in the confused masses of rubble which have sometimes resulted from intense dynamical action. The metamorphic character of the phthanites is manifest both from their structure and from the transitions—which exist, for example, at Venado Peak, New Idria—into ordinary shales. Under the microscope, also, the most highly indurated specimens are found to contain fossils

The peculiar habitus of the phthanites appears to arise from the fact that the shales have offered great resistance to serpentinization, although they have not wholly escaped this alteration, while they were admirably adapted both to silicification and to the display of a net-work of quartz veins.

The mass of the phthanites as seen under the microscope consists mainly of fine-grained, crystalline silica, occasionally accompanied by a

[1] Compare Mr. Renard's Recherches lithologiques sur les phthanites du calcaire carbonifère de Belgique: Bull. Acad. roy. Belgique, vol. 46, 1878.

little opal. Mixed with the silica is ferric oxide or ferric hydrate, sometimes in very uniform distribution and again in patches or streaks. The iron oxide is somewhat translucent and is soluble in dilute chlorhydric acid with a yellow color. The mass is ordinarily intersected by extremely numerous quartz veins. These are seldom more than 0.5^{mm} in thickness, while the thinnest are often visible under the microscope as mere white lines of insensible width. The veins are usually continuous across the slide, but may sometimes be observed pinching. When this is the case the fissure narrows very gradually as the point is approached, as is the case with fissures of all sizes in all rocks. There are nearly always, if not invariably, two sets of fissures in the phthanites, crossing each other at a high angle, and all the phenomena are precisely similar to those accompanying torsional fracture as investigated by Mr. Daubrée.[1] Small dislocations of course inevitably accompany fractures of this description.

The veins are principally filled with crystalline quartz in which fluid inclusions have not been detected with certainty. Besides the quartz, however, there are often found numerous prisms of zoisite. In the larger veins these are usually arranged along the walls, from which they appear to have grown. In the smaller veins long, jointed prisms, such as are illustrated in Fig. 1 (page 78), often lie parallel to the strike of the vein. The zoisite in these rocks is thoroughly characteristic, showing jointing of the crystals, fluted surfaces, tolerably high refraction, yellow interference colors, and extinction strictly parallel to the main axis, as given under the description of the mineral. The prisms are too much fluted to give good cross-sections. In its mode of occurrence it differs somewhat from the zoisite of the sandstones, for, while in the latter it is usually embedded in products of metasomatosis, in the phthanites it occurs in an infiltrated mass and appears to result from a reaction between the silica and the shale. In certain spots the silica seems to have eaten into the walls of the veins, and here zoisite is especially abundant. Sometimes, on the other hand, the veins show no

[1] Mr. Daubrée has written several papers on fractures in rocks, which are illustrated by experiments. They will be found in the Bull. Soc. géologique France, 1878–1879, 1881–1882, and in the Annuaire du club alpin français, 1881, 1882. The figures of the second plate in the first paper in the latter journal, which represent the fissures produced by torsion in glass plates, might, so far as I could tell, be from photographs of somewhat weathered phthanites from the Coast Ranges.

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zoisite. It is probable that only calcareous spots or areas in the shales have yielded zoisite.

The occurrence of zoisite in the fossiliferous phthanites, associated as they are with the other metamorphic rocks, is very significant and affords ample justification, if this were needed, for regarding zoisite as indicative of the metamorphic character of all the rocks in the Coast Ranges, in which it is found under conditions excluding the supposition that it is of later formation than the accompanying minerals.

In the mass of the phthanites included between the quartz veins remains of clastic structure are often visible, especially in reflected light. The most interesting constituents of foreign origin are round spots, which often retain evidences of organic character. Prof. Joseph Leidy, at my request, has examined some of the thin sections containing such spots, which he regards as probably foraminiferous shells.

SERPENTINE.

Mineralogical character.—Serpentine occurs in irregular areas throughout the quicksilver belt, sometimes in comparatively pure masses and sometimes as one of the mineral constituents of altered sandstones and granular, metamorphic rocks. No exact estimate can be made of the area covered by serpentine, but it is believed to occupy not less than 1,000 square miles between Clear Lake and New Idria. As important results concerning the genesis of serpentine and the history of the rocks with which it is connected depend upon the correctness of its identification, a somewhat detailed description of its chemical and physical properties is essential to the purposes of this investigation. In studying the collections it was found that, although the physical properties of the hand specimens seemed in many cases clearly indicative of their mineralogical character, the microscope revealed such great differences in the optical behavior of the substance supposed to be serpentine as to lead to a doubt of its mineralogical homogeneity. Such differences might indeed be anticipated from the statements in previous publications. Prof. J. D. Dana[1] says that in serpentine when pseudomorphic there is no polarization or only irregular colors as in amorphous or cryptocrys-

[1] System of Mineralogy, p. 461.

talline substances, but that colors are usually apparent in laminated and fibrous varieties. According to Professor Rosenbusch[1] the distribution of color in polarized light varies with the structure, here in patches, there sinuous or in parallel streaks. Especially where the structure is fibrous and chrysotile-like the change of colors, though not strong, is unmistakable. Where the structure permits of optical examination the substance is found to polarize light more or less strongly and to be biaxial, with a highly variable angle between the optical axes. Messrs. Fouqué and Michel-Lévy[2] pronounce serpentine a colloid mineral without any proper action on polarized light, although eminently susceptible of presenting the optical phenomena due to pressure. Thus, in very thin sections the colors of polarization affect very pale, bluish tints and the greater part of the substance does not react between crossed nicols; but in thick slabs, on the contrary, the colors are often vivid and brilliant. On the other hand, foliaceous varieties of the mineral have been described in a number of very important investigations of the serpentinoid rocks which agree with Professor Rosenbusch's description. Rocks of this class were investigated by Mr. von Drasche and later by Messrs. Weigand,[3] Becke,[4] and Hussak,[5] all of whom found them mainly composed of foliaceous, distinctly polarizing, serpentine varieties, such as bastite, picrosmine, and metaxite. Mr. Hussak has described this material minutely and referred it to antigorite. According to this authority it has considerable pleochroism, is biaxial, and shows blue-gray tints between crossed nicols. The analysis is that of a somewhat ferruginous serpentine. Mr. F. Eichstädt,[6] in discussing the antigoritic serpentines of northern Sweden, says that the foliaceous mineral always extinguishes light when the cleavage plane coincides with a principal plane of the nicols, but that when the cleavage plan is horizontal the mineral remains dark between crossed nicols. It does not dichroise sensibly. The interference colors are often quite vivid, especially in the coarser, foliaceous varieties, but are frequently feeble and then change from black to grayish blue.

[1] Phys. der Mineral., p. 372.
[2] Min. mic., p. 441.
[3] Tschermaks mineral. Mittheil., vol. 3, 1875, p. 183.
[4] Ibid., vol. 1, 1878, p. 459.
[5] Ibid., vol. 5, 1883, p. 61.
[6] Geol. Föreningens Stockholm Förhandl., vol. 7, 1884, p. 358.

No serpentine which remains dark between crossed nicols is found in the slides from the Coast Ranges, and excellent cleavage pieces mounted in balsam give biaxial interference figures and show that the bisectrix and the plane of the optical axes are perpendicular to the cleavage. The angle of the optical axes in the cases thus examined is not very small. In cross-section the extinction always takes place exactly parallel to the traces of the cleavage.

The colors of polarization vary greatly. They are sometimes confined to different shades of gray; often, however, portions of slides in which gray is the prevalent color show dull, yellow tints, and in rather exceptional cases reddish tints are visible. This variation is frequent in slides of irreproachable thinness and uniformity and does not depend on a mere difference in the thickness of the rock section. In grinding slides, however, it is found, as would be supposed, that thick masses give more brilliant colors than thin ones. The serpentine usually shows the merest trace of dichroism, but occasionally a very perceptible change of color may be observed. Only one case is known (No. 21, New Almaden) where a remarkably vivid-green serpentine is strongly dichroitic and might readily be confounded with chlorite unless examined between crossed nicols. A particularly pure-looking, light-green, marmolitic serpentine (No. 110, New Idria) was selected for investigation. A complete analysis was made, with the following result:

Silica, SiO^2	41.540
Magnesia, MgO	40.420
Water, H^2O	14.175
Alumina, Al^2O^3	2.480
Ferrous oxide, FeO	1.370
Nickel oxide, NiO	0.040
	100.025

In pure serpentine 40.42 per cent. of magnesia corresponds to 41.52 per cent. of silica. It appears, therefore, that this mineral is in fact a serpentine comparatively free from impurities and certainly containing no talc. A slide was also cut across the lines of structure at a point where the specimen appeared extremely uniform. When reduced to the proper thinness it was found that the material was far from homogeneous. A portion as seen under the microscope appeared absolutely colorless by transmitted light, while the remainder was of yellowish and brownish tints, in spots almost opaque, although by reflected light this portion retained the pale apple-green color of the hand specimen. The more highly colored portions of the slide appear to be clouded by the presence of extremely microcrystalline particles, perhaps ferric oxide; but these particles can hardly have any direct connection with the more brilliant colors of polarization, for the portions containing them, when in proper relation to the nicols, extinguish light almost as completely as the others.

The entire slide has a banded structure, occasioned by the arrangement of fibers, which is similar in character to that most usual in the serpentine of the Coast Ranges, though more simple. The colorless portion between crossed nicols varies from black to light gray, and the brilliancy of the tints increases with the coloration, being yellow in certain positions where the mass is lightly colored and red where the color in natural light is more intense. Precisely the same relation was observed in slides from other localities and of all degrees of impurity.

For comparison two serpentines from Sulphur Bank (Nos. 78*b* and 78*e*) were analyzed. The former is a nearly black, impure-looking mass, through which are distributed foils similar to those of bastite, excepting that they lack the metallic luster. Under the microscope it was found to contain, besides much opacite, serpentine polarizing in yellow tints, though the preponderating mineral shows gray interference colors. No. 78*e* is a light-green mineral from the same locality as that last mentioned, but much purer in appearance.

	Dark serpentine.	Light serpentine.
Water, H^2O	13.81	14.16
Silica, SiO^2	39.64	41.86
Alumina, Al^2O^3	1.30	0.69
Chromic oxide, Cr^2O^3	0.29	0.24
Ferrous oxide, FeO	7.76	4.15
Nickel oxide, NiO	0.33	Trace
Manganous oxide, MnO	0.12	0.20
Magnesia, MgO	37.13	38.63
	100.38	99.93

Both specimens are evidently essentially serpentine and the principal difference is in the amount of ferrous oxide.

While the comparison of these analyses with the slides of the specimens from which they were made might seem sufficient to test the relations of the chemical and optical properties, it was considered best to pursue the subject somewhat further, because minute quantities of minerals other than serpentine might escape detection in the analysis. It seemed especially desirable to establish the absence of talc and chlorite from the substances regarded as serpentine under the microscope. Talc, indeed, could not escape detection in flakes or grains of sufficient size to be submitted to optical examination, but it seemed possible that intimate mixtures of talc and serpentine might be present, since talc is known to occur pseudomorphically after most of the minerals which have been shown to be converted into serpentine and after many more besides. Chlorite, on the other hand, shows a considerable range of optical properties and bears some resemblance to serpentine. A series of simple microchemical tests was therefore made upon the slides and specimens. Serpentine is readily attacked by warm sulphuric or chlorhydric acid, while talc is decomposed by neither and chlorite is not sensibly attacked by chlorhydric acid. It was shown by the application of these tests that the more vividly polarizing serpentine did not differ in chemical behavior from that which gives only gray tints between crossed nicols and that the serpentine in the altered sandstones behaves exactly like the massive serpentine. The optical discrimination between chlorite and serpentine was fully confirmed, and no trace of an admixture of talc in the serpentine could be detected.[1]

[1] A more detailed account of these tests may possibly be of interest to some readers, since the published statements as to the behavior of these minerals are in part not quite consistent and are in some cases incomplete. The marmolitic serpentine of which an analysis has been given was found to be slowly but completely decomposed by both chlorhydric and sulphuric acids when hot, a colloid mass remaining. A slide of a serpentine from near Knoxville, which showed great variation in the colors of polarization, was uncovered, and a portion which gave brilliant tints was cut off and after washing in alcohol was heated with a drop of sulphuric acid. The serpentine was completely decomposed, and on partial evaporation prisms of magnesium sulphate, extinguishing light at about 16°, and later hexagonal uniaxial scales were formed, as described by Professor Haushofer (Mik. Reactionen, p. 90). No other salts were formed. To test the serpentine of the sandstones, specimen No. 57, Clear Lake, was selected, because it contains a very remarkable pseudomorph, to be described hereafter. A portion of the slide was selected containing a quartz surrounded by supposed serpentine, from which distinct, tooth-like projections penetrated the quartz. A perforated cover was placed over this spot and the balsam washed away with alcohol. A minute drop of chlorhydric acid was added and the slide heated

Talc occurs abundantly in the metamorphic areas of the gold belt, and the Survey collections contain fine specimens from that region. According to Mr. H. G. Hanks it is also found at two or three localities in the Coast Ranges. Nothing would be less surprising than the discovery in the Coast Ranges of serpentines containing flakes of talc such as are described by Hussak, but this combination is not as yet known to occur. The analyses also exclude deweylite and the minerals allied to it. It still remains possible that some hitherto unrecognized mineral closely allied to serpentine enters into the serpentinoid mass, but the gradation of properties is so complete that this seems improbable. The variations in the colors of polarization possibly correspond to the replacement of a greater or smaller portion of magnesium by iron, accompanying which there is likely to be a change in the angle of the optical axis. This angle is known to vary greatly in serpentines. The higher color in natural light of the portions which polarize most vividly may be due to the presence of ferric oxide as an impurity. The association of a partial replacement of magnesium by iron and a separation of a little iron oxide would not be unnatural.

The mineral described as antigorite by Mr. Eichstädt corresponds in most respects to that described by Mr. Hussak and others and to the ser-

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nearly to the point at which balsam softens. It was soon found that the serpentine was attacked. Fresh portions of acid were added from time to time, and at last it appeared that most of the serpentine was decomposed, leaving a colloidal mass. Some portions in immediate contact with the quartz grain at points where indentation had been observed appeared to be entirely converted into gelatinous silica. The portions which were only partially decomposed almost ceased to give interference colors. At the edge of the acid drop upon the cover there formed prisms supposed to be magnesium chloride, giving angles of extinction of over 30°. The solution was washed off, evaporated on a second glass, and sulphuric acid added. Prisms giving a low angle of extinction formed on partial evaporation. On evaporating until fumes of sulphuric anhydride were given off, the hexagonal scales appeared, and on standing a few moments under the microscope these uniaxial crystals deliquesced. The substance under examination was thus certainly a magnesium silicate, and not a talcose mixture. No other crystals made their appearance. To test the behavior of chlorite a pseudodiabase (No. 26*b*, Sulphur Bank) was selected and a portion, exposed through a perforated cover, was treated with chlorhydric acid exactly as the serpentine had been. There was no evidence under the microscope of any attack, even after repeating the treatment several times. On boiling powder from the same specimen in chlorhydric acid it was found that the chlorite was decomposed when the acid was strong, but not when it was dilute. Both magnesia and alumina went into solution. It is probable therefore, but not certain, that this chlorite is the prochlorite of Dana. The highly dichroitic serpentine (from No. 21, New Almaden) was similarly tested. It dissolved in warm, dilute chlorhydric acid in the thin section and when the pulverized rock was boiled in strong acid magnesia, but no sensible quantity of alumina was dissolved.

pentines of the Coast Ranges. The Swedish serpentine, however, is stated to be sensibly uniaxial, which, as Eichstädt remarks, perhaps means only that the angle of divergence of the optical axis in this case is extremely small. It seems doubtful whether the isotropic mineral referred to by Messrs. Fouqué and Michel-Lévy can be the same as that of the Coast Ranges.

Microstructure of the serpentine.—Of the many varieties of serpentine which have received separate mineralogical names several are recognizable macroscopically in the Coast Ranges. The most ordinary is the massive green mineral of different shades usually intersected by highly polished, curved surfaces. Such rock is often traversed by narrow veins of white or light-green, fibrous chrysolite. Marmolitic modifications are also abundant In many of the serpentines dark, rounded scales are frequent, and these often show in some lights a metallic luster answering to bastite or schiller-spar in part.

Under the microscope there are found to be great differences in the structure and arrangement of the groups of fibers or scales of which the serpentine is built up. These are sometimes felted, but more often united in bundles of approximately similar orientation. In the latter form they answer to the descriptions of antigorite. Not infrequently groups of scales are seen under the microscope, forming masses of considerable size, in which the orientation is substantially uniform, and in sections cut obliquely to the predominant cleavage of these masses a fine, yellow, metallic luster is sometimes observable once in every complete revolution. It is uncertain to what this luster is due. These masses are of course the so-called bastite scales. There are, however, many other aggregates similar in all respects excepting that they show no metallic luster. The groups of parallel foils are sometimes separated from the surrounding mass by sharp lines, which in no case present crystallographic outlines, but often the demarkation is not sharp.

The mineral of which the antigoritic, chrysolitic, and bastitic aggregates are built up appears to be essentially the same, and in no way different from that of the felted aggregates. It corresponds well to the descriptions of antigorite, but answers equally well in all essential particulars to

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other biaxial varieties. To give separate mineralogical names to mere variations in the arrangement of the foils of a foliaceous mineral seems an unnecessary complication of terminology, nor can I see why the presence of a peculiar luster in the so-called bastite should entitle it to a separate name. Lustrous labradorites are not regarded as of a different mineralogical species from labradorites not possessing this interesting peculiarity. It thus appears sufficient to classify the mineral characterizing the serpentinoid rocks of the Coast Ranges as a distinctly biaxial serpentine. This separates it from the colloid mineral of Messrs. Fouqué and Michel-Lévy and from the possibly uniaxial antigorite of Mr. Eichstädt. The necessity of a division of serpentine into more than these three mineralogical varieties seems to me doubtful.

Of more interest and importance than this minute classification of varieties is the structure resulting from the grouping of adjacent microscopic aggregates. Two types of such structure are known, one in serpentine, produced by the decomposition of olivine and representing the net-work of cracks of the parent mineral, usually emphasized by the presence of more or less opaque matter. The other, called grate structure, was first studied by Mr. von Drasche in Alpine serpentines, which he showed to be derived from augitic and amphibolic rocks. In serpentines of this class the foliated or fibrous mineral is arranged in narrow, somewhat sharply limited bands, which are nearly straight, though often discontinuous, and cross one another at high angles. The interstitial spaces are filled with less regularly disposed material. Mr. F. Becke observed the same structure in some of the Grecian serpentines. Mr. Eichstädt has shown that in some of the Swedish serpentines olivine decomposes into serpentine, exhibiting this grate-structure, which consequently does not necessarily represent cleavages in a parent mineral. It appears to me probable that it is at least in part connected with a change of volume attending the decomposition of the minerals from which the serpentine is derived. There can be little doubt, however, that in some cases the position of the grate-bars has been influenced by cleavages in the original mineral.

In the serpentines of the Coast Ranges the olivinitic net-structure has not been detected, nor has any olivine been found either in the serpentine or in the rocks with which it is geognostically associated. Basalt, it is true, is common in some districts where serpentine abounds, but this basalt appears to be Post-Tertiary, while the serpentinization took place early in the Cretaceous. At New Almaden also pebbles of an olivinitic gabbro have been found, which probably come from the neighborhood of Mt. Bache. This rock does not occur in place at New Almaden and is very fresh, the olivines showing the merest traces of serpentine. Macroscopically it strongly resembles the gabbros from Mt. Diablo and the Great Western, which contain no olivine. It is not impossible that some of the serpentine of the Coast Ranges may have been derived from an olivinitic rock like this, but if so the quantity thus formed must be inconsiderable compared with the rest, since no trace of it has been detected elsewhere.

The greater part of all the serpentine shows more or less perfectly developed grate-structure. In polarized light the bars usually give higher colors of interference than the interstitial matter, but this relation is sometimes reversed. With low powers a single bar often appears to extinguish light simultaneously all over, but when more magnified the extinction is seen to be undulous and to correspond to the composite nature of the bars, which are made up of foils or fibers in nearly parallel positions. The interstitial matter often gives very faint and undulous colors of interference, but has not been found isotropic. The more regular grate-structure passes over by gradations into a less symmetrical disposition, and felted fibrous masses are not uncommon in which irregular patches show slight differences of tint both in polarized and in natural light.

In the altered sandstones many substances are of course included, and in some cases it might be questioned whether these rocks should be classed as serpentines with very abundant inclusions or as sandstones carrying much serpentine. So, too, a part of the granular metamorphics contain a very large amount of serpentine. In the purer serpentines residual grains are not abundant, but augite may sometimes be observed with cleavages parallel to the grate-bars. These isolated augite grains show appropriate oblique extinction and characteristic colors of polarization Chromic iron is a common inclusion in the purer serpentines, but by no means invariably present. It is of a deep, dull-brown color, transparent, monochroitic, isotropic, and when separated gives a strong chromium reaction. Numerous deposits of chromic iron intimately associated with serpentine are known in the Coast Ranges. Magnetite is almost always present.

The origin of serpentine.—No extended historical account of the views held of the origin of serpentine is necessary here. The present investigation is not founded on any similar inquiry, nor do I suppose that all serpentines in other regions have had an origin similar to that of the serpentine of the Coast Ranges. A few historical notes, however, may serve to refresh the reader's memory.

The occurrence of serpentine in dikes led to its classification as an eruptive rock by the earlier geologists, who were unaware of its composition, and even long after it was known to be a hydrated mineral there are frequent references to it in the literature, unaccompanied by any qualification or explanation, in which it is classified as igneous. The close and frequent connection between gabbro and serpentine led L. von Buch, in 1810, to suppose that serpentine was a dense or cryptocrystalline form of that rock. This suggestion is interesting as showing how long the relationship of the rocks has been recognized. Direct eruption of the serpentines has also been maintained, in a modified form, by more recent Italian geologists, who suppose outbursts from the depths of the earth of a hydrated, magnesian mud which consolidated to serpentine.

In 1857 Dr. T. Sterry Hunt showed that when a mixture of magnesium carbonate and free silica is heated in a solution of alkaline carbonate a hydrous, magnesian silicate is formed and the alkaline carbonate is regenerated. He soon afterwards came to the conclusion that this process, though locally important, would not explain the greater part of the occurrences. In 1860 he proposed as an explanation of the massive serpentines the reaction between the soluble silicates of lime and alkalis from decaying rocks and the magnesian salts of natural waters. Dr. Hunt admits, however, that serpentines are also formed by epigenesis, at least from olivine and enstatite.[1] Dr. Hunt's view, while not generally accepted, has earnest advocates, and some geologists who reject this theory for a majority of cases believe it to be the true explanation of some occurrences.

[1] Geol. History of Serpentines, 1883, § 117; Origin of Crystalline Rocks, 1884, § 105.

The theory of the origin of serpentine most usually entertained is that it results from the alteration of other minerals. There is much variation of opinion, however, as to what minerals may yield serpentine. Breithaupt is said to have been the first to detect the pseudomorphosis of serpentine after hornblende (1831) and to infer the derivative character of serpentine rocks. Later, serpentine was found pseudomorphic after a long list of minerals. Olivine, brucite, hornblende, augite, diallage, chondrodite, calcite, staurolite, dolomite, spinel, chromite, mica, and garnet are mentioned by Prof. J. Roth. Prof. J. D. Dana has personally identified the greater part of this list from a New York locality and also found pseudomorphs after apatite.[1] Bischof, Professor vom Rath, and others have shown that the conversion of feldspars to serpentine is probable, and, at the congress of Bologna, Professor Szabó, as reported by Mr. Lotti, stated this as his opinion; but I am not aware that full proof of this change has ever been offered. That it occurs in the rocks of the Coast Ranges, however, seems beyond doubt.

In 1866 Professor Sandberger[2] and in 1867 Professor Tschermak[3] studied the transformation of olivine rocks to serpentine, though neither of them asserted that olivine, which had long been known to yield serpentine, was the sole source whence serpentine was derived. "The occurrence of embedded pyrrhotite," Professor Sandberger says, "may be said to be almost characteristic of the serpentines which have been derived from hornblende rocks, and the same mineral occurs in serpentines which are derived from diabases." Professor Tschermak, though stating that the masses known as serpentine and schiller-spar rocks, which he had had an opportunity of examining, all contained olivine as a principal constituent, also remarks that diallage and bronzite grains are often converted into schiller-spar in these rocks. For some time afterwards, however, there was a strong tendency to ascribe almost all serpentine to the alteration of olivine, which was found to be more widely distributed and more frequent than had previously been suspected. Thus, in 1873 Professor Rosenbusch wrote: "It appears to be

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[1] Am. Jour. Sci., 3d series, vol. 8, 1874, p. 380.

[2] Neues Jahrbuch für Mineral., 1866, p. 385; ibid., 1867, p. 171.

[3] Ibid., 1868, p. 88.

more and more confirmed by the investigations, particularly the microscopical ones, hitherto made, that only the alteration first described by Sandberger from olivine rocks to serpentine occurs in nature." This supposition, still maintained by some, was soon found too narrow to include the observed facts, and in 1877 the same distinguished lithologist acknowledged that serpentines or serpentinoid rocks are often formed from pyroxene and amphibole. In view of the earlier literature of the subject it seems indeed most improbable that the serpentines should have a single origin. The evidence of actual pseudomorphism in many cases was sharply questioned by Scheerer as early as 1846 and later by Mr. Delesse and Dr. Hunt, and no doubt some cases of erroneous determination were detected. Many instances, however, stood the test of these challenges. All the more important cases have also been reobserved since 1867, and at present the number of occurrences of serpentine shown by microscopic research to be derived from rocks containing olivine as a subordinate constituent only or not at all is on the increase.

According to the law of thermochemistry, in any mixture of substances capable of reacting upon one another the resulting compound will be that whose formation is attended by the most rapid evolution of heat.[1] Any given mineral will therefore be produced not in general under a single set of conditions, but under any combination of the whole range of conditions in which the formation of any other compound would be attended by a slower liberation of heat. The wider the range of these conditions the commoner will be the mineral, and, since conditions are never exactly repeated, the assertion that a mineral is common is nearly equivalent to the statement that its formation is attended by the most rapid evolution of heat under diverse sets of conditions. Thus, to take one of many examples, there are but few ferruginous compounds which in weathering or in roasting do not yield hydrous or anhydrous ferric oxide; or, in other words, whether the temperature be low or high, the formation of ferric oxide from almost numberless compounds of iron involves the liberation of heat more rapidly than any other change. That serpentine occurs at all is sufficient evidence that its formation is attended by the liberation of heat under certain conditions.

[1] See my paper, A new law of thermochemistry: Am. Jour. Sci., 3d series, vol. 31, 1886, p. 120.

That it is common leads to the belief that these conditions are not narrowly restricted, and this is confirmed by the fact that it forms in the olivines of decomposing basalts and also in limestone beds. It is no more surprising that serpentine should form from many and different minerals or under different circumstances than that ferric oxide should do the same.

Bischof held a similar opinion, calling attention to the fact that serpentine is among the last products of alteration and that in it the series of processes of mineral formation and alteration have nearly reached the limit of possibility. Indeed few geological chemists would be inclined to dispute a proposition of this kind. Dr. Hunt, for instance, who points out the analogy between the modes of occurrence of serpentine and pinite, says of the latter that its constancy of composition and wide distribution show it to be a compound readily formed and of great stability. Such being its character, he continues, it might be expected to occur as a frequent product of the aqueous changes of other and less stable silicates, and "its frequent occurrence as an epigenic product is one of the many examples to be met with in the mineral kingdom of the law of the 'survival of the fittest.'"[1] That the same statement applies to serpentine is manifestly true.

It would seem to follow that the origin of serpentine in each naturally defined geological area requires independent investigation and that the results obtained in one such area are not necessarily applicable to others. It will be seen in the following pages that the observations are not reconcilable either with the supposition that the serpentines of the Coast Ranges are derivable from a single mineral or that they are unaltered sediments. They seem to be in this region the most stable compound which could result under a certain set of physical conditions from the mutual reaction of siliceous and magnesian substances.

Structural evidence as to origin.—Serpentine is found throughout the metamorphic areas of the Coast Ranges in very irregular patches, both near quicksilver deposits and at long distances from the mines. In some metamorphic regions—for example in the immediate neighborhood of Clear Lake—it is found only in small quantities, while at Knoxville and at New Idria large areas are almost exclusively composed of more or less pure serpentine.

[1] Origin of the Crystalline Rocks, 1884, p. 53.

Near the Golden Gate, at Mt. Diablo, and in many other localities it is very abundant. In fact, though the quantitative relations of the various metamorphic rocks vary greatly in different neighborhoods along the quicksilver belt, all varieties are to be found in almost every district. Serpentine is commonly, but not always, intimately associated with pseudodiabase. These rocks stand in such relations to the unaltered sandstones in very numerous cases that no geologist carefully examining the localities could fail to conclude that they are modifications of the sandstone. This was substantially the conclusion at which Professor Whitney arrived. Knoxville affords admirable opportunities for studying this connection. Highly inclined strata strike into serpentine areas in such a manner as wholly to preclude the supposition that the serpentine represents an earlier mass; one side of an anticlinal fold is serpentinized, while the other is unaltered and carries excellent fossils, and there are clear cases of transition through altered sandstones. Mt. Diablo affords equally favorable opportunities for determining the age and relations of the serpentine. In many other localities the relations of the serpentine to unaltered rocks are evident, although it is seldom that the age of these unaltered rocks can be immediately determined. The reason for assigning them all to the Neocomian will be given in Chapter V.

Field observation makes it clear that in most cases the transformation to serpentine began along cracks in sandstone or in rocks resulting from the alteration of sandstone and worked toward the centers of the fragments thus separated from one another. Where this process is incomplete, partially rounded nuclei of rock retaining the sandstone habitus are to be seen, divided by a net-work of serpentine. Such exposures remind one of the appearance presented under the microscope by olivines in process of conversion into serpentine. Sometimes, but not often, the serpentine assumes a radial form, the fibers being normal to the surface of the nucleus. Professor Whitney observed such an instance at New Idria; I found some very beautiful ones at Knoxville. Two cuts illustrating such occurrences will be given in the description of the Knoxville district.

It is not possible from a mere field examination to determine whether the serpentine results directly from the action of solutions upon sandstone or whether the sedimentary rock first becomes crystalline and is subsequently

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serpentinized. The observer would incline to the belief that both methods were followed, but the conclusion would not be certain, because many rocks which are really holocrystalline appear to the eye to be mere sandstones somewhat modified. It will be seen in the sequel that both processes can be traced microscopically.

The serpentinoid rocks invariably show evidence of violent dynamic action. Traces of stratification are often visible, but can never be followed more than a few feet, and single croppings frequently exhibit remnants of stratification in all sorts of contradictory directions. There is usually little evidence of plication; as a rule, the rock was reduced to a confused mass of rubble prior to serpentinization. The blocks indeed were often some yards long, but even these were generally divided by numerous cracks.

Microscopical evidence of derivation.—While it is not possible to follow in the field the transitions of the components of the altered rocks, the indications of field observation were found to be borne out by microscopical and chemical examination. It can be shown, as I think beyond dispute, that all of the principal minerals of sandstones and granular, metamorphic rocks are converted into serpentine, and the inference with regard to some of the less important ones is also strong. After the investigations of the last fifteen years, together with the earlier macroscopical examinations, it will surprise no one to hear that in the granular, metamorphic rocks of the Coast Ranges augite and hornblende are found passing into serpentine. The attack takes place along the surfaces and cracks, exactly as in uralitization and chloritization, while the resulting mineral has all the distinctive characteristics described in the preceding pages. Sometimes partial pseudomorphs may be observed in which a kernel of the bisilicate is embedded in a mass of serpentine, surrounded by an outline characteristic of the parent mineral. This, however, is rare, apparently because well developed crystals of augite and hornblende are also rare.

Though Bischof, vom Rath, and others have shown that the conversion of feldspar to serpentine was probable, I am not aware that it has ever been conclusively proved. In the altered sandstones and the granular metamorphics of the Coast Ranges, however, it seems beyond doubt that this alteration has taken place. In very numerous cases grains of feldspar remain embedded in serpentine, and these grains show outlines differing essentially from those of deformed crystals or clastic fragments, but resembling in all respects corroded masses. Cracks in such feldspars are also filled with serpentine, and it is manifest under the microscope that feldspathic material has been removed from the walls of these cracks, so that they would no longer fit were they brought together. This evidence is of exactly the kind commonly accepted as proving the attack of other minerals. In one instance the phenomena are still more conclusive. In a slide from Sulphur Bank (specimen No. 107), a feldspar shows such a crack much widened, and, from the serpentine mass occupying it, sharp, elongated teeth of serpentine bite into the clear feldspar. It is impossible to explain such a case otherwise than as an actual conversion of the feldspathic material under the action of corrosive solvents. The serpentine is characteristic and unmistakable. The feldspar is unstriated, but probably triclinic. Other satisfactory occurrences show that both plagioclase and orthoclase are converted into serpentine.

FIG. 4. Clastic quartz partially converted to serpentine, which penetrates from the outside in needles. The specks within the quartz are fluid inclusions and the straight prism is a small apatite. Magnified 53 diameters.

That quartz is sometimes converted into talc is well known In the altered sandstones of the Coast Ranges it is converted into serpentine. This is shown, exactly as in the case of feldspar, by the presence, in patches of serpentine, of irregular grains of quartz with corroded surfaces. A very beautiful case of the conversion of quartz to serpentine occurs in altered sandstone from Clear Lake (specimen No. 57), and is illustrated in Fig. 4. A clastic quartz grain of characteristic form, full of fluid inclusions, containing an embedded apatite microlite, and behaving as usual in polarized light, has been attacked from the outside. The exterior of the original mass is now entirely occupied by felted fibers of serpentine, and long, slender microlites pierce the quartz grain toward its center like pins in a cushion. That there might be no doubt as to the correct interpretation of this important case another quartz was selected in the same slide, which showed the same phenomena, though less beautifully. This was tested by chemical methods, as described on page 112, and the green mineral was proved to be a silicate of magnesium, attackable by chlorhydric acid. The serpentine which was chemically tested in this second case was absolutely indistinguishable in color, texture, or behavior in polarized light from that surrounding the quartz shown in the figure, and the distance of the two occurrences from each other was only about 3^{mm}. The long microlites which pierce the quartz are of the same color as the strip of serpentine occupying the periphery of the section. Their optical properties cannot be well observed, because they are embedded in the brilliantly polarizing quartz, but there appears no reason to suppose that they differ chemically from the serpentine at their bases. Even if they belonged to another mineral species, however, the structure is such as to show that they must be regarded as an intermediate product between quartz and the surrounding serpentine, which would make little difference from a geological point of view.

Apatite is found in process of conversion to serpentine in specimen No. 107, Sulphur Bank, one of the specimens in which the presence of authigenetic apatite was proved by chemical as well as by optical means. The apatite crystals embedded in serpentine in this slide are seen to be corroded and the indentations are occupied by serpentine. As already mentioned, Professor Dana has observed pseudomorphs of serpentine after apatite.

There are also a number of cases in which chlorite appears to be altered to serpentine. Thus in specimen No. 26*b*, Sulphur Bank, a chloritized pseudodiabase, areas of chlorite are intersected by cracks, along the walls of which serpentine is disposed in such a way as to lead to the belief that the latter mineral is epigenetic; but, as in the case of the conversion to epidote, the fibrous character of the chlorite somewhat weakens the evidence obtainable from observation. Bischof regarded the serpentinization of chlorite as probable.[1] Mica and garnet have been observed elswhere undergoing conversion to serpentine. The mica foils are so small and possess such irregular outlines in most of the rocks of the Coast Ranges where serpentinization can be traced that this change, though probable, cannot be definitely asserted. Garnet is seen in the few slides which show it in process of conversion to chlorite; but a change to serpentine has not been distinctly traced in the Coast Ranges. Zoisite, as it occurs in these rocks, is not well suited to exhibit pseudomorphic alteration. It appears in smaller quantity in the rocks containing much serpentine, however, than in those containing little. The prevalence of this mineral in the saussuritic gabbros of Europe, the intimate relations between these rocks and the serpentines, and the absence of observations on the presence of zoisite in massive serpentines, either in the Coast Ranges or elsewhere, point towards the probability of a serpentinization. Olivine has not once been detected in the rocks associated with serpentine in the Coast Ranges or in the serpentines themselves, and olivine cannot have contributed in an appreciable degree to the formation of these serpentines, important as is the part which this mineral plays in some other serpentinoid areas.

The chemical changes indicated by the observations described above on the alteration of bisilicates, feldspar, quartz, and apatite to serpentine are very strange, and the results may possibly fail to be accepted by some because of their strangeness. It is a truism, however, that observation almost always outstrips scientific theories, or that these are commonly framed to embrace the results of observation, while the changes indicated here are not more perplexing than many other reactions once were, for which reasonable explanations have been discovered. Mineral chemistry is full of puzzles, some of them so familiar that their chemical difficulties are hardly appreciated. That a number of different minerals should all be replaced by serpentine under certain appropriate conditions is in itself not more remarkable than that from a single solution an equal number of minerals should be precipitated almost or quite simultaneously; yet in the study of veins such cases occur so frequently that they attract no attention.

[1] Lehrbuch chem. und phys. Geol., vol. 2, 1864, p. 789.

It has doubtless happened in times past that observers have attempted to cut the gordian knot of metamorphism by assuming such replacements as seemed convenient. This method of dealing with the subject is as superficial as a flat denial of all conceivable methods of genesis, excepting one, of a certain product.

General course of serpentinization.—Having stated in detail the character of the evidence as to the serpentinization of the mineral constituents of the sandstones and the granular metamorphic rocks, it only remains to indicate the course of the transformation as a whole. In the sandstones which have merely weathered, but which have not been subjected to even incipient recrystallization, or, in other words, in the sandstones of later age than the Neocomian, serpentine has not been detected with certainty, though it has been carefully sought, while chlorite is common. I know of no reason, however, why small quantities of serpentine should not hereafter be found in these rocks. There is abundant evidence that serpentinization was not widespread or important in the later rocks, but this does not exclude local or partial repetition at later dates of the conditions which induced serpentinization at the close of the Neocomian.

One of the important results of this investigation is that the slightly recrystallized, older sandstones were subject to serpentinization as well as those which had undergone complete transformation. In these rocks, of course the more permeable aggregates yielded most readily to attack and were first affected by the change. In such cases the phenomena of recrystallization and serpentinization may be studied side by side, and it is rarely the case that some small patches and streaks of serpentine are not observable in these sandstones. At a further stage the interstitial space between the remains of the clastic grains is almost wholly filled with serpentine, which then attacks these nuclei, as has been described, though, as might be expected, the process is irregular, so that one portion of a slide is often more serpentinized than others. The quartz appears to yield more slowly to serpentinization than the feldspar, and this more slowly than the fine-grained cement. The extent of surface exposed is of course an important factor. As the amount of the serpentine increases, traces of grate-structure make their appearance; but, though this fact is easily established, the material at hand does not afford the means of following in detail the history of the grate structure.

In the pseudodiabase and pseudodiorite it is naturally the bisilicates which first show traces of the serpentinization process, and for these minerals the history is exactly parallel to that of direct chloritization. The ferromagnesian silicates yield to this process much more easily than the feldspar and the quartz, which behave as in the slightly altered sandstones. This fact leads to the belief that the greater part of the massive serpentine has resulted from pseudodiabase and pseudodiorite, a view supported by structural considerations; for, since both recrystallization and serpentinization are dependent on a fissure system, serpentinization in slightly altered sandstones appears to mean that during this process the solutions diverged from their old channels or that, where in the first stage solutions permeated to but a slight extent, they penetrated abundantly at the later period. This would probably be less common than a similar distribution of solutions at each of the two periods.

Decomposition of serpentine.—In nearly all the serpentine localities it is evident that this rock is subject to tolerably rapid decomposition under the action of the atmosphere. The subject has been studied in Bohemia by Mr. A. Schrauf,[1] with whose results the observations made in the Coast Ranges agree. Where the serpentine is directly exposed to the action of the atmosphere, it is often bleached and converted to a porous mass, which is nearly pure silica, containing very little magnesia or iron. Where serpentine has been subjected to solfataric action in the immediate neighborhood of ore bodies, the bases have often been removed and silica has replaced nearly or quite all of the original mass. While this is a common change near ore bodies, such replacements have also occurred to a small extent at long distances from known occurrences of ore, and it may be that this process has gone on to some extent at different periods. Since by far the greater part of the silicified serpentine bears such a relation to the ore bodies as to lead to the conclusion that the process was attendant on that by which the ore was produced, it will be discussed hereafter in that connection.

[1] Zeitschr. für Krys. und Min., Groth, vol. 6, p. 321.

Serpentine is also converted into carbonates of lime and magnesia in the Coast Ranges, and the process can be followed in detail in some cases. No. 223, Knoxville, is a grayish-green serpentine full of minute veins, the material of which does not effervesce with cold, dilute chlorhydric acid. Under the microscope these veins are seen to be composed of carbonates often exhibiting cleavage. On removing the cover it was found that a portion of the carbonates dissolved slowly in cold acid, while a portion remained unattacked. Dolomite and magnesite are thus probably both present. No attempt was made to determine the quantity of magnesia in these carbonates.

It is manifest from this slide that the substance of the serpentine has actually been replaced, for the masses between the veins are rounded and would no longer fit together were the veins removed. The result is a net-structure similar to that observed when olivine is decomposed to serpentine.

METAMORPHIC ROCKS OF UNCERTAIN AGE.

Gavilan Range and Steamboat rocks.—In the foregoing pages those metamorphic rocks only have been considered which are actually known to be of Knoxville age or which there are good grounds for referring to that epoch. In the course of this investigation metamorphic rocks of uncertain age have been encountered at two localities. One of these is in the Gavilan Range, where an extraordinarily crystalline limestone is associated with granite and gneissoid rocks. The occurrence is so different from the remainder of the altered rocks of the Coast Ranges examined that it could not be referred to the same series without much more investigation than it has been practicable to devote to it. I suspect it to be of far greater age than the rest of the exposures. Under the microscope the gneissoid rock is found to be of the Archæan gneiss type. It is chiefly composed of quartz, orthoclase, plagioclase, and biotite. There is a decided tendency to granophyric structure, and veins and clusters of fibrolite are abundant. This rock contains no zoisite.

At Steamboat Springs the sedimentary rocks are greatly disturbed and in part highly metamorphosed. They seem to belong to the series regarded as Jura-Trias by the geologists of the fortieth parallel, and are certainly older than the Tertiary. The area examined is too small to make any investigation of the metamorphism very profitable. The sides show that a portion of these rocks are thoroughly recrystallized and that in mineral composition and in structure they strongly resemble the metamorphosed rocks of the Knoxville group in the Coast Ranges. There is at present nothing improbable in the supposition that they were actually metamorphosed at the same time. The study of these rocks will be resumed in connection with the geology of the gold belt of California.

CONDITIONS ATTENDING THE METAMORPHISM.

In the foregoing pages the unaltered and the metamorphosed rocks of the Coast Ranges have been described from a lithological point of view. It remains to consider the metamorphic process as a whole in its geological and chemico-physical relations.

Proofs of metamorphism.—The division of opinion as to the origin of many of the crystalline rocks is such that it is not superfluous to insist upon the proofs of the derivative character of the holocrystalline rocks and of the serpentine of the Coast Ranges. It appears that at least one mineral of nearly universal distribution in the granular and schistose rocks and in the phthanites is especially significant in this respect, and that a sound argument may be based upon its occurrence independently of other evidence.

Zoisite seems to be characteristically the result of secondary processes which have taken place at no very high temperature. It has never been observed as an original constituent of eruptive rocks, which could hardly be the case if it were at all common. This merely negative evidence is supported by that afforded by its composition, which includes basic hydrogen, while no such compounds, so far as I know, have ever been proved to form original constituents of eruptive masses, and, judging from what is known of eruptions, it is difficult to conceive that they should so occur.[1] On the

[1] Zoisite is usually referred to the epidote group, of which only allanite is known to occur in eruptive rocks. The composition of allanite, however, is somewhat uncertain, since, according to Professor Rammelsberg, it has the oxygen ratio of garnet rather than of epidote, while there appear to be both hydrous and anhydrous varieties. According to Prof. J. D. Dana, the hydrous allanites are properly altered forms of the species. There can be little doubt that the unaltered allanites of eruptive rocks are anhydrous.

Messrs. Fouqué and Michel-Lévy regard zoisite as a scapolite, for which I know of no ground excepting that its centesimal composition is the same as that of meionite. The scapolites also are known only as the result of secondary or metamorphic action.

other hand, zoisite has been abundantly proved by Hunt, Cathrein, and others to be peculiarly characteristic of rocks which, whether regarded as decomposed eruptives, as metamorphic, or as original crystalline sediments, indicate the formation of this mineral at moderate temperatures.

Taking all these circumstances into consideration, it appears that scarcely a single mineral species could have been selected which would afford a better criterion of the prevalence, at the epoch of its formation, of temperatures decidedly below a red heat, and probably much below. Zoisite might conceivably occur in two ways, and it is not improbable that it actually does so occur. If found among mere decomposition-products, replacing primary minerals pseudomorphically as aggregates, it would seem to prove that the rock in which it occurred had simply been decomposed under physical conditions appropriate to the formation of zoisite. But, if zoisite is found embedded in clear, continuous masses of minerals which can be shown to be authigenetic, it would seem to afford conclusive evidence that these minerals have been formed at moderate temperatures. This latter mode is characteristic of a great portion of the rocks of the Coast Ranges and very often in cases where from the mere inspection of slides it might readily be supposed that the material under examination was eruptive.

While zoisite appears to form an admirable indication of the metamorphic character of the holocrystalline rocks of California, it must not be supposed that their determination as altered sediments is dependent on the identification of zoisite. Before the mineral character of the constituent which proved to be zoisite was known, there was abundant evidence, both from field examination and from microscopical study, that the rocks in question were metamorphic, and the conclusions would remain substantially as here presented if it should be proved that zoisite is a common, original constituent of the most typical eruptive diabases and diorites. The present investigation may properly be regarded as proving, quite independently of its chemical constitution or of its occurrence in whatever class of rocks elsewhere, the wide distribution in metamorphic rocks of zoisite both as an authigenetic constituent and as one of the first of these constituents in the order of development.

The stratigraphical relations of the holocrystalline and serpentinoid rocks to unaltered beds, in part fossiliferous, at a great number of localities are such as absolutely to preclude the supposition that these masses are either older sedimentary rocks or that they are intrusive. The field relations of the holocrystalline rocks and of the serpentine to the sandstones, as well as their microscopical character, are such as equally to preclude the supposition that they represent local or regional precipitations of crystalline sediments of the same age as the fossiliferous rocks.

I feel almost justified in stating that at the Post-Neocomian epoch of metamorphism the rocks of the Coast Ranges between Clear Lake and New Idria contained no intrusive masses and that no eruptions accompanied this upheaval. It is true that in a few cases isolated specimens of the crystalline, metamorphic rocks simulate the microscopic appearance of eruptive masses to an extraordinary degree, but these occurrences when examined on the spot prove to pass over into manifestly metamorphic material. Two or three such pseudoeruptive rocks were discovered in the collections from the Sulphur Bank and, after the microscopical work recorded in this chapter was completed, these localities were revisited. In none of them was there the slightest structural evidence of eruptivity; in all it was manifest that the suspected rock passed over into ordinary, unmistakably metamorphic beds within a few feet and in every direction. By no means the whole country between Clear Lake and New Idria has been investigated, but so many localities have been examined with care and so many reconnaissances have been made into the intervening regions that it would be very strange if any considerable quantity of eruptive rock occupying the position indicated had escaped detection. For, though a particular variety of lava may sometimes be confined to very narrow limits, as is the case with the rhyolite of New Almaden, eruptive phenomena, once initiated, usually and perhaps invariably extend over wide areas

Epoch of metamorphism.—As will be shown in a subsequent chapter, the age of all the fossiliferous rocks associated with the metamorphics is Neocomian Some of the most important areas of metamorphic rocks are certainly of this age, and reasons will appear hereafter for supposing that no considerable portion of the metamorphic series was deposited at an earlier date.

The epoch of the uplift lies between the end of the period in which the Knoxville and Mariposa beds were deposited and the beginning of that in which the unmetamorphosed Wallala series was laid down, or, according to the paleontological determinations, between the Neocomian and a middle Cretaceous period resembling the Gossau. Unless the violent dislocation which took place between these periods was preceded by a gentle uplift of the country above water—and of this no evidence is known—the folding and crushing which form so prominent a feature of the Coast Ranges must have taken place at the close of the Neocomian.

That the metamorphism cannot have preceded the uplift is certain, from the fact that the confused mass of rubble resulting from dynamic action has often been recemented by the metamorphic processes. The association of the evidences of dynamic action with the alteration is such as to make it clear that the metamorphism was to a great extent dependent on the crushing of the rock. There is no evidence that any considerable time elapsed between the crushing and the ensuing chemical changes; but, since the rocks now exposed were then buried at a considerable depth, such an interval might have elapsed without leaving recognizable traces. On the other hand, it appears certain that the metamorphism was effected under different physical conditions from those now prevalent, because, as has been pointed out, the process of decomposition now progressing is inconsistent with the process of recrystallization. It is most natural to suppose the difference to have been one of temperature. That a higher temperature prevailed in the rocks at the time of the upheaval is also certain; for the crushing of the rocks was of the utmost intensity and indicates the dissipation, or conversion into heat, of an enormous energy. There is therefore strong reason to suppose that the metamorphism followed immediately upon the upheaval.

Former depth of the present exposures.—In comparing the metamorphic Cretaceous rocks of the Coast Ranges with the older crystalline schists, particularly as described by Dr. Lehmann, one point of difference is especially striking. In the older rocks fractures are comparatively rare, and it also appears altogether probable that at a sufficient depth below the surface solids must flow rather than undergo comminution. Hence the intense plication of such rocks, in which even crystals of feldspar are bent at sharp angles instead of breaking, indicates that they have been subjected to mechanical forces of great intensity while under immense pressure or when buried at a great depth. In the Coast Ranges, on the other hand, the metamorphic rocks have been crushed to an astonishing degree. This is especially observable in the phthanites, which are often intersected by so fine a network of minute fissures, now filled with quartz veins, that a portion of the net is visible only under the microscope. Plication of strata is indeed extremely frequent; but, at least in a great proportion of cases, this has not been accomplished to any great extent by flexure of the rock mass. It was attended by the formation of innumerable cracks, which have gaped more or less and thus permitted readjustment without great displacement of the fragments. The fragments having been recemented in their new position, the strata became once more coherent. Often also the rocks have been crushed to a mere, confused mass of rubble, in which the original stratigraphical relations are entirely obscured. These relations appear to demonstrate not only the expenditure of enormous energy, but also that the Cretaceous rocks at the time they were metamorphosed were not buried at great depths, perhaps not more than two or three thousand feet below the surface. This being granted, it may readily be understood that, even if the character of the rocks and of the metamorphism in the Archæan were exactly similar to that of the Cretaceous strata of the Coast Ranges, the latter would inevitably be less uniformly altered, while at least the quantitative relations of the products of alteration in these mountains would probably differ from those characteristic of similar masses altered under a far greater and far more uniform pressure.

Dynamic conditions.—The Post-Neocomian uplift was accompanied by intense compression in a northeast and southwest direction. The strata of the Coast Ranges were partly plicated and partly crushed, while on the gold belt they were driven into a nearly vertical position. Both areas appear to have been and still to be underlain by granite at no very great depth. What the bed rock in the great valley of California may be is not definitely known, but there seems no reason to suppose that it is not granite there also. It is impossible to suppose any force which would crumple the overlying strata by horizontal translation over the granitic surface while the granite remained undisturbed, and it therefore inevitably follows that the granite must have been fissured and crushed or deformed, or, more probably, crushed in the higher portions and plastically molded in the deeper regions. The granite, like the sedimentary rocks, must have been heated by the conversion of sensible motion into molecular motion.

Nearly all rocks are permeable by water, and in every region there is a system of percolating, subterranean currents. There must have been such systems in the sedimentary and massive rocks of California before the great upheaval, and this system must have been as thoroughly disturbed at the uplift as were the rocks themselves. Old vents were closed, porous beds compressed, and the fractures caused by the convulsion certainly afforded new paths of weak resistance. The waters were warmed by the heated rocks, and consequently became more powerful solvents, and cannot but have attacked many of the minerals with which they were in contact.

So far all the circumstances appear simple and certain, and it may be added that, since the uplift as a whole bears the character of a violent compression, the interstitial space was probably greatly diminished and the heated mineralized waters were driven toward the surface When one attempts to pursue the subject further and to reason upon the special character of the mineral waters, or the particular temperature, or the ensuing reactions, observation appears to be the only guide. A priori it is clear only that very considerable modifications in the character of the sedimentary rocks must be expected and that as the action diminished a series of transformations might occur. So far as can be known, there is nothing unreasonable in the supposition either that the solutions may have been basic at some points and acid at others or that at the same points they may have been basic at some stages of metamorphism and acid at others.

Chemical indications.—The pseudodiabase and pseudodiorite are much more basic than the sandstones, as is also the serpentine, while the phthanites are more acid than the shales from which they are derived. Serpentinization and silicification have often gone on in the same rock mass, and the evidence from many widely separated localities appears to indicate that silicification followed serpentinization, while it is certain that serpentinization postdated the formation of the holocrystalline metamorphics. The serpentinoid rocks, like the phthanites, are sometimes intersected by quartz veins, but the conversion of serpentine into opal has taken place only locally and is for the most part referable, not to the Post-Neocomian epoch of metamorphism, but to the volcanic period of ore generation.

A difficulty must always arise in discussing metamorphic rocks, from the inevitable lack of positive knowledge as to the composition of the sediments prior to metamorphism. It is indeed one of the advantages which the Coast Ranges afford for the study of metamorphism that the origin of the sediments is known and that the composition of the unaltered strata as a whole is uniform. No geologist needs to be told, however, that this uniformity cannot extend to hand specimens. It is impossible to say that any particular sample of pseudodiabase or serpentine once had the composition of a second sample representing unaltered sandstone, and it is consequently also impossible to ascertain the exact quantity and quality of the changes which have been wrought in it by the action of mineral solutions. It follows, however, from the study of the relations of many metamorphosed masses to the unaltered or slightly altered rocks surrounding them, that the pseudodiabase, pseudodiorite, and serpentine are as a whole derived from sandstones of average character.

The fresh sandstones carry magnesia, but not in great quantities, for the allothigenetic, ferromagnesian silicates form a small part of the mass, while the matrix is sometimes nearly pure calcium carbonate and never appears to contain considerable quantities of magnesia. The observations cannot be reconciled without supposing that very large quantities of magnesia have been supplied in solution from extraneous sources, though the precise quantity cannot be determined in any given case. One and only one evident source for this supply of magnesia exists, viz, the ferromagnesian silicates of the underlying granite. The wide horizontal extension of the granite is well established. Its depth is entirely unknown, but must be very great, since it is nowhere cut through. An inexhaustible supply of magnesia was thus at hand, as well as heated waters, with a probable upward tendency at the period of metamorphism, but under what precise conditions magnesia passed into solution is not known, nor even what salt of magnesia was dissolved. The structural evidence, however, strongly favors the supposition that the silica of the sandstones reacted directly upon magnesian solutions. Were it otherwise, the sandstones might have been impregnated with hydrous and anhydrous, ferromagnesian silicates, but the quartz grains could not have been attacked, as they certainly are in the altered sandstones, while in the recrystallized rocks they have altogether disappeared.

The experimental researches of Dr. Hunt and of Mr. Daubrée indicate the kind of reaction which must be supposed to have gone on in the rocks of the Coast Ranges. As has already been stated, Dr. Hunt found that when alkaline carbonates in solution are heated with silica and magnesium carbonate an alkaline silicate is formed which reacts upon the magnesium carbonate, yielding an insoluble magnesium silicate and regenerating the alkaline silicate. So, also, Mr. Daubrée discovered that water heated at a high pressure in glass with kaolin results in the formation of zeolites, feldspar, pyroxene, and quartz. In such experiments the temperature and pressure must of course be reduced below the boiling point before any satisfactory examination of the results can be made. Consequently, it is not at present possible to say under what special conditions of temperature and pressure each mineral was formed. The heated waters in the granite and the overlying strata of the Coast Ranges must have contained carbonic acid in solution. It is not inconsistent with any known facts to suppose that these waters attacked the granite at great depths, dissolving alkalis, magnesium, and iron, with perhaps a certain amount of silica; nor is there anything to forbid the supposition that at lower pressures, and perhaps also at lower temperatures, such solutions brought in contact with calcareous sandstone would form feldspars, pyroxene, amphibole, and serpentine. In the experiments solution and precipitation were confined to the same locality, while in the Coast Ranges solution went on at great depths and precipitation at more moderate ones; but nothing is as yet known which makes it necessary to suppose that the conditions of temperature and pressure or the general character of the reactions in the Coast Ranges differed essentially from those in the experimental investigations referred to. It would be easy, but hardly profitable, to speculate further on this subject, to which I hope to contribute by experiment on a future occasion.

The basic solutions rising from the granite converted the acid sandstones into more basic compounds: feldspars, ferromagnesian bisilicates, serpentine, etc. The solutions thus became more acid, and it can hardly be doubted that after producing their full effect upon the sedimentary rocks the waters contained free silica in solution. It is an interesting and important question what became of this silica, which was certainly in part extracted from the sandstones. It is absolutely certain from the principle of maximum dissipativity that any solution will deposit its contents or change its chemical character at the very first opportunity or at the first moment when heat can be set free by any chemical or physical alteration. Hence, in general, mineral solutions permeating rock masses can only in very extreme cases traverse long distances without substantial change. The silica dissolved by the waters which effected the metamorphism of the rocks of the Coast Ranges must consequently have redeposited this material as near the place where it was dissolved as possible. There appear to be only two possibilities in the case: either the silicification which is so prominent in the Coast Ranges was due to these siliceous waters or the solutions penetrated to the surface of the region as it then existed and there precipitated so much of their load as could be thrown down under diminished temperature and pressure. My own preconceptions would incline me to the former of these hypotheses, which involves a speedy precipitation and makes a portion of the process of metamorphism independent of material derived from extraneous sources. This may be the true theory, but I have not been able to gather any information confirmatory of it. Throughout the field work efforts have been made to determine the relative age of the processes of metamorphism, and in each area it has appeared that silicification was probably a later phenomenon than serpentinization, which, again, certainly followed the recrystallization of the sedimentary rocks. Thus serpentinoid rocks are often intersected by quartz veins, while such veins partially converted into serpentine or showing infiltrated serpentine have nowhere been detected. Massive serpentines, it is true, are seldom penetrated by quartz veins excepting in the mines, but this rock is too soft and tough to be readily fissured. While serpentinization and silicification are usually so associated as to lead to the belief that the latter followed the former, it is anything but improbable that exposures may hereafter be discovered from which it will appear that at least in some cases silica was thrown down very near areas of serpentinization and simultaneously with the progress of the latter process.

To sum up the results in a few words, it appears reasonably certain that the conversion of sandstones and shales to holocrystalline rocks took place at the period of the Post-Neocomian upheaval at temperatures somewhat above those now prevalent, at considerable but not at enormous pressure, and at the expense of basic solutions rising from the underlying shattered granite; further, that serpentinization of holocrystalline, metamorphic rocks and slightly altered sandstones took place at somewhat lower temperatures, also at the expense of rising solutions. It is probable, but not absolutely certain, that the regional silicification was subsequent to serpentinization and mainly produced in a similar manner. The formation of ore deposits was not contemporaneous with the metamorphism. Impregnation of the rocks with calcite and gypsum went on at ordinary temperatures and is still in progress. Chloritization was effected at least mainly at ordinary temperatures. In no case which has been examined are the holocrystalline rocks of the metamorphic series injected eruptives or original sediments, nor are any of the serpentines studied original sediments. No considerable portion of the serpentines can have been derived from olivine and in no case has any occurrence of serpentine been traced to an olivinitic rock.

Comparison between Neocomian metamorphics and the Archæan.—Whether the Archæan rocks are metamorphosed sediments or crystalline precipitates or of igneous origin is a question upon which eminent authorities differ, and one upon which neither evidence nor argument will be offered here. It is a matter of interest, however, to compare the altered strata of the Knoxville group with the crystalline Pre-Paleozoic rocks, since they appear to have much in common. That there is no slight similarity between the metamorphic rocks of the Coast Ranges and the strata of Archæan areas is evident from the fact that more than one well known geologist has believed that he recognized as Archæan, areas now known to be Neocomian. The metamorphism of the Coast Ranges may fairly be considered, at least in part, as regional, since most of the rocks of the Knoxville group are considerably altered and there are areas of many hundred square miles now exposed in which no patches of unchanged or very slightly modified rocks are known to exist. Nothing like the uniformity often prevalent in Archæan areas, however, is to be found in the Coast Ranges. On the other hand, though the general appearance of many of the Knoxville rocks differs widely from that of corresponding Archæan masses, there is much similarity in detail. Recrystallization is very prevalent in the California metamorphics and a crystalline development is characteristic of the Archæan. Muscovite rocks are frequent in the Coast Ranges, while biotite, though rare, is certainly one of the authigenetic minerals in the California metamorphic area. Plagioclase, augite, and hornblende are also abundantly developed. Mineral combinations similar to those of diabase, gabbro, and diorite are common both in the Coast Ranges and in many Archæan areas. Gneissoid rocks carrying albite and orthoclase, though not predominant in the Coast Ranges, are found there, and the mixture of zoisite and plagioclase, called saussurite, is frequent in both series, as are also the accessory minerals ilmenite, titanite, rutile, apatite, and chromic iron Finally, serpentine is even more common in the Coast Ranges than in most Archæan areas. Of the more important features of the Archæan series none appears to be entirely absent among the metasomatically recrystallized rocks of the quicksilver belt which have thus far been investigated, but the quantitative relations of the various minerals and rocks in the two series are widely different. A slight difference in the chemical composition of the sediments of the Coast Ranges, or of the solutions by the help of which their recrystallization has been effected, or of the pressure under which the reactions took place would have considerably changed the quantitative relations of the minerals formed. A greater depth from the surface would manifestly also have promoted uniformity. Whatever, then, is the real origin of the Archæan series, it appears certain that rocks indistinguishable from them might have been produced under conditions not greatly dissimilar to those which prevailed in the Coast Ranges at the close of the Neocomian.

CHAPTER IV.

THE MASSIVE ROCKS.

General character of the massive rocks.—The lithology of the Pacific slope has received so much attention of late years that it is unnecessary and would be undesirable to treat the eruptive rocks of this area as if they were undescribed. The region is indeed vast; but it is also one in which the character of the rocks is remarkably persistent. In the following pages, therefore, only the more peculiar features of the massive rocks encountered in the present investigation will be enlarged upon. These are granite, older porphyries, andesites of several varieties, rhyolite, and basalt.

PRE-TERTIARY ERUPTIVES.

Distribution of the granite.—As has been stated in the preceding chapter, granite appears to underlie the sedimentary rocks of the Coast Ranges and of the Sierra Nevada. According to Professor Whitney, a large portion of the mountain system from Fort Téjon southward is composed of granite. There are also large exposures of it in Shasta and Trinity Counties. In the region between Clear Lake and New Idria it is found in the Gavilan Range, occupies considerable areas near Monterey, forms the Farallone Islands, and appears at Point Reyes and other localities in the neighborhood. Near the town of Guadala, on the coast, in Mendocino County, large masses of conglomerate are formed of granite bowlders cemented by granitic detritus. In the interior of the Coast Ranges north of San Francisco it has not been met with in place to the south of the Trinity Mountains, but probably occurs in some of the chaparral-covered hills, since a very large part of the pebbles in Cache Creek are granite.

The arcose character of the sandstones of the Coast Ranges has been described. In the Sierra Nevada granite is abundant, even in the foot-hills. The higher Sierra, where not masked by lavas, consists chiefly of this rock. From the main Sierra range the granite extends to Steamboat Springs and Washoe Lake. Here it disappears under the eruptive rocks of the Virginia Range, but reappears on the eastern side of this range near the southern end of the Comstock lode.

The lithological character of the granites examined, from the Washoe district to the Farallone Islands, does not greatly vary, the chief difference being in the proportion of hornblende present. Some of the granite from the neighborhood of the Comstock carries little or no hornblende, while at Washoe Lake hornblende is particularly abundant. A moderate amount of hornblende occurs in the granite of Steamboat Springs and on the westerly slope of the main Sierra. The Rocklin granite, from the western base of the range, is also hornblendic. In the central Coast Ranges hornblende is not abundant in the granite, only a portion of the specimens showing this mineral and none a very large amount.

At the Comstock and at Steamboat Springs, as well as on the eastern slope of the Sierra, the granite immediately underlies strata at least as old as the Mesozoic. In the Coast Ranges, also, Neocomian beds rest upon it. No distinctly intrusive granite of Mesozoic or Tertiary age has been recognized in the present investigation. That such exists, as asserted by Professor Whitney, I by no means deny; but there is at least some ground for supposing that the main part of the rock is Archæan.

Granite of Steamboat Springs.—This is a rather coarse-grained, gray rock, the grains averaging 1.5^{mm} to 2^{mm} in diameter. Plainly visible are quartz, feldspar (in part triclinic), dark-green hornblende, and black mica. Under the microscope are seen quartz, oligoclase, orthoclase, dark-brown, uniaxial biotite, dirty-green hornblende, and accessory minerals. These last are apatite, titanite, zircon, magnetite, chlorite, epidote, and ferric oxide. The quartzes are in large part composite grains and of course contain fluid inclusions. The feldspars show in many cases undulous extinction and very often also zonal structure. The crystals of primary consolidation are better distinguished from those of secondary consolidation than is usual in granites. Of these the first are long prisms of oligoclase (with appropriate extinctions), more or less irregular prisms of hornblende (often with good hexagonal cross-sections), and irregular foils of biotite. The minerals of secondary consolidation are quartz and orthoclase, with perhaps a portion of the oligoclase. This division is only approximate, however, for grains of quartz are embedded in well developed hornblende prisms of first consolidation.

The plagioclase in some of these specimens is much more striking under the microscope than the orthoclase, and this fact might lead an observer to doubt which mineral predominated. In cases of this kind there is really no means of determining by microscopical examination the relative quantities present, for, since the areas of the grains cut by the slide vary with the form and position of the grains as well as with their cubic contents, the most careful study of the areas exposed, or even of the areas of each grain, will lead to no definite result unless the difference in quantity is very great. To test the matter 42 grams of such a specimen were reduced to a grain of 0.5^{mm}, which, in consideration of the coarseness of the rock, was considered sufficiently fine, and separated by the Thoulet method. The separation seemed very successful, there being a very small loss from dust. The following is the result:

	Per cent.
(1) At specific gravity 2.77, ferromagnesian silicates	17
(2) At specific gravity 2.67, impure feldspar	5
(3) At specific gravity 2.64, feldspar	12
(4) At specific gravity 2.62, quartz	34
(5) At specific gravity 2.60, feldspar, with some quartz	9
(6) At specific gravity 2.58, feldspar	12
(7) At specific gravity 2.56, feldspar	5
(8) At specific gravity 2.54, feldspar	6

The only triclinic feldspar detected under the microscope was oligoclase, and the feldspar heavier than quartz was undoubtedly of this species. As appears from the table, about 17 per cent. of this mineral fell before the quartz. At first sight it would appear that orthoclase predominated greatly in the rock, since the larger part of the feldspar is lighter than quartz. It is a suspicious circumstance, however, that the range of densities is so great, and mixtures are to be suspected. Chemical tests of (5), (6), (7), and (8)

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showed considerable quantities of soda in all excepting the last. Quantitative determinations of the alkalis in (6) were then made, giving 3.08 per cent. potash and 5.54 per cent. soda. This, however, does not settle the matter, since it is well known that orthoclases sometimes contain more potash than soda.[1] The specific gravities of these minerals also vary greatly, but it is certain that many specific-gravity determinations have been made with impure material. No less an authority than Professor Tschermak gives the specific gravity of orthoclase as 2.558; albite, 2 624; anorthite, 2.758. These figures, on Tschermak's theory, would give oligoclase at 2.658. If the specific gravities of (5), (6), and (7) be assumed to be each 0.01 higher than that at which they fell and if the mixture of orthoclase and oligoclase, which would give these specific gravities, be computed at Professor Tschermak's figures, it will appear that the granite in question must have contained almost exactly equal quantities of oligoclase and orthoclase. Taking into account its association with less plagioclastic rocks, its habitus, etc., there can be no doubt that it is to be classed as a granite, and not as a plagioclase rock.

There are light-colored bands in the granite at Steamboat Springs which bear the appearance of dikes of granitic rock. Under the microscope these dike-like masses are found to be somewhat decomposed granite-porphyry, showing rounded grains of quartz, orthoclase, oligoclase, and remains of ferromagnesian silicates in a microcrystalline groundmass which appears to consist mainly of orthoclase and quartz. The larger quartzes in this rock show abundant fluid inclusions. These dikes were not observed to penetrate the overlying metamorphic rocks, and are probably older than the latter, if not substantially of the same age as the granite.

The granites collected from the eastern ridges of the Sierra are not distinguishable from those of Steamboat Springs; but a granite from Washoe Lake shows exceptionally well developed, long hornblende-crystals embedded in a very white quartz-feldspar mass. The mica is less prominent.

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[1] Compare Dana: Syst. of Min.; and Roth: Allg. und chem. Geol.

Granite from the Coast Ranges.—The specimens from the Gavilan Range, from the Farallones, from Marin County, and from Horsetown, Shasta County, do not differ notably from those of Steamboat Springs. A portion of the Monterey granite is extremely coarse. Microcline was observed in slides from two of the localities mentioned; muscovite occurs, but is not common; and hornblende is present in some of them, but not in large quantities. The crystals of primary and secondary consolidation are less marked in the Coast Ranges than in the Nevada granite, and in a granite from Olema, Marin County, there is some granophyric structure. These differences, slight as they are, are probably due rather to the accidents of collection than to any persistent difference in type.

Older porphyries of the Coast Ranges.—No eruptive rocks antedating the Post-Miocene upheaval have been detected in place during the present investigation; but in the conglomerates of the Knoxville series, at Knoxville, and in a conglomerate stratum lying just above the base of the Chico, at New Idria, pebbles of porphyry have been found. In appearance these sets of pebbles strongly resemble each other, and, although there is considerable variation in their mineralogical composition, they seem at present fairly referable to a single group. They are all quartzose and the quartzes contain fluid inclusions, often in abundance. There are also patches in the quartzes which resemble devitrified glass. There are in some cases remains of porphyritic hornblende-crystals, mostly decomposed. A large portion of the porphyritic feldspars are plagioclastic and appear to be referable to oligoclase and andesine. Many of the porphyritic feldspars are unstriated, but none was detected showing good cleavages and certainly referable to orthoclase. The feldspar of the groundmass is microcrystalline and cannot be satisfactorily determined under the microscope. The quantity of the groundmass is usually so large that the feldspar which it contains must determine the classification of the rock. A partial analysis was made of one of the Knoxville specimens (No. 76) with the following result:

	Per cent.
Silica, SiO^2	68.800
Soda, Na^2O	10.021
Potassa, K^2O	0.912

This is evidently a plagioclase rock and must be considered a porphyritic diorite.

Had the porphyries found in the Chico conglomerate been ejected after the Post-Neocomian upheaval they would almost certainly have been detected in the extensive exposures examined at and to the south of New Idria. The porphyry at this point is therefore probably of nearly the same age as the similar rock found associated in the Knoxville conglomerates with granite pebbles and with fossils characteristic of the Knoxville series. The eruption of this porphyry must antedate a part of the Knoxville period, and the negative evidence is that it preceded the entire group of strata in which the fragments occur. Like the porphyry found in the granite at Steamboat Springs it is not improbably little younger than the granite.

Diabase from Steamboat Springs.—Among the greatly disturbed, partially metamorphosed, highly inclined, sedimentary rocks of Steamboat Springs, which are overlain by andesites and basalts, occur some conglomerates. In these were found dark pebbles of a crystalline rock strikingly resembling the material which forms the east wall of the Comstock lode in Virginia City. Under the microscope these pebbles proved to be plagioclase-pyroxene porphyries with a crystalline groundmass. The pyroxenes are entirely decomposed, but the chlorite and other decomposition products retain the characteristic forms of augite or hypersthene. To which of these minerals the original substance belonged cannot therefore be told. This rock is microscopically as well as macroscopically indistinguishable from the porphyritic diabase of the Comstock. The beds in which the pebbles occur are at least as old as the Mesozoic.[1]

LAVAS.

Volcanic rocks of Steamboat Springs.—The andesites and basalts of Steamboat Springs form a most interesting series both in themselves and because they throw some additional light upon the important occurrences near the Comstock lode, which is only six miles from the Springs in a straight line and

[1] I have already drawn attention to the rocks of Steamboat Springs in a paper entitled "Washoe rocks": Bull. California Acad. Sci. No. 6, 1886, p. 93; see, also, my paper On the texture of massive rocks: Am. Jour. Sci., 3d series, vol. 33, 1887, p. 50; and Bull. U. S. Geol. Survey No. 17, On the Development of Crystallization in the Igneous Rocks of Washoe, Nevada, with Notes on the Geology of the District, by Messrs. Hague and Iddings.

lies on the opposite flank of the same range. A portion of this series also possesses a close analogy to some of the andesites of the Coast Ranges. A detailed account of the occurrence of these rocks will be given in the descriptive geology of the locality. Here it is sufficient to state that the latest eruption is normal basalt and the earliest a normal, dense hornblende-andesite, while between the two comes a series of pyroxenic eruptions which form a natural group. All of this group have the rough fracture and porous texture which a few years ago would have led to its being called trachyte.[1] The exposures, as is so usual in the Great Basin, are admirable, a large proportion of the entire neighborhood being bare rock.

Andesites of Steamboat Springs.—The predominant variety of the older hornblende-andesite of Steamboat Springs is a grayish-blue, dense, fine-grained, thin-bedded rock, with a few porphyritic feldspars of small size. It is entirely similar to one variety of the earlier hornblende-andesite of the Washoe district. Intermingled with this rock in the eastern portion of the mass are patches of coarser-grained and more porphyritic modifications. The relations of these patches to the fine-grained material were studied with great care, and no evidence was found that they were separate eruptions; on the contrary, it was clear at several points that they represented merely local modifications of structure. These coarser-grained rocks are indistinguishable from the prevalent older hornblende-andesite of the Washoe district. In the western area of the earlier hornblende-andesite the fine-grained, fissile rock is also abundant, but here it is associated with considerable masses of what is plainly glassy rock. Transitions were distinctly traced here also.

Under the microscope no very definite lines can be drawn between these older rocks. Thus, No. 313 is a gray rock showing many porphyritic, black hornblendes. Under the microscope this specimen is found to be composed of brownish-green hornblendes with heavy, black borders (many

[1] Previous to my examination of the Comstock, the United States geologists and Professor Zirkel regarded the later hornblende-andesite of Washoe and many similar occurrences elsewhere as trachyte. I showed that the Washoe rock contained no sanidine and stated that, from a cursory examination of the trachyte slides of the fortieth parallel collection, there was "much reason to believe that trachyte occurs less often than had been supposed in the Great Basin area" (Second Ann. Rept. U. S. Geol. Survey, 1880–'81, p. 300; Geology of the Comstock Lode, Mon. U. S. Geol. Survey No. 3, p. 374). A year later Messrs. Hague and Iddings announced that there were no trachytes in the collections of the fortieth parallel from the Great Basin (Third Ann. Rept. U. S. Geol. Survey, 1881–'82, p. 12).

of which have entirely replaced the amphibole), a very little pyroxene, and a moderate number of porphyritic plagioclases embedded in a fine-grained, holocrystalline groundmass of magnetite and feldspar, a portion of the latter being granular and a portion microlitic. In No. 25*a*, a light-gray rock with small porphyritic hornblendes, the amphibole is entirely replaced by black border, the porphyritic feldspars are small and few in number, and the groundmass is a more uniform, fine-grained material. No 18 is a specimen of the prevalent fine-grained variety and presents under the microscope no considerable difference from No. 25*a*, excepting that the hornblendes are smaller. The glassy variety of this rock shows under the microscope small brown hornblendes with heavy black borders, an occasional pyroxene, a few small porphyritic feldspars, and a groundmass consisting of feldspathic microlites and magnetite embedded in a glass base. Fluidal structure is common.

The younger andesites of Steamboat Springs are all of the trachytic type, gray or reddish or yellowish rocks, rough and soft. Though these rocks stand in such close relations that I shall venture to propose a single name to embrace them all, they are divisible into three groups. In one large area the rock is extremely uniform and is essentially a pyroxene-andesite containing abundant augite and hypersthene. A few very minute, black-bordered hornblendes are usually visible under the microscope, but they certainly do not form 1 per cent. of the entire quantity of bisilicates. This rock contains no mica. Large porphyritic plagioclases, which appear to be andesine, are embedded with the bisilicates in a groundmass of feldspar microlites and magnetite. A second pretty well defined variety is a hornblendic rock in general appearance similar to the first variety. It always contains more or less pyroxene. It also often contains mica. This last mineral seems to be entirely absent in some croppings and even over small areas. A few flakes only occur in other masses, while in others still it is fairly abundant, and in one area brown mica with a variable angle between the optical axes forms a large part of the rock. This rock appears to be substantially identical with that which I called later hornblende-andesite in the Washoe district, where also mica is present in variable quantities and is sometimes absent. Messrs. Hague and Iddings prefer to rename this rock hornblende-mica-andesite, a term which would be misleading as applied to Steamboat Springs, where later hornblende-andesite is certainly appropriate, since five well defined dikes of it cut the earlier hornblende-andesite. A portion of these dikes show mica; the others, none. The greater part of this rock is holocrystalline, but some croppings contain glass, sometimes in imperfect spherolitic forms. In two cases hornblendes with concentric, double, black borders were noticed.

More interesting than either of these varieties of the younger andesites is the third, which, for lack of a better name, I will call provisionally transition andesite. This variety occurs in a number of areas shown on the western portion of the map, some of which are small, isolated, and excellently exposed. They are as trachytic in texture as the associated varieties and are frequently laminated, the sheets being half an inch to an inch in thickness and not very sharply divided from one another. The andesites of Clear Lake show the same structure. The transition andesites are of exceedingly variable composition, even in the smaller areas. Some specimens are almost purely pyroxenic; others, at a distance of only a few feet, carry much more hornblende than pyroxene. Sometimes mica is present, but oftener absent, though it has been found in all of the principal areas. In one area olivine also has been detected in several specimens. One of these comes from a portion of the rock which appears to lie beneath the remainder and is much denser than usual, but other olivinitic specimens are of the ordinary trachytic type.

The younger andesites are comparatively recent, though older than the basalt. They show few signs of erosion and cap a large part of the Virginia Range near Steamboat Springs. They also form the Hufaker Buttes, between Steamboat and Reno, where, too, micaceous and non-micaceous rocks are found in company. The younger andesites are nearly contemporaneous. The highly micaceous, later hornblende-andesite overlies and appears to have followed the less micaceous portion of the same variety. The relative ages of the pyroxenic and hornblendic varieties are not absolutely certain. On the map will be found a dike of later hornblende-andesite, which should cut pyroxene-andesite were it younger than the latter. It is not thus shown, but it is not impossible that it may do so, for at the points where it should be exposed the ground is so covered with bowlders of the pyroxene-andesite, which have rolled down from the adjoining hill, that the croppings may have been concealed. Repeated and careful search was made for them in vain. The transition-andesite, though, like the others, certainly younger than the earlier hornblende-andesite, does not stand in structural relation to the other varieties. That it is very nearly of the same age seems certain. In the Washoe district the micaceous rocks succeeded the pyroxene rocks of Mt. Kate,[1] but are connected with them by transitions. On the other hand, Mr. Lindgren found that near Bodie pyroxene outflows succeeded micaceous ones.

It would be a very easy matter so to arrange the slides of the older and younger andesites of Steamboat that they would seem to form a continuous series, and a tolerable argument might thus be offered for regarding the rocks as substantially one. It would be more difficult to treat the hand specimens in this way, while no observer could examine the rocks in place at Steamboat without perceiving the difference in age and geological position of the older and younger andesites

The services which the microscope renders to lithological geology are very great, but there are facts connected with this study which are not best elucidated by examining the rocks a square millimeter at a time. It might, indeed, be said that since these rocks are so closely allied it is useless to make geological distinctions between them; but, if the purpose of lithology is to ascertain the causes which underlie the variations in composition and structure of rocks, the progress of this branch of science could only be delayed by a failure to study and record all the distinctions which it is possible to trace. When these causes are once understood, and not before, it will be possible to judge what differences are truly significant.

A natural group of andesites.—A fact of some importance, at least to the field geologist, which is clearly brought out by the study of the rocks of Steamboat Springs and confirmed by observations in California, is that there is a group of comparatively recent andesites, varying considerably in mineralogical composition, but possessing much macroscopical similarity and a close geological relationship. Most of the younger andesites of Steamboat

[1] Bull. California Acad. Sci. No. 6, vol. 2, 1886, p. 99.

would unquestionably have been classified as trachytes by nearly every American geologist a few years since. They are nearly all soft, rough, light-colored rocks, possessing great similarity in external appearance and in their mode of occurrence. This similarity cannot be regarded as accidental, for the series of younger andesites found at Steamboat is repeated at Mt. Shasta, which I visited for the purpose of instituting a comparison, and in part also near Clear Lake, while the area regarded as trachyte by all field observers at Washoe previous to my study of that district embraces highly pyroxenic, non-micaceous rocks as well as micaceous, hornblendic andesite. If the macroscopical resemblance and the intimate association of these rocks be not accidental, it must be due to common features in their origin or history, and they may therefore properly be regarded as forming a natural group, recognized by earlier observers, though wrongly named. They are all more or less pyroxenic rocks, which may contain both mica and hornblende or one of these minerals or neither. Hornblende occurs in this series over large areas without associated mica, and mica (near Clear Lake) in large areas without associated hornblende. The members of this series are connected by transitions wherever I have studied them. There is certainly a marked distinction between this series and the older hornblende-andesite, both at Steamboat and at Washoe, as there is also at the latter locality between it and the earlier dense pyroxene-andesite. Near Clear Lake also the earlier pyroxene-andesite is distinct. The causes of these differences are not as yet known. I do not believe that they depend simply upon the rate of cooling or upon the pressure under which the rock has cooled. As has been mentioned, a portion of the older hornblende-andesite of Steamboat is glassy, while directly associated with the glass is ordinary, dense, older andesite. That a glassy magma cooled slowly under considerable pressure will crystallize appears almost certain, and it is to be inferred that the earlier andesite at this locality has not been very deeply eroded. Consequently dense andesites may consolidate near the surface. On the other hand, there are many exposures of the younger andesites at depths of hundreds of feet, and in the Sutro tunnel at a depth of some 2,000 feet below what must be supposed to have been the surface of the rock at the period of eruption. Such exposures are indeed holocrystalline, but they retain their trachytic character in spite of having cooled at great depths. I incline to the supposition that, owing to chemical differences in the material of secondary consolidation, a greater change of volume has accompanied this final process in the more recent series than in the earlier one and that the cracked feldspars and the smaller cohesion of the trachyte-like rock are due to this change of volume. Bulk analyses of the younger andesites indicate a slightly more acid composition, but it would be a matter of great difficulty to separate the crystals of primary and secondary consolidation for analysis. Means of deciding this question may, however, be devised.

Should the series of younger andesites discussed above, together with the transitional varieties, prove common on the Pacific slope and, as a rule, distinct from the earlier and denser rocks, these plagioclase rocks might conveniently be termed *asperites*,[1] at least for field purposes, in reference to their trachytic character. If these relations, traced by me at four important localities and suggested by hasty inspection at other points, are general, it will only be necessary to substitute the term asperite for trachyte on many of the earlier geological maps of the western United States to represent the facts from a modern point of view. Even if the term asperite does not obtain a permanent place in lithological nomenclature, it cannot be amiss to consider its expediency. The nomenclature of lithology is and must always remain more or less arbitrary. That classification is the best which takes account of the greatest number of natural relations; but no classification can embrace them all. To my mind it is an advantage that the term asperite expresses structural as well as mineralogical distinctions, for, though a purely mineralogical classification of rocks is extremely simple, it ignores many of their properties which are of the utmost interest and importance. That the ultimate classification will be purely mineralogical appears to me in the highest degree improbable, nor can I believe that it will be founded solely upon microscopical peculiarities.[2]

[1] From asper, rough, the Latin equivalent of τραχύς.

[2] C. W. Gümbel (Sitzungsber. k. bayer. Akad. Wiss., Munich, vol. 2, 1881, pp. 365–368) suggested tentatively that the andesitic rocks of South and Central America might be divided into two types, one trachytic, the other basaltic in habitus. I was not aware of this suggestion when the text was written. Gümbel's material was meager. In his specimens of trachytic habitus, corresponding to my asperites, he found no mica. The specimens of basaltic habitus which he examined included none in

Andesites of the quicksilver belt.—Andesite is abundant near Clear Lake, and thence southward. This region was studied chiefly for its bearing upon the geology of the Sulphur Bank, and no attempt was made to investigate the separate varieties of andesite minutely. Besides the information to be derived from specimens, however, it is certain that the andesite of this region was ejected at two distinct periods, of which one preceded the Pliocene Cache Lake beds. This earlier andesite is largely represented in the conglomerates or uncompacted, pebbly beds of Cache Lake. The later andesitic eruption which forms the mass of Mt. Konocti closed the Cache Lake period very late in the Pliocene, but preceded the basalt eruptions by an unknown though considerable interval. The older andesite, represented by Chalk Mountain and by the pebbles in the Cache Lake beds, is a rather dense, bluish-gray rock, somewhat altered in most cases. Under the microscope it is found to be composed of pyroxene and feldspar crystals embedded in a groundmass consisting of feldspar microlites and magnetite. The feldspar of the groundmass is all microlitic and the structure is similar to that of the "felted" groundmass so common in pyroxene-andesites, except that it is unusually coarse. The pyroxene is mostly rhombic, but is very light colored and shows no dichroism. Precisely similar to this andesite is one from the northern end of Thurston Lake. This occurrence appeared from field examination to be older than the asperites by which it is accompanied, while from its similarity under the microscope to the rock of Chalk Mountain it seems altogether probable that it is of the same age as the latter. These rocks contain no hornblende.

The younger andesites of Clear Lake are referable to the group of asperites discussed above. Macroscopically they are dark-gray or tawny, soft, trachytic rocks, often showing lamination more or less distinctly. In fact these lavas are entirely indistinguishable from some of the andesites of Steamboat Springs. They are pyroxene rocks, and not a single slide shows a particle of amphibole. In one slide, however, are a few minute patches of opacite with irregular outlines, which possibly, but by no means certainly, replace hornblendes. On the other hand, mica is a frequent though

which hornblende was the prevalent bisilicate. In the western United States the asperites are usually micaceous and dense hornblende-andesites are abundant. The latter are generally distinct from the dense, pyroxenic rocks. Gümbel divides his types at 57 per cent. of silica.

not universal constituent of these rocks. The occurrence of biotite and pyroxene, unaccompanied by a trace of hornblende, is somewhat exceptional in eruptive rocks; at least I am unacquainted with any area so large as that at Clear Lake which is thus characterized. In other respects these andesites are not peculiar, showing porphyritic plagioclases with augite and hypersthene in a groundmass of feldspar grains and magnetite, sometimes holocrystalline and sometimes accompanied by glass. In some cases where biotite makes its appearance the pyroxene is found to be exclusively hypersthene, suggesting that the mica in a sense replaces or represents augite, but augite and biotite sometimes appear in the same slide. One specimen shows augite, hypersthene, biotite, and a few sharply defined, vividly polarizing olivines. The groundmass in this case contains some base, but no appreciable amount of pyroxene, and there is nothing basaltic in the appearance of either the specimen or the slide. The porphyritic feldspars of these rocks, as determined by optical methods, are referable to labradorite and probably in part to andesine, while the microlitic feldspars show the extinctions of oligoclase.

At two localities on the southerly slope of Mt. Konocti dacite is found. One of these is about half way up the slope, the other near the foot. It is remarkable that cinnabar is associated with each and that from the higher occurrence, known as the Uncle Sam mine, considerable quantities of ore have been taken. The rock at each of these spots is much decomposed, but what remains of the feldspar is all triclinic and the ferromagnesian silicates were certainly principally pyroxene. No distinct evidence of hornblende or mica is perceptible, but it is not impossible that some of each existed.

Andesitic glass.—Closely associated with the more or less glassy asperites of Clear Lake are large areas of volcanic glass. This glass is often opaque, excepting in very thin splinters, and possesses a high luster, as if charged with metallic oxides. Sparsely distributed in it, and forming certainly less than 1 per cent. of the mass, are sometimes crystalline grains. Such a specimen is No. 13, Clear Lake, collected half a mile south of Kelseyville. Under the microscope it is found to be a mass of light-brown glass, full of excessively minute, black trichites, usually arranged in stellar groups. A few small grains, but no lath-like microlites, of plagioclase and a group of augite and hypersthene crystals also appear. The microscope thus confirms the reference of this material to the andesitic eruptions. This specimen was analyzed with the result given below.

For comparison with this glass an analysis was also made of No. 7, Clear Lake, an asperite from the southeast peak of Mt. Konocti. This rock contains a few quartz grains, but is otherwise similar to most of the asperites of the region. It is sensibly holocrystalline. The components are plagioclase, augite, hypersthene, iron ores, and quartz. The porphyritic feldspars are probably andesine. The hypersthene occurs in prisms of considerable length, while the augite is found in small grains. The groundmass is chiefly made up of microlites and irregular grains of plagioclase. The rock is slightly decomposed and contains a little calcite.

In the following table, I is the andesitic obsidian, No. 13, Clear Lake, and II is the asperite, No. 7, Clear Lake, just described:

	I.	II.
Specific gravity	2.391	2.604
Silica, SiO^2	74.013	65.430
Phosphoric acid, P^2O^5	0.010	Trace
Titanic acid, TiO^2	0.242	0.825
Alumina, Al^2O^3	12.949	17.105
Ferric oxide, Fe^2O^3	....	2.391
Ferrous oxide, FeO	1.415	1.191
Manganous oxide, MnO	Trace	0.697
Nickel oxide, NiO	....	0.202
Lime, CaO	0.995	3.879
Magnesia, MgO	0.480	1.477
Soda, Na^2O	5.340	3.656
Potassa, K^2O	4.649	2.834
Chlorine, Cl	0.074	....
Loss at 100°, H^2O	0.000	0.200
Loss above 100°, H^2O	0.286	0.361
Total (less 0.033 O)	100.420	100.248

Atomic ratio of I, $H^2 : Si : R^{vi} : R'' = 0.032 : 4.934 : 0.760 : 0.363$.

Atomic ratio of II, $H^2 : Si+Ti : R^{vi} : R'' = 0.032 : 4.403 : 1.004 : 0.448$.

The obsidian is much more acid than the holocrystalline rock into which it passes by transitions, but this is not the only chemical difference. The sum of the quantities of lime and magnesia is less than one-third as great as the corresponding sum in the asperite, while the glass contains half as much again alkali as the other rock. The difference in the specific gravities is also noteworthy. A comparison between these analyses and those of some basaltic lavas will be made below.

Andesites south of Clear Lake.—Extensive areas of andesite occur to the southward of Clear Lake. Mt. Cobb and Mt St Helena and, indeed, a great part of the range of which the latter forms the culminating peak, known as the Mayacmas Mountains, are andesitic. The andesites extend down almost continuously to within a few miles of Vallejo, at the head of the Bay of San Francisco. A considerable amount of reconnaissance work has been done in this area for the purpose of studying the many quicksilver mines or prospects which occur in the same region; but no attempt has been made to map this andesite area or to work out the separate eruptions. Both dense andesites of the earlier type and the asperites are represented. All the specimens excepting one appear to be purely pyroxenic, and no mica has been observed. A single slide from near Napa City shows some small greenish-brown hornblendes, accompanied by augite and hypersthene. As a rule there is more hypersthene than augite in these rocks, but this relation is sometimes reversed. The pyroxene never enters in considerable quantities into the composition of the groundmass. The feldspars, both porphyritic and microlitic, in the Mayacmas Range andesites seem to be mainly labradorite, a fact of special interest in view of the abnormal acidity of some of them. The groundmass of most of the slides shows feldspar microlites and magnetite embedded in glass, which is sometimes partially devitrified and sometimes full of trichites. The glass often shows a banded or rhyolitic structure.

To the south of the estuary of the Sacramento River volcanic rocks are much less abundant than to the north, but they are not entirely wanting. While hornblende is unusually rare in the northern andesites, asperite, carrying both hornblende and mica, occurs near Mt. Diablo. Professor Whitney[1] mentions a belt of "trachyte" some fifteen miles northeast of Tres Pinos. It may be considered certain that asperite is meant. My party has not visited this locality, but we collected pebbles from comparatively recent gravel beds and from the present streams between Tres

[1] Geol. Survey California, Geology, vol. 1, p. 47.

Pinos and New Idria, many of which are entirely similar to the northern andesites. That these rocks must be in place somewhere in the hills is of course certain, but they were not encountered.

Rhyolite.—Only one occurrence of rhyolite is known in the whole area dealt with in this memoir. This is a dike at New Almaden, far from any other known outcrop of eruptive rock. Its occurrence here is specially significant when considered in connection with the ore deposits. The croppings are mostly of a tufa-like consistency, and in consequence have decomposed to a considerable extent. They are light colored, and without careful scrutiny might be mistaken for clastic material. Under the microscope they are found to be composed of porphyritic grains of quartz and feldspars, both striated and unstriated, with a little brown mica in a groundmass, which is sometimes holocrystalline (possibly as a result of devitrification) and sometimes shows the pseudospherolitic structure so common in rhyolites. In the latter case some glass remains in the groundmass, and inclusions of glass are common in the quartzes of both varieties. To determine the character of the predominant feldspars a portion of specimen No. 47 was reduced to coarse powder as usual and separated in a Thoulet solution of a specific gravity of 2.59. Eighty-one per cent. floated. This consisted of feldspar with groundmass and a little adhering quartz It gave a strong potash reaction. This rhyolite is later than the Post-Miocene upheaval.

Basalt.—Basalt is very widely distributed on the Pacific slope. Being the last eruption, it is seldom covered over by material of any kind. The thin flows of this rock have also spread over a greater area than the comparatively viscous andesites of equal volume could have done. Both macroscopically and microscopically the rock is very monotonous in its character and presents comparatively few points of interest.

At Steamboat Springs the thin flows of olivinitic basalt are found under the microscope to be entirely normal and precisely similar to the basalt of the Washoe district. Similar rocks are found in the Panoche Valley, in the San Benito Valley, near Mt. Diablo, and at many points between the Bay of San Francisco and Clear Lake. Near Clear Lake they are somewhat more notable, since much of the rock at this point is scoriaceous and forms pretty well developed volcanic cones of small size. The scoriaceous basalt does not differ from the ordinary variety under the microscope, except by the presence of many cavities and a comparatively large amount of ferruginous decomposition-products. In this region olivine is very irregularly distributed, some croppings showing unusually great quantities of this mineral, while in others it is macroscopically and microscopically absent. This irregularity was noticed even in single patches of the rock, which could not possibly be assigned to different eruptions. Whether olivine is absent or present, the structure of the rock remains the same, the interstices between small, lath-like plagioclases being filled with pyroxene microlites. Olivine is thus a frequent but not an essential constituent of the California basalts, and the microscopic distinction between this rock and andesite consists in the order of genetic succession of the component minerals. The olivine frequently includes quadrilateral picotite crystals and as a rule shows signs of incipient decomposition.

The feldspars of the basalts of the quicksilver belt are seldom porphyritic and they usually assume the form of elongated, more or less microlitic crystals, often with terminal faces. The predominant species is labradorite, but oligoclase may be present among the smaller individuals. The predominant pyroxene is augite, which is sometimes present in large grains, but always as small grains in the groundmass. It presents no peculiarities. Hypersthene is also found in a few sections. It of course extinguishes light when the principal nicol sections are parallel to the main axis, and it shows interference colors which are gray and yellow, differing markedly from those of augite. Like the hypersthene of the Chalk Mountain andesite, however, its dichroism is not sensible. So far as ascertained, only the larger pyroxene crystals are ever hypersthene, that of the groundmass where determinable being augite. Hypersthene has been supposed by Messrs. Hague and Iddings to replace olivine. To some extent this appears to be the case in the basalts of the quicksilver belt; at least there are a number of thin sections in which hypersthene occurs and which do not contain olivine. Olivine and hypersthene also occur in the same sections, however, and there are many slides in which neither olivine nor hypersthene appears.

At Sulphur Bank the basalt bears peculiar and very interesting relations to volcanic glasses. Field examinations showed that an area of obsidian south of Borax Lake passed over into a rock which bore every appearance of being an ordinary basalt. This glass is a dark-gray material, transparent in masses a quarter of an inch or more in thickness and without any peculiarly high luster. It occurs some miles from any andesite area and presents a very different appearance from the andesitic glass described above. On analysis, however, it proved to contain above 75 per cent. of silica. This seemed at first to preclude its reference to a basaltic eruption. It was afterwards found that No. 48*b*, a fine-grained basalt from one of the craters at Sulphur Bank, normal in structure, but without olivine, of a specific gravity of 2.82, contained 57.03 per cent of silica, a very high content for a basalt; while No. 202, occurring at the outskirts of the obsidian area, is a somewhat glassy basalt, density 2.69, carrying olivine, augite, and hypersthene, with feldspar microlites, and showing the characteristic structure of this rock, contains no less than 66.87 per cent. of silica. Even No. 150*j*, which is macroscopically a pure glass, with a specific gravity of only 2.33, and which carries 75.22 per cent. silica, proves under the microscope to contain numerous small grains of pyroxene and long microlites of plagioclase entirely similar to those in the basalts. Neither free quartz nor orthoclastic feldspar has been detected in the slides of this obsidian. The abundance of lath-like plagioclases in this glass distinguishes it microscopically from the andesitic obsidian, in which the feldspars are mostly, if not wholly, irregular grains or developed crystals of primary consolidation.

The microscope thus supports the conclusion, reached from field observation before either microscopical examinations or chemical determinations had been made, that the obsidian near Borax Lake is a portion of a basaltic eruption. The transition has been again tested in the field since the laboratory work was completed.

In the following table the analysis of the obsidian from the area immediately south of Borax Lake is given under I. For comparison a second basalt (No. 85, Clear Lake) was analyzed, and its composition is given under II. This latter is from the basalt bluffs south of Burns Valley, at no great distance from the obsidian. It is a dense, gray rock, remarkably rich in olivine. Under the microscope the rock appears wholly normal, showing the usual microlitic groundmass of plagioclase needles and small augite grains, while the porphyritic olivines are undecomposed. The analysis shows, however, that it is rather siliceous for a basalt, in spite of the great quantity of olivine. Under III is given the composition of an ordinary basalt from Knoxville.

	I.	II.	III.
Specific gravity	2.390	2.830	....
Silica, SiO^2	75.400	57.374	51.66
Phosphoric acid, P^2O^5	....	0.016	....
Titanic acid, TiO^2	....	0.602	Trace
Chromic oxide, Cr^2O^3	....	......	0.25
Alumina, Al^2O^3	7.722	15.661	11.22
Ferric oxide, Fe^2O^3	1.410	2.061	....
Ferrous oxide, FeO	....	4.456	[1]7.62
Manganous oxide, MnO	0.116	0.271	0.12
Nickel oxide, NiO	....	0.411	....
Lime, CaO	1.554	4.011	7.72
Magnesia, MgO	1.260	8.838	13.01
Soda, Na^2O	8.090	3.047	5.98
Potassa, K^2O	4.515	1.507	0.89
Chlorine, Cl	0.139	......	....
Loss at 100°, H^2O	0.420	0.614	1.06
Loss above 100°, H^2O		0.123	
Total (less 0.027 O = 0.110 Cl. in I)	100.585	99.928	100.13

[1] A small amount of iron in the ferric state was not determined, because unnecessary for the purpose for which the analysis was originally made.

Atomic ratio of I, $H^2 : Si : R^{vi} : R'' = 0.047 : 5.027 : 0.506 : 0.474$.

Atomic ratio of II, $H^2 : Si : R^{vi} : R'' = 0.082 : 3.825 : 0.907 : 0.887$.

Atomic ratio of III, $H^2 : Si : R^{vi} : R'' = 0.118 : 3.444 : 0.669 : 1.376$.

The difference in composition between the glass and the nearly holocrystalline basalts is extremely similar to that pointed out between the crystalline and glassy forms of andesite. There is nearly three times as much alkali in the glass as in the olivinitic basalt from Burns Valley, and only one-fifth as much lime and magnesia.

It is a curious fact that if 10 per cent. of lime were added to this obsidian it would closely approximate in composition to some kinds of window-glass.

Analogous occurrences.—The association of comparatively acid glasses with neutral or basic lavas is not unknown. In the trachyte of Mt. Amiata, in Tuscany, Professor vom Rath found small grains of a substance which had

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been taken for quartz, but which on separation and analysis proved to be glass.[1] The inclosing rock contained 67.06 per cent. of silica, while the following analysis shows the composition of the glass:

Specific gravity	2.351–2.369
Silica, SiO^2	76.82
Alumina, Al^2O^3	14.01
Lime, CaO	1.76
Water, H^2O	0.40
Alkalis (by difference)	7.01
	100.00

In this case, therefore, the amorphous material accompanying well crystallized components contained nearly 10 per cent. more silica, a large quantity of alkalis, and very little lime.[2]

In the basalt of the Rossberg, near Darmstadt, also, Mr. T. Petersen[3] found a bottle-green glass inclusion, or segregation, which differed very greatly indeed in its chemical composition from the surrounding mass, as is shown by the following analyses:

	Rock.	Glass.
Specific gravity	3.043	2.524
Silica, SiO^2	40.53	66.42
Titanic acid, TiO^2	1.80	0.31
Alumina, Al^2O^3	14.89	13.07
Ferric oxide, Fe^2O^3	1.02	3.66
Ferrous oxide, FeO	11.07	
Manganous oxide, MnO	0.16	Trace
Magnesia, MgO	8.02	1.30
Lime, CaO	14.62	1.19
Soda, Na^2O	2.87	6.09
Potassa, K^2O	1.95	7.36
Phosphoric acid, P^2O^5	1.32	....
Carbonic acid, CO^2	0.17	....
Water, H^2O	1.44	0.73
	99.86	100.13

[1] Zeitschr. Deutsch. geol. Gesell., vol. 17, 1865, p. 413.

[2] About the time at which this monograph was transmitted, a very elaborate study of the Amiata rocks was published by Mr. J. Francis Williams in the Neues Jahrbuch für Mineral., V. Beilage-Band, 1887, p. 381. He regards the whole mountain as a single massive which is typically developed as trachyte toward the center, but tends sometimes to an andesitic and sometimes to a rhyolitic composition at the edge. The rock is all more or less glassy. A very pure glass from Fosso del Diluvio gave: Sp. gr., 2.346; SiO^2, 73.57; CaO, 0.99; MgO, 0.26; Na^2O, 3.09; K^2O, 5.74. An analysis of typical trachyte from the Poggio Traburzolo gave: Sp. gr., 2.562; SiO^2, 64.76; CaO, 3.24; MgO, 1.74; Na^2O, 2.67; K^2O, 5.49. As in the case of the Clear Lake andesite and basalt, the glass is more acid than the rock, and the proportion which the alkalis bear to the earths is much greater in the amorphous material. Here also the glass was prevented from crystallizing by peculiarities of composition, not of the physical conditions to which it was subjected.

[3] Neues Jahrbuch für Mineral., 1869, p. 36; ibid., 1873, p. 587.

These analyses are directly comparable with those of the basalt and basaltic obsidian and with the andesite and andesitic obsidian from Clear Lake, and the character of the differences is manifestly the same. In each case the glass is comparatively very rich in alkalis and silica and contains only a little lime or magnesia.

Inferences.—In the rocks from Amiata and the Rossberg only small blebs or streaks of acid glass are found. At Clear Lake, on the other hand, immense quantities of glass, covering large areas, accompany crystallized rocks in such a manner as to leave no doubt of their direct connection. The nature of the cases is the same, but the size of the masses is very different, and I am not aware that any instance has ever been studied in which areas of glass which must be measured by the square mile are thus connected with crystallized rocks of a different chemical composition. It is plain from these occurrences that associated masses of very different chemical composition and of great volume sometimes form portions of the same eruptions. They pass over into one another by transitions, but, whether they never have been more thoroughly mingled than they now are or whether, having been intimately mingled, they have separated by eliquation, it is perhaps impossible to decide at present. The conditions show that they were in contact in a fluid state and that the passage from the crystalline to the amorphous rocks is a gradual one.

It is manifest that, in the case of these comparatively recent and superficial rocks, the crystallization has been governed by the chemical composition, for the glassy and crystalline masses, while of different composition, have been subjected to physical conditions which were nearly identical. It cannot be doubted that there are many cases in which the differences in structure of massive rocks are referable to chemical variations which are perhaps numerically small. Even in the lavas it is not an infrequent thing to find rounded masses which differ greatly in mineralogical composition from the surrounding mass, and yet these have been subjected to exactly the same physical conditions as the material in which they are embedded. Even, therefore, if no chemical difference known to be significant could be discovered, it would inevitably follow that such a difference nevertheless existed, for variations in texture must be due to variations either in composition or in the physical conditions to which the several masses have been subjected. A few tenths of 1 per cent. of carbon in iron changes its fusibility and texture enormously and trifling quantities of silica or alumina cause immense variation in the fusibility of the normal bisilicate, iron blast-furnace slag. It is well known that when furnace men desire a slag which fuses less readily than this they do not dare to add either alumina or silica, because either raises the melting point so rapidly. Lavas, which are natural slags, must be affected in a similar way by these or by other substances, such as titanium.

Granitoid and porphyritic texture.—While the obsidians of Clear Lake and of the Rossberg have evidently remained amorphous because of their peculiar chemical composition, it by no means follows that had they been cooled sufficiently slowly they might not have crystallized. On the contrary, theory and experiment alike point to the supposition that vitreous substances will always crystallize if they have sufficient opportunity. This is generally admitted.

It is often supposed to be merely an extension of the acknowledged tendency to crystallization to maintain that, if glassy magma is only cooled slowly enough, the result will be a mass which is not merely holocrystalline, but of granitic structure

The difference between typical granular texture and porphyritic texture, however, is a very different matter from the distinction between holocrystalline and glassy structure, a fact which appears to have escaped the attention of many lithologists. The conclusion to be drawn from granular structure is that various minerals crystallized simultaneously, while the larger mineral constituents of porphyries have evidently crystallized in advance of the groundmass surrounding them.

If a substantially homogeneous fluid cools very slowly indeed, the tendency will be for some of the resulting compounds to crystallize in advance of others, and therefore to attain a considerable size and good crystallographic development. This follows both from theory and experiments familiar to every chemist. If the cooling of such fluid is continued at a very slow rate, the interstices must fill with other crystals the growth of which will be interfered with by mutual opposition and the obstruction of the earlier crystals, and the final result will in general be a porphyry. Only in the limiting and just supposable case that the formation of the various final mineral ingredients of a rock liberates heat at exactly the same rate can they all crystallize simultaneously from a substantially fluid mass and produce a granular structure. This inference is strengthened by observations on typical porphyries. It is acknowledged that the larger crystals of good porphyries antedate eruption and have been formed at the enormous pressures which must prevail at the sources of eruption. Had such rocks never been ejected and had they cooled in place at an almost infinitesimal rate, it seems to me that only porphyries could have resulted from the process.

On the other hand, if a heterogeneous but more or less intimately mingled mass is acted upon by chemically active solutions, the reaction yielding heat most rapidly will vary from point to point with the composition. In such a magma a granular structure would naturally result. These are the conditions attending metamorphism, and highly metamorphic rocks are typically granular. Eruptive granular rocks (or those which most geologists believe to be eruptive) frequently, if not always, exhibit the best of evidence that they are by no means of uniform composition, and have therefore never been thoroughly or substantially fluid. Portions of such rocks a few inches apart present differences in structure and mineralogical composition much more marked than those observed in lavas. The differences can be due only to physical or chemical causes, and, since so closely adjoining portions of rocks must have been subjected to the same pressure and must have cooled at the same rate, the only possible conclusion is that the composition changes. These variations are so great and so abrupt as to indicate that the original magma was not substantially fluid, a conclusion long ago reached by Scheerer. A lack of fluidity and of homogeneity thus characterizes magmas which yield granular rocks. This partial fusion cannot be in general the result of pressure, for, while it is certain that some magmas would yield porphyries if cooled at depths of many miles below the surface, granular rocks of analogous composition are known in many cases to overlie sedimentary material later than the Archæan, and cannot have been subjected to pressures so great as those under which the magmas of the corresponding porphyries were substantially fluid.

Conclusions.—It will readily be seen to be a consequence of the above facts that granular rocks having precisely the same composition as porphyries cannot have been so highly heated as the latter and that granular rocks as a group, unless they differ from the porphyries in chemical composition far more than has hitherto been suspected, cannot have been subjected to temperatures on the whole so intense. Differences in texture are in a great proportion of cases certainly due to differences in composition, and, even if one were to find a continuous column of rock porphyritic at the upper end and gradually passing over into a granitoid mass at the lower end, the occurrence would not prove that the difference in texture was due to difference in pressure and rate of cooling, unless the composition were also proved to be identical (an impossibility) or it could be shown that the granular rock had once been a real fluid and not merely a half-fused mass full of solid particles of various kinds. Such instances as the lavas of Clear Lake, the mingled granular and porphyritic diorites of the Comstock, and many exposures of granite show that the homogeneity of any single body of massive rock cannot be taken for granted and that differences of composition lead to differences of texture almost certainly greater than those resulting from the weight and slow conduction of thousands of feet of rock.[1]

ORIGIN OF THE MASSIVE ROCKS.

Importance of the subject.—Granite underlies the Coast Ranges and the Sierra Nevada, and much of the surface of these ranges is flooded with lava. The question of the origin of these rocks is of great importance to a thorough discussion of the ore deposits, for it is from the granite or the lava that the ore is most likely to have been derived. The genesis of the re-

[1] I have discussed this subject more fully in a paper on The texture of massive rocks: Am. Jour. Sci., 3d series, vol. 33, 1887, p. 50. Prof. A. Lagorio has published a very valuable memoir on the nature of glass base and on the process of crystallization in eruptive rocks (Tschermaks mineral. Mittheil., vol. 8, 1887, p. 421). This paper reached me after the transmission of this volume. The author carefully considers both the chemical and physical influences affecting the tendency to crystallization. He points out the high alkali contents of the glasses and reaches the conclusion that potassium silicates are the last to solidify. He refers granitoid structure to the sudden consolidation under pressure of supersaturated solutions of several salts. This does not seem to me a satisfactory explanation. Simultaneous supersaturation of a solution of several silicates seems to me improbable, as does also their simultaneous precipitation from supersaturated solution.

agents in which the ore was dissolved previous to its deposition was also, beyond a doubt, closely connected with the origin of the massive rocks.

Hypothesis of sedimentary origin.—As is well known, many geologists suppose not only granite, but all eruptive rocks, to be products of the more or less complete fusion of the sedimentary strata. On this supposition there would be more or less organic matter or carbon distributed throughout all rocks, and this material would exercise a most important influence on subterranean chemical reactions. While the writers referred to maintain that the massive rocks, without exception, have passed through the sedimentary state, all are agreed that the material of which they are composed must have originally formed a portion of the primeval massive crust of the globe. Most of them are of the opinion that these primeval rocks are so deeply buried beneath their own accumulated waste as to be totally inaccessible and that we know nothing of their character. The opinion here sketched in its leading features is an old one, and, though a large number of leading geologists dissent from it, it has found many able defenders. These seem to me to have overlooked some objections and to have generalized too broadly from certain analogies. It is difficult to understand how on a globe continually affected by upheaval and subsidence the rocks underlying the sedimentary material can ever be entirely buried. It is equally difficult to imagine any means by which the primeval rocks can have been reduced to a clastic state at the enormous depth called for by the hypothesis, a depth of at least twenty miles from the surface.

Primeval conditions.—Geologists and physicists are substantially agreed that the earth was once an intensely heated, plastic or fluid spheroid. This I will assume to be true. When water began to condense on the cooling globe there were of course no sediments. Even as they first solidified the rocks cannot have been absolutely level, so that some portions of the surface were more exposed than others. For the sake of simplicity in reasoning, one may first consider what would have happened after the first oceans formed, had there been no such thing as upheaval and subsidence. It is clear that all the more elevated portions of the original surface of the globe would have been cut down by erosive processes and that the entire globe would have been eventually covered by a shallow ocean, the bottom of which would have been in general a sedimented area. In certain localities one may suppose that oceanic currents might have cut through this stratum of sediment and eroded the underlying primeval rocks to some extent, but it is certain that action of this description would soon find a limit, and that thereafter no sensible mechanical action would be exerted on the primeval rocks. Consequently, the quantity of sediment could never increase perceptibly beyond a certain fixed and very moderate limit.

Effect of upheavals.—If upheaval were now supposed to be introduced into terrestrial economy, portions of the universal sedimented area would be raised into continents and would undergo erosion. The stratum of sediment having been removed, the primeval rock would again be exposed and its degradation would increase the total amount of sedimentary material.

If upheaval were confined to certain areas and were a continuous process, while corresponding subsidence took place in other and distinct areas, primeval rocks would continue to be exposed in continental regions, at least for a very long time. If upheaval and subsidence were to alternate in the same areas, but if in certain regions the upheavals were on the whole somewhat in excess of the subsidences, primeval rocks would appear at the surface of these areas from time to time and the total quantity of sediment on the globe would at these times receive accessions.

Upheavals and subsidences could alternate and balance one another on each portion of the globe only if the influences tending to produce these movements were everywhere exactly balanced. The mere fact that the poles receive less heat than the equatorial regions establishes a difference of physical conditions on various portions of the earth, which certainly influences erosion and cannot but affect changes of level. However complex and remote the connection may be between upheaval and evaporation, some relation certainly subsists between them, and it is not possible that on a globe like ours there should not be a tendency to a greater prevalence of uplifts in some regions than in others.

Bearing of Dana's continental theory.—It is clear that, if Professor Dana's theory of the permanence of continental areas is correct, it substantiates the conclusion drawn above, that there are areas in which the tendency to upheaval on the whole exceeds the tendency to subsidence. There is much evidence in favor of Professor Dana's theory, though some geologists do not accept it. If this theory were absolutely disproved, it would still be impossible to suppose that upheaval and subsidence everywhere exactly balance each other in the long run. If continents once existed where the great oceans now lie, a perfect history of the earth would show that there were continents in some parts of the world through larger portions of geological time than in other regions. In regions where the total erosion has exceeded the total sedimentation, the original crust must almost certainly be exposed.

Bearing of principle of hydrostatic equilibrium.— Nothing in geology is more certain than that the earth is very nearly in a condition of hydrostatic equilibrium,[1] and it is the maintenance of this equilibrium which necessitates upheaval and subsidence. This is perfectly evident if the interior of the earth is fluid. It is also true if the earth is solid to the center and as rigid as steel or glass; for a mass as large as the earth of either of these substances could not maintain a shape diverging considerably from a form of fluid equilibrium for any length of time. Even masses of metal of a few tons (e. g., metallic mirrors for astronomical purposes) undergo deformations by their own weight. So also will a slab of marble supported at its extremities, and, in short, the flow of solids in general is a well recognized fact.[2] Now, if the earth is a solid, highly viscous mass, as Thomson and Darwin have concluded, the effect of the subsidence of, say, a sedimented oceanic area must be felt to the center of the earth, and the earth from the center to the surface must partake in an upheaval. If, on the other hand, the globe consists of a solid shell, which is growing thicker, and a fluid ball upon which the shell floats, the effect of the subsidence of a given area must be to depress the fluid magma underlying this area and to raise some other column of the fluid under eroded regions. Even in this case, then, at least the superficial portion of the fluid ball partakes in the movement attending upheaval and subsidence.

[1] Babbage, I believe, was the first to point out this now familiar fact.

[2] In discussing the question of the solidity of the earth, geologists seem sometimes to forget that time enters into the conception of viscosity. The earth may be as rigid as steel with reference to forces which rapidly change their directions like those exerted by the sun and moon, but as plastic as putty to much smaller stresses acting continuously through long periods of time in a single direction. The rigidity of the earth claimed for it by physicists is not inconsistent with the flexure of strata. So a stick of sealing-wax may be slowly contorted by its own weight, but a smart blow will break it like glass.

Consequent effects of upheaval.—Granting, as one inevitably must, that there are areas over which there is a tendency to the prevalence of upheavals over subsidences, the layer of a supposed fluid interior of the globe which congealed to-day on the under surface of the crust in such areas must rise gradually or intermittently and will be exposed to the air at some remote future period. Or if the globe is a viscous solid, the plastic mass beneath the lowest sediments in areas of predominant upheaval must be rising toward the surface. In either case it would appear from the above that the exposure at the surface of the earth of material upon which no ray of light has ever fallen since the outer layer of the earth congealed must be of daily occurrence.

Logical consequences of sedimentary hypothesis.—The supposition that all the material now exposed to view has passed through the sedimentary condition seems to be conceivable only in one way. It implies the hypothesis that upheaval and subsidence are substantially superficial phenomena, in which the interior of the earth has no part. It supposes that the sediments which subside, off a coast perhaps, afterwards flow laterally and again ascend to the surface at some other point, perhaps in a fluid or plastic state, as lava or granite. This is a condition of things which cannot always have existed. The primeval massive rocks must evidently have been exposed until the entire quantity of material which has ever been brought into the form of sediment was eroded from their surfaces, and, during that period, the interior of the earth must have partaken in the movements of upheaval and subsidence. The greater the quantity of matter which is assumed to have been at some time sedimentary, the longer must the exposure of primeval massive rocks have continued and the more difficult does it become to understand how the interior can ever have ceased to be affected by upheaval and subsidence. The geologists who take this view are compelled to assume an enormous thickness for sedimentary material, and they must consequently also suppose that primitive rocks have been exposed during an enormous period. The fact appears to be, however, that the supposed failure of the earth's interior, say beneath a mean depth of twenty miles, to partake in the movements of upheaval and subsidence is totally inexplicable on mechanical principles. Some geologists have hotly assailed physicists for maintaining that no great part of the earth can be fluid. The hypothesis that only a superficial layer of the globe is affected by upheaval and subsidence appears to me to imply that beneath this thin shell the earth is not the highly viscous solid of Sir William Thomson, but a body of absolute, ideal, and impossible rigidity, for only then could it fail to share in the deformation of the surface.

The problem viewed as one of erosion.—The average thickness of the sedimentary rocks is in my opinion often greatly exaggerated. It is true that if the greatest thicknesses of the formations are added they form an enormous total; but we all know that sediments are thickest near shore lines and disappear altogether at a distance from the shore. According to those authorities who maintain that even the igneous rocks are fused sediments, of course the later sedimentary rocks are composed of the same material which entered into earlier strata. That this is to a large extent the case is evident. Clearly, however, it must also have been the case to some extent from the date of the first upheaval after oceans formed on the surface of the globe. As time went on the exposed areas of the primitive rocks must have decreased while a larger and larger proportion of freshly formed rocks was produced at the expense of the older beds. After a certain time the additions to the total amount of detrital material in a given period, say one thousand years, would be very small, and from that time onward the quantity of detrital material would remain nearly constant. Now, if one supposes the average thickness of sedimentary rocks at some past epoch to have been only one mile, it is evident that only a minute proportion of any land area similar to the present continents, or even of much bolder configuration than these, could be occupied by exposed primeval rocks.[1] If an average thickness of one mile of sedimentary material would reduce the area of primitive rocks to a very small one, how is it possible to account for the formation of twenty times this quantity of detritus? I do not think it can be done.

Character of the process of degradation.—The hypothesis that this almost incredible quantity of detrital material exists, as applied by advocates of the sedimentary origin of massive rocks, involves the assumption that degradation

[1] Gannett's estimate of the mean elevation of the United States, excluding Alaska, is 2,600 feet, say half a mile. Leipoldt's estimate for Europe is 297 meters, or 975 feet, say a sixth of a mile.

of primitive rocks came to a complete close. The last exposed primitive rocks must have subsided and have been buried under sediments formed from pre-existing strata, and this subsidence must have exceeded in amount the sum of all the upheavals to which they have since been subjected. This seems to me a very artificial hypothesis, quite out of harmony with those theories which have been found to accord best with other geological facts. It is seldom that we find in nature abruptly arrested processes, such as this is supposed to be, excepting where these are reversible, which this is not. It is more natural to suppose that the area of primitive rocks diminished progressively without ever being completely or irrevocably buried. Thus, in the second million of years after oceans came into existence, one may imagine half as much fresh detritus to have formed as in the first million years; in the third such period half as much as in the second, and so on to the present day. Had this been the actual case, the total amount of sediment at the end of an infinite time would differ infinitely little from twice the quantity of sedimentary material at the end of the first million years, and infinitesimal areas of primeval rocks would still remain exposed even after the process had continued for an infinite time. In using this numerical illustration I do not of course intend to imply that the particular numbers selected are in themselves probable. The length of the successive periods, in each of which the total quantity of fresh detritus derived from the primeval massive rocks was half that similarly produced in the preceding period, may have varied regularly or irregularly. But I do maintain that neither theory nor observation affords any ground for the hypothesis that, during some one period in the earth's history, the entire area of primeval rocks was obliterated, never to reappear. If I am right in doing so, it is improbable that the primeval rocks have been or ever will be entirely concealed from view at all points on the earth's surface during any considerable time. In other words, contemplation of the process of erosion leads to the same result as was reached by considering the mechanism of upheaval.

Relations of granite.—The observations which are usually cited in support of the sedimentary origin of lavas depend upon the relation of granites to other rocks. That granites are sometimes so connected with crystalline schists as to lead to the belief that they pass over into one another is certain. It is also maintained by many geologists (erroneously, as I believe) that cases occur in which a series of transitions exists from granite to glassy lavas. If both these propositions were correct, it would follow that a transformation of sediments into lavas would be possible under certain conditions, but it would not follow that this is the usual history of lavas or even that it is the history of a single lava. Neither does it follow that because some granites are metamorphosed sediments all granites are of this class.

Possible character of primeval rocks.—The oldest sedimentary rocks compose the Archæan wholly or in part. These rocks are also much more uniform in composition than later stratified rocks. They must have been derived in great part from the primeval rocks, which therefore possessed the same mean composition as the schists. This composition is substantially identical with that of granite. Hence, a rock chemically similar to granite formed the primeval surface. This rock must also have formed at high temperatures, very slowly, and under great pressure. It must inevitably have been chiefly crystalline, and all analogy and experiment lead to the belief that it can have contained no glass. It must have been a holocrystalline porphyry or a granular rock. The atmosphere previous to the solidification of the surface of the globe must have contained at least as much water as the ocean now holds, as well as most of the carbon now present in limestones, coal beds, etc. The pressure of this atmosphere must have been at least three or four thousand pounds per square inch and the boiling point of water must have been correspondingly high. When, or soon after, the temperature at the surface sank to the critical point of water (580° C., Mendelejeff), and therefore while the surface was still red-hot, water must have condensed upon it. Judging from what is known experimentally of igneo-aqueous fusion, conditions more favorable to this process could not be imagined. Now there is much reason to suppose that granite has been produced by igneo-aqueous fusion. It is therefore in the highest degree probable that the terrestrial surface when the earth first ceased to glow was granite, very probably accompanied to some extent by allied plagio clastic rocks. It is far from impossible that portions of it may have had a gneissoid structure.

The foregoing paragraph contains no novel statement. Scrope,[1] in 1825; MacCulloch,[2] in 1831; and Élie de Beaumont,[3] in 1847, all maintained that the primeval rock from which the strata are derived must have been granitic. In 1859 Mr. Daubrée[4] entered more fully into the physical theory of the formation of the primitive rocks. Taking as a basis Humboldt's estimate of the mean depth of the ocean (3,500 meters), he calculated that the barometric pressure of the sea water alone in the form of vapor would amount to almost exactly two hundred and fifty atmospheres, or say 3,700 pounds per square inch. Later estimates of the area and depth of the sea diminish this figure somewhat, but only to the extent of about a hundred pounds.[5] When the temperature of the earth was too high to permit of the condensation of water, this pressure was further augmented by other vapors and gases. The purely igneous rocks formed prior to the condensation of any water, as Daubrée infers, must have been changed by the action of the water first precipitated at very high temperatures and pressures into a mass of crystallized minerals, exactly as in his own experiments in sealed tubes crystals were developed from amorphous materials. Inquiring whether the earliest aqueous precipitation corresponds to the period of the formation of granite, he replies that we cannot affirm this in an absolute manner, but may presume it. This presumption of Mr. Daubrée, previously indicated by others on less satisfactory grounds, seems to me to gain greatly in force by the reasons which I have adduced above. My argument shows it utterly improbable that the rocks which antedate the formation of considerable seas should even now be everywhere concealed, while it is well known that the lowest visible rocks the world over are granitic. In 1879, again, Mr. R. Mallet[6] speculated upon the character of the earliest seas. He

[1] Considerations on Volcanoes Leading to the Establishment of a New Theory of the Earth, quoted by Dr. Hunt, Origin of Crystalline Rocks, sec. 17.

[2] System of Geology, vol. 2, p. 88. "That very granite," he adds, "may be visible; but we cannot as yet distinguish it from the many successive ones which have acted in the elevation of the strata."

[3] Bull. Soc. géologique France, 2d series, vol. 4, pp. 1321 et seq. He regards granite as formed by igneo-aqueous fusion and speaks (p. 1327) of "the first granitic crust of the terrestrial globe."

[4] Études et expér. synth. sur le métam: Ann. des mines, 5th series, vol. 16, p. 471.

[5] Dr. Krümmel's revision of the question of the total quantity of water in the ocean (extract from a note to the Göttingen Academy, Nature, vol. 19, 1879, p. 348) leads to about 3,584 pounds per square inch.

[6] Quart. Jour. Geol. Soc. London, vol. 36, 1880, p. 112.

deduced the conditions as Daubrée had done and pointed out the bearing of the critical point of water. But the chief application which he makes of the results is in the endeavor to account for the great quantity of detrital material in existence. He points out that the degradation of elevations would be more rapidly effected by heated waters than by cold ones, and infers, as I understand him, that hot waters would also ultimately yield a greater quantity of detritus than cold waters. The latter of these propositions does not appear to me to follow from the former or from Mr. Mallet's arguments. It would seem to me certain that the maximum accumulation of clastic material would be more rapidly approached were the water hot, but that this maximum would be a similar quantity whether the water were hot or cold.

It is perhaps unnecessary to point out that if the purely igneous superficial layer of the earth's mass was converted into a crystalline rock resembling granite at enormous pressures and at temperatures approximating to 500° C. the quantity of water in the fluid state which was instrumental in the transformation must have been comparatively small, for the great pressure was due to the fact that most of the water formed a gaseous constituent of the atmosphere. This accords with the views of Scheerer and subsequent investigators, that no great quantity of water is needed to render aqueo-igneous fusion possible. Sedimentation must, therefore, at this period have been an extremely subordinate phenomenon.[1]

There is thus every reason to suppose that the original massive rocks were granitic in composition and in texture. The fact that eruptive granites were ejected in later times only shows that at certain depths beneath the surface the conditions of heat, pressure, and moisture which once prevailed upon the surface were repeated. That detritus from the original granite under great pressure and at high temperature may also sometimes be metamorphosed into a material similar to the original granite is cer-

[1] As the temperature sank still further and oceans began to accumulate, the water must have been highly charged with mineral matter. It is to this later period that Dr. Hunt, who accepts Daubrée's exposition of the action of the earliest condensed water, ascribes the formation of the Archæan schists as chemical precipitates. In the text I am not concerned with the formation of the crystalline schists, but I wish to state that it appears to me impossible to suppose no crystalline precipitates to have been deposited. I do not doubt that such were formed in a manner nearly or quite identical with that which Dr. Hunt maintains. As appears in a preceding chapter, however, I cannot agree with this brilliant thinker in ascribing nearly all crystalline stratified rocks to this process, nor can I believe that anything like the entire Archæan has been thus produced.

tainly not surprising. Neither of these facts even tends to prove that the primeval rocks were not granitic or that they are now nowhere exposed. How primeval granite is to be discriminated in all cases and with certainty from that which was erupted in subsequent geological ages or from highly metamorphosed rocks is another question, to which a definite answer cannot yet be given. At present general evidence only is attainable.

California granites.—Granite underlies the greater part of the State of California. This granite must be exposed to very different depths. The Sierra has been undergoing erosion ever since the early Paleozoic, and on the lower portions of its eastern flanks are metamorphosed strata not younger than the early Mesozoic. At the McCloud River the Carboniferous also appears to rest on granite. The granite of the Coast Ranges has been covered by sediments a large part of the time which has elapsed since the Paleozoic and has been far less exposed to erosion than that of the Sierra; yet granites from the various localities are almost indistinguishable. Though there may be granites within this area of different origins and ages, I can see no reason to suppose that the great underlying mass is not substantially one It is probably continuous with the granitic areas of Idaho and Arizona and is too extensive to be regarded as an eruption or a series of eruptions. Were it metamorphic, evidences of the fact would probably be frequent, whereas, so far as is known, there are very few localities in the State that suggest this derivation. While both metamorphic and eruptive granites will probably be found, the main mass must be at least as old as the Archæan, and, while I do not assert positively that it is primitive granite, this appears to me far more probable than any other hypothesis. As was pointed out above, the formation of more or less gneissoid rock probably accompanied that of the primeval granite and the presence of such material in a granitic area does not prove that it is not primeval.[1]

California lavas.—The lavas have unquestionably come up through the granite and are of infragranitic origin. There is no direct evidence what-

[1] A portion of the primeval crystalline rocks, though perhaps a small one, was probably plagioclastic. It would be difficult otherwise to account for the quantity of soda in the clastic rocks. If Professor Lagorio is correct, as he seems to me to be, in asserting that sodium silicates separate from magmas more readily than potassium compounds, it would seem that orthoclase should have predominated in the outer crust of the earth, or in the primeval granitic rocks, and that plagioclase should have predominated in the infragranitic rocks, or in the lavas. This, of course, accords with observation.

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ever that the material of which they are composed has ever yet been deposited from water, and, on the contrary, there are weighty reasons for supposing that they have ascended through primeval rocks. The absence of hydrocarbons in a part of volcanic emanations is also, as Bunsen showed, a very strong argument against the supposition that any organic matter (or any sedimentary rocks of later date than the origin of life) exists at the sources of volcanic activity. An argument in favor of the sedimentary origin of lavas is often drawn from the supposed great variations in the composition of these rocks. This seems at first sight to be justified by the literature of lithology, but those who have specially occupied themselves with that branch of geology are well aware that the uniformity of eruptive porphyries is astonishing and that typical rocks are the rule the world over. In geological reports hundreds of square miles of a normal lava will be described in a paragraph, while a few square yards of some abnormal, highly exceptional variety of the rock will require pages of description and discussion. The literature of the subject is thus apt to convey a false impression.

Conclusions.—The arguments presented as to the origin of the massive rocks of California may be briefly summarized. If the mechanism of upheaval and subsidence is considered, it seems impossible that rocks from beneath the accumulation of clastic material should not often be brought to the surface. If the mechanism of erosion is considered, it appears most improbable that, through degradation in any combination with subsidence, the entire area of primeval rocks should ever disappear for any length of time. The deepest-seated rocks known are granitic. If the conditions attending the earliest precipitation of water on the earth's surface be considered, these conditions seem to be those known experimentally to favor the production of crystalline minerals and which are believed on good grounds to be those attending the formation of granite. The evidence in California is all in favor of the hypothesis that the main mass of the underlying granite is primeval, or that it antedates the formation of extensive oceans, and that it is free from organic matter. The lavas come from beneath the granite and are, a fortiori, thoroughly Azoic.

CHAPTER V.

STRUCTURAL AND HISTORICAL GEOLOGY OF THE QUICKSILVER BELT.[1]

General results.—No attempt has been made in the present investigation thoroughly to elaborate the general geology of the entire area in which the quicksilver deposits occur, but, in addition to what has been made known by other geologists on this subject, it was found indispensable for a proper discussion of the quicksilver deposits further to elucidate some of the more important structural and historical relations of the rocks inclosing them. Such facts bearing upon the general geology of these ore deposits as are now known will be presented in this chapter in chronological arrangement Their bearing will perhaps be clearer if the reader is at once put in possession of some of the main conclusions reached, which are as follows:

The Coast Ranges experienced a great upheaval (the first traced) probably about the close of the Neocomian, this being the same disturb-

[1] Messrs. Antisell, Blake, and Newberry contributed valuable papers, containing information on the geology of the Coast Ranges, to the Pacific Railroad reports. Under Professor Whitney, Messrs. Brewer, Gabb, King, and others studied this area. Their results are to be found in the well known publications of the California survey. Mr. Jules Marcou has also written on the subject, especially in the Bulletin of the French Geological Society, vol. 2, 1883, p. 407, and the Proceedings of the California Academy of Sciences contain numerous pertinent papers. I have endeavored to make such use of this material as seemed advisable. Dr. C. A. White has co-operated with me in the study of the general geology of the region, his standpoint being that of the paleontologist. The importance of some of the results reached led us to publish a part of them in advance of this memoir. The papers in which these were announced are: On the Mesozoic and Cenozoic Paleontology of California, by C. A. White (Bull. U. S. Geol. Survey No. 15); On New Cretaceous Fossils from California, by C. A. White (Bull. U. S. Geol. Survey No. 22), and Notes on the Stratigraphy of California, by G. F. Becker (Bull. U. S. Geol. Survey No. 19). I have also used facts and arguments adduced by me in a paper entitled "The relations of the mineral belts of the Pacific Slope to the great upheavals" (Am. Jour. Sci., 3d series, vol. 28, 1884, p. 209) and in Statistics and Technology of the Precious Metals, by S. F. Emmons and G. F. Becker, Tenth Census Repts. U. S., vol. 13, Chapter 1. The present chapter also contains much that is new.

ance which added an important portion of the auriferous slates to the Sierra Nevada. The Coast Ranges belong to the same mountain system as the Sierra Nevada. The upheaval mentioned was accompanied or followed by intense metamorphism, the only event of the kind known to have occurred in the history of the Coast Ranges. A great non-conformity exists between the metamorphic rocks and the overlying late Cretaceous strata. The Téjon formation is shown to be Eocene, as it was regarded by Conrad, and it is here shown to be absolutely continuous with the Upper Cretaceous. The ore deposits have an intimate structural connection with the system of fissures along which the upheaval of the ranges took place. So, also, has the distribution of volcanic rocks, the earliest of which probably date from the Pliocene. The ore deposits appear to be contemporaneous with and later than the eruptions and have a more or less intimate chemical relation to them.

Formations found in California.—The reader may perhaps be glad to be reminded of the formations which have hitherto been recognized in California. It is not absolutely certain that the Archæan occurs in this State, but, as I pointed out some years since, the unquestionable occurrence of the Archæan in Arizona, together with the similarity of the rocks of southeastern California to those of the adjoining territory, makes it highly probable that San Bernardino County is largely Archæan.[1] If so, this formation may enter into the composition of the southern Sierra. The geologists of the fortieth parallel exploration also found the Archæan in central Nevada in its normal relation to the Paleozoic and determined areas close up to the California line in this latitude as Archæan. Their investigations did not extend into California, but they showed that during the Paleozoic a continental area existed west of longitude 117° 30′, latitude 40°, and it appears certain that this area must have embraced at least a portion of the great Sierra, which is thus probably composed to a considerable extent of Archæan schists. The Carboniferous was first recognized by Dr. Trask in 1854[2] on the McCloud River. Professor Whitney's party found it near

[1] Tenth Census Repts. U. S., vol. 13, p. 47.

[2] Report on the Geology of the Coast Mountains etc., by Dr. John B. Trask, Senate [of California] Doc. No. 14, 1855, p. 50.

Pence's ranch, in Butte County, and inferred from similarity of position and lithological character that other rocks on the western flank of the Sierra may also be of this age. No Carboniferous fossils are known to occur in the Coast Ranges.

Fossiliferous beds were found by Professor Whitney's party at Genessee Valley, in Plumas County, which Mr. Meek determined as Triassic. The material upon which this determination rests appears, however, to be somewhat meager and unsatisfactory. A similar fauna has been found at a few points in Nevada,[1] but not elsewhere in California. Near the southern end of the gold belt of California fossils were found on the Mariposa estate in 1864[2] They were figured and described by Meek.[3] The most important shell he determined as *Aucella Erringtonii*, the specific name being given in honor of a resident who drew attention to the occurrence of the fossil. Meek observes:[4]

> As this genus is, so far as known, entirely confined to the Jurassic rocks, while an *Amussium* like shell from the same slates is closely allied to a Jurassic species, and the genus *Belemnites* is not generally regarded as dating back beyond the commencement of the Jurassic period, I can scarcely entertain a doubt that these gold-bearing slates really belong to that epoch, and probably to some of its lower members, at which horizon most of the known European species of *Aucella* are said to occur.

The same species of *Aucella* was found by Professor Whitney's party, after the publication of Meek's determination, at a number of localities on the gold belt, and ammonites were also discovered. It will be observed that Meek laid the chief weight in his determination of the age of these beds on the occurrence of *Aucella.*

Previous to the discovery of the fossil fauna of the Mariposa estate fossils had been found at many points on the Coast Ranges and along the foot-hills of the Sierra, which were described by Mr. Gabb as Cretaceous.[5] Many more were added later, and Mr. Gabb ultimately divided the Cretaceous of California into the Shasta, Chico, Martinez, and Téjon groups, the last being the highest.

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[1] King: U. S. Geol. Expl. 40th Parallel, vol. 1, Systematic Geology.

[2] The honor of the first discovery of these fossils was somewhat warmly contested. See Whitney's Auriferous Gravels and Proc. California Acad. Nat. Sci.; also, Mr. Clarence King's Mountaineering in the Sierras.

[3] Geol. Survey California, Geology, vol. 1, p. 477.

[4] Ibid., p. 478.

[5] Geol. Survey California, Palæontology, vol. 1.

The following paragraphs, copied from Professor Whitney's preface to Geol. Survey California, Palæontology, vol. 2, pages xiii and xiv, give a concise account of these formations in accordance with Mr. Gabb's later views and as they were finally adopted by the State survey:

(1) The Téjon group, the most modern member, the Division B of Paleontology, Vol. I, is peculiar to California. It is found most extensively developed in the vicinity of Fort Téjon and about Martinez. From the latter locality it forms an almost continuous belt in the Coast Ranges to Marsh's, 15 miles east of Monte Diablo, where it sinks under the San Joaquin plain. It was also discovered by the different members of the survey at various points on the eastern face of the same range as far south as New Idria, and, in the summer of 1866, by Mr. Gabb, in Mendocino County, near Round Valley, the latter locality being the most northern point at which it is as yet known. It is the only coal-producing formation in California.

This group contains a large and highly characteristic series of fossils, the larger part peculiar to itself, while a considerable percentage is found extending below into the next group, and several species still further down into the Chico group. Mr. Gabb considers it as the probable equivalent of the Maestricht beds of Europe.

(2) The Martinez group is proposed provisionally, to include a series of beds of small geographical extent found at Martinez and on the northern flank of Monte Diablo. It may eventually prove to be worthy of ranking only as a subdivision of the Chico group.

(3) The Chico group is one of the most extensive and important members of the Pacific Coast Cretaceous. Its exact relations with the formation in Europe have not yet been fully determined, though it is on the horizon of either the Upper or Lower Chalk, and may probably prove to be the equivalent of both. It is extensively represented in Shasta and Butte Counties and in the foot-hills of the Sierra Nevada as far south as Folsom, occurring also on the eastern face of the Coast Ranges bordering the Sacramento Valley at Martinez, and again in Oristimba Cañon, in Stanislaus County. It includes all of the known Cretaceous of Oregon and of the extreme northern portion of California, and is the coal-bearing formation of Vancouver's Island.

(4) The Shasta group is a provisional name, proposed to include a series of beds of different ages, but which, from our imperfect knowledge of the subject, cannot yet be separated; it includes all below the Chico group. It contains fossils, seemingly representing ages from the Gault to the Neocomian inclusive, and is found principally in the mountains west and northwest of the Sacramento Valley. Two or three of its characteristic fossils have been found in the vicinity of Monte Diablo, and one of the same species has been sent from Washington Territory, east of Puget Sound. Few or none of its fossils are known to extend upwards into the Chico group.[1]

To these I have added another series of Cretaceous strata lying above the Shasta, and, according to the paleontological evidence, below the

[1] Mr. Gabb's work on the fossils of California is mainly contained in Geol. Survey California, Paleontology, vols. 1 and 2; but the following papers may be referred to for other discussions which relate to his work in that State: Am. Jour. Conchol., vol. 2, pp. 87–92; ibid., vol. 5, pp. 5–18; Am. Jour. Sci., 2d series, vol. 44, 1867, pp. 226–229; Proc. California Acad. Nat. Sci., vol. 3, pp. 301–306; ibid., vol. 5, pp. 7–8.

Chico. This will be called the Wallala series. Above the Téjon is found unquestionable Miocene, and resting unconformably upon the Miocene the Pliocene is met with in a few localities. To the Pliocene also belong the fresh-water beds of Cache Lake, which will be described later in this chapter. Between these last eras occurred an important upheaval recognized by Professor Whitney, and to which he ascribed the formation of the Coast Ranges, while a great uplift of the Sierra and of the Basin ranges he attributed, in accordance with the evidence before him, to a Post-Jurassic upheaval.

Nomenclature here adopted.—To facilitate reference to the various groups of strata Dr. White and I have agreed to give local names to several of the California occurrences. The fossiliferous beds of the Mariposa estate will be known as the Mariposa beds; the groups especially characterized by the presence of *Aucella* in the Coast Ranges will be referred to as the Knoxville series, because they are typically developed and have been specially studied in the neighborhood of the mining town of that name; the rocks from which Messrs. Gabb and Whitney obtained a large fauna, considered by them as probably equivalent to the Gault, will be called the Horsetown beds; and a series which occurs along the coast north of the Russian River will be denominated the Wallala beds. Meek's Jurassic on the western slope of the Sierra Nevada is thus equivalent to the Mariposa beds. The Shasta group of Messrs. Gabb and Whitney is here divided into two series, recognized by them as distinct, the Knoxville and the Horsetown. The designations Chico and Téjon are retained, but the latter is considered Eocene. The Martinez is regarded as a portion of the Chico series.

Granite.—As has been shown in the preceding chapters, there is much evidence that granite underlies the entire quicksilver belt, and indeed the whole of central California. South of San Francisco it is frequently exposed in positions where erosion has been greatest, viz, along the axial lines of ranges and at the sea-coast; it is also exposed at a few points somewhat north of San Francisco, on the coast; and the Farallone Islands, 20 miles off the Golden Gate, are granite. To the north of the Bay of San Francisco, away from the coast, granite is not known to occur in place for about one hundred and twenty-five miles, but this is probably for want of exploration, since in some parts of Cache Creek, for example, granite predominates among the stream pebbles.[1] According to Professor Whitney[2] the highest portions of the Trinity or Shasta Mountains are granite. The Wallala beds, too, though far from any known outcrop of granite, are in large part granitic conglomerates and the sandstones of the entire quicksilver belt are arcose. I have nowhere met granites along the quicksilver belt which appeared to me to be intrusive.

Gavilan limestone.—In the Gavilan Range, some sixty miles south of the Bay of San Francisco, the lowest sedimentary formation encountered is in part limestone, which at the points examined is extraordinarily crystalline, oftentimes consisting of a loosely adherent mass of imperfect calcite crystals. Associated with it are rocks of the Archæan gneiss type. This occurrence has been very little investigated and nothing further is known of its age. It is possible that it is a member of the Knoxville series much more metamorphosed than usual, but it appears to me more probable that it is a remnant of some older formation which has perhaps undergone repeated metamorphism. For the purposes of this memoir an exact determination of its character is not important.

Before passing to a general characterization of the Knoxville beds, which will be found to be the most important and most interesting in the State of California, it seems best to present the somewhat complex evidence obtained as to the distribution and affiliations of this series; indeed, it appears hardly practicable to describe it without discussing its chemical and structural relations, unless the results which I have reached as to these are taken for granted.

Metamorphism in the Coast Ranges.—Throughout the Coast Ranges of California there occur large, irregular areas in a somewhat peculiar condition of metamorphism, which has been discussed in a preceding chapter. Its prominent macroscopical characteristics are the predominance of recrystallization, serpentinization, and silicification.

[1] A very large part of the country in this neighborhood is covered with thickets (chaparral) which are practically impenetrable.

[2] Geol. Survey California, Geology, vol. 1, p. 323.

The dynamical action which accompanied or preceded this metamorphism was of a very violent character, so that in the greater proportion of cases it is a manifest impossibility to construct sections of the metamorphic areas, no stratum being continuous for more than a few feet. Sharp contortion and plication are also common, but where they occur it is usually apparent that the flexures have been accomplished not in the main by plastic deformation, but by comminution of the entire mass, the residual fragments often averaging less than a quarter of an inch in diameter. In the accompanying distortion these particles have retained approximately their original relative positions and have subsequently been recemented, chiefly by silica. The minute, polyhedral rock fragments, however, have undergone no visible distortion. These occurrences coincide in a remarkable manner with the results of Mr. Daubrée's experiments on the fracture of various substances by torsion and pressure.[1] As is shown in Chapter III, this probably indicates that, at the time of upheaval, these strata were buried at a depth of not more than a few thousand feet below the surface.

The most striking instances of such fracturing are met with among thin-bedded rocks, either sandstones or sandy shales, and such are remarkably frequent in this series; indeed, they might be said to be characteristic of it.[2] They are occasionally met with in other formations, and it would be strange indeed if the conditions favorable to thin bedding had prevailed along the Coast Ranges only during a single era. As a rule, however, the rocks which rest upon the metamorphic series are thick-bedded, rather coarse and uniform sandstones.

Besides this series of metamorphic rocks there are others of different age in the Coast Ranges to which the term metamorphic might not improperly be applied. These will be described a little later.

Age of the principal metamorphic rocks.—With the possible exception of the limestone mentioned above, this metamorphic series is stratigraphically the lowest in the Coast Ranges and appears to rest upon the granite. It forms the crests of many mountain ranges and occupies the whole surface in some of the more mountainous regions. Detailed studies of the structure show

[1] Bull. Soc. géologique France, 3d series, vol. 7, 1878-'79, p. 108.

[2] The peculiarity of these thin-bedded, plicated, metamorphic rocks was observed by Professor Whitney.

that as a rule the hills of metamorphic rock are synclinal,[1] and consequently they must have undergone great erosion. The elevations of later age do not exhibit this peculiarity.

Rocks of the metamorphic series ~~often~~ pass over into unaltered beds in the Coast Ranges under such circumstances as to leave no doubt that they are of the same age; but unfortunately the unchanged strata seldom contain determinable fossils and only a small number of occurrences is known in which the age can be satisfactorily established by direct evidence. In addition to these cases, however, there is a considerable amount of tolerably satisfactory indirect evidence available, when all the circumstances are taken into consideration. The neighborhood of Knoxville affords an excellent opportunity for the study of the metamorphic rocks. The section across the north fork of Davis Creek, a little north of the Reed mine, a short distance from Knoxville, shows that the ravine occupies an eroded anticlinal, of which the western portion is highly metamorphic, while the eastern consists in part of highly fossiliferous strata containing *Aucella* of two varieties, with other molluscan remains characteristic of the horizon which in this memoir is called the Knoxville series. The geological map of the district shows that the strike of the unaltered strata throughout is tolerably constant, but that areas of metamorphic and unaltered rocks, the latter nearly all containing a few fossils, are interspersed in the most irregular manner. While the passage from metamorphosed to fresh rock is usually rather sudden, there are also clear cases of transition. The whole structure and the stratigraphical relations are such as to preclude every hypothesis except one, viz, that the metamorphic rock is an alteration product of the same beds which contain *Aucella* and the accompanying fossils.

Close to the Manzanita gold and quicksilver mine on Sulphur Creek, in Colusa County, the metamorphic rocks contain impressions of *Aucella Piochii*, and close by are beds of limestone full of *Rhynchonella Whitneyi*.[2] The metamorphic rocks of this region are serpentinized and silicified, and

[1] Also observed by Professor Whitney: The Auriferous Gravels, Mem. Mus. Comp. Zoöl. Harvard Coll., vol. 6, No. 1, 1880, chap. 1.

[2] These specimens were determined by direct comparison with specimens in the collection of the State survey. The figure given in Geol. Survey California, Palæontology, vol. 2, Pl. XXXIV, is incorrect in important particulars.

the thin-bedded strata show the characteristic contortions accompanied by a fine net-work of veins of silica. At Mt. Diablo, too, there is abundant proof of the Knoxville age of the metamorphic rock. Professor Whitney, writing before Mr. W. M. Gabb had made his final divisions of the California Cretaceous, mentions the occurrences at Mt. Diablo as conclusive of the Cretaceous age of the metamorphic rocks, but without enumerating the associated fossils. From an examination of the fossil localities in Mr. Gabb's work, however, it appears certain that these were *Aucella* etc. An examination which Dr. White and I undertook for the purpose shows that in Bagley Creek, about a mile from the summit, *Aucella* occurs abundantly close to the edge of the metamorphosed area—indeed, in partially metamorphosed strata conformable with those extremely altered and in structural relations to them which very clearly indicated the same age. Mr. Turner subsequently found a series of beds, some of which had escaped transformation and contained *Aucella*, though inclosed on both sides by highly metamorphic strata. At Ætna Springs, in Napa County, near the Ætna and Napa consolidated quicksilver mines, *Aucella* also occurs in the same unmistakable relation to the metamorphic rocks. In the examinations described in this volume, *Aucella* has been detected in immediate connection with the metamorphic beds near the St. John's mine, Solano County, and in the Santa Lucia Range, near San Luis Obispo. Mr. Gabb further mentions an *Aucella* locality below the New Almaden mines. I have not succeeded in finding *Aucella* in this region, which, however, in the neighborhood of the area surveyed, shows only metamorphic rocks exactly similar to those of Mt. Diablo and Knoxville, Miocene rocks lying unconformably upon the metamorphics and volcanics. It appears substantially certain therefore that the *Aucella*-bearing beds which Mr. Gabb detected must have belonged to the metamorphic series. The age of the metamorphic rocks is thus determined at a considerable number of points scattered along the Coast Ranges for a distance of 300 miles, or nearly three-quarters of the entire length of the Coast Range system of mountains. Alcatraz Island, close to San Francisco, consists of metamorphic sandstone and shales not distinguishable from those of San Francisco or of Mt. Diablo. Here Major Elliot discovered an *Inoceramus* not known to occur elsewhere, considered by Mr. Gabb and Dr. White as establishing the Cretaceous age of these rocks, though indecisive of the portion of this formation to which they should be referred. The above comprise all the instances definitely known in which the age of the silicified and serpentinized metamorphic rocks is directly determinable by paleontological evidence. Mr. Gabb also found *Aucella* along Puta Creek, Lake County. This stream runs through a region chiefly occupied by highly metamorphosed rocks, and, were the exact locality known, it would probably furnish another instance of transition.

Besides the rocks referred to above, the Coast Ranges include others which have been subjected to more or less complete alteration. Thus, along the shore of Carmelo Bay, Miocene schists have been locally changed to a cindery mass, as if by the action of heat; but these rocks bear no resemblance to the serpentinized and silicified material just described. More or less complete induration is common, even in the most recent rocks of the coast, and oxidation and impregnations with calcite and gypsum occur abundantly in rocks of all ages. In the Arroyo de la Penitencia, above Alum Rock, near San José, there is also an area of altered Miocene sandstones referred to by Professor Whitney.[1] The rock here is much indurated and is full of veins of calcite. No objection can be made to its description as metamorphic by Professor Whitney; but it is not serpentinized and silicified and does not partake of the characteristics so strongly marked in the highly metamorphosed rocks of the Knoxville group. On the other hand, there are plenty of rocks of this group no more altered than the Miocene of the Arroyo de la Penitencia and some areas still less modified. The Tertiary of the Arroyo has been subjected to influences seemingly identical with those which have affected portions of the Knoxville beds, but not to those which have produced in the older strata the characteristic serpentinization and silicification.

Professor Whitney also refers twice[2] to altered beds in the San Francisquito Pass, which, indeed, is to the south of the Coast Ranges as usually defined. In the first reference he states that "this belt of metamorphic is referred by us to the Cretaceous formation from general analogy rather

[1] Geol. Survey California, Geology, vol. 1, p. 51.

[2] Ibid., p. 195; The Auriferous Gravels: Mem. Mus. Comp. Zoöl. Harvard Coll., vol. 6, No. 1, 1880, p. 19.

than from any direct evidence of fossils." In the second reference they are mentioned as "Miocene rocks turned up on edge and in places so much metamorphosed as to be converted into mica-slate." No statement of the means of determination of the age of these beds accompanies this remark, which, however, occurs in a brief summary of the geology of the Coast Ranges. Whatever the evidence may be upon which the change of reference was made it can have little bearing upon the age of the metamorphics in the central Coast Ranges, nor is serpentinization referred to as forming a part of the phenomena.

So far as is known, therefore, no beds in the Coast Ranges of California younger than the Knoxville group have experienced the peculiar magnesian and siliceous metamorphism so characteristic of these ranges. This fact raises a presumption that the metamorphism was effected prior to the deposition of the rock resting upon the metamorphic series, and this presumption is confirmed by examination of the conglomerates of the later rocks. There rest upon the metamorphic series at different localities Wallala beds, which Dr. White regards as middle Cretaceous; Chico beds, representing the very close of the Cretaceous; and Miocene strata. The fossils of the Wallala series were found in a conglomerate consisting largely of serpentine pebbles, accompanied by siliceous, metamorphic rocks exactly similar to those accompanying the serpentine in the altered rocks of the Knoxville series. At New Idria there is a bed of conglomerate associated with Chico fossils near an extensive metamorphic area. The pebbles are mainly siliceous, as, indeed, is usually the case in conglomerates derived from the metamorphic rock, for the simple reason that serpentine is both easily decomposed and easily abraded. Careful search, however, revealed pebbles in this conglomerate which consisted in part of serpentine, a result confirmed by microscopical examination. The Miocene, too, for instance at New Almaden, contains abundant pebbles manifestly derived from the surrounding metamorphic rock.

No fossils older than the Knoxville group are known to occur in the Coast Ranges and no known fact suggests the existence of older rocks, excepting the character of the limestone and gneissoid rocks of the Gavilan Range already mentioned, for the habitus of the peculiar metamorphic rocks under discussion is remarkably uniform.

Similarity of lithological and physical character may, I think, be given too much weight in geological diagnosis. I cannot conceive, for example, that any degree of similarity between the rocks of California and those of Switzerland should properly be considered as even tending to prove the age of either.[1] I go further, and refuse to regard the metamorphism of the rocks of Butte County as necessarily contemporaneous with that of the strata of Napa County, in spite of external similarity. On the other hand, within properly limited areas, observations show that the same fauna is associated with similar rocks; while, if it were impracticable to draw any conclusions as to age except where the rock is fossiliferous or where absolute continuity with fossiliferous localities uninterrupted by faults could be proved, geological mapping would be impossible. In California great use can be made of resemblances. Thus the Téjon strata of New Idria are mostly heavy-bedded sandstones of a peculiarly light color, which there distinguishes them from the tawny Chico sandstones. Both are fossiliferous there, as also near Mt. Diablo, where, at a distance of 125 miles from New Idria, they preserve the same external characteristics. Similarly, the Knoxville beds of Knoxville and Mt. Diablo are externally indistinguishable, and in their typical development, even when unaltered, very different from most of the later rocks.

Strata older than the Knoxville period may nevertheless be included in the metamorphic series and may have undergone upheaval and metamorphism at the same date. There is also a possibility that older rocks not only exist, but were metamorphosed before the deposition of the Knoxville, so that the metamorphic areas in contact with the Wallala beds on the coast and with the Chico strata at New Idria may conceivably be earlier than the Knoxville. Even this hypothesis, which, in the absence of any evidence tending to establish it, seems rather strained, would have no effect on the principal conclusions drawn in this chapter, unless it could also be

[1] The resemblance between the Miocene sandstones and the Molasse of Switzerland was advanced by Mr. Jules Marcou (loc. cit.) as an evidence of the Tertiary age of the California rocks. That the resemblance exists I can testify from observation. To me it indicates only that the California Miocene and the Molasse were both deposited near the shore of land areas largely composed of Archæan rocks. Mr. Marcou attributes to ignorance of lithology my failure to appreciate it as an indication of age, and he regrets that "a competent person has not been selected for the study of the Tertiaries of California" (American Geological Classification and Nomenclature, 1888, p. 52). I am very sorry that my work produces so bad an impression on this veteran geologist.

maintained that the violent upheaval and metamorphism which followed the Knoxville left the supposed older areas undisturbed. This would conflict with all analogy.

The foregoing facts and the necessary inferences from them appear to justify the statement that the silicified and serpentinized metamorphic rocks of the Coast Ranges include a portion of the Knoxville beds, and do not include any portion either of the Chico or of the Wallala series, while if there were pre-Knoxville rocks within the metamorphic areas they must have undergone at least a fresh disturbance at the time when the Knoxville beds were broken up and metamorphosed.

Non conformity between the Knoxville beds and the Chico.—Had the proof of this non-conformity been a simple matter, it could not have escaped the attention of some one of the able geologists who have worked in the Coast Ranges. The difficulty is in part due to the rarity of fossils in the older groups over a great portion of the area in question, which often leaves the observer without absolute proof of the age of the rocks about him; but complexity of structure is the main obstacle. Few geological phenomena are more striking than a non-conformity where the overlying strata are nearly horizontal, the underlying rocks greatly inclined, and the exposure tolerable. This combination is rare in the Coast Ranges, and no such case is known where the Shasta and Chico beds meet. The Post-Miocene uplift traced by Professor Whitney has folded, faulted, and broken the later Cretaceous and the Tertiary rocks, as well as the earlier strata upon which these were unconformably deposited; so that it is usually far from easy to make out the effects due to the earlier and later disturbances, respectively, and still more difficult to prove that no explanation except that of a non-conformity beneath the Chico will account for the facts. I believe that the structural evidence to be presented clearly establishes this non-conformity, but the proof, though convincing, is less abundant than could be wished. The evidence will first be presented from a purely structural point of view and will then be re-enforced by an independent, paleontological argument.

In the neighborhood of the New Idria mine the metamorphic rocks have been greatly disturbed, while the Chico strata, though tilted at a high angle, are remarkably regular. Owing to the steepness of the contact, however, no exposures showing both series together could be found from which thoroughly satisfactory inferences could be drawn as to the relations of the underlying and overlying rocks. I therefore resorted to a study of the exposures of each separately, for which the region offers unusual facilities. It was found possible to follow single strata of the Chico uninterruptedly for the greater part of a mile, and, by the aid of lithological peculiarities, combined with topographical indications and the strikes observed at the exposures, to recover the croppings with substantial certainty after passing intervals covered with detritus. The contact with the metamorphic rocks was also laid down and numerous dips were observed in the metamorphic area. In order to eliminate the disturbing influence of the irregularities of the topography, the croppings of each of these continuous strata and the contact of the metamorphic were reduced to their intersections with normal planes cutting the surfaces respectively at the mean elevation of their exposures. The results showed that adjoining Chico strata are parallel and thrown into extremely gentle undulations, while the metamorphic area is merely a shattered mass The contact has approximately the same general direction as the Chico beds, but does not entirely coincide with their strike. It is a rough line, but not rougher than one which would represent the vertical section of an ordinary sea-bottom near the coast. The dip of the Chico strata decreases as the distance from the contact increases.

Either this structure represents a non-conformity or else the metamorphism and accompanying disturbances occurred after the deposition of the Chico beds, but ended sharply at a certain line. It might at first sight seem impossible that an area several miles in width should be crumpled and broken quite as thoroughly as a representative area of the Archæan along the eastern coast, the rocks being also for the most part converted into serpentine and chert, and that, nevertheless, both mechanical and chemical action should cease abruptly at a given line. Yet instances, of which the above might pass for a description, actually occur and are perhaps more frequent in the Coast Ranges than elsewhere. All geologists who have visited this region are aware of the very irregular distribution of the metamorphic areas, and it has already been pointed out that the metamorphic rocks pass over into unaltered or very slightly altered Knoxville beds suddenly, though under circumstances which preclude the supposition that the adjoining areas represent different formations. There are, however, significant differences between these occurrences and the conditions at New Idria. The limits of metamorphism in areas consisting of Knoxville beds, however sharp they may be, are exceedingly irregular, the outline being substantially independent of stratification, cutting strata more often than following them and presenting all sorts of convolutions; there are almost invariably also outlying areas of metamorphic rock and included masses of unaltered rock; furthermore, at least here and there, distinct transitions occur between unaltered and metamorphic rock. At New Idria, on the other hand, a section of the contact normal to the surface extends over at least several miles (as far as it was followed) in a tolerably persistent general direction. There are no outlying patches of metamorphic rocks; the included masses of comparatively unaltered rock seem wholly different from the Chico strata above them, and, though there is a considerable alteration of a portion of the overlying mass, this alteration is not of the same character as the magnesian and siliceous metamorphism of the underlying rock; nor could I find any distinct case of transition. Finally, as has already been mentioned, in the Chico conglomerates a part of the pebbles entirely resemble the silicified or jaspery portions of the present metamorphic area, while a few are both macroscopically and microscopically indistinguishable from the serpentinized rocks of Knoxville age

Some further evidence of the relation of the two series was found a few miles to the southeast of New Idria, where a branch of Cantua Creek cuts through a portion of the range. Here the heavy-bedded, tawny Chico sandstones, lying at an angle of about 30°, cap the hills which are intersected by the brook, while in the bed of the stream the thin-bedded, metamorphic strata stand vertically. No actual contact, however, could be found, the interval being covered with detritus.

There seems no reasonable explanation of the structure at and near New Idria, except on the theory of a non-conformity. Though the evidence may seem less satisfactory than that which would be presented by an ideal exposure, it is derived from the correlation of the structural evidence along the contact for miles, and in this respect is superior to any but that furnished by the very best local exposures of unconformable contacts; for every geologist must have observed cases where unconformable exposures are closely simulated by local faults Could it be proved that the underlying mass is of greater age than the Knoxville, the evidence would nevertheless indicate a non-conformity between the Chico and the Knoxville, unless it could be shown that the convulsion which has so marvelously crushed the Knoxville beds, at least from Clear Lake to the neighborhood of New Almaden and again at San Luis Obispo, was unfelt at New Idria, which it would be difficult to do, in view of the fact that the comparatively gentle Post-Miocene upheaval certainly extended throughout the Coast Ranges of California and Oregon.

Mt. Diablo and the surrounding country consist of a core of metamorphic rock inclosed nearly or quite quaquaversally by rocks of Chico and Tertiary age. The core is highly contorted and for the most part is in an extremely metamorphosed condition, though here and there it is comparatively fresh and in some cases contains *Aucella* and associated fossils. The overlying Chico, Téjon, and Miocene strata are tilted, but otherwise comparatively undisturbed. Over wide areas these three series seem to be perfectly conformable, nor have I seen any case on the Pacific Coast where there seems any ground for suspecting a non-conformity within these limits. Mr. Turner spent several days in this region, collecting fossils from various beds and searching for some exposure in which the relations of the Knoxville beds and the Chico could be well made out. The result was negative, no exposure being detected from which a non-conformity could be conclusively established. On the other hand, the structure is much more easily accounted for by supposing a non-conformity to exist than by assuming conformity. The upturned edges of the more recent strata form long, smooth curves, enveloping the plicated and metamorphosed core, and nowhere was there any metamorphism in the strata identified as Chico.

On the coast in Sonoma County, about two miles below Ft. Ross, there is a sharp contact between the Wallala beds and the metamorphic, serpentinized rock which extends from this point to below the Russian River, if not to the Golden Gate. Passing back into the hills, the Wallala beds are found capping the first range of elevations opposite portions of the shore, which

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are composed of the metamorphic rocks. I believe no one could examine this locality without being convinced that the Wallala beds rest unconformably upon the metamorphic, nor could any one pass inland from the mouth of the Russian River to Knoxville without feeling sure that the metamorphic is uniform in character and substantially continuous, though occasionally masked by eruptive rocks and possibly by a few patches of unaltered strata.

There is, furthermore, much indirect structural evidence that a non-conformity must exist between the Knoxville beds and the Chico. Somewhere between the end of the Knoxville and the beginning of the Miocene there was a great upheaval, accompanied by siliceous and magnesian metamorphism and followed by enormous erosion, for at many points the unaltered Miocene clearly rests unconformably upon the metamorphic rocks. This I have observed on San Bartolo Creek and in the valley of the San Benito, to which the other is tributary, and there is evidence of similar relations at Mt. Diablo and at New Almaden. Professor Whitney found the Miocene resting uncomformably upon the metamorphic between the Guadalupe mine and Forbes's mill, and also near McCartysville,[1] as well as north of the Golden Gate,[2] for instance, near Tomales,[3] while, in speaking of the neighborhood of Suscol, he says:[4] "It is probable that the most extensive disturbances of the Cretaceous, as also the larger portion of the metamorphic action upon it, had taken place before the Tertiary marine and volcanic beds were deposited."

If this non-conformity does not occur between the Knoxville and the Chico, it must be sought between the Chico and the Téjon or between the Téjon and the Miocene. The stratigraphical relations at New Idria and at Mt. Diablo show that there was continuity of sedimentation from the Chico to the Téjon and the organic remains prove that there was continuity of life. The great non-conformity cannot, therefore, have been between these groups. Between the Téjon and the Miocene there is at least no general non-conformity.[5] Near New Idria and at Mt. Diablo, for example, the Mio-

[1] Geol. Survey California, Geology, vol. 1, p. 69.

[2] Ibid., p. 79.

[3] Ibid., p. 83.

[4] Ibid., p. 103.

[5] Professor Whitney (Aur. Grav., p. 26) writes: "The Miocene and the Cretaceous seem everywhere to be conformable with each other." The Cretaceous here referred to is of course the Téjon. Mr. J.

cene seems as strictly conformable with the Téjon as is this with the Chico. So, too, along the flank of the Sierra Nevada, both Chico and Miocene remain almost perfectly horizontal. Had there been a great upheaval, accompanied by intense metamorphism, between the Téjon and the Miocene, it seems impossible that no Chico or Téjon strata should have been found metamorphosed.

This indirect evidence alone would seem sufficient to establish the fact of a non-conformity between the close of the Knoxville and the beginning of the Chico. Add to this the direct evidence at New Idria and Ft. Ross, and the conclusion appears irresistible, irrespective of the paleontological argument, which, again, of itself would have sufficed to lead to the same result.

The paleontological argument for a non-conformity between the Knoxville series and those which are found succeeding it may be very briefly stated. Dr. White regards the fauna of the Knoxville group as lower Neocomian, or at any rate as not later than this. The Chico, in his opinion, represents the very latest portion of the Cretaceous formation. The exposures at Mt. Diablo, for example, show that there, at least, no deposits now intervene between the Knoxville and the Chico. Hence, the Knoxville beds at this locality must have been above water in the interval. If this interval had been a short one, the facts could be explained on the assumption of a mere, gentle oscillation of sea-level relatively to the land, and the non-conformity might be one of erosion, or, in other words, would not necessarily imply a movement of great structural importance. But the Knoxville beds must either have been above water during the entire interval preceding the Chico or during a sufficient part of it to allow of the removal by erosion of any strata deposited subsequent to the close of the Knoxville. If one supposes denudation to be as rapid as sedimentation, which could hardly be the case with the class of sediments composing the Coast Ranges, the region of Mt. Diablo must have been above water for at least one-half of the interval between the close of the Knoxville and the beginning of the

Marcou in his paper on geological classification, 1888, p. 49, asserts that there is a great break between the Téjon and the Miocene near Ft. Téjon. In the description of the locality to which he refers (Ann. Rept. Geog. Surv. West of the 100th M., 1876, p. 167), I find no mention of this non-conformity. In the text I am concerned to show only that there was no disturbance at this epoch great enough to correspond to the metamorphism.

Chico. Now this interval is an enormous one, comprising nearly the whole of the Cretaceous period.

The Chico represents only a small portion of the Cretaceous, yet its sediments are thousands of feet in thickness. The same is true of the Wallala, which represents a different portion of the Cretaceous. On the most unfavorable supposition, therefore, Mt. Diablo must have been exposed for a sufficient time and at a sufficient elevation to allow of the erosion of thousands of feet of strata between the Knoxville and the Chico periods, thus indicating not a gentle oscillation, but a great uplift.

Applied to the quicksilver belt in general the argument is less precise and indeed negative; for, while an enormous interval of time elapsed between the epochs at which the Knoxville and Chico faunas flourished, it might be possible to find other intermediate groups as well as the Wallala. To account for the conditions except on the theory of a non-conformity, however, it would be essential to find such faunas in beds stratigraphically intercalated between the Knoxville and the Chico, and even such a discovery would not disprove a non-conformity. Now, although the geology of the Coast Ranges has by no means been exhaustively studied, they have been carefully examined at a great number of points by many geologists holding diverse views, and no one of them has ever discovered a trace of fossiliferous beds stratigraphically intercalated between the Chico and the Knoxville series. It is therefore very improbable that a substantially full series filling the gap between the Knoxville and the Chico exists in any one locality, and much more so that this is the general condition and that Mt. Diablo is merely a local exception.

The paleontological argument, though negative, is thus so strong as to give to the hypothesis of a great non-conformity between the Knoxville and the Chico a very high degree of probability without any aid from direct observations of non-conformity or from observations on the age of the metamorphosed rocks.

A similar argument applies, though with less force, to the relations existing between the Knoxville and the Wallala, for here, too, a long interval is indicated between the eras of the respective faunas; but the relations of the Knoxville and Horsetown beds cannot as yet be thus elucidated, because their relative age is not sharply enough defined. Unfortunately, positive structural evidence on this point also is as yet wanting.

The evidence of the existence of this important non-conformity may be recapitulated in a few words. The pebbles in the conglomerates of the Wallala and the Chico groups show that metamorphic rocks existed near them when these beds were deposited, and these pebbles entirely resemble rocks known to be of Knoxville age. If they are really of this age, the metamorphism and upheaval of the Knoxville beds must have preceded the Wallala period and there must be an unconformity. Again, the stratigraphical relations of the Wallala beds on the coast and of the Chico beds at New Idria to the adjoining metamorphic areas seem inexplicable excepting on the theory of a non-conformity. Furthermore, a great non-conformity certainly exists somewhere between the Knoxville beds and the Miocene. None such is found between the Miocene and the Téjon or between the Téjon and the Chico. Hence the non-conformity must be between the Chico and the Knoxville. Finally, the fossils prove that an immense time elapsed between the end of the Knoxville and the beginning of the Chico, while the Chico is now found in contact with the Knoxville at various points. This could not be the case unless an upheaval had intervened.

Identity of the Mariposa and Knoxville beds.—The gold belt of California, as hitherto traced out by miners and geologists, is an area of peculiar form. From Mariposa County to Nevada City, in Nevada County, a distance of about one hundred and fifty miles, the belt is a strip of country nearly parallel to the crest of the Sierra and about thirty miles in width. Northward from Nevada City it rapidly widens, becoming at the same time less well defined. To the north it is finally terminated by extensive lava fields, while toward the northwest the country gradually loses its auriferous character as the coast is approached. Within the gold-bearing region three fossiliferous areas are known to exist. From the McCloud River to Pence's ranch extends a belt of highly indurated limestone containing Carboniferous fossils. In Genesee Valley the State survey found fossils regarded as Triassic and Jurassic. Both of these localities are far removed from the narrow strip of country lying along the foot-hills from Mariposa to Nevada, which is often known as the gold belt proper. The fossiliferous Mariposa beds already mentioned occur near the southerly end of this narrow portion of the auriferous area.

Previous to the discovery of fossils on the Mariposa estate in the series which I shall call the Mariposa beds, Professor Whitney and his associates had collected in the Coast Ranges *Belemnites*, a shell determined as *Inoceramus Piochii*, and some others, from the strata which I have entitled the Knoxville beds. Mr. Gabb described them as Cretaceous forms.[1] Some years after Mr. Meek had referred the Mariposa beds to the Jurassic Mr. Gabb redescribed *Inoceramus Piochii* as *Aucella Piochii*,[2] a change of genus which I understand to be unquestionably correct. This correction appeared to me at the very beginning of this investigation of great importance to the stratigraphy of the State, for through it the fauna of a large part of the known rocks supposed to belong to the Shasta group of the Cretaceous acquired the strongest resemblance to the fauna of the Mariposa County Jurassic. Indeed there seemed scarcely room left for a distinction; if *Aucella* is distinctively Jurassic, the *Aucella*-bearing beds of the Coast Ranges must be members of that system, while if these *Aucella* beds are Cretaceous *Aucella* is not a distinctively Jurassic genus, even in the State of California, and Mr. Meek's principal reason for assigning the Mariposa beds to the Jurassic is shorn of its validity. Dr. White afterwards fully confirmed this view, and after examination of Meek's types, together with new and better specimens which we collected, he is unable to draw any specific distinction between the *Aucella* of the Mariposa beds and that of the Knoxville beds.

Professor Whitney states that, while the Mesozoic age of the Mariposa beds is proved by their fossils, the Pre-Cretaceous age of these strata is demonstrated by their stratigraphical relations. Professor Whitney has indeed shown that Cretaceous strata rest unconformably[3] upon the upturned edges of the auriferous slates along the foot-hills of the Sierra at several points;

[1] Geol. Survey California, Palæontology, vol. 1.

[2] Ibid., vol. 2.

[3] I am perfectly satisfied of the existence of this non-conformity, though the localities where the Chico beds have been found resting on the upturned edges of the auriferous slates are not near those in which Mesozoic fossils have been found in the older rocks. The Chico beds, where they occur along the foot-hills, have suffered little if at all from the Post-Miocene uplift in the Coast Ranges and are nearly horizontal. The Mariposa beds are almost vertical.

but I find no record of any such bed so low as the Knoxville group.[1] All the fossils recorded in this position are Chico. This does not, indeed, preclude a possibility that the Mariposa beds are Jurassic and the *Aucella* beds of the Coast Ranges Cretaceous, for the former might have been above water during the Shasta epoch; but, were Cretaceous strata containing the so-called *Aucella Piochii* to be found resting in a nearly horizontal position upon the Mariposa beds, it would prove not only that the genus had persisted from Jurassic into Cretaceous times, but that in essentially the same locality the genus was represented immediately after a great and widespread upheaval by a species nearly or quite indistinguishable from one which had inhabited it prior to this convulsion and the attendant metamorphism. Zoologists would think such a survival very strange if it could be proved and highly improbable unless the proof were ample.

On the other hand, if the Mariposa beds are considered as equivalent to the Knoxville beds of the Coast Ranges, the non-conformity between the Chico beds and those of Mariposa is the same which has been traced in the preceding pages as existing in the Coast Ranges; and, even if the species of *Aucella* found in the respective beds were different, the upheaval and metamorphism of the two series, still referable to nearly the same period, would be presumptively simultaneous.

The lithological resemblance of the rocks of the Mariposa estate to those of many portions of the metamorphic rocks of Knoxville age is very strong. There is a similar prevalence of thin-bedded strata, while silicification and serpentinization are equally the predominant characteristics. Plication and fracture are less noticeable than in the Coast Ranges. One geologist has maintained that the fossiliferous rocks of this locality do not form an integral portion of the auriferous series. Neither Dr. White nor I was able to see any ground for this assertion. The fossiliferous rocks are metamorphic, like the entire series; they have the same dip and strike and they are unquestionably auriferous, gold quartz veins occurring between the fossil-bearing strata and not simply near them. In short, we could see no way of separating the strata containing shells from the

[1] The shell from Tuscan Springs recorded as *Inoceramus Piochii* (Geol. Survey California, Geology, vol. 1, p. 207) is redetermined as a *Mytilus* in ibid., vol. 2, p. 191.

remainder of the immense thickness of similar and apparently conformable slates.[1]

The Knoxville and Mariposa series.—Though the beds of the Knoxville and Mariposa groups, which on the structural and paleontological grounds already stated are considered as of the same age, appear to have a very wide distribution in California, particularly along the two great mineral belts of the State, they have been found fossiliferous at only a comparatively small number of localities in Lake, Colusa, Yolo, Napa, Solano, Contra Costa, Santa Clara, San Luis Obispo, and Mariposa Counties. Owing to the extremely disturbed and highly metamorphosed condition of the greater part of the series, all of these localities are of very restricted area. The areas covered by unaltered or very slightly altered rocks apparently of the same age are considerably larger, yet even these are small and seem to represent mere patches which by accidents of structure have escaped the general and very intense metamorphism. The features presented by the rocks of these series as a whole are somewhat unusual among beds so recent, and their general facies has led some able and experienced geologists to suspect for them a far greater antiquity than is warranted by the detailed evidence.

Though in some of the fossil localities shells are extremely abundant, sometimes making up a large portion of particular strata, the number of species found is small, and of the short list which can be enumerated many are so imperfect as to make their identification doubtful or hopeless.[2] The following were published by Mr. Gabb:

Belemnites impressus Gabb.	*Liocium punctatum* Gabb.
Palæatractus crassus Gabb.	*Modiola major* Gabb.
Cordiera mitræformis Gabb.	*Aucella Piochii* Gabb.
Atresius liratus Gabb.	*Rhynchonella Whitneyi* Gabb.
Ringinella polita Gabb.	*Pecten complexicosta* Gabb.

[1] Mr. J. Marcou stated that these schists "sont souvent très rapprochés des veines métallifères, sans toutefois jamais en renfermer" (Bull. Soc. géologique France, 1883, p. 410). He now accepts without objection my statement that gold quartz veins occur between the slates of the Mariposa beds, and not simply near them. It does not follow, he thinks, that because the Mariposa beds, which in his opinion are Triassic, form an integral portion of the auriferous series, the apparition of gold in the Sierra Nevada is to be put as late as the Jurassic. This, in his opinion, took place not later than the Lower Paleozoic. "The extrication of gold from the quartz matrix being due to pressure, naturally gold dust entombed in the Triassic marl of the Mariposa may have been united into small nuggets during the process of lamination and crushing" (American Geological Classification etc., 1888, p. 37). I must confess myself unable to follow this reasoning.

[2] The paleontological statements are all on the authority of Dr. White and are in part extracted verbatim from Bull. U. S. Geol. Survey No. 15.

Three other species, viz, *Ammonites ramosus* Meek, *Potamides diadema* Gabb, and *Lima shastaensis* Gabb, the types of which Gabb obtained in the Horsetown beds, Dr. White thinks probably, but not certainly, identical with specimens obtained by my party from Knoxville.

In addition to these published species the following have been generically recognized among the collections from Knoxville, all the specimens of which are, however, too imperfect for specific determination: *Ammonites?*, *Margarita?*, *Dentalium*, *Arca*, *Nuculana*, and *Rhynchonella*. Besides all these forms there are fragments among the collections from Knoxville which indicate two or three other molluscan species not considered in the enumeration of the fauna of the Knoxville beds. The specimens which have been referred to as probably representing a species of *Ammonites* are only a few small fragments, which show only portions of the sides and periphery of the shell. These seem to indicate a species related to the *A. Newberryi* of Meek. The *Dentalium* is probably undescribed, as are probably also the *Arca* and *Nuculana*. The *Rhynchonella* is apparently an undescribed species and seems to be identical with one which Dr. White discovered at Horsetown.[1] The collection contains only one fragment of a shell which he refers with doubt to *Margarita*.

The specimens of *Ammonites* which in the foregoing list of published species are referred with doubt to *A. ramosus* Meek consist only of the small inner whorls, none of them reaching an inch in diameter. The form, surface markings, and septa of the shell, so far as these characters are shown by the Knoxville specimens, seem, however, to agree well with those of the species as it is described by both Meek and Gabb. Meek's type specimens came from Vancouver Island, but Gabb identified the species in the Horsetown beds of the Shasta group of California.[2] The specimens of the shell which in the foregoing list are referred with doubt to the *Potamides diadema* of Gabb are embedded in compact rock, so that all its characters cannot be observed. They are probably identical with Gabb's species which he describes as coming from the Horsetown beds. Finally, so far as the specific identity of any *Belemnites* can be determined, there seems to be compara-

[1] This form is closely like the *R. oxyoplicata* Fischer, from the Jurassic of Moscow.

[2] See Bull. U. S. Geol. Sur. Terr. (1876) No. 2, p. 371, Pl. V, Fig. 1; also, Geol. Survey California, Palæontology, vol. 1, p. 65, Pl. XI, Fig. 13, and Pl. XII, Fig. 12*b*.

tively little reason to doubt that the specimens which have been found in the Horsetown and Knoxville beds, respectively, and referred to *Belemnites impressus* Gabb, are specifically identical.

Comparing the nineteen species of fossils now known to exist in the Knoxville beds with those from the Horsetown beds, or, in other words, with all the other species which Gabb refers to the Shasta group,[1] it appears that all except six of them are certainly different from any of the latter. One of these six, the *Ammonites Newberryi??*, offers only a mere suggestion of identity; four are probably, but not certainly, identical, namely, *Ammonites ramosus?*, *Potamides diadema?*, *Lima shastaensis?*, and *Rhynchonella* ———*?;* and the specific identity of one, *Belemnites impressus*, has been regarded as certain. The fact that the *Belemnites,* as a rule, do not present salient, or even satisfactory, features by which to determine specific differences, detracts somewhat from the certainty of the last identification.

Dr. White's opinion that *Aucella Erringtonii* and *A. Piochii* Gabb are specifically identical has been formed after he had had better advantages for investigating the subject than seem to have been enjoyed by any other person who has written upon the paleontology of California. He has not only examined the original types of those two forms, but hundreds of other specimens of *A. Piochii* from Gabb's original locality, as well as from other places. Furthermore, we made a personal visit to the locality on the Mariposa estate where the type specimens of *A. Erringtonii* were obtained, and collected better specimens of it from the auriferous slates there and in the immediate neighborhood than had before been known. We also obtained from the same slates fragments of an ammonite, some impressions of a shell apparently the *Pholadomya orbiculata* of Gabb, others that represent a species of the Pectinidæ (perhaps the *Amussium aurium* of Meek), and still others which are undeterminable. On adding to these the *Belemnites pacificus* of Gabb, the fauna of the auriferous slates of the Mariposa estate amounts to at least five species of mollusks. It is true that only the *Aucella* has been satisfactorily identified as occurring in both the auriferous slates[2]

[1] Geol. Survey California, Palæontology, vol. 2, pp. 209-254.

[2] Some of the specimens found in the auriferous slates of the Mariposa estate show more or less distinct, radiating lines, and the same peculiarity has been observed among examples from the Knoxville beds, as well as among Russian and Alaskan examples.

and the Shasta group, but there is nothing in the character of the other four species of mollusks from the auriferous slates which would render inconsistent their reference to the age of the Knoxville beds.

The specimens of *Aucella* and other auriferous slate species just referred to were obtained by us from the rocks in place, those found near the left bank of the Merced River, Mariposa County, Cal., about a quarter of a mile below Benton's mills, being especially satisfactory as regards both their position in the strata and their condition of preservation. Here the strata have an almost vertical dip and they are plainly an integral part of the great auriferous slate series. A part of our collection, as well as some of those which were collected by King, Gabb, and Miss Errington, were obtained from within a few feet of the famous great quartz vein which traverses the Mariposa estate and which is inclosed in the auriferous slates.

We did not obtain any *Belemnites* from the auriferous slates, as King and Gabb did, nor has Dr. White seen Gabb's *B. pacificus*, obtained from this formation, but not figured. From the description it is supposed to be identical with *B. macritatis* White,[1] obtained by Mr. Dall from Alaska and found associated with an *Aucella* regarded as of the same species as *A. Erringtonii* and *A. Piochii*.

That the Mariposa beds and the Knoxville beds are of the same age is considered as proved by the identity of *Aucella Piochii* and *A. Erringtonii*, supported by the general character of the other fossils which the strata of both respectively bear. It is true that this is the only specific identification that has been made; but the species in question is one of extraordinarily wide geographical range and it is also one of great constancy and exclusiveness as regards its distinguishing characteristics.

Certain of the species which characterize the strata of the Shasta group in California have been recognized among the collections which have been reported by different persons from Washington Territory and British Columbia, as well as from Alaska and the Aleutian Islands. But none of the species of that group has been found in any North American strata to the eastward of the Pacific Coast region, if we except Greenland. While

[1] See Bull. U. S. Geol. Survey No. 4, p. 13, Pl. VI.

it is probable that the Horsetown beds of California are represented in those northern localities which have been referred to, it is more especially the equivalent of the fauna of the Knoxville beds that has been recognized as existing there. This recognition is mainly through the identification, among the collections which have been made there, of the *Aucella*, which so strongly characterizes the Knoxville division of the Shasta group in California. Specimens regarded as specifically identical with the form which Mr. Gabb published under the name of *Aucella Piochii* have been presented to the Survey by Prof. Thomas Condon, which he collected at Puget Sound, Washington Territory. These specimens were in bowlders, but they nevertheless indicate the existence of an otherwise unknown locality to the north of Oregon. Mr. Whiteaves refers to the same species as being abundant at Tatlayoco Lake and other places in British Columbia,[1] and Professor Eichwald, Dr. P. Fischer, and Dr. White have published forms from different parts of Alaska which the last regards as specifically identical with it.

Among the fossils collected in Alaska by Peter Doroschin, Eichwald[2] recognized all the forms of *Aucella* which Keyserling had published as occurring in Russia, namely, *A. concentrica* Fischer, *A. mosquensis* von Buch, *A. pallasii*, and *A. crassicollis* Keyserling. The last two he considered as only varieties of *A. concentrica*. Dr. Fischer recognized only one species among Pinart's Alaskan collections,[3] which he referred to *A. concentrica*.

Dr. White also recognized only one species among the collections brought from Alaska by Mr. Dall. Although the specimens were numerous and presented quite a wide variation of form, he regarded them all as representing a variety of *Aucella concentrica*.[4] Mr. Whiteaves (loc. cit.) recognized only one species among the collections from British Columbia, and this he referred to *Aucella mosquensis*.

In the Knoxville beds of California there are two recognizable varieties of *Aucella*, which are connected more or less closely by intermediate forms,

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[1] See Trans. Royal Soc. Canada, sec. 4, 1882, p. 84.

[2] See Geognost.-palaeont. Bemerkungen über die Halbinsel Mangischlak und die aleutischen Inseln, 1871, pp. 185–187, Pl. XVII.

[3] See Voyage à la côte nord-ouest de l'Amérique, par M. Alph.-L. Pinart, pp. 33–36, Pl. A.

[4] See Bull. U. S. Geol. Survey No. 4, pp. 13, 14, Pl. VI.

but are decidedly different in extreme examples. It is usually the case also that one variety will be found to prevail in certain layers of rock, sometimes almost exclusively, and the other variety in other layers.

Adult examples of one of these varieties are large, robust, and often inflated. These approach the typical forms of *A. concentrica* more nearly than the others. Those of the other variety are smaller, more slender, and have a more delicate appearance. They seem to correspond more nearly with the type of *A. mosquensis*. Still, after examining numerous examples from Alaska, British America, Washington Territory, and California, besides some Russian examples of *A. concentrica* and *A. mosquensis*, believed to be authentic, in the collections of the Smithsonian Institution, Dr. White is of the opinion that all of them represent only one species. Indeed, he is disposed to regard as at most only varieties of one species all the forms which have from various authors received the names *Aucella concentrica*, *A. mosquensis*, *A. pallasii*, *A. crassicollis*, *A. Piochii*, and *A. Erringtonii*. However, it will be convenient, when discussing the *Aucella*-bearing strata of California, to retain the names *A. concentrica* and *A. mosquensis* to indicate the more robust and the more elongate forms, respectively, as they occur in that State.

Before dismissing this reference to *Aucella*, it is well to note how wide is the geographical distribution of the variable form which has been known under the various names which have just been mentioned. This shell was first known in various parts of Russia and subsequently upon the eastern coast of the Caspian Sea,[1] in northern Siberia,[2] on the island of Spitzbergen,[3] on Kuhn Island (off the east coast of Greenland),[4] and in Alaska, British Columbia, Washington Territory, and southward to central California, as mentioned on previous pages. Although it is so variable in certain of its features, so constant is it in its general characteristics and so distinct from related forms that paleontologists are now generally agreed as to its identity in all the widely separated localities which have just been indicated.

[1] See Eichwald's Geognost.-palaeont. Bemerkungen über die Halbinsel Mangischlak und die aleutischen Inseln, 1871, p. 53.

[2] See Middendorff's Reise in den äussersten Norden und Osten Siberions, vol. 1, part 1, p. 255.

[3] See Lindström: Om Trias- och Juraförsteningar från Spetsbergen, Kongl. svensk. Vet.-Akad. Handl., vol. 6, No. 6, 1867, p. 14.

[4] See F. Toula, Die zweite deutsche Nordpolarfahrt, vol. 2, 1874, pp. 497–505; also Quart. Jour. Geol. Soc. London, vol. 31, 1876, p. 560.

The age of the *Aucella*-bearing beds, whether in California or elsewhere, is not fully determined, apparently on account of the equivocal character of the faunas associated with this fossil.

Both Eichwald and Whiteaves contend that all the strata which bear *Aucella concentrica* and *A. mosquensis* are certainly of Neocomian age. On the other hand, Keyserling, Trautschold, D'Orbigny, and others as confidently assert that they are of Jurassic age and many paleontologists have hitherto regarded *Aucella* as an exclusively Jurassic genus. Even so late as the year 1884 Mr. A. Pavlow, a member of the official geological commission of Russia, placed in the Jurassic series the well known strata which in eastern and other parts of Russia bear *Aucella concentrica*, as the earlier Russian geologists also did.[1]

Dr. White thinks it not impossible that *Aucella* occurs in the Jurassic in some regions and in the Neocomian in others, just as a number of Lower Carboniferous species of Europe are found in the Upper Carboniferous of North America and as certain species are known to pass from the Devonian to the Carboniferous. He inclines, however, to the opinion that the California occurrences are referable to the Lower Neocomian, which, as has been seen, is substantially the result at which Gabb arrived for the group here called the Knoxville series.

As has been seen, the age of the metamorphic series of the Coast Ranges (which is that most usually associated with the quicksilver deposits), the age of a highly important portion of the auriferous slates of California, and consequently also the structural relations of the Coast Ranges and Sierra Nevada depend almost entirely upon two closely allied species, or on two varieties of a single species, of *Aucella*. The very great importance which this fossil thus acquires is much increased by the fact that it occurs along the Pacific Coast at various points up to Alaska, a distance of about two thousand miles, and again at very widely separated points in Europe.

In the hope that it may lead to a more extended knowledge of the distribution of this peculiar and important fossil, I have induced Dr. White to prepare a description, with illustrations, of *Aucella*, which appears as an appendix to this chapter.

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[1] See Bull. Soc. géologique France, 3d series, vol. 12, 1884, pp. 686-696.

The Horsetown beds.—The Horsetown beds, as it seems convenient to call the group which occurs near Cottonwood Creek, Shasta County, are confined to that locality, so far as known, and their stratigraphical relation to the Knoxville series is undetermined. The solution is very probably to be found in the eastern Coast Ranges in Tehama County, but this region is not known to have been geologically explored and it probably will not be examined until a special study of the Coast Ranges as a whole is undertaken. The Horsetown beds are somewhat altered, but at the points visited by Dr. White and myself they do not show the characteristic serpentinization and silicification of the metamorphosed Knoxville beds. It cannot by any means be asserted definitely, however, that they were not involved in the upheaval and metamorphism which took place after the Knoxville and before the Wallala period, because much of the Knoxville series is also little altered. On the other hand, the Horsetown beds rest unconformably upon the auriferous slates of that region, which are of uncertain age, though apparently continuous with the Carboniferous of Pence's ranch. Professor Whitney detected this non-conformity, though expressing the result in somewhat guarded terms.[1] The mining operations which have since been prosecuted have so exposed the rocks as to leave no room for any possible difference of opinion. The slates upon which the Horsetown beds lie are somewhat peculiar and differ physically from those of the Mariposa beds, showing a very thin cleavage and an unusual, silver-gray luster. They give to the eye an impression of great geological age. The fauna of the Horsetown beds includes the whole of Gabb's Shasta group, excepting the species already enumerated as belonging to the Knoxville. Mr. Gabb and Dr. White agree in considering the affinities of these fossils to be with those of the Gault, and therefore decidedly later than the Knoxville series. Though the Horsetown beds lie not far from the general line of the quicksilver belt, they are not known to occur anywhere in close connection with the ore deposits.

The Cascade Range.—It is hardly possible to contemplate the close relation shown to subsist between the eastern and western ranges of central California without inquiring what connection, if any, exists between them

[1] Geol. Survey California, Geology, vol. 1, p. 321.

and those north and south of the great valley of the State. Dr. White and I therefore visited Oregon and made several trips into the mountains of the Cascade Range from Roseburg.

The sedimentary rocks appear to be underlain by granite, for, though we did not meet with this rock in place, it constitutes a large proportion of the stream pebbles. It is stated on the excellent authority of Rev. Thomas Condon to occur in place somewhat to the northward of this point. In a great number of localities we found upturned, crumpled, silicified, and metamorphosed rocks exactly similar to those of Mt. Diablo, but our search for *Aucella* was not rewarded. Upon the metamorphic rocks lie unconformably somewhat tilted, unaltered sandstones. These are certainly Miocene, for, though we found no fossils ourselves, Dr. White examined extensive collections of Miocene shells in entirely similar rock made by Rev. Thomas Condon, who gave us full information as to their occurrence in precisely similar positions, but somewhat north of Roseburg. Overlying the sandstones are large areas of volcanic rocks.[1]

In the section made by the Columbia River no metamorphic rock or granite appears, but at least the southern portion of the range has a foundation similar to that of the California Coast Ranges, and, as I think, probably of the same age. This cannot be stated as a certainty until *Aucella* has been found in the Cascades; but, considering that this fossil certainly occurs near Puget Sound and that the lithological character and geological association of the metamorphic rocks at Roseburg are indistinguishable from those of known Neocomian localities in the Coast Ranges, no grave doubt remains.

Chico beds, however, occur in central Oregon, and on this ground the Blue Mountains have been regarded as the northerly continuation of the Sierra.[2] But shore lines and lines of structure, though intimately associated, do not always coincide. A depression of only 30 feet to-day would put Sacramento, Stockton, and an immense area of the Great Valley under water, while a depression of 400 feet would convert the Great Valley into

[1] In answer to an inquiry, Prof. Joseph Le Conte states that his remarks concerning the lower portion of the Cascade Range in Am. Jour. Sci., 3d series, vol. 7, p. 177, were not from personal observation. He there suggested that the Cascades were a continuation of the Sierra.

[2] U. S. Geol. Expl. 40th Parallel, Systematic Geology, vol. 1, p. 452.

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a gulf, extending from Tulare Lake to above the town of Red Bluff. There is, indeed, abundant reason to suppose the Great Valley did form such a sheet of water within the recent period, for the marsh lands bordering on the lower Sacramento and San Joaquin Rivers seem mere continuations of the mud flats of the Bay of San Francisco exposed at low tide, and the relations of the alluvial plains to the neighboring hills are indicative of the same conditions, while the character of some of the terraces on the sea-coast demonstrates that the sea-level not long ago was at least over 200 feet higher, relatively to the land, than it is now.[1]

There would be nothing strange, therefore, in the discovery of brackish-water shells or even salt-water remains in the alluvium of the Great Valley, but this would not indicate that the Coast Ranges were non-existent at the time when such mollusks were alive. So, also, the Gulf of California now extends some one hundred and fifty miles to the eastward of the true coast line, or the western limit of Lower California. The fact that Chico fossils are found in central Oregon only proves, therefore, that the Cascades must have been broken through at one or more points during this period, and not that this range is more recent than the Chico.

Southern continuation of the Coast Ranges.—The main structural continuation of the united Coast Ranges and Sierra Nevada to the southward appears to be the peninsula of Lower California. Mr. Gabb,[2] who visited this region, stated that it is possible to trace an uninterrupted granite ridge from the San Gabriel Mountains, north of Los Angeles, through Los Angeles, San

[1] Prof. George Davidson has traced from Lower California to Alaska the terraces which line the western coast (Proc. California Acad. Nat. Sci., vol. 5, p. 90). So great is the regularity of the surfaces of some of these terraces that he feels compelled to deny that they have been cut by wave action. He considers it probable that ice was the agent. My own opportunities for examining these terraces have been very limited, but in the region between Ft. Ross and Gualala I have studied them with some care. Their topography appeared to me indistinguishable from that of the beaches exposed at low water, and at two points I detected *Pholas* borings on the terraces at a distance of several miles from one another. One of these points was by estimation 150 feet and the other 250 feet above sea-level. However the terraces of this region were formed, therefore, they have been at sea-level within a period which has been insufficient to obliterate extremely superficial markings in a very soft sandstone. Neither in this region or at Santa Cruz nor on the Farallone Islands was I able to see the necessity for attributing the excavation of the terraces to any other agency than that of the waves. That there are such terraces for which wave action may seem an inadequate explanation I do not of course deny; yet, if the level of the coast were to remain absolutely constant for a very long period, it appears to me that hard rocks and soft must eventually be cut away to a very nearly uniform depth. Mr. Goodyear (ibid., vol. 4, p. 295) has called attention to evidences of oscillation in the level of the coast of Oregon.

[2] Geol. Survey California, Geology, vol. 2, appendix, p. 137.

Bernardino, and San Diego Counties, into Lower California and along the peninsula to within a few miles of the old mission of Santa Gertrudis, while, from the exposure through denudation at Santa Gertrudis and again near Loreto, it is probable that between the mission and Cape San Lucas the granite nowhere lies at a greater depth than 1,000 feet. Dr. White has pointed out that fossils of the Atlantic Cretaceous fauna, which is entirely distinct from the fauna of the Pacific Cretaceous, are found on the western side of the Sierra Madre of Mexico, thus showing that Lower California was during the Cretaceous the dividing isthmus between the oceans and confirming Gabb's view.

Though the probabilities are thus strongly in favor of the theory that the Cascades and the mountains of Lower California are the main structural continuations of the united Sierra and Coast Ranges, it by no means follows that these ranges form an isolated system or that these continuations of the California mountains are the only ones. On the contrary, there is much evidence that the Sierra is inseparable from the basin system, which appears to continue through Arizona and to unite with the Rocky Mountain system. Too little is known of northern Mexico and the territory of the United States immediately adjoining it to justify any extended speculation on this subject.

Pre-Cretaceous upheavals and metamorphism.—Two important areas of serpentinized and silicified, metamorphic rocks have been shown in the foregoing pages to be of the same age, probably Neocomian, and it has been established that these series were upheaved and metamorphosed prior to the deposition of the Wallala beds, regarded by Dr. White as Turonian. But there are other metamorphic rocks in California deposited long before the Neocomian. Thus the Carboniferous limestones on the McCloud River are crystalline and the metamorphic shales near Pence's ranch, in Butte County, are at least in part Carboniferous. They bear considerable similarity to those of the Mariposa group, and, furthermore, they are nearly vertical and strike in nearly the same direction as those of the gold belt proper. The question therefore at once arises whether their upheaval and metamorphism are ascribable to the same period as the uplift and alteration of the Mariposa and Knoxville beds.

It is hoped that work now being done on the gold belt may afford a definite answer to this and other questions. In the absence of distinct evidence, however, the probabilities appear to be against the supposition that all the metamorphism which can be traced in this State is referable to a single period.

It may be asserted with some confidence, as a result of all the geological work done from the Rocky Mountains to the Pacific, that there has been throughout geological time a definite tendency in the structural development of this area. The geologists of the fortieth parallel exploration showed that a fault began upon the west flank of the Wahsatch in the Archean, the same fault which Mr. Gilbert has traced as still in progress. The last-named geologist and Prof. Joseph Le Conte have also detected a similar fracture on the east side of the southern portion of the Sierra. The eastern portion of the Great Basin was lifted above the surface of the ocean after the close of the Carboniferous, the western portion of the same area followed before the Cretaceous, and at one or both of these epochs the country was laterally compressed, an action no doubt closely connected with the progress of the great faults. About the time of the Neocomian California experienced an east and west compression, and again at the close of the Miocene an uplift threw the horizontal strata of the coast into north and south folds. From the Wahsatch to the Pacific Coast there thus appears to have been a recurrent, if not a constant, tendency to lateral compression in substantially one and the same direction and to an increase of the land area west of the Wahsatch.

This repetition of movements in a similar direction has tended to obscure the time relations of geological phenomena, particularly along the great Sierra Range, which has probably been one of the most persistent topographical features of the continent. Dr. White points out that an extraordinary difference has existed between the marine fauna of the Pacific Coast and that of the waters east of the Sierra from a time prior to the Cretaceous onward, and hence that a land barrier must throughout have occupied substantially the position of the Sierra Nevada, which must therefore have experienced repeated upheavals to compensate for constant erosion. There are also said to be some paleontological grounds for supposing at least a partial separation of these areas during the Carboniferous. This supposition is in entire accord not only with the structural analogies of the region, but with the detailed observations of Mr. Clarence King[1] and his colleagues, who were led to infer the existence of a continental area during the Paleozoic west of longitude 117° 30′, in latitude 40°. Such a range as the Sierra, though partaking in the general compression and movement of the whole country, must offer a tremendous resistance, and, at any one of the active periods during which the physical conditions permitted contortion of strata along the western flank of the Sierra, these must have been driven against the barrier until they could yield no more. Thus if a pile of cloths were compressed from their edges (as in Hall's famous experiment) with enormous energy, they would be forced into plications so sharp that the dip at any point would be nearly vertical It seems to follow that at different upheavals (some of them perhaps as yet untraced) strata to the west of the great Sierra may have been driven into the nearly vertical position of the gold slates, their original stratigraphical relations thus becoming completely obscured. I do not consider it certain, therefore, or even probable, that the Carboniferous slates near Pence's ranch first assumed their present position subsequently to the Knoxville period. It may be that they have stood nearly as now ever since the Carboniferous of Utah was raised above water, while the slates of Horsetown, of the age of which nothing is known, may possibly owe their vertical dip to still earlier convulsions.

The Carboniferous slates of Pence's ranch are serpentinoid, and, though distinctions between them and the metamorphosed Knoxville beds might perhaps be drawn, the rocks are very similar. But, just as it seems to me that successive upheavals may have produced similar effects upon the arrangement of strata, I think the association of a certain uplift with a particular series of chemical changes tends to show that analogous dynamical conditions might lead to molecular changes of the same kind. It seems therefore not at all impossible that both upheaval and metamorphism at Pence's ranch were in the main earlier phenomena than those traced in the Coast Ranges. If so, their effect must have been felt throughout a great por-

[1] U. S. Geol. Expl. 40th Parallel, vol. 1, Systematic Geology, p. 534.

tion of California, though the results in the Coast Ranges may have long since been obliterated. On the other hand, the post-Knoxville disturbance must have been felt at Pence's ranch, though its effects may have been trifling as compared with those of earlier convulsions.

The Coast Ranges members of the western Cordillera system.—As has already been stated, I am unable to see any reason for dissenting from Professor Whitney's opinion that the fossiliferous beds of Mariposa form an integral portion of the modern Sierra Nevada range. It seems simply impossible that they should have assumed their present vertical position with a strike parallel to the crest and that they should have been profoundly modified by chemical action, except under conditions of disturbance amply sufficient to bring about essential modifications of the whole range. That there were at the time, or at least had been, mountains in nearly the same position does not impair the claim of this addition to be considered as much a part of the modern Sierra as any older portion. If the conclusions thus far stated be accepted, it follows at once that subsequently to the close of the Knoxville, but long before the beginning of the Chico, both the Sierra and the Coast Ranges experienced an upheaval. This was in all probability not the first along the line of the Sierra and very possibly did not actually originate the Coast Ranges, but for the latter it is the first distinctly traceable movement. It is conceivable that within the limits of time indicated two upheavals should have taken place, one affecting only the Sierra, the other only the Coast Ranges; but the probability of this alternative will scarcely be seriously maintained. The earlier determinable portion of the Coast Ranges must therefore be considered as due to the same disturbance which added the gold belt proper to the Sierra Nevada. There is much probability that a portion at least of the Cascade Range was elevated and metamorphosed at the same time. The relationship thus established is brought out more clearly by a comparison of the history of the ranges so far as it can be traced.

Both the Sierra Nevada and the Coast Ranges were above water and underwent erosion during the interval between the Knoxville and the Chico epochs. Both ranges also sank just before the beginning of the Chico, admitting the ocean over a great part of the Coast Ranges and over considerable areas at the base of the Sierra. Both appear to have risen partially and gently before the Téjon, particularly toward the north; at least the rocks of this epoch, so far as is known, are confined to the southern extremity of the Sierra and to the Coast Ranges south of Martinez. A slow subsidence would appear to have taken place before the Miocene, rocks of this age extending along the Sierra far to the north of the Téjon localities, while in the Coast Ranges they lie directly upon the metamorphic at a great number of points, clearly indicating a lower general level than during the preceding epoch. During the Pliocene very little of either range was below water.

Not only was an important uplift of the Sierra Nevada contemporaneous with the first known upheaval of the Coast Range, but, even with the imperfect information at command, it is clear that the successive fluctuations of level of the country since the close of this disturbance have affected these ranges substantially in the same manner, and I cannot but conclude that the new facts brought forward necessitate the reference of the Sierra Nevada and the Coast Ranges to a single mountain system. The Coast Ranges are, and probably always have been, of less altitude than the great Sierra, and they have consequently been more extensively immersed, just as would be the case if both were now to sink any given number of thousand feet. Between the Miocene and Pliocene periods the Coast Ranges also suffered disturbances in which at least the western base of the Sierra has not shared perceptibly. The Sierra, too, has undergone some faulting in which neither the Coast Ranges nor the basin ranges are known to have shared, but these differences do not appear to me sufficient to counterbalance the important coincidences in the history of the ranges.

Date of upheaval and metamorphism.—There seems every reason to suppose that the upheaval of the Knoxville and Mariposa beds was substantially contemporaneous with their metamorphism, but the exact period at which these phenomena took place is uncertain. That it was prior to the deposition of the Wallala beds, and therefore before the Turonian, is indubitable. It must be left to future investigation to determine whether the uplift preceded the Gault. This, however, is more probable than the alternative hypothesis, for the limited occurrence of the Horsetown beds seems to indicate that an uplift, though possibly a gentle one, occurred between the Neocomian and the Gault; so that, if it should prove that the Horsetown beds were involved in the metamorphism, there were probably two distinct uplifts between the Knoxville and the Wallala, and of these the later must have been much the more violent. This appears less likely than that a single great movement took place at the close of the period characterized by the presence of *Aucella* and prior to the Gault.

The Wallala series.—Along the coast in Sonoma and Mendocino Counties, from a little below Ft. Ross to beyond the town of Gualala or Wallala,[1] occurs a series of beds of very considerable thickness, standing at a high angle and mainly composed of thick-bedded, soft, tawny sandstones externally similar to those of the Chico group as it is found at New Idria and elsewhere. This series also includes large masses of conglomerate, the pebbles of which are chiefly granite and metamorphic rocks. That these beds lie unconformably upon the metamorphic has already been stated. The Wallala beds are for the most part extremely barren in fossils and no considerable number in any tolerable state of preservation were found excepting at a point on the shore about a mile above the town of Gualala At other points to the southward, however, fragments of *Inoceramus*, easily recognizable by the peculiar structure of the shell, and a few other imperfect fossils were found, so that there could be no doubt as to the faunal continuity of the beds, even had the exposure been less satisfactory.

The National Museum has also received from Mr. C. R. Orcutt, of San Diego, a few fossils from Todos Santos Bay, in Lower California, a part of which Dr. White has determined as identical with those from Mendocino county. He has described the following:

Coralliochama Orcutti (gen. et sp. nov.).
Trochus euryostomus, n. sp.
Nerita —— ?.

[1] The name of this town and of the river which there empties into the Pacific is variously spelled Gualala, Guadala, Walhalla, and Wallala. It is of Indian origin, and the first form is an attempt to convert it into Spanish. The third form is evidently due to the resemblance of the sound to a famous mythological name. The Coast and Geodetic Survey, after careful consideration, have chosen the last spelling, which will no doubt eventually be adopted on maps of the Coast.

Cerithium Pillingi, n. sp.
Cerithium totium sanctorum, n. sp.
Solarium wallalense, n. sp.

The collection from Mendocino County included the first and the last of these and also imperfect specimens of an *Inoceramus* about a foot in length, *Ostrea*, *Pecten*, and *Turritella*. Dr. White believes this fauna to indicate the middle Cretaceous and in some respects it reminds him of the Gossau.[1]

The Wallala beds have never been recognized except at these two points, which are 600 miles apart. The northern locality was manifestly close to the shore of the ocean of that time, and the locality in Lower California appears to have been similar. It thus seems probable that the western shore of California was approximately in its present position during the Turonian epoch.

The Chico-Téjon series.—This group of rocks occurs for the most part on the slopes of the great valley of California, the western side of the Coast Ranges being covered with Wallala beds or Miocene strata where the metamorphic series is not exposed. The prevalent rock variety is sandstone of medium grain and usually very soft.[2] The lower portion of the series is generally ferruginous and of a tawny hue, and spheroidal concretions, though met in later sandstones, also are particularly abundant in the Chico. The origin of these concretions is discussed in Chapter III. The upper part of the series is commonly characterized by an extremely light color, approaching pure white. The series also includes shales, though these are subordinate, and a very little limestone is met with in some localities, though not forming continuous strata. Along the Coast Ranges the Chico-Téjon series is, so far as I know, always perceptibly inclined and usually at a considerable angle, but in some of the localities on the west flank of the Sierra Nevada, as at Chico, the beds are very nearly horizontal. Traces only of cinnabar are known to occur in these rocks and no case of metamorphism similar to that which prevails in the rocks of the Knoxville group has been observed, though induration and a greater or less impregnation with calcite and gypsum are not uncommon.

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[1] Bull. U. S. Geol. Survey No. 22.

[2] The branches of bushes growing close to croppings of these sandstones often wear grooves into the rock which are sometimes as much as three inches in depth.

New Idria affords a fine exposure of these rocks, which at this point appear to be not less than 10,000 feet in thickness. The beds are tilted at angles reaching 45° and are so little concealed by soil that a continuous stratum may often be followed for a considerable distance. There is no indication at this point of any break in the continuity of deposition of the sandstones, which carry a sufficient number of fossils to show that both the Chico and the Téjon are represented. At Mt. Diablo, too, these formations appear exactly conformable, and, so far as is known, this is the case wherever they are found together. The difference in color is the only physical peculiarity by means of which a division can be made.

Near the Vallecitos Cañon, a few miles northwest of New Idria, and therefore close to the locality known as Griswold's in the reports of the State survey, the Téjon and Miocene occur near to each other and both are fossiliferous. This region appeared to me well adapted to test the question whether or not there existed between the Téjon and Miocene any fossiliferous strata or any barren strata which might represent an intermediate age, for Messrs. Whitney and Gabb, regarding the Téjon as Cretaceous and Eocene fossils as absent, believed that there were unfossiliferous beds in the position which the Eocene should have occupied. Mere collections of fossils would scarcely be adequate to determine this point, and at my request Dr. White examined this locality with the special purpose of determining the presence or absence of an intermediate fauna. He found the Miocene and Téjon conformable here, as they usually are elsewhere, and traced the fossiliferous Téjon beds so close to the fossiliferous Miocene beds as to leave no room for an intermediate series.

The age of the Chico-Téjon series has been much discussed. Conrad first determined fossils from the Téjon which were collected by Prof. W. P. Blake near Ft. Téjon.[1] Of these specimens Conrad wrote: "The Eocene period is unequivocally represented by the beautifully perfect shells from the Cañada de las Uvas." Either through a misunderstanding or a difference of opinion these are referred to in the reports of the State survey as a "few imperfect fossils."[2] Conrad repeatedly reasserted, but never retracted, his

[1] Pacific Railroad Reports, vol. 5, p. 318.

[2] Geol. Survey California, Geology, vol. 1, p. 191.

view.[1] Gabb[2] vigorously maintained the Cretaceous age of the Téjon in his contributions to the State geological reports and elsewhere. Prof. J. D. Dana considers the Téjon as probably Lower Eocene and gives a list of the Téjon genera to show the Tertiary character of the fauna.[3] Prof. Jules Marcou asserts the Tertiary character of both the Chico and the Téjon on paleontological and apparently on lithological grounds.[4] Prof. Angelo Heilprin, who has charge of Gabb's types, has ably reviewed the Téjon question and pronounces emphatically for its Eocene age[5] Finally, Dr White has examined many of the principal localities in the field and the collections made by my party, as well as Gabb's types. His conclusion, as already stated, is that the Chico is distinctly Cretaceous and the Téjon distinctly Eocene, but that the two form an unbroken series with a gradual faunal change.

At the time of the principal controversy on the subject of the age of the Téjon the doctrine of evolution had not permeated science. It is now generally accepted that transitions must exist between the faunal groups or the geological periods which have received distinct names, and that the divisions actually adopted were determined by the local conditions of those regions in which geology was first studied. Twenty years ago the influence of earlier views was still very strong, cases of transition were accepted with reluctance, and few doubted that any series of beds exhibiting internal evidence of continuity of life and sedimentation must be referred to a single one of the standard series of formations, however remote the occurrence might be from the typical localities of western Europe. This feeling was particularly strong with reference to the Cretaceous and the Tertiary, between which, as everyone knows, there is a peculiarly sharp break, both in Europe and in the eastern United States. It was not unnatural therefore that Gabb should deny with as much emphasis as italics are capable of giving that the case in hand was one of transition or that Conrad should resort

[1] Am. Jour. Conchol., vol. 1, 1865, p. 362; ibid., vol. 2, 1866, p. 97; Am. Jour. Sci., 2d series, vol. 44, 1867, p. 376.

[2] Am. Jour. Conchol., vol. 2, 1866, p. 87; Am. Jour. Sci., 2d series, vol. 44, 1867, p. 226; Proc. California Acad. Nat. Sci., vol. 3, 1868, p. 301. The last is the most elaborate.

[3] Manual of Geology, pp. 457, 458, 491, 508.

[4] Rept. Chief Eng. U. S. A., 1876, p. 387; Bull. Soc. géologique France, vol. 2, 1883, p. 407.

[5] Proc. Phila. Acad. Sci., 1882, p. 195; Contributions to the Tertiary Geology and Paleontology of the United States, 1884, p. 102.

to the hypothesis of fossils washed out of earlier beds and redeposited in younger strata to account for the commingling of Cretaceous and Tertiary types in the Chico-Téjon series. In correcting their opinions Dr. White and I have simply taken advantage of the advances which geological science has made since their day.

Dr. White sums up the evidence as follows:[1]

The Maestricht, Faxoe, and other beds of Europe, although they are intermediate between the Upper Chalk and the Eocene, are too closely related by specific and generic forms to the Chalk to be regarded as separate from the Cretaceous proper. Their faunal relations to the Eocene are also too remote to allow of their being regarded as in any proper sense transitional between the Cretaceous and Tertiary. In New Zealand, however, it appears probable from the reports of the government geological surveys that there is in those great islands a true transition from the Cretaceous to the Tertiary similar to that which occurs in California.

I think the evidence which has been adduced to show the Eocene age of the upper or Téjon portion of the Chico-Téjon series is as conclusive as any evidence of that kind can be. Now, if we apply the paleontological standard for indicating the age of formations which is generally accepted by geologists, we necessarily refer the fossils of the lower or Chico portion of that series to the Cretaceous. The question then arises, to what portion of the full Cretaceous series, as it is recognized in other parts of the world, is the Chico group really equivalent? If the Téjon group is Eocene, it is plain that the Chico group represents the upper portion of the Cretaceous, and it necessarily represents the very latest portion of that period. My opinion, therefore, is that it is, at least in part, later than any formation that has yet been referred to the Cretaceous period either in Europe or in America, and that it practically fills the gap which is indicated by * * * Sir Charles Lyell.[2]

An examination of the figures and descriptions of the fossils which Mr. Gabb has referred to the Chico group, together with his catalogue of California Cretaceous fossils,[3] shows that while a considerable portion of them, especially the Cephalopoda, are of types which indicate their Cretaceous age, a large part of them are of genera which are known to range from the early Cretaceous to the present time, and some of them belong to genera which are generally accepted as not older than the Tertiary. Therefore there appears to be no inherent reason why this Chico fauna, even as it is represented by Mr. Gabb, should not be regarded as belonging to the very latest portion of the Cretaceous period. The fact that one or two Mesozoic types of cephalopods pass up from these strata into those of the Téjon portion does not necessarily prove that the latter ought also to be referred to the Cretaceous, any more than the discovery of *Ammonites* in the Carboniferous of Texas and of India ought to require us to refer those strata to the Mesozoic.

[1] Bull. U. S. Geol. Survey No. 15, pp. 16, 17.

[2] See Lyell's Elements of Geology, 1871, p. 281.

[3] See Geol. Survey California, Palæontology, vols. 1 and 2, for the figures and descriptions, and vol. 2, pp. 209-254, for the catalogue.

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The intimate relation to each other of all the strata of this great Chico-Téjon series, as shown by the mixed character of its fossils, is very perplexing when that condition is considered in relation to the established taxonomy of the formations, but it is very suggestive when considered with reference to a search after the complete sequence of geological events. Indeed, such a condition of things is what one ought to expect to find somewhere; but hitherto no other part of the world, if we except New Zealand, has furnished so striking an example of the intimate connection of two geological ages, or at least of such connection between the Cretaceous and the Tertiary.

The Miocene.—No sensible non-conformity is known to exist between the Téjon and the Miocene, yet the distribution of these two formations appears to indicate a change of level at or near the period which separates them, for the Miocene frequently rests upon the metamorphic rocks without the intervention of other beds During the Téjon these areas of metamorphic rock must have been land and the subsidence must have been a gradual one. It may have been more rapid in some localities than in others, however, and it thus appears not unlikely that an appreciable lack of conformity may yet be detected at some point or points between the Téjon and the Miocene.[1] The Miocene occurs on both sides of the Coast Ranges and on the lower western flank of the Sierra. It is also abundant in western Oregon, but is not well represented, if it exists at all, in northern California. It is composed in large part of sandstones somewhat irregular in texture and color and usually distinct from the earlier rocks. A great area, however, is mostly occupied by extremely fine-grained schists. These are associated with bitumen in the lower counties and extend up the coast to Santa Cruz and beyond. They are unusually barren of fossils, while the sandstones often contain almost incredible quantities of shells. The San Benito Valley is very remarkable in this respect.

The Post-Miocene upheaval.—The Pliocene of the Coast Ranges is of very limited extent and lies, as Professor Whitney showed, unconformably upon the Miocene, which is itself greatly disturbed. The combination of these facts shows that a great uplift took place between the two. As has been stated already, it is often far from easy to distinguish in detail the effects of this upheaval from those of the Post-Neocomian disturbance, and it may be added that still later uplifts further confuse the structure of the Coast

[1] Since this memoir was transmitted Mr. J. Marcou states that he has observed such a want of conformity as is mentioned in a former foot-note.

Ranges. In certain localities, however, as at New Idria, Mt. Diablo, and the Blue Range on Cache Creek, northeast of Knoxville, these effects can be somewhat satisfactorily compared, and it then appears that the Tertiary upheaval, important as it was, was far less violent than that which took place near the beginning of the Cretaceous. The extraordinary crushing so conspicuous in the Knoxville beds, and in which an almost inconceivable amount of energy must have been expended, is not observable in the disturbed strata of later age, which, as a rule, though inclined, form large adherent masses with gentle curves interrupted only at long intervals by faults. The beds from the Wallala to the Miocene are sometimes nearly vertical, but more generally lie at an angle of less than 45°. Along the western base of the great Sierra the effect of the Post-Miocene upheaval of the stratified rocks is, so far as I know, scarcely perceptible. It does not follow that it produced no effect in this region; on the contrary, the absence of known Pliocene beds from the Sierra foot-hills seems to show that the range was raised considerably at this epoch, though the energy of this movement was insufficient to produce considerable flexure in the beds. At the eastern side of the range, on the other hand, the fresh-water Truckee Miocene beds were thrown into bold folds, their dip reaching 30°.[1] The same upheaval was felt thoughout western Oregon, where it had the same comparatively gentle character as in the Coast Ranges.

Pliocene and Post-Pliocene strata.—Pliocene beds, in part of marine origin, were shown by Professor Whitney to exist at a number of points in the Coast Ranges. None of these is included in the areas surveyed in connection with this memoir. An interesting fresh-water series, however, occurs to the east of Clear Lake,[2] about the north fork of Cache Creek. The beds belonging to it are entitled Cache Lake beds on the map of the region accompanying this volume. They are composed of gravel, sand, and calcareous beds, partially indurated in spots, probably by the action of humus acids.[3] These beds appear to have a great thickness when measured perpendicularly to the dip, which varies from 10° to 40°, and the up-

[1] King: Op. cit., p. 455.

[2] This occurrence is referred to by Professor Whitney, who discovered no fossils in it (Auriferous Gravels, p. 23).

[3] See page 64.

turned edges are much eroded. They contain abundant but imperfect plant remains. Shells are rare, but were found at four localities. These are only partially fossilized, but the larger ones are compressed and broken by the weight of the superincumbent strata or by the movement accompanying their uplift. Most of these were found in light-colored, calcareous, soft, and excessively fine-grained material, manifestly a lake deposit.

The character of the deposits and the fact that the area occupied by them is continuous with a portion of Clear Lake led me to infer that Cache Lake might be regarded as representing Clear Lake at a more or less distant period. The recent lake deposits seem at some points to rest immediately upon those of Cache Lake, and I was unable to see any distinction between the fossil *Anodonta* and a species which is now abundant in Clear Lake These facts seemed to indicate that, in spite of very considerable upheaval, there existed a continuity of sedimentation and of life from the Cache Lake epoch to the present The shells were referred to Mr. R. E. C. Stearns, who fully confirmed my views from a paleontological standpoint, as the following abstract of his report will show:

The most conspicuous form among the fossils is *Anodonta Nuttalliana* Lea, of the winged or connate variety, described by that author as *A. wahlamatensis.* The numerous examples of this shell collected in the Cache Lake beds vary in no respect from living specimens readily obtainable in the present lake. The living specimens from Clear Lake are also characteristic and remarkable for the extreme development of the dorsal wing. The prominence of this feature Mr. Stearns has observed to coincide with areas subject to periods of drought and severe freshet. It certainly appears from the deposits of Cache Lake that there must have been great periodical variations in the quantity of sediments emptied into it. In Mr. Stearns's opinion this shell implies that the character of the streams emptying into Cache Lake was not markedly different from that of the present streams of the same area. The specimens range from an inch (adolescent) to over three and a half inches in breadth.

Another shell represented by numerous specimens from the Cache Lake beds is *Valvata virens* Tryon. This species was originally described from living specimens from the modern Clear Lake. A third abundant species is *Bythinella intermedia* Tryon. This shell is not known to exist in Clear Lake, but has a wide distribution on the Pacific slope. The fauna of Clear Lake, however, has not been systematically investigated, and Mr. Stearns thinks it by no means improbable that *B. intermedia* still exists there. A single specimen, certainly belonging to the genus *Pisidium*, and probably to the species *abditum* Hald., is not perfect enough for specific identification. There are several similarly imperfect specimens of *Helisoma ? ammon* Gould and an imperfect *Physa*, which is either *P. gyrina* or *P. heterostropha*. All these are living forms.

The age of these beds cannot of course be satisfactorily determined from fresh-water shells. The most careful watch was kept for vertebrate remains, but only a few fragmentary bones were discovered. These were referred to Prof. O. C. Marsh, who reports finding among them the fragments of a pelvis, apparently of a horse; the lower portion of a scapula, which he thinks belonged to a camel; and the head of a large femur, probably of an elephant or a mastodon. These imperfect fossils, he concludes, suggest a very late Pliocene age for the beds in which they occur. The continuity of life between Cache Lake and Clear Lake, with the continuity of sedimentation mentioned above, appears to preclude the supposition that the beds are older than the latter part of the Pliocene. Professor Marsh's report seems to show conclusively that they are not recent, and that they must therefore represent the close of the Pliocene. This determination is of great importance; for it fixes with accuracy the age of the asperites of Clear Lake and, in conjunction with other facts, determines approximately the age of the asperites of Mt. Shasta.

Distribution and age of the lavas.—The region about Steamboat Springs, Nev., includes the Washoe district, the eruptive rocks of which have been more extensively discussed than those of any other locality on this hemisphere. In the chapter on the massive rocks it will be seen that my studies of the rocks of Steamboat Springs and of the Washoe district have led me to the conclusion that the younger andesites form a natural group of trachyte like rocks, which I have called asperites. This same group is widely distributed in California. It forms a large and apparently the chief portion of the material of Mt. Shasta and the country surrounding it. Between this region and Clear Lake the country is practically unknown. At Clear Lake asperites form the bulk of the andesitic eruptions. Andesitic areas also extend almost uninterruptedly in a southwesterly direction along the Mayacmas Range, including Mt. St. Helena, to the neighborhood of Vallejo, on San Pablo Bay, which is practically the northern end of the Bay of San Francisco. Most of this andesite belongs in the asperite group. Andesites reappear at Mt. Diablo and to the eastward of Tres Pinos. Comparatively small amounts of older dense andesites occur at Clear Lake and in the Mayacmas Range. Rhyolite in the areas under discussion has been found only at New Almaden, but basalt is widely distributed. It occurs at Steamboat Springs and at Washoe and is abundant near Mt. Shasta and at Clear Lake In the ranges to the southward of Clear Lake basalt appears to be more widely distributed than andesite, occurring at Knoxville, in Sonoma County at the Mt. Pisgah quarry, at Mt. Diablo, and to the south of the Bay of San Francisco as far at least as the Panoche Valley. The volume of the basaltic eruptions is much inferior to that of the andesites.

No eruptive rocks of the Pre-Tertiary age are known to be intercalated in the Knoxville or Chico-Téjon series or to have broken through them. The only earlier eruptions encountered are represented by pebbles in the Knoxville and Chico conglomerates, and these are believed to have cut the granite before the deposition of the Knoxville beds. Excepting these pebbles, the earliest eruption known is pyroxene-andesite, which preceded the Cache Lake period. Had this eruption antedated the Miocene, pebbles of the lava would almost certainly have been found in the Chico-Téjon series of Lower Lake. It may have accompanied the Post-Miocene upheaval or it may have followed this uplift after an interval. I think it probable that the eruption took place at the time of the orographical change which dammed back the waters of Cache Lake, probably early in the Pliocene or just before it. Another outbreak took place at the close of the Cache Lake period after an interval long enough to permit of the deposition of at least a thousand feet of fresh-water strata. This eruption, represented by the asperites of Mt. Konocti, accompanied an orographical change which shifted the waters of Cache Lake to the present Clear Lake, and the lava now rests in places upon the older fresh-water strata. The beds immediately below the andesite contain a few fossil remains which, as shown above, correspond to the close of the Pliocene. The Pliocene beds near Mt. Diablo also contain andesite pebbles. In addition to the relations of the andesites to the sedimentary rocks at Clear Lake and Mt. Diablo, there is some other evidence bearing upon their age.

The asperites of Steamboat Springs and of Washoe show by the forms of their flows, by the slight traces of erosion, and the abundance of glassy modifications that they are comparatively recent. A comparison of the form of Mt. Shasta with that of a theoretically perfect volcanic cone shows that it is indeed considerably eroded, yet not so much so as to obscure its derivation from a form closely resembling that deduced from theory. This is also true of Mt. Konocti, on Clear Lake. The forms of these cones, as well as the character of the material of which they are composed, thus show that they, too, are comparatively recent. Furthermore, the amount of departure of these cones from the theoretical form is about the same for each, and so, too, are the other evidences of erosion. Hence they are approximately of the same age. From the relations of the asperite at Clear Lake to the strata, this age is known to be that of the end of the Pliocene, and Mt. Shasta, consequently, also dates from about the beginning of the Quaternary. I know of nothing tending to prove that the asperites of Washoe and Steamboat are either much older or much younger than the similar rocks of the Coast Ranges.

Of the age of the rhyolite of New Almaden as compared with the other lavas nothing is known. It is clear, however, that it postdates the Post-Miocene uplift, for, while the Miocene of New Almaden is much disturbed, the rhyolite dike intersects the disturbed Miocene and has itself not been affected.

The basalts are still younger than the andesites. The eruptions near Clear Lake are evidently referable to a somewhat extended period, but perfect volcanic craters remain. There are also said to be among the Indians of the region traditions of eruptions. In northern California there is good reason for believing that there has been a small basaltic eruption within forty years.

There thus seem sufficient grounds for asserting that a more or less continuous, but very irregular, volcanic belt stretches along the trend of the Coast Ranges from Clear Lake[1] at least to the neighborhood of New Idria, and that the eruptions, beginning in the Pliocene, extended into the recent period The andesites preceded the basalts and may perhaps be considered as confined to the Pliocene, if indeed this period can be sharply defined. There is considerable reason for believing that the andesitic eruptions of the volcanic belt of the Coast Ranges are of pretty nearly the same age as the main portion of the similar rocks of Steamboat and Mt. Shasta, and that there is no great difference in age between the basalts of Steamboat and those of the Coast Ranges. I by no means assert, however, that the successive phases of volcanic activity were absolutely contemporaneous over the whole coast.

No uplift which the Coast Ranges have experienced compares in violence with that of the Post-Neocomian epoch, and consequently, whether the initiation of volcanic action is referable to the very important Post-Miocene upheaval or not, it is a notable fact that volcanic activity did not accompany the most profound disturbance of the Pacific Coast. The metamorphism of the rocks at the period of the Post-Neocomian upheaval, on the other hand, seems reasonably ascribable to the co-operation of the heat thus engendered.

During the enormous period which elapsed from the close of the Neocomian to the close of the Miocene the erosion was extremely great, yet no eruptions took place. But at the close of the Miocene great masses of soft sandstones were elevated, which under similar meteorological conditions would be eroded much more rapidly than the harder rocks of the metamorphic series. The conditions in the Coast Ranges do not, therefore, exclude the hypothesis that the relief of pressure due to the rapid erosion of these soft rocks brought about the fusion of the lavas.

It is manifest that the eruptions took place substantially along old belts of uplift lines of weakness which are certainly not younger than the Post-Neocomian upheaval, and, as I have pointed out on a preceding page,

[1] Professor Whitney's parties met with no volcanic rocks in the Coast Ranges proper northward from Clear Lake.

are probably far older The distribution of volcanic rocks in the belt where they occur, however, is very irregular, corresponding to the irregularity of the entire chain of mountains called the Coast Ranges.

A close connection exists between the structural and historical geology of the quicksilver belt and deposits of cinnabar, as will appear in subsequent chapters. Here it is sufficient to say that ore deposition has taken place only since the earlier volcanic eruptions and seems in all cases to have been brought about by heated solutions of volcanic origin. Cinnabar occurs in almost every variety of the rocks found in the Coast Ranges, and the age and origin of the inclosing rocks do not seem to have affected the deposition of ore in any way.

APPENDIX TO CHAPTER V.

REMARKS ON THE GENUS AUCELLA, WITH ESPECIAL REFERENCE TO ITS OCCURRENCE IN CALIFORNIA.

By Charles A. White.

The fossil shells of the genus *Aucella*, although presenting no features which especially attract the attention of the ordinary observer, have come to possess unusual interest in certain fields of paleontological and geological inquiry. This is mainly due to the constancy of the distinguishing characteristics of the genus, its wide geographical distribution, its restricted range in geological time, and the controversy which has arisen as to the particular geological epoch which it represents. During the progress of his work, the results of which are recorded in this volume, these shells have become of especial interest to Dr. Becker because of their prevalence in certain of the strata with which he has had to deal. I have therefore, in compliance with his request, prepared the following remarks upon the genus, its geographical distribution, probable range in geological time, and the variation of the forms which have been referred to it under various specific names.

It is well known to paleontologists that at least a large part of the different genera which have been proposed for the Aviculidæ, the family to which *Aucella* belongs, are not so clearly definable and distinguishable from one another as could be desired, and also that the forms which have been ranged as species under those genera respectively are often found to be so exceedingly variable that it is difficult to decide whether they ought to be treated as species or only as varieties. While the features which distinguish *Aucella* as a genus are not so conspicuous as those which characterize many other molluscan genera, they have been found to be very constant in all the specimens yet known, even in cases of the most extreme variation in size and shape of the shell. Consequently this genus has not been found to merge into related generic forms by a modification of its distinguishing features, as have some of the other recognized genera of the Aviculidæ, and we may speak of *Aucella* as a genus with much more definiteness than we are able to do concerning any of the species which have been recognized under it.

The feature which more than any other distinguishes this genus being the short and peculiarly infolded anterior ear, the embedding of the shells in the stony matrix in which they are usually found obscures that feature in a large majority of the specimens which are collected. These shells in their general shape so much resemble small examples of *Inoceramus* that they have been frequently referred to that genus by authors and collectors when their distinguishing generic features have been obscured as before mentioned; but when their full characteristics are visible they are of course found to be without the transversely grooved hinge area and prismatic shell structure which characterize *Inoceramus.*

The genus *Aucella* has been recognized in certain of the Mesozoic rocks of both the northern and southern hemispheres, but its remains have been found far more abundantly in the former than in the latter part of the world, and they seem to be usually more prevalent in high northern latitudes than farther south. Indeed, so far as I am aware, this genus has been recognized at only two localities in the southern hemisphere, one being upon the northern island of New Zealand[1] and the other in the province of Sergipe, in Brazil.[2] In both these cases the recognition of the genus has not been so complete and satisfactory as could be desired, because of the imperfection of the only specimens discovered. Still, there seems to be no reason to doubt the correctness of its identification in either case. In the former case the specimens studied by Professor von Zittel seem to have been few as well as imperfect and in the latter case only two or three imperfect examples were discovered. Therefore the following remarks will refer mainly to those forms which have been obtained from the rocks of the northern hemisphere and referred to *Aucella* under various specific names.

The geographical distribution of *Aucella* in the northern hemisphere is circumpolar, extending far to the eastward in certain regions, and it has been found at numerous localities and in great numbers. Its known north and south range in the northern hemisphere is from far within the Arctic Circle to about latitude 45° in western Asia, to southern India, and nearly to latitude 35° in North America. It was first known in the vicinity of Moscow,[3] when it was referred to the genera *Inoceramus* and *Mytilus*, and afterward in Petschora Land,[4] when Keyserling proposed the generic name by which it is now known. Subsequently it was discovered upon the eastern shore of the Caspian Sea,[5] in northern Siberia,[6] upon Nova Zembla,[7] Spitzbergen[8] and Kuhn[9] Islands (the latter lying near the east coast of Greenland), in southern India, as already mentioned,[10]

[1] Karl A. Zittel: Reise der österreichischen Fregatte Novara. Geologischer Theil, vol. 1, part 2, Palaeont., p. 32, Pl. VIII, Figs. 4, *a*, *b*, *c*.

[2] C. A. White: Contribuições á Palaeontologia do Brazil (in both Portuguese and English), Archivos do Museu nacional do Rio de Janeiro, vol. 7, p. 56, Pl. III, Figs. 11, 12, and 13.

[3] Fischer De Waldheim: Oryctographie du gouvernement de Moscou, p. 177, Pl. XIX, Fig. 5. and Pl. XX, Figs. 1, 2, and 3.

[4] A. Keyserling: Wissenschaftliche Beobachtungen auf einer Reise in das Petschora-Land, pp. 297–301, Pl. XVI, Figs. 1–17.

[5] E. Eichwald: Geognost.-palaeont. Bemerkungen über die Halbinsel Mangischlak und die aleutischen Inseln, p. 53, Pl. VI, Figs. 10 and 11.

[6] Middendorff: Reise in den äussersten Norden und Osten Siberiens, vol. 1, No. 1, p. 255.

[7] S. A. Tullberg: Bihang till kongl. svensk. Vet.-Akad. Handl., vol. 6, pp. 1–24, Pl. II, Figs. 9–18.

[8] G. Lindström: Om trias- och Juraförsteningar från Spetsbergen, Kongl. svensk. Vet.-Akad. Handl., vol. 6, No. 6, p. 14, Pl. III, Figs. 3 and 4.

[9] F. Toula: Die zweite deutsche Nordpolarfahrt, vol. 2, pp. 497–505; also, Feilden and de Ranco: Quart. Jour. Geol. Soc. London, vol. 34, 1876, p. 56.

[10] F. Stoliczka: Pal. Indica, vol. 3, p. 404, Pl. XXIII.

in Alaska,[1] British America,[2] and in various parts of California.[3] In the latter region the first-discovered examples were referred to the genera *Inoceramus* and *Lima*, respectively, and their relation to the *Aucellas* of the eastern hemisphere was not then suspected.

Shells of this genus have been found at various other localities and have been referred to by various authors in their publications, but the foregoing references are sufficient to indicate the wide geographical and the interesting circumpolar range of the genus.

While the distinguishing generic features of the shells which have been found at all these widely separated localities in the northern hemisphere are constant, the range of variation in subordinate features, especially size and shape, is so great that no less than nine specific and several varietal names have been proposed by different authors who have studied them. The figures on the accompanying plates have been prepared to show the extremes of the variations which have been observed and to illustrate the principal forms respectively which have been selected as types of the proposed species. If only those forms to which the respective specific names have been applied had ever been known, the real specific identity of each might not have been questioned. Fortunately, however, *Aucella* having been a gregarious mollusk, great numbers of specimens have usually been found wherever any have been discovered, except at the New Zealand, Brazilian, and Indian localities. Consequently, so large a number of intermediate varietal forms have been found that I do not hesitate to express the opinion that none of the proposed species can be clearly diagnosed from the others, nor to treat as a specific unit all the forms referred to, with perhaps the exception of the Indian, Brazilian, and New Zealand examples.

It frequently happens that all or the greater part of the specimens found commingled in any given layer agree closely with some one of the recognized specific forms; and it is also true that two or three of those forms are often found commingled in one and the same layer. It thus often happens that a collection of these shells made at one locality or in one neighborhood is found to contain representatives of more than one, and sometimes of the greater part, of the forms which have been recognized as species by different authors. These representative forms have usually been selected by authors for reference and illustration, while little mention has been made of the intermediate forms. That the foregoing statement is correct appears from the publications of the various authors referred to, and it also accords with my own observations upon the collections that have been made in North America.

In view of the facts just stated, the conclusion seems to be necessary that all the forms of *Aucella* which have yet been discovered, especially those of the northern hemisphere, have so close a genetic relationship with one another as to hardly exceed the

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[1] E. Eichwald: Geognost.-palaeont. Bemerkungen über die Halbinsel Mangischlak und die aleutischen Inseln, pp. 185–187, Pl. XVII, Figs. 1–17; P. Fischer: Voyage à la côte nord-ouest de l'Amérique, par M. Alph. Pinart, pp. 33, Pl. A, Figs. 4 and 5; C. A. White: Bull. U. S. Geol. Survey No. 4, pp. 10–14, Pl. VI, Figs. 2–12.

[2] J. F. Whiteaves: Proc. Trans. Royal Soc. Canada, vol. 1, 1883, p. 84.

[3] W. M. Gabb: Geol. Survey California, Palæontology, vol. 1, 1864, p. 187, Pl XXV, Fig. 173; ibid., vol. 2, 1868, p. 194, Pl. XXXI, Fig. 92; Proc. California Acad. Nat. Sci., vol. 3, 1885, p. 173; F. B. Meek: Geol. Survey California, Geology, vol. 1, 1865, p. 479, Pl. I, Figs. 1–5; C. A. White: Bull. U. S. Geol. Survey No. 15; G. F. Becker: Bull. U. S. Geol. Survey No. 19.

limits which may be reasonably assumed as those of a single species. Professor von Zittel recognized the close relationship of the New Zealand form with *A. concentrica*, I found the Brazilian form to differ from the latter in hardly a greater degree, and Stoliczka's Indian species is evidently closely like certain varieties of *A. concentrica*. It may be, therefore, that we ought to regard this relationship as extending to the *Aucellas* of the southern hemisphere and possibly also to the Indian form, although the latter comes from strata which we seem bound to regard as of considerably later age than the others.

Admitting this close genetic relationship of all the known forms of *Aucella*, it is necessary to further conclude that they have been dispersed from some geographical center. The only published reference to such dispersion that has come to my notice is a brief suggestion by Mr. A. Pavlow that in Russia they were derived from the north,[1] but this does not fully meet the broader question of circumpolar and still more extensive distribution.

Having been dispersed from a single geographical center, the strata which bear the remains of the original colony are necessarily older than those which bear the remains of the colonies which were last established before the extinction of the genus to the extent of the time which was occupied by the dispersion and colonization. If, therefore, the dispersion was primarily from the north, the northern *Aucella*-bearing strata are necessarily older than the more southerly ones, and, if subsequent dispersion was from the eastern to the western hemisphere, the eastern strata referred to are necessarily older than the western. I think our present knowledge of this subject is too meager to warrant any definite statement as to the directions in which dispersion has occurred, but the geographical distribution of this assumed single species is so extremely wide and its climatic range has been so very great that the time required for its dispersion may easily have extended from the closing epoch of the Jurassic into the Neocomian epoch of the Cretaceous, and there are apparently good reasons for believing that such was really the case.

The genus *Aucella* has been regarded by the majority of authors who have written upon it as diagnostic of the Jurassic age of the strata which bear it; but certain authors whose opinions are worthy of consideration are equally confident that all such strata should be regarded as of Neocomian age. Professor von Zittel refers his *A. plicata* from New Zealand to the "Jura or Lower Cretaceous." The form described by me (op. cit.) from the province of Sergipe, Brazil, under the name of *A. braziliensis*, is from strata that I have referred to the Neocomian and there seems to be no possible reason to question the Cretaceous age of the Indian species described by Stoliczka. It is Professor Eichwald more especially who has contended for the Neocomian age of the *Aucella*-bearing strata of Europe and northern Asia, and he also makes the same claim for those of Alaska. Mr. Whiteaves (op. cit.) is equally confident of the Cretaceous age of the *Aucella*-bearing strata of British Columbia. In California, although a part of the strata which bear *Aucella* have been referred to the Jurassic, those which bear these shells most abundantly have been referred by all the geologists who have studied them to the Shasta group of the Cretaceous series, and there seems to be no good reason to doubt the correctness of that reference.

[1] Bull. Soc. géologique France, 3d series, vol. 12, 1884, pp. 686–696.

We do not yet know enough of the general geology of Alaska to speak confidently of the stratigraphical relations of the *Aucella*-bearing strata there; but there seems now to be no reason to doubt that all such strata in other parts of western North America ought to be referred to the opening epoch of the Cretaceous. I do not think, however, that the question of the exact geological age of these strata is of great importance in this connection, but no reasonable doubt can be entertained that a large proportion of the discoveries of *Aucella* have been made in strata of unquestionably Cretaceous age.

In the year 1864 Mr. William M. Gabb published specimens of *Aucella* from two separate localities in California and, as was then supposed, from two separate formations. The first of these was published under the name of *Inoceramus Piochii*[1] and the other under the name of *Lima Erringtonii*.[2] The first-mentioned fossils were afterward published by him as *Aucella Piochii*,[3] and Mr. Meek afterward republished and illustrated the others under the name of *Aucella Erringtonii*.[4] Mr. Gabb never doubted the Cretaceous age of the first-mentioned forms; but it seems that he regarded the strata from which came his *Lima Erringtonii* as of Jurassic age. Mr. Meek agreed with him in this respect, as did also other authors.

Upon an examination of the collections made in California by the division of the U. S. Geological Survey in charge of Dr. Becker, which were submitted to me in 1884, I became satisfied that the *Aucella Piochii* and *A. Erringtonii* of Gabb belong to one and the same species and that that species was no other than the one which had long been known under the various names of *A. concentrica*, *A. mosquensis*, *A. pallasii*, *A. crassicollis*, etc. (see Bull. U. S. Geol. Survey No. 15, p. 23).

As *Aucella Erringtonii* was obtained from the auriferous slate series in California, this conclusion of course involved the opinion that at least a part of that series is equivalent to the Knoxville division of the Shasta group, and therefore of Cretaceous age. This conclusion was supported by the personal discovery in the auriferous slates of the Mariposa estate, in company with Dr. Becker and his assistant, Mr. Turner, of specimens of *Aucella* that are plainly identical with the *A. Piochii* of Gabb, which is found abundantly in the Knoxville division of the Shasta group. These and other facts bearing upon the relations of the *Aucella*-bearing strata of different districts in California are discussed by myself in Bulletin No. 15 of the U. S. Geological Survey and by Dr. Becker in Bulletin No. 19. So far as I am aware, no other forms than those mentioned in this article are properly referable to the genus *Aucella*. It is plain that neither the *A. contracta* nor the *A. impressa* of Quenstedt belongs to this genus.[5] It is also evident that the greater part of the species which Stoliczka ranged under the genus *Aucella* were not intentionally so placed by him.[6]

EXPLANATION OF THE PLATES AND COMMENTS.

In the foregoing paragraphs I have expressed serious doubt whether more than one clearly definable species of *Aucella* is yet known, at least in the northern hemi-

[1] Geol. Survey California, Palæontology, vol. 1, 1864, p. 187, Pl. 25, Figs. 173, 174.
[2] Proc. California Acad. Nat. Sci., vol. 3, 1868, p. 173.
[3] Geol. Survey California, Palæontology, vol. 2, 1869, p. 194, Pl. 32, Fig. 92, *a*, *b*, *c*.
[4] Geol. Survey California, Geology, vol. 1, 1865, pp. 479, 480, Pl. I, Figs. 1, 2, 3, 4, and 5.
[5] Der Jura, p. 501, Pl. 67, Fig. 2, and p. 582, Pl. 73, Fig. 47.
[6] Pal. Indica, vol. 3, index, p. 513.

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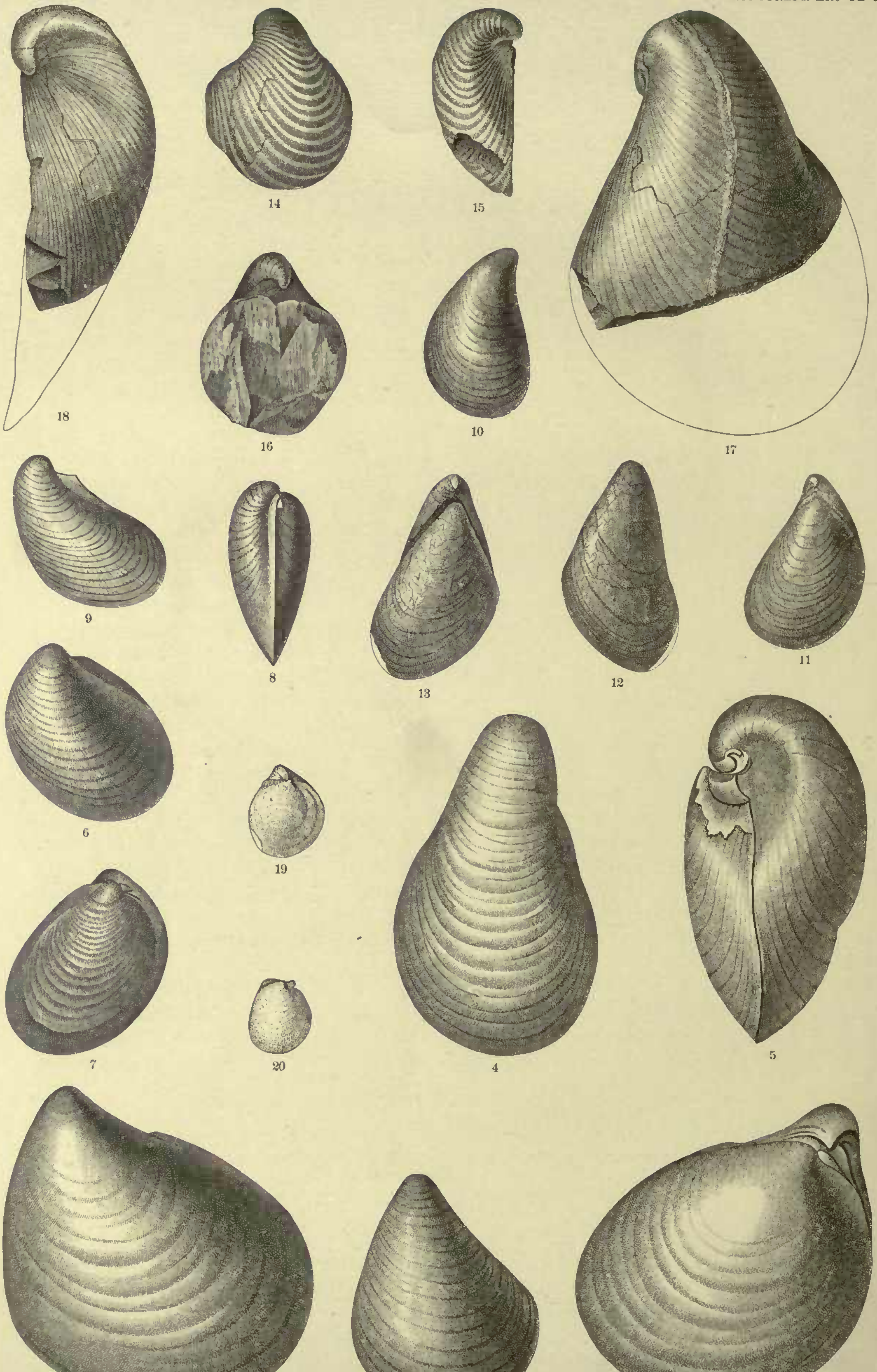


EUROPEAN AND OTHER FOREIGN FORMS OF AUCELLA.

sphere, with perhaps the exception of the species from southern India. If that view is to be accepted without qualification, some one only of the various names which have been proposed must be selected to designate that widely variable species. A common custom among naturalists in such cases is to take the specific name first used or proposed by the author of the genus, which is finally recognized as the true one. But I do not think the judgment of subsequent naturalists who have availed themselves of constantly increasing knowledge should always be hampered by rigid rules of this kind I have therefore selected the specific name *concentrica* to be used in ordinary cases, because the form to which that name is applied appears to have been the first one discovered and also because it is more generally prevalent than the one to which Keyserling gave the name *pallasii*, although he placed the latter name first under the genus *Aucella*. But in referring now to the various forms here illustrated I shall use the names which the different authors have applied to them.

The figures on Pl. III are mostly copies of those which represent the different forms that have been recognized in Europe, together with those from southern India, New Zealand, and Brazil. Those upon Pl. IV represent North American forms, a part of them being copies of figures previously published and a part having been prepared for this occasion.

PLATE III.

FIG. 1. A copy of Keyserling's figure of *Aucella concentrica*, from Reise in das Petschora-Land, Pl. XVI, Fig. 16.

FIGS. 2 and 3. Copies of Keyserling's figures (loc. cit., Figs. 13 and 14), representing *A. concentrica* var. *sublævis*.

FIGS. 4 and 5. Copies of Keyserling's figures of *A. crassicollis* (loc. cit., Figs. 9 and 11).

FIGS. 6, 7, and 8. Copies of Tullberg's figures of *A. mosquensis*, from Nova Zembla (Bihang till kongl. svensk. Vet. Akad. Handl., vol. 6, Pl. II, Figs. 16, 17, and 18). These figures are regarded by Tullberg as representing the form which Keyserling gave as the type of *A. mosquensis*. Keyserling figured only the right valve of one example, and, as the left valve was not illustrated, several authors besides myself have hitherto regarded *A. mosquensis* as having a more elongate form. Specimens having the beak of the left valve so short and so slightly prominent as is shown by Tullberg's figures have not often been observed in North American strata.

FIG. 9. A copy of one of Keyserling's original figures of his *A. pallasii* (loc. cit., Fig. 4). The radiating lines shown on this figure are often, but not always, observable on this form. They are sometimes observable on the other forms, but are more often absent.

FIGS. 10 and 11. Opposite views of a specimen in the U. S. National Museum from the vicinity of Moscow. It appears to belong to the form *A. pallasii*.

FIGS. 12 and 13. Opposite views of another example from near Moscow, presented to Dr. Becker by Professor Holzapfel. It may perhaps be regarded as a variety of *A. pallasii*, although some authors would probably regard it as quite as near to *A. mosquensis*. This uncertainty of specific recognition by different authors is of itself an indication of the instability of all the forms which have been designated as species.

FIGS. 14, 15, and 16. Copies of Professor von Zittel's figures of his *A. plicata* from New Zealand (Reise der österreichischen Fregatte Novara, Geol. Theil, vol. 1, part 2, Paleont., p. 32, Pl. VIII, Figs. 4, *a*, *b*, *c*).

FIGS. 17 and 18. Copies of original figures of *A. braziliensis* White (Contribuições á Palaeontologia do Brazil, Archivos Museu nac. do Rio de Janeiro, vol. 7). The narrow, rough seam along the middle of the figure is a mineral vein, and not a natural feature of the shell.

FIGS. 19 and 20. Copies of Stoliczka's figures of his *A. parva* (Pal. Indica, vol. 3, Pl. XXXIII, Figs. 2*a* and 3).

PLATE IV.

FIGS. 1 and 2. Copies of Gabb's original figures of his *Inoceramus* [*Aucella*] *Piochii* (Geol. Survey, California, Palæontology, vol. 1, Pl. XXV, Figs. 173 and 174).

FIGS. 3, 4, and 5. Copies of Gabb's subsequent figures of *Aucella Piochii* (Geol. Survey California, Palæontology, vol. 2, Pl. XXXII, Figs. 92, 92*a*, and 92*b*).

FIGS. 6, 7, 8, 9, and 10. Copies of Meek's figures of *Aucella Erringtonii* (*Lima Erringtonii* Gabb) (Geol. Survey California, Geology, vol. 1, Figs. 1, 1*a*, 2, 2*a*, and 5*e*). The radiating lines shown on these specimens seem to have been somewhat exaggerated by lateral pressure.

FIGS. 11, 12, 13, 14, and 15. Copies of the author's figures of specimens from Alaska, published in Bull. U. S. Geol. Survey No. 4, Pl. VI, Figs. 2, 3, 8, 9, and 10.

FIGS. 16 and 17. Two views of a remarkably ventricose left valve from the Knoxville division of the Shasta group near Knoxville, Cal.

FIGS. 18 and 19. Lateral views of two left valves from the Knoxville division of the Shasta group near Knoxville, Cal. These examples have suffered no lateral pressure, but the radiating lines have been made a little too distinct by the artist.

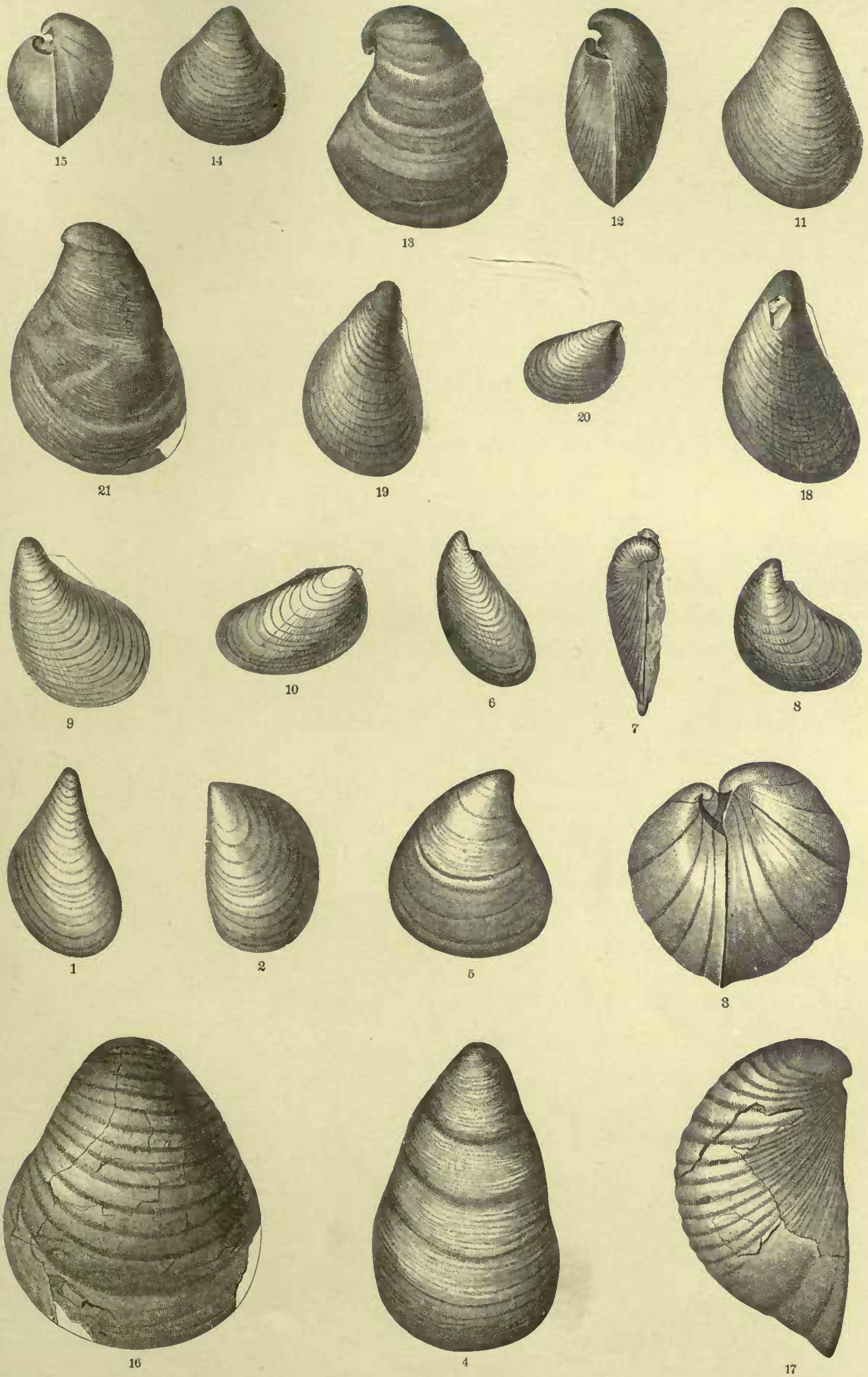
FIG. 20. A right valve from the same locality.

FIG. 21. A left valve from Washington Territory, collected by Prof. Thomas Condon.

These figures of North American specimens of *Aucella* show, if possible, a greater range of variation than do the figures given on Pl. III. The forms known by the specific names of *concentrica*, *pallasii*, and *crassicollis*, respectively, are readily recognizable among these figures of American *Aucellas*. There is, however, one form among them which has apparently not been recognized outside the limits of North America, and yet it is probable that it exists elsewhere. Figs. 16 and 17 represent an extreme example of this form or variety from California and Figs. 14 and 15 represent a less pronounced example from Alaska. On the other hand, the form which Tullberg figures as *A. mosquensis*, of which Figs. 6, 7, and 8, Pl. III, are copies, does not appear among the North American forms which are here figured, and it is probably rare in North American strata.

Figs. 4, 13, and 21 may be taken as representatives of the form *A. crassicollis*, and yet in each case the specimens represented by these figures were found commingled and embedded with other forms. Figs. 6, 7, 8, 9, and 10 are apparently referable to the form *A. pallasii*, as represented by Fig. 9, on Pl. III. Figs. 18, 19, and 20 ought probably to be regarded as varieties of that form, although there seems to be quite as much reason for referring them to *A. mosquensis*.

The radiating lines which appear upon some of these figures, as well as those of some European examples, are oftener seen upon the form *A. pallasii* than upon the other forms; but such markings are not exclusively confined to any one form. There is also much difference observable in the strength of the concentric markings of all the forms; but this cannot be regarded as even a varietal character. Many of the specimens appear unnaturally smooth, because of the fact that a large part of the examples discovered are casts of the interior of the shell, the test itself having been destroyed or removed.



AMERICAN FORMS OF AUCELLA

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CHAPTER VI.

DESCRIPTIVE GEOLOGY OF THE CLEAR LAKE REGION.

[Atlas Sheet III.]

General character.—Clear Lake is an irregular and picturesque sheet of water, lying at an elevation of 1,310 feet[1] in the heart of the Coast Ranges. Many of the surrounding hills rise to an elevation of about one thousand feet above the level of the lake, but the dominant feature of the scenery is the prominent mass of Konocti (or Uncle Sam), the summit of which, as measured by Mr. J. D. Hoffmann, stands 2,936 feet above the lake at high water (March, 1884). Konocti is a group of volcanic cones considerably eroded, but retaining clear traces of its original form, to which it approximates as nearly as do Mt. Shasta and Mt. Hood.[2] Like those mountains, too, it is composed of andesites of the group called asperites in a preceding chapter and is probably of very nearly the same age. The peaks are rocky and the declivity toward the remarkable basin of Little Borax Lake is precipitous. The eastern flank also is steep and the rock is exposed to view over a wide area. Here it is scored with three sets of concentric lines, which sweep across the mountain side in graceful curves and mark series of bedded flows of the lava composing the mass. The lower portions of Konocti and a very large proportion of the ranges of the district are densely clothed with brush, chiefly dwarf oaks, chamisal, and manzanita. These remain green throughout the summer and mitigate the impression of drought which the scenery in general creates. They also afford a refuge

[1] Determined by Mr. R. K. Nichols for the Clear Lake Water Company.

[2] See my paper "On the geometrical form of volcanic cones," Am. Jour. Sci., 3d series, vol. 30, 1885, p. 283.

for numerous deer and other wild animals, but neither the topographer nor the geologist can contemplate these smooth, green surfaces with any satisfaction, for the brush is often impenetrable for men or horses, while the matted roots and accumulated mold seldom allow an inspection of the underlying rock. The growth of the brush seems capricious and is not altogether dependent on either the exposure or the soil, for often a portion of a slope is densely covered with brush while the remainder is wholly free from it. The distribution, however, is probably governed to a great extent by the amount of moisture, for the southern exposures are much less often obstructed than the northern ones. The valleys, on the other hand, are usually free from brush and, like a portion of the hills, are studded with fine oaks, growing as a rule at distances of one or two hundred feet from one another and often as picturesquely disposed as if set out by a skillful landscape gardener.

This portion of California is full of mineral springs, and Clear Lake possesses its share, of which the warm chalybeate rising through the waters of the lake at Soda Bay is the best known and, with the charms of scenery, yearly attracts a number of visitors. Of more scientific interest are the two borax lakes—pools without outlets—in which borax has concentrated and accumulated to such an extent as to have yielded a large quantity of this salt to commerce. But by far the most remarkable locality in the region is the Sulphur Bank, where extremely hot springs and large accumulations of native sulphur were long ago known to exist. When this sulphur came to be exploited it was found that underlying and in part mingled with it there were large quantities of cinnabar. As may be seen from Chapter I, the production of quicksilver at this locality has reached a large total, though it has not proved the almost inexhaustible source of supply it was once supposed to be.

Geological map.—The Sulphur Bank lies at the extreme northwest limit of the area investigated by Professor Whitney and his assistants, and its general geological relations were so little known at the time when this investigation was undertaken that it was found indispensable to a clear understanding of the occurrence of ore to submit a district of considerable size to examination. The oldest rocks in the neighborhood of Clear Lake belong to the Knoxville group. They occupy the greater portion of the surface and are in great part highly plicated and metamorphosed or silicified. On this foundation rest Chico-Téjon beds, Pliocene strata, and volcanic rocks, with the last of which are associated the quicksilver deposits.

The distribution of the rocks is shown on the reconnaissance map (Atlas Sheet III). The topography of this map was not prepared for the Survey, the necessity for the examination of so large an area not having been apparent until the detailed examination of the Sulphur Bank had begun. It was compiled by Mr. C. F. Hoffmann from the published work of the former State geological survey, from plats in the surveyor general's office, private surveys by Mr. R. K. Nichols, of Lower Lake, the detailed map of Sulphur Bank prepared for this volume, private notes of the compiler, and a little supplementary work by Mr. J. D. Hoffmann. While it makes no pretension to the detailed accuracy of the special maps prepared by the geographical division of the Survey, it represents the country fairly well, perhaps as accurately as the present needs of this section of the State demand. The geology is represented upon it as minutely as the character of the map will permit, preference of course being given to the indications of the topography rather than to the bearings of known points wherever there was a slight discrepancy. The data are on record for still more accurate plotting, should the preparation of a detailed map ever be undertaken.

The Knoxville series.— No fossils of the Knoxville group were discovered in the immediate vicinity of Clear Lake, but the series was followed almost without a break to the Manzanita mine on Sulphur Creek, Colusa County, where *Aucella concentrica* and *Rhynchonella Whitneyi* are abundant. The lithological character of the altered rock of Clear Lake, its structural peculiarities, and its relation to the Chico-Téjon series, when compared with those of fossiliferous occurrences elsewhere, all indicate beyond any reasonable doubt that it belongs to the Knoxville group.

The Knoxville beds of the Clear Lake region have undergone very violent disturbances. A great deal of time and pains were spent in a systematic investigation of the dips of these rocks in the area shown on the map of Sulphur Bank for the purpose of constructing sections, but this was found wholly impossible. The entire mass has been shattered, and the blocks are very frequently so displaced that there is an utter discordance between the various dips observable in a single cropping of a few feet in diameter. That there may be predominant faults (Daubrée's paraclases), as well as the innumerable piesoclastic fissures, is not improbable; but between the extreme disturbance shown by the exposed rock and the proportion of the surface covered by soil this could not be determined. Only one result was obtained by the study of dips. This is, that the ridges are mainly synclinal folds, so that the prevalent dip of the Knoxville beds is into the hills. This result is not unimportant, because it shows that the region is deeply eroded and establishes another point of resemblance between the rocks of this group here and elsewhere.

The degree of metamorphism of the Knoxville beds of Clear Lake varies greatly. Some of the sandstones are extremely little altered and are characteristic micaceous arcose. Granular metamorphics, glaucophane schists, and serpentine also occur; but the transitions are so frequent and seemingly so capricious that it would be impossible to define the different varieties by areas.

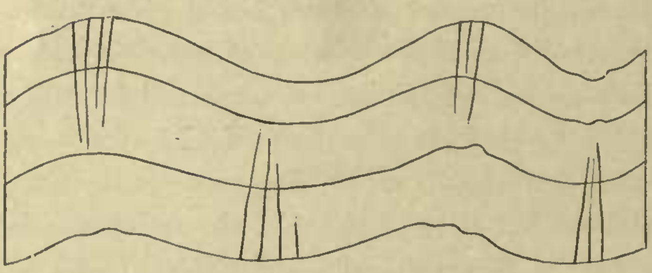

FIG. 5. Ruptures produced by compression of strata.

Structure of the ranges.—The regularity of some of the ranges is in strong contrast to the irregular disposition of the strata and is possibly due to the combined effect of plication and metamorphism. If a series of beds is thrown into folds, as in the accompanying diagram (Fig. 5), it is clear that the upper surface of the anticlinals will tend to crack open and also that a similar tendency will exist in the lower surface of the synclinals. If metamorphism is then induced by rising waters holding mineral matter in solution, such as silicic acid, the compressed under surface of the anticlinal will offer a resistance to percolation, while the fractured under surface of the synclinals will afford paths of least resistance. Metamorphism thus induced will therefore affect the synclinals more than the anticlinals, and, if erosion follows, not only will the relief and the fractured surface of the anticlinals tend to their degradation, but the resistance of the synclinals will be increased by the silicification and cementation of the mass. It is quite conceivable that the combined effect of plication and metamorphism as here imagined should be such as to result in a much more regular modeling of the surface by erosion than would have been induced had either plication or metamorphism alone influenced the course of degradation.[1]

The Chico-Téjon series.—Toward the southern end of the map the Chico-Téjon series appears. It consists chiefly of soft sandstones of a tawny hue where exposed to oxidizing influences, but bluish in color below the water-line, as is usual with sediments containing a small amount of iron. This series, though tilted and disturbed, is not crushed or plicated like the older strata to the north. It also includes conglomerates full of metamorphic pebbles, in some cases showing an unusually brilliant polish. These pebbles are highly siliceous and on this account do not at first sight appear to resemble the extensively developed metamorphic series. In cases of this kind, however, it is necessary to remember that even feldspathic rocks are rapidly disintegrated in moving water and that quartz is almost the only mineral which will long retain the form of pebbles. Concretions are common in these rocks, occasionally with fossil nuclei, but usually without any distinguishable nucleus. They sometimes weather more and sometimes less rapidly than the rock in which they are embedded and are often composed of concentric shells. Some argillaceous deposits and a little limestone occur in this formation. The Chico-Téjon series of this region is fossiliferous, though organic remains are by no means generally distributed through it. Mr. Gabb collected a considerable number of fossils here, and so also did my party.

The Chico-Téjon series does not come in contact with the metamorphic rocks in such a way as to demonstrate a non-conformity, alluvium and lava intervening on the surface; but the sudden change in lithological character and the comparatively trifling disturbance of the unmetamorphosed rocks

[1] See Dana, Manual of Geology, p. 750.

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are sufficient to suggest a non-conformity. When this relation has been shown to exist elsewhere it is manifest that it affords a satisfactory explanation of the facts at Clear Lake.

No Miocene strata have been detected with certainty in this part of the country. It is possible that such were deposited and have since been completely removed by erosion; but this appears to me very unlikely. Remnants of them would almost inevitably have been preserved, if not elsewhere, at least beneath the fresh-water Pliocene. I believe it much more probable that a gradual rise of this region took place in the early Tertiary, such as has occurred in recent times throughout the State, and that during the Miocene this was a land area. No violent uplift can have intervened between the Téjon (Eocene) and the Miocene, however; for, wherever the two come in contact, as is frequently the case to the south, they almost always appear entirely conformable.

First andesitic eruption.—After the deposition of the Chico-Téjon rocks the first geological event traced was the eruption of Chalk Mountain. This was probably coeval with the ejection of some of the rock near Thurston Lake. These lavas are dense pyroxene-andesites, which have been described in Chapter IV. Chalk Mountain lies upon the north fork of Cache Creek, about half a mile above the highest point of the creek shown on the map. It is a small conical hill, from a part of which the heavy bases have been extracted by sulphur springs, still feebly flowing. Portions of the mass are fresh, however. Chalk Mountain rests upon crumpled, metamorphic strata, which were deeply eroded before the ejection of the rock. The outflow of this rock certainly preceded the Cache Lake period, for the lake beds are found upon its sides, and fragments, either from Chalk Mountain or from other unknown masses of precisely similar lithological character, are abundant throughout all the lake beds shown on the map. Chalk Mountain may have somewhat antedated Cache Lake, but there is as yet nothing to indicate an interval, and it seems more probable that its eruption accompanied the orographical changes which in the Pliocene, and probably early in that period, dammed back the waters of the region.

Cache Lake beds.—That Cache Lake occupied an extensive area is certain. It extends to the east an unknown distance, and how great a proportion of it is included in the map has not been ascertained. These beds consist, first, of conglomerates, carrying pebbles of metamorphic rock identical with that which underlies them, and of pyroxene-andesite which cannot be discriminated from that of Chalk Mountain; secondly, of sand beds; and, thirdly, of argillaceous and calcareous deposits. For the most part the strata are but little compacted and may be reduced to powder in the hand; but there are frequently nodular masses which are consolidated to firm rock. Some of the bluffs of conglomerate—for example, those in Grizzly Cañon—are studded with such nodules, distributed somewhat uniformly over the surface. Elsewhere single strata of sand or clay are petrified, and occasionally, as on Perkins's Creek, considerable areas of sandstone fully solidified are met with. The impression conveyed by the prevalent distribution of the more extended and irregular, hardened masses is that they represent the local action of cold, calcareous or siliceous waters upon the surrounding rock, an action which, if sufficiently prolonged, would result in the complete petrifaction of the whole system of beds. A similar effect of mineral springs on recent deposits may be seen at several points in the district, particularly along Sweet Hollow Creek. The isolated nodules cannot be produced in this way and, like those in the Chico of New Idria, they are probably due to the decomposition of organic matter, as explained in Chapter III.

The Cache Lake beds have been subjected to comparatively little disturbance. They are tilted at angles varying from 10° to about 40°, but the inclination seldom changes rapidly, and there is very rarely anything which can be regarded as contortion. Within the area of the map, too, no faulting was traced, though more or less important disturbances of this nature occur near Chalk Mountain and on the north fork of Cache Creek, east of the map limit. The thickness indicated by measuring the strata perpendicularly to the planes of stratification is very great—some thousands of feet. I confess myself unable either to comprehend this or to ignore its significance. There is certainly no confusion between these beds and others of marine origin, since fresh-water shells were found in them at widely separated horizons; but the accumulation of several thousand feet of sediment in any lake except one of vast dimensions seems an impossibility. A careful search was made for faults without finding any. The probabilities, however, seem to me in favor of the supposition that these really exist, but thus far have escaped detection. Even on this assumption I believe it impossible to reduce the estimate of the thickness of this deposit below 1,000 feet.

Cache Lake fossils.—The argillaceous strata of the Cache Lake period are full of organic remains, but unfortunately these are chiefly vegetable. Shells were detected in only four localities: on the Grizzly Cañon road near the top of the divide between Burns's Valley and the north fork of Cache Creek; at an exposure on the hillside about a quarter of a mile north of this point; close to the mouth of Indian Creek; and in an exposure on Cache Creek a quarter of a mile below its intersection with the road from Lower Lake to Sulphur Bank. Of these the first and second are much the richest. They show a series of mollusks, the most important of which are identical with those now abundant in Clear Lake, while all of them survive on the Pacific slope, and not improbably in Clear Lake itself. They have been enumerated and discussed in Chapter V. According to Mr. Stearns, who is unquestionable authority on this subject, they show that the physical conditions prevailing in Cache Lake were not markedly different from those of the present Clear Lake. The peculiarities of form of one of the shells, the ordinary *Anodon* of Clear Lake, are also such as to show that in spite of the difference of position and notwithstanding the very great orographical modification which the country has undergone, there has been an absolute continuity of life from the Cache Lake period to the present time. No doubt mollusks, and particularly locomotory species like this *Anodon*, are able to survive tolerably vigorous disturbances, but the facts show that from a faunal point of view the elevation of these lake beds was not catastrophic. In spite of careful search vertebrate remains were found in only two localities. These points are a small side ravine leading into Grizzly Cañon from the north and a vineyard near Lower Lake.

Other characteristics.—As might be expected from the character of the Cache Lake deposits, they are extensively eroded. In many cases the resulting forms are strongly suggestive of those of the Bad Lands of Wyoming, showing fantastic pinnacles, pillars, and gorges. This is especially noticeable north of Chalk Mountain and in Cub Gulch. In most portions of the area the erosion has been largely controlled by the stratification, and the resulting hills show straight slopes on one side parallel to the stratification and abrupt declivities on the other where the strata have been broken through. As seen from the Grizzly Cañon road about two miles south of the north fork of Cache creek, a succession of such hills might be taken for a series of monoclinal uplifts. Near the stream the Cache Lake strata have also been extensively terraced. But, while the erosion of these beds has been considerable, when their prevalent earthy character and exposed position are taken into consideration it is clear that, geologically speaking, they must be comparatively recent, since otherwise they would long ago have been washed entirely away.

On and near the north fork of Cache Creek the lake beds are covered unconformably by a deposit of gravel usually 50 feet or less in thickness. This is somewhat obscurely stratified, unconsolidated, and has been tilted, though less than the underlying lake beds. It presents no strata in which there would be any hope of finding fossils and its origin is not certain. It may possibly represent the very last stages of Cache Lake, or, as seems to me more probable, the earliest river deposits after the close of the Cache Lake epoch.

The lake beds can best be studied in the eastern corner of the area mapped, for in the volcanic areas near Lower Lake the strata have been considerably altered. Especially is this the case near the andesite, which lies upon the Cache Lake beds conformably and has produced a decidedly metamorphic influence upon them. This consists in depositions of calcareous matter, silica, and ferric hydrates, apparently through the action of hot springs or of water heated by contact with the volcanic rock, rather than by the direct influence of the heat of the lava. Similar results are noticeable where the basalt has come in contact with the lake beds; for example, near the lime kilns, northeast of Burns Valley. The metamorphosed lake deposits yield a red soil full of white masses of calcareous rock, which is said to be extremely fertile.

Relation of Cache Lake to Clear Lake.—As may be seen from the map, Cache Lake overlapped the area at present occupied by Clear Lake, while, as has been pointed out, the identity of the shells in the two and other circumstances show that their history must have been continuous. The later andesite, represented by Mt Konocti, overlies the latest Cache Lake strata and also underlies the Clear Lake sediments. It is impossible to avoid the conclusion that the eruption of this rock accompanied the obliteration of Cache Lake and the orographical changes which confined the waters to their present bed. The vertebrate remains in the vineyard near Lower Lake thus fix the geological date at which the Cache Lake period terminated and also the date of the eruption of the asperites of Mt. Konocti. As was noted in Chapter V, the vertebrate fossils are Pliocene, while the amount of erosion and the relations to the modern lake beds show that they are Upper Pliocene. The date of the eruptions is thus fixed at about the close of the Pliocene epoch.

Later andesitic eruption.—The later andesite is most prominently represented by Konocti (or Uncle Sam) Mountain, but the same rock covers a large area to the southeast and a considerable tract to the northeast of the more southerly branch of the lake. It is described from a microscopical point of view in Chapter IV. The prevalent variety of the rock is a coarse-grained porphyry, sometimes dark and sometimes rather light colored. One of its marked features is the frequency of laminated structure.[1] The laminæ are usually half an inch or more in thickness and not very sharply divided from one another. Weathered surfaces of such rock are corrugated, and at a little distance the rock might be thought sedimentary rather than volcanic. Where heavy masses are cut through, columnar structure is sometimes seen. It is particularly fine near Little Borax Lake. Between Konocti and Thurston Lake there are also vast quantities of obsidian and pumice, the former covering almost continuously a large tract, through which the road from Kelseyville to Lower Lake passes. On this line it is about four miles in width and it is said to extend a still greater distance to the southwest. The best locality for the study of these forms is on Thurston Creek, between one and two miles northwest of Thurston Lake. Here the obsidian and pumice are interbedded with the porphyritic ande-

[1] In Geol. Survey California, Geology, vol. 1, p. 96, Professor Whitney states that, as seen from the opposite side of the lake, Uncle Sam appears to be made up of a closely folded, synclinal mass, probably of somewhat metamorphic Cretaceous sandstones. This impression he certainly received from the exposed edges of these flows. In Auriferous Gravels, p. 23, this mountain is correctly mentioned as volcanic.

site, all being intermingled, often with the accompaniment of transitional forms. In some cases nodules of obsidian are immediately inclosed in concentric layers of pumice and vesicular obsidian, while in other instances angular fragments of obsidian are directly embedded in structureless pumice. In this locality the stream has cut through solid obsidian, leaving sheer walls ten or more feet in height. Elsewhere in the district this glass is rarely found exposed in place, owing to its tendency to break up into small fragments which cover the surface. The andesitic obsidian is usually distinguishable with ease from basaltic glass by its higher and more resinous luster and its greater opacity. The andesitic origin of this glass is demonstrated by its manner of occurrence. The microscopic character agrees with this reference.

About three miles from Kelseyville, on the Lower Lake road, and again a little northwest of Thurston Lake, stratified, andesitic tufa is found The former occurrence is very considerable and of course indicates the presence of water during the eruption, though Cache Lake beds have not been recognized in the neighborhood. The presence of ponds or lakes near volcanoes is of course a usual phenomenon, due to the damming back of streams by ejecta or to more or less important orographical changes.

Age of the younger andesite.— Excepting the bed of Clear Lake, the whole region has been undergoing erosion ever since the andesitic eruption, and the surfaces of the flanks and peaks of Konocti show that the degradation has been considerable. There is no recognizable trace of a crater on the peak; on the contrary, the bedded flows of rock near the summit are shown in cross section. Sufficient time has elapsed since the eruption to permit considerable decomposition in exposed masses of rock. The summit, however, is more exposed to degradation than the general surface of the country, which has been little lowered in recent times, the underlying metamorphic Cretaceous and Pliocene rocks, where they have been protected by the andesite, not lying perceptibly above the ordinary level. The main area of andesite southwest of the lake probably overlies metamorphic hills, for altered Cretaceous strata appear under the volcanic rock at the extremity of Elgin Point ("Snake Rocks") and at Bailey Point. The present topography of the country between Konocti and Thurston Lake is scarcely intelligible except upon the supposition that its principal features are due in great measure to those of the original lava surface; for it presents a series of elongated basins either without apparent outlets or with only very narrow, sharply cut outlets, and these depressions either contain permanent lakes, like Thurston, or winter pools, like some others in the neighborhood, or present flat surfaces of fine soil, evidently the result of the silting up of lakes. These areas of sedimentation, flanked as they are by massive ridges of lava, cannot be due to erosive agencies, and there is nothing whatever to indicate that they are due to orographical changes postdating the andesite eruptions.

Thurston Lake.—Thurston Lake is a peculiar body of water, surrounded on three sides by heavy masses of andesite, with high and steep slopes. On the fourth side, toward the northwest, the lake bottom rises at a very slight angle and merges into an elongated valley of considerable length. The addition of a few feet of water would double the length of the lake in this direction, while adding almost imperceptibly to its extent elsewhere. The water marks show that the height of water varies about eleven or twelve feet. In spite of its lack of any visible outlet, this lake is fresh and abounds in animal life, some of the fish being apparently of the same species as those of Clear Lake. Its fluctuation is also sensibly the same as that of Clear Lake, and, as nearly as can be estimated without a special survey (a task which the dense brush would render very expensive), its level is the same. The only probable explanation of these facts would seem to be that there is an underground passage between the lakes—a supposition in which there is no inherent improbability, since channels such as that supposed frequently exist in volcanic masses, especially within a moderate distance of their original surfaces.

Little Borax Lake.—As has been seen, there is much structural evidence to show that the andesitic rock of Konocti Mountain is not recent, but that it is geologically of late origin. The surroundings of Little Borax Lake, however, seem to indicate a local activity long postdating the andesitic eruption. This little saline body of water lies in a crater-like depression at the foot of the mountain, a portion of the walls being very abrupt and evidently representing fractured surfaces, while the basin itself contains very little detritus. Were it a crater anything like so old as the mass of the mountain, an outlet would almost certainly have been cut through the low swell of land separating it from Clear Lake on the east and much material must have fallen into the basin from the perpendicular cliffs of columnar andesite to the south. On the other hand, there seems to have been no outflow of lava, either andesitic or basaltic, from this basin. There is, moreover, evidence that Elgin Point has been considerably raised in very recent times, and it appears probable that the basin of Little Borax Lake was formed by an explosive outburst, which was nearly or quite contemporaneous with the basalt eruptions to the southeast. A partial renewal of volcanic activity on the old line of eruption at a period of volcanic disturbances in the immediate neighborhood is certainly nothing to be wondered at. The origin of the borax in this lake is no doubt entirely similar to that of the borax in the other and more important lake near Sulphur Bank, which will be discussed in the next chapter. There are now no hot springs flowing into it, though there are warm springs associated with the andesite at several other points.

Quicksilver deposits in andesite.—At two localities on the southern side of Mt. Konocti cinnabar has been found. One of these is close to the base and was known as the Bowers mine. It is abandoned, and all that could be made out from the accessible workings was that the associated andesite is quartzose and is bleached by solfataric action. The Uncle Sam mine is high up on the flank of the mountain. It, too, is in dacite, much decomposed, as if by the action of heated waters or gases. A considerable quantity of ore was formerly extracted at this point and sold to the Sulphur Bank Company, but statistics were not obtainable.

It is possible that the dacite eruptions were later than the mass of the mountain and that the solfataric action accompanying the outflows of this rock induced the deposition of ore, but no conclusion on this subject was reached. It is certainly remarkable that the only dacite occurrences known in the district are thus associated with the only quicksilver deposits known among the andesites.

Basaltic eruptions.—The eruptions of basalt of the Clear Lake region were greatly inferior in volume to those of andesite, even more so than would appear from an inspection of the map, for, owing to the greater fluidity of the lava, the basalt fields are of less depth than the andesitic masses. While, too, some general orographical changes appear to have accompanied the emission of basalt, as was almost inevitable, these were far smaller in amount than those which closed the Pliocene epoch.

The basalt of the region under discussion is a fairly typical rock, presenting the usual structural peculiarities and mineralogical composition on the whole, though the distribution of olivine is irregular. In some occurrences this mineral forms a large percentage of the whole mass, while in others considerable search with the lens, or even with the microscope, must be made to detect it. Very interesting glassy forms of basalt occur near Borax Lake, of which further mention will be made in the next chapter. It does not appear that all the basalt was emitted at the same time, or even approximately so, for the evidences of erosion on some of the areas are very perceptible, while on others there has been no considerable degradation. On the whole, the basalt must be considered as decidedly recent, for only on that supposition can its state of preservation be accounted for. Thus, McPike crater is a rounded mass, unfurrowed by rivulets, at the top of which is an extremely regular, basin-like crater about nine hundred feet in diameter and fifty to one hundred feet deep, presenting a surface entirely covered with lapilli. That this basin contains no water is probably due to the porosity of the sides, which seem to be composed of lapilli. The walls are unbroken and vegetation has only begun to find root between the pebbles. The only sign of age is the fact that the surfaces of the lapilli are reddened with ferric oxide. On the hills directly north of McPike crater the surface is covered with lapilli, which almost entirely conceal the underlying metamorphic rocks. These pebbles could not possibly have been transported to their present position by water, which, on the contrary, must eventually sweep them down into the valley. In fact, they appear to have fallen as they lie during an eruption, since which there has not been sufficient rainfall to remove them. The north and south craters at Sulphur Bank are similarly fresh, excepting that in each case one side of the crater is broken down; but there is no evidence that this is a result of erosion, for there is no stream bed or dry wash leading into them. Close to the

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Sulphur Bank, on Indian Island, on Red Hill, and west of Lower Lake contorted masses of lava remain on the surface, where they chilled after oozing from vents or from cracks in the lava streams. It is also indicative of the lateness of the basalt eruptions that fragments of the rock are usually to be found only in the immediate neighborhood of the main areas. There does not seem to have been time enough since the eruptions to effect any general or even widespread distribution of pebbles. At Sulphur Bank it is also said that the Indians have traditions of eruptions. While this fact might have little significance were any portion of California now the seat of volcanic activity, it seems not without weight when it is remembered that the nearest volcano now active is very far away. At all events, it seems to me by no means impossible that the latest eruption may have occurred within a thousand years or even less.

The relations of the basalt areas to the general structure of the underlying metamorphic rocks are not easily studied, for lack of exposures. I have endeavored to make out the fissure system which no doubt connected the various vents of the basaltic eruptions, but have failed to reach any satisfactory conclusion.

There are but two places in the district where basalt tables occur. Of these one is at the extreme eastern end of the McPike area, where the lava appears to have followed the bed of the north fork of Cache Creek and to have been subsequently undermined by the stream. The rock has fallen off in columns, leaving perpendicular walls. The other bluffs are comprised in the area northeast of Red Hill, and, like all similar occurrences, are a result of undermining. In both cases I can but suppose that the lava represents much earlier eruptions than those which left the unimpaired craters nearer the Sulphur Bank, though they are both Post-Pliocene, resting unconformably upon the uplifted Cache Lake beds.

Clear Lake.—Both the topography and an examination of the soils show that Clear Lake formerly occupied a considerably greater area than it now does. The flat land about Sulphur Bank once formed a portion of the lake bottom, and would again do so were the lake to rise 50 or 70 feet. A much smaller rise would flood the valley now in part occupied by Borax Lake, the surface of which is but a few inches above the level of the lake.

This valley must once have been much deeper than now and in part have silted up.

Burns Valley, an area near the town of Lower Lake, the whole of Big Valley, and portions of the country about Upper Lake, as well as many small flats along the lake shore, are clearly also covered with recent lake deposits.

The causes which might have produced this shrinkage of the surface of the lake are erosion of the outlet or orographical changes, or both. Had the lake bed only been tilted to the southeast, the tendency would have been to expose the bottom to a considerable depth at the west end, but not near Lower Lake. Orographical changes alone are consequently insufficient to explain the exposure of the meadows. Cache Creek, just beyond the limits of the map, passes through a narrow gorge of Cretaceous sandstone, and the mere erosion of this barrier would produce the effect under discussion, but there is some evidence to show that orographical causes have influenced the grade of Cache Creek and consequently its capacity for eroding its bed. On the north fork of Cache Creek the banks are extensively terraced and four or five flood plains are distinctly visible. This appears to mean a tilting of the country to the eastward, though probably to the extent of only a very few inches to the mile. Such a widespread secular change would increase the velocity of Cache Creek, as well as of its northern fork, and accelerate the erosion of the sandstone gorge near its source. Were the circumstances more favorable, such a change, if it really took place, might be detected on the banks of the lake, which would also be terraced. Two causes seem to have stood in the way of such a modification of the shore. The first of these is the resistance offered by the sandstone of the gorge, which would yield but slowly to an increased velocity of a current carrying little sand in suspension. It is well known that the erosive power of lake water is slight because it is so free from sand, and the erosion of the gorge would probably be still slower than it is were it not for the fact that Herndon Creek flows into Cache Creek between the lake and the gorge. The second influence tending to prevent the formation of terraces is the tule belt. A strip of these reeds, from a few feet to a few yards in width, grows almost everywhere along the lake shore, separated from the beach by a few feet of open water. Even when the lake is in a state of very considerable agitation scarcely a ripple reaches the shore thus protected, and not only is the erosion of the banks in great measure prevented, but sedimentation is favored, so that in some places the shore appears to be growing into the lake by the accumulation of tule roots and sediment. On the whole, therefore, the lowering of the lake level in comparatively recent times is not improbably the result of the erosion of the bed of Cache Creek, assisted by a very gradual and gentle tilting of the whole region toward the east or southeast.

Certain limited orographical changes have unquestionably taken place about the lake in very recent times. At the end of Elgin Point is a steep bank, consisting of uncompacted strata of material precisely similar to that found on the old lake bottom areas at the Sulphur Bank, in Big Valley, and below the high-water mark of the lake. It consists of mud, in which pebbles of metamorphic rock and of later andesite are abundant. In the lower strata of this bank, which is about one hundred and fifty feet high, scoriaceous forms of andesite occur, which are no longer to be met with on the surface in the neighborhood. The southern side is a curved slope parallel to the planes of stratification and essentially unsculptured by water, and the bank would seem to represent an uplift of about the same date as the finely preserved craters near Sulphur Bank. If the hypothesis suggested with regard to the formation of the basin occupied by Little Borax Lake be correct, this uplift was probably its concomitant. These recent strata rest in part upon metamorphic rocks and in part upon the andesite which constitutes the main mass of Elgin Point. A very similar bank of the same date, but less well exposed for study, occupies the south side of the entrance to Upper Lake.

It is the inevitable fate of lakes to be filled with sediments to a dead level, but, as the evidence seemed to be that the sediments of Clear Lake are not of great thickness, it appeared to me desirable to examine the topography of the bottom. Several hundred soundings were made for this purpose, the results of which are shown in the subaqueous contours on the map of the lake. From these it appears that the water is deepest near the narrows, as would be the case if the lake occupied valleys of erosion between ranges which had attained essentially their present configuration prior to the formation of this sheet of water.

The map, in accordance with the rules of the U. S. Land Office, shows the outline of the lake at high water. The subaqueous contours are referred as nearly as may be to the same level, or 10 feet above the lowest point which the lake has reached in ten years. This point was noted by Capt. R. S. Floyd, who has kept a full record of the level of the lake referred to throughout this period. The lake occasionally rises a little more than 10 feet above low-water mark, but not enough to make any important difference.

CHAPTER VII.

DESCRIPTIVE GEOLOGY OF SULPHUR BANK.

[Atlas Sheet IV.]

Sedimentary rocks of the district.—The results of a general study of the region of Clear Lake, undertaken for the purpose of throwing light upon the history and geological relations of Sulphur Bank, have been presented in the preceding chapter. The area delineated in the detailed map of Sulphur Bank includes few formations. The underlying rock everywhere belongs to the Knoxville series (Neocomian), representing the opening of the Cretaceous period. This rock was intensely crushed and irregularly metamorphosed not long after its deposition, but neither the quicksilver deposits of this locality nor those of any other included in this memoir were formed at the epoch of metamorphism. All the varieties of metamorphic rocks described in Chapter III occur in this small area, from almost unaltered sandstones up to material so highly recrystallized as closely to resemble an eruptive porphyry. Serpentine is also found in very small quantities on the ridge north of Borax Lake. It appears again near the end of Sunken Point, shown on Atlas Sheet III. The little spot of serpentine near Borax Lake might be shown on the detailed map by a separate color, but the metamorphism is so irregular in intensity that it would be quite impossible to delineate areas of pseudodiabase, pseudodiorite, and glaucophane schist.

No eruptive rocks are interbedded in the metamorphic series at Sulphur Bank. This was established by careful observation in the field prior to the microscopical examinations. The latter showed that some specimens, so far as their microscopic character is concerned, might possibly be either extreme members of the crystalline metamorphic series or true eruptive rocks. The region was revisited for the purpose of verifying the structural relations of these occurrences. The questionable rocks were then found to be surrounded by and to pass over into indubitable metamorphic material in such a way as to preclude any separation of them.

The Sulphur Bank map shows no Chico-Téjon beds or Pliocene fresh-water strata and no andesite. Here, as elsewhere on Clear Lake, it is manifest that the level of the present sheet of water has sunk within no very long period, leaving fertile meadows. The composition, as well as the topographical relations of these meadows, shows that they are drained portions of the lake bed, for they are full of roots of the tule, which grows only near the water's edge and preferably in shallow water. Close to the basalt and in beds continuous with those which underlie the lava these roots are sometimes found petrified.

Basalt.—The only volcanic rocks on this map are basaltic, but their character and mode of occurrence are rather unusual and therefore interesting. They are in part olivinitic and in part free from olivine, but their microstructure is the same in both cases. In the area south of Borax Lake, just beyond the limits of the map, ordinary olivinitic basalt occurs. It adjoins a large field chiefly composed of obsidian and pumice, but containing also rocks which, while manifestly in part glassy, have a thoroughly basaltic appearance. It is impossible to separate these occurrences in the field, and the more they are studied the more certain it appears that all this material is substantially from a single eruption. This is confirmed by microscopic examination, although the glass is an acid one, containing over 75 per cent. of silica (see pp. 158–162). The glass is usually of a gray color and is transparent even in masses a quarter of an inch or more in thickness. Between it and the pumice there is every conceivable gradation. The glassy forms sometimes include small fragments of crystalline basalt. This area is the only one in which this obsidian appears to be in place, yet the dissemination of chips of the same glass a square inch or less in area is something astonishing. In the immediate neighborhood of the obsidian field these chips are so plentiful that it is difficult to draw its outline with any accuracy. They gradually grow less abundant, but are still to be found beyond the crests of the hills surrounding the locality. Similar chips are occasionally met with all over the district; but this is in part due to human agency, for a spearhead of this glass was found miles away. Most such chips, however, are quite isolated and show no marks of artifice. Explosions attending the eruption may account for the greater part of the fragments near the obsidian field; how the more distant ones were transported I cannot guess

Another feature of the basalt of this district, somewhat unusual in California, but not unknown in other portions of the State, is the formation of regular crater-cones. Dense basalts, when in a state of fusion, are probably too fluid to build cones. Those at Sulphur Bank are composed of extremely porous basalt, much of it in the condition of lapilli. Each of them is broken through on one side, apparently by lava streams, not by water. The lapilli are more or less oxidized, but have accumulated no considerable quantity of soil and are not concealed by the scant herbaceous vegetation, though trees, particularly conifers, have taken root among them. Contorted forms of lava, too, are abundant at some of the croppings and everything points to a very recent date of eruption.

General description of the bank.—The Sulphur Bank is an area exhibiting most manifest indications of solfataric action. It is not practicable to outline the exact area of decomposition, which, however, is substantially coincident with the southern half of the small basalt area in which it lies, including all the more elevated portions of this area. The ore-bearing ground takes in a narrow strip of the sedimentary area to the south. The surface indications of solfatarism consist in complete decomposition of a large portion of the basalt to a white, pulverulent mass, sulphur deposits, and hot mineral springs holding gases in solution. The locality was first worked for sulphur. At a distance of a few yards below the surface, however, cinnabar was found occurring with the sulphur, and lower still cinnabar was found in large quantities. The property has been worked for the most part by open cuts, with little regard to system. Its appearance is very peculiar. The glare of white decomposition-products, the labyrinth of deep, open pits and trenches, and the acrid dust and evil smells of the locality produce a strong impression on the observer; but even to the geologist it is an interesting rather than an agreeable one. Work in these cuts is so trying that few white miners have ever accepted employment in them a second day and almost all the labor is performed by Chinamen.

Origin of the basalt.—To my mind there is little question that the basalt of the Sulphur Bank was erupted on the spot. In the comparatively little decomposed portions of the area contorted forms and cindery masses of the lava still exist. This shows that it has experienced but little erosion. The two craters shown on the map are also extremely recent, as has been pointed out in the preceding chapter. Between the craters is a lava stream of very evident character; but the lava is not continuous from the craters to the bank, the highest portion of which is over 50 feet above the level of the ground at the points of discontinuity. Had the basalt of the Sulphur Bank come from the volcanoes, its original surface must have been lower than that of any point in the lava stream connecting the localities, and, if they were once thus connected, at least 50 feet of the rock has since been eroded. There is no ravine crossing the track of the flow to produce a local effect of this kind, and the surface indications entirely preclude the supposition that there has been any general degradation approaching such an amount since the basalt was extruded, or, indeed, any sensible amount of degradation.

I look upon the hot springs as of volcanic origin and as a later phenomenon than the ejection of the basalt. There appears to be nothing to warrant the hypothesis that these springs were in action before the basalt eruption. On the contrary, the basalt lies upon recent lake deposits, sometimes filled with tule roots, and a part of these are within the influence of the solfataric action, as is shown by their petrifaction. Had these springs existed for an indefinite time before the basalt was ejected the tule roots could not have grown.[1]

Deposition of sulphur.—The composition of the waters from different portions of the Sulphur Bank varies considerably, but that a large portion of them carry hydrosulphuric acid is evident from the smell. The formation of sulphur and sulphuric acid from hydrosulphuric acid by oxidation is one of

[1] These silicified roots of the tule (*Scirpus lacustris*) bear a strong resemblance to *Caulinites*, and my specimens, in the absence of sufficiently full information, have been described and figured by Mr. Leo Lesquereux as a new species of that genus (Proc. U. S. Nat. Mus., 1887, p. 36).

the most familiar facts of chemical geology and of experimental chemistry. The relations of the two processes are readily seen from a thermo-chemical standpoint, for the reaction

$$H^2S + 40 = H^2SO^4 \text{ liberates } 201{,}500 \text{ calories and}$$

$$H^2S + \ 0 = H^2O + S \text{ liberates } 59{,}100 \text{ calories.}$$

Hence if oxygen is present in excess, as it is at the surface of sulphur springs and in porous sinters partially saturated with solutions of hydrosulphuric acid, this will simply be oxidized to sulphuric acid. But if oxygen is deficient, as it must be a short distance from the surface, a single atom of oxygen by combining with $\frac{1}{4}H^2S$ to $\frac{1}{4}H^2SO^4$ would produce only 50,375 calories, or 8,725 less than it sets free according to the second of the above reactions. Assuming, therefore, that the two reactions are accomplished in nearly the same time, sulphuric acid will be formed at the surface of such a region as the Sulphur Bank and free sulphur below the surface. This is in correspondence with observations at sulphur springs the world over and with laboratory experiments. When sulphides of the alkalis are present the reactions are more complex, but sulphur is also separated while hyposulphites are formed. There is thus nothing strange or novel in the occurrence of sulphur under the conditions present at Sulphur Bank.

A portion of the sulphur occurring at the Sulphur Bank is formed by a slightly different reaction. Both on the surface and in the mine sulphurous acid may be smelt, and early in 1887 the odor of this gas was suffocatingly strong, even at some distance from the Hermann shaft. The sulphurous acid undoubtedly comes up with the other volcanic emanations, though perhaps not in direct contact with the hydrogen sulphide. Hydrogen sulphide and sulphur dioxide decompose mutually, forming water and sulphur. As a consequence, the timbers of the building above the shaft were coated with incrustations of sulphur crystals in February, 1887, and, at the Fiedler shaft as well, sulphur crystals had deposited in smaller quantity by the same method.

Sulphuric acid and its effects.—The sulphuric acid formed at or close to the surface percolates downward to some extent and is eventually neutralized by free bases and by salts of feebler acids. The neutralization of the acid is chiefly effected by the sodium carbonate brought up in the hot waters and

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aided by the ammonia. The basalt is attacked by the acid waters and no doubt by the sulphuric acid they contain. It is true that labradorite and augite are but little acted upon by acids in laboratory experiments, but this basalt has been exposed to the action of hot sulphuric acid for hundreds of years at least. Its resistance is also considerable, many kernels of fresh rock remaining in the decomposed envelopes.

Concentric decomposition.—It is clear from numerous exposures that, after the basalt solidified at the Sulphur Bank, it was divided by cracks, marking in many cases a distinct though imperfect columnar structure. As usual, also, there were cross-fissures in the vertical columns. These cracks formed the passages by which the waters reached the surface and by which the acid formed at the surface became diffused. The solid masses of basalt separated by cracks from surrounding blocks were attacked from the outside by the acid waters. As decomposition progressed successive shells were formed, which grow more and more spherical as the centers are approached. This has been attributed to "ball structure" in the rock, but it appears to me unnecessary to assume any such predisposing cause, of which there is no other evidence in the structure of this lava either macroscopically or microscopically. It is shown in an earlier portion of this work (page 68) that this conformation is the natural result of the action of a corrosive fluid on a slightly porous, tolerably homogeneous material in blocks which approximate to regular polyhedrons in form. The concentric shells which are so well developed here are themselves the results of the decomposition process and are not, in my opinion, pre-existing envelopes the presence of which has controlled the course of decomposition. Decomposed basalts showing this structure so strikingly do not occur, to my knowledge, elsewhere in California, though such are found in other parts of the world. An instance from Great Britain similar to that of Sulphur Bank is illustrated by Dr. Geikie.[1]

The ultimate residue, when the attack is complete, is almost pure silica. The depth to which the basalt has been decomposed by the acid waters varies in different exposures, and perhaps averages 20 feet. The limit is usually very sharply defined, and it may be considered certain that this

[1] Text Book of Geology, 1st ed., Fig. 86.

represents the permanent level of the alkaline waters prior to the beginning of mining operations.

Occurrence of cinnabar.—The mode of occurrence of cinnabar at the Sulphur Bank is interesting and significant. It does not occur in sensible quantities at or close to the surface, but is found to a considerable extent mixed with sulphur in the lower portion of the zone of oxidation. The principal deposits are below this level. They are found in the more or less decomposed basalt, in the underlying recent lake bottom, and in the Knoxville shales and sandstones. The cinnabar is associated chiefly with silica, in part crystalline and in part amorphous. In the lava it appears as small seams, which commonly follow either the original cracks between the blocks or the concentric surfaces of the decomposed masses. In the lake deposits below the basalt the cinnabar is found as impregnations or irregular seams. In the workings from the Hermann shaft the ore occurs exactly as it does in most of the quicksilver mines of California, more or less completely filling interstices in shattered rock masses. Sometimes ore of this kind has been found which was simply a brecciated mass of rock cemented by cinnabar. The cinnabar in these cases has crystallized on the rock fragments, exactly as quartz often does, and frequently leaves hollow inclosed spaces.[1] To a small extent the more porous sandstones have been impregnated with ore. Besides quartz, iron pyrites and marcasite frequently appear in the gangue, calcite is not uncommonly also present, and small quantities of bitumen are often found. It is a fact of great interest that Dr. Melville has found small quantities of both gold and copper in the marcasite accompanying the cinnabar. The inferences to be drawn from the mode of occurrence of the cinnabar at this locality are not unimportant. The intimate association of the ore with sulphur, opal, quartz, pyrite, and to a smaller extent with calcite, is amply sufficient to show that it has been deposited from water. This would also be clear if the cinnabar were not accompanied by and mixed with minerals which can have formed only in the wet way. The vuggs lined with cinnabar and the relations of the veinlets of ore to the fissure system of the rocks are of a character to convince any

[1] See an illustration of such a specimen in Le Conte and Rising's paper on this locality (Am. Jour. Sci., 3d series, vol. 24, 1882, p. 29).

practiced observer that the deposition has taken place from solution, and not from vapor. The occurrence also limits the possibilities as to the origin of the ore. The formation of sulphur is still going on, and so also must be the decomposition of the basalt and the deposition of pasty hydrous silica. The association of cinnabar with the sulphur and its deposition along the concentric partings of the decomposed basalt blocks close to the fresh nuclei show that cinnabar is either now being deposited or that its deposition has ceased only very recently and must have gone on while the conditions were almost precisely those now existing.

The copiously flowing springs which existed here before mining operations began and the sulphur deposition show that the waters rising toward the surface come from a considerable depth. This must have been the case during the entire period of sulphur deposition. The ore cannot have leached downward from the basalt into the underlying rocks, nor can a trace of quicksilver be detected in the undecomposed basalt. Neither can the quicksilver have been derived from the layer of recent lake deposits underlying the basalt. This layer is thin, at least in places, and lies hundreds of feet above some occurrences of the ore. The original source of the quicksilver must then have been either in the Knoxville beds, chiefly sandstone, or below them. This sandstone is proved by microscopic examination to be arcose, or granitic detritus, and abundant evidence has been given in preceding chapters to show that granite underlies the Coast Ranges. The source of the quicksilver is consequently either granitic detritus or granite or it lies below the granite. Further than this the facts at this one locality do not justify conclusions as to the origin of the ore.

Solfataric springs.—A very remarkable feature of this mine is the abundance of hot springs, frequently carrying gases. These gases are often ammoniacal and many of them carry sulphureted hydrogen. Others again have a nauseous smell which plainly indicates an organic origin. An analysis of gas from the Hermann shaft gave —

Carbon dioxide, CO^2	89.34
Hydrogen sulphide, H^2S	0.23
Marsh gas, CH^4	7.94
Nitrogen, N	2.49
Total	100.00

On the southwest drift of the fifth level hot water and vapor are expelled from cracks with some force and with a noise resembling that of escaping steam. The quantity of steam condensed to a visible vapor, however, is not very great, and the thermometer shows only 80° C. (176° F.). The escaping gases smell of ammonia. This is the hottest water met with, though other springs show over 70° C.[1]

Composition of the waters.—It being clear that the cinnabar has come to the surface in solution under conditions little if at all different from those now prevailing, the composition of the waters becomes a matter of special interest. The following analyses show the composition of the contents of 1,000 cubic centimeters of hot water from two of the shafts in their probable combinations:

	Hermann shaft.	Parrott shaft.
Silica, SiO^2	0.03715	0.04185
Ferrous carbonato, $FeCO^3$	....	0.00008
Calcium sulphate, $CaSO^4$	0.02340	....
Calcium carbonate, $CaCO^3$	0.03520	0.05055
Magnesium carbonate, $MgCO^3$	0.01890	0.00555
Sodic carbonate, Na^2CO^3	1.94675	0.32200
Ammonium carbonate $(H^4N)^2CO^2$	0.00664	0.00282
Borax, $Na^2B^4O^7$	1.87840	2.40435
Sodic sulphate, Na^2SO^4	....	0.68905
Sodium chloride, NaCl	1.10270	1.03975
Potassium chloride, KCl	0.04705	0.07470
Fixed organic matter	0.00500	0.00760
Hydrogen sulphide, H^2S	0.00455	0.00074
Carbon dioxide, CO^2	0.26241	1.75131
Total weight, grams	5.36815	0.39185

The simple instead of the acid carbonate of sodium is assumed in these analyses because the acid salt is at least in part dissociated in hot solutions. The sulphydric acid was combined to some extent as a soluble sulphide, but with what base it was united was not ascertained. Not a trace of mercury could be detected in solution, though, as will be seen in Chapters XI and XV, waters very similar to these are certainly capable of dissolving cinnabar.

Nature of the mercuriferous solutions.—In the hope of obtaining further light on this subject Dr. Melville visited Sulphur Bank with chemical appliances

[1] I am not aware that mining operations have ever been carried on before where the inflowing water had so high a temperature as 176° F. The highest temperature which I observed in the Comstock was 170° F.

early in 1887. The most favorable opportunity for investigating the water at that time was presented at the Fiedler shaft, which communicates below ground with the Hermann shaft. Both had then been abandoned and water escaped from the top of the former into the lake. Its temperature was 128° F. (53⅓° C.) and it was in a constant state of agitation from the escape of carbon dioxide and hydrogen sulphide. Large quantities of water were collected in new wooden pails and filtered hot. The filtrate on evaporation and analysis showed all the substances recorded in the above analyses, and, in addition, alumina, manganese, cobalt, phosphoric acid, hyposulphurous acid, and some organic matter resembling humic or crenic acid. Repeated experiments showed not a trace of mercury, though the filtered water left small quantities of mercuric sulphide on the filter.

This water under these physical conditions would thus appear to be incapable of dissolving cinnabar; for otherwise the suspended sulphide must have been accompanied by the same substance in solution. This insolubility is probably ascribable to the ammonia present; for in laboratory experiments we have found that different ammonia compounds precipitate mercuric sulphide from analogous solutions. It is not impossible that at pressures above one atmosphere ammonia compounds lack this precipitating power, and if the waters of Sulphur Bank were always ammoniacal, as they have certainly been for the last twenty years, this hypothesis would account for the fact that no cinnabar whatever appeared at the surface of the Sulphur Bank, the ore being met with only at a depth of several yards. It would also account for the mercuric sulphide in suspension in the water.

The ores of the open cuts of the bank were also submitted to a careful examination, in order to ascertain the correspondence between their composition and that of the material dissolved in the waters. In immediate contact with the cinnabar all of the bases detected in the water were found, but neither chlorine nor boracic acid. A sufficient reason for the absence of these acids appears to be the solubility of the chlorides and the borates, which have never been found in any of the quicksilver mines beneath the surface, though at Knoxville and at Steamboat Springs borax exists in the waters, and it was very probably also present during the time of ore deposition at other mercuriferous localities. That the ores of Sulphur Bank have been in contact with solutions of chlorides and borates is very certain, for the water of the mine carries a large amount of them, and, in the underground workings near ore, I collected efflorescences largely consisting of them, as was proved by analysis. Indeed, analyses of the salts crystallized out on the walls of the drifts showed all of the bases and acids detected in the water or the ore, excepting hyposulphurous acid, gold, and nickel. As cobalt was present in two cases, nickel might doubtless have been detected in traces. Hyposulphurous acid I suppose to result only from the oxidation of alkaline sulphides and gold is present only in very minute quantities in the marcasite. The waters as they reach the surface are far from being saturated solutions of borax or of alkaline chlorides, and there is no reason to assume any tendency for the metallic bases detected to decompose sodium chloride. On the other hand, sulphates of the alkaline earths are comparatively insoluble and might be deposited with the ore. Sulphuric acid has, moreover, constantly formed at the surface, diffusing downward to a greater or less extent. It is very likely that a large part of the sulphates now present in the ores of the surface workings have formed since the ground was broken, for the excavations have interfered with the flow of the water to the lake.

It is plain from the foregoing that the waters are capable of depositing exactly such mineral mixtures as the ores represent, with the very important exception of the cinnabar. The conclusion that the ores have been deposited from similar waters is inevitable. At the time of deposition either some slight variation in composition—possibly the absence of ammonia—enabled these waters to hold cinnabar in solution at ordinary pressures or they are now capable of dissolving cinnabar under somewhat different physical conditions, as was suggested above.

Precipitation of the ore.—The hypothesis that these waters under other physical conditions would dissolve cinnabar finds some support from observations of the circumstances attending the deposition of the ore. Cinnabar was found in the workings of the Hermann shaft several hundred feet below the surface, and in the open workings the richer portion of the ore occurs in part beneath the basalt and in part in its lower portion. Above the richer bodies comes a mixture of sulphur and cinnabar and at the original surface no mercuric sulphide whatever was found. These facts can hardly be accounted for by supposing that the ore was precipitated by the sulphuric acid forming at the surface. The rock is attacked by acid to a depth of only about twenty feet, and the richer ores are found at lower levels, where no evidence of the presence of unneutralized acid occurs and where the composition of the ore is substantially similar to that in the deep workings. If the ore had been precipitated by acidification of the solutions, it would be mainly found in the upper part of the bank or along the under surface of the layer of basalt which has been bleached by acid. This is not the case, and hence, while acidification of the solutions would undoubtedly have thrown the quicksilver down, other causes of precipitation must have been at work, and indeed must have been the chief ones. The fact that sulphuric acid forms at the surface is also insufficient to account for the absence of cinnabar from the surface, for at Steamboat Springs, where acid forms in the same way as at Sulphur Bank, cinnabar did reach the surface. The formation of sulphuric acid from hydrogen sulphide is not a rapid process, and in springs from which there is a considerable flow of water neutralization by the acid thus formed could take place only to a very short distance from the surface. The resulting distribution of ore would also be extremely irregular.

There is indeed no proof that the main period of deposition of ore at Sulphur Bank was contemporaneous with the chief deposition of sulphur and the formation of sulphuric acid. One might rather suppose that when the deposition of ore was progressing most actively the upward flow of solutions and the emission of gases were too vigorous to permit the permeation of the upper part of the bank by atmospheric oxygen. Little sulphur or sulphuric acid would then form, and only at the surface. As the activity of the springs diminished the permeation of oxygen would increase, and the sulphuric acid slowly formed at the surface would have an opportunity to diffuse through the rock. The sulphur beds may thus not improbably be in the main of later origin than the ore.

While acidification is insufficient to account for the precipitation of the ore, diminution of pressure and of temperature must certainly have taken place as the solutions rose to the surface. So far as is known, too, these causes may be sufficient to explain the observed effect, but dilution with waters percolating from the lake or from springs may have contributed to the result.

There is no trace of substitution of ore for the rock in any part of the mine. It is true that ore is sometimes found in the crevices of concentric layers of decomposed basalt, but it is evident that these crevices have first formed through decomposition and that the cavities have subsequently been partially filled with ore, as any other openings would have been. In true substitution, the solution of the substance of the rock is a condition of the deposition of ore and the interchange takes place molecule by molecule.

It appears from the above that no absolute evidence of the deposition of ore at the present time has been reached, but that the precipitation of cinnabar, under some pressure, in the lower portion of the ore-bearing ground, is not improbably still in progress.[1] Professors Le Conte and Rising have also expressed the opinion that ore deposition has not ceased.

The mine.—The surface mine at Sulphur Bank is a labyrinth of excavations in and below the decomposed layer of basalt. In a few spots the workings have passed through the basalt, and lake beds, carrying cinnabar in greater or less quantity, were found below it. Between the Hermann shaft and the air shaft shown on the map an important ore body was followed down for several hundred feet. This body had been worked out before my examination and only the lowest portion of it was accessible. The small amount of ore remaining consisted, as has already been stated, of partially metamorphosed sandstones and shales of the Knoxville group, carrying small stringers of cinnabar, quartz, and pyrite. The top of the ore body is said to have been in lake beds similar to exposures made near by during my visit, but I was not able to get satisfactory information as to the depth from the surface of the contact between the pebble-bearing lake deposits and the brecciated, metamorphic sandstones and shales. This, however, is not a matter of great consequence.

The underground mine consists of a shaft 417 feet deep, with seven short levels. The rock is everywhere of the Knoxville group and sandstone predominates; it is much disturbed and is full of slickensides, but the prevalent dip is to the southeast. No second ore body of importance has been discovered, though traces of cinnabar are common.

Excepting for the solfataric springs the underground mine at Sulphur Bank resembles the other principal quicksilver mines of California. The

[1] For a confirmation of this deduction, see the addendum to this chapter (p. 269).

same rocks are met in other mines and the gangue minerals and the relations of these substances to the vein rock are those most usual in California. This fact is an important one, for it proves that deposits indistinguishable from those found in the Redington, New Almaden, and other mines may be formed in the same manner as those at Sulphur Bank, by precipitation from hot springs of volcanic origin.

Partly, perhaps, on account of the degree to which the hot water and foul gases interfere with mining operations the prospecting of this property has been neglected, and there is an insufficient opportunity to study the structural relations of the ore and the fissures. I can, however, see no reason to suppose that the deposit is exhausted. A drift should be run through the ground which shows solfataric action beneath the surface mine at a depth of at least 200 feet, and from this gallery at least one cross-cut should be driven, so that the hopeful ground would be completely intersected in two directions. It would probably be found that these drifts would meet one or more dikes of basalt, the direction of which would mark the main fissure system; but for some hundreds of feet from the surface the structure and the disposition of ore are probably very irregular, and a system of straight drifts and cross-cuts would be the only thorough method of exploration.

The abandoned mines on Mt. Konocti appear to have had an origin entirely similar to that of the Sulphur Bank. Their chief interest is due to the fact that they occur in andesitic lavas, thus adding to the list of different rocks in which cinnabar in some quantity is found and increasing the probability that all the cinnabar is derived from a single source.

Little Sulphur Bank and Borax Lake.— A few hundred feet to the east of the mud flat of Borax Lake, and just at the edge of the obsidian area, is the so-called Little Sulphur Bank. Here slight excavations only have been made. These show a considerable quantity of impure sulphur, and I was positively informed that traces of cinnabar had been found, though not enough to encourage further exploration. No water flowed from this locality during my visit, but the ground was moist and hot in spots. It is possible that during some seasons hot water may still find its way to the surface and drain into Borax Lake. Everything thus indicates that the locality is properly named and that there is here a repetition on a small scale of the phenomena of the larger Sulphur Bank.

Borax Lake is a small and shallow sheet of water of variable area. Professor Whitney was informed that in 1861 it dried up entirely. The examinations of the region described in the last chapter make it clear that the nearly flat area in which this pond is situated was formerly covered by the waters of Clear Lake. Although Borax Lake receives the drainage of the surrounding hills, it is still but little elevated above the larger body of water From this it is separated by a low ridge mainly and perhaps wholly composed of the obsidian and pumice described upon a preceding page.

The boracic character of the lake was first detected by Dr. J. A. Veatch[1] in 1856. Later large quantities of borax crystals were extracted from the mud and borings were made in the bottom with a view to renewing the supply, but in vain. Professor Whitney very properly regarded this lake as an evidence of former volcanic activity; but, to make sure that the borax was not leached out of the surrounding declivities by rain and merely concentrated here, I had careful tests made of large quantities of the metamorphic rock and obsidian. They showed no borax.

The water of Borax Lake was analyzed by Dr. Melville, and the composition of one liter was found to be as follows:

	Grams.
Silica, SiO^2	0.0109
Alumina, Al^2O^3	0.0029
Ferrous carbonate, $FeCO^3$	0.0056
Manganous carbonate, $MnCO^3$	0.0018
Calcic carbonate, $CaCO^3$	0.0233
Magnesium carbonate, $MgCO^3$	0.9448
Sodic carbonate, Na^2CO^3	29.1671
Calcic phosphate, $Ca^3P^2O^8$	0.0225
Calcic sulphate, $CaSO^4$	0.0204
Sodic sulphate, Na^2SO^4	0.1248
Borax, $Na^2B^4O^7$	5.0040
Sodic chloride, NaCl	38.9900
Potassic chloride, KCl	2.2003
Potassic bromate, KBr	0.0447
Organic matter	3.6184
Carbon dioxide, CO^2	0.6839
Total	80.8654

[1] Geol. Survey California, Geology, vol. 1, p. 98.

When this analysis is compared with those of the waters of Sulphur Bank it is manifest that there is a very close resemblance. Taking into consideration also that the waters which must formerly have issued from Little Sulphur Bank flowed into Borax Lake, it may be considered absolutely certain that the formerly active springs of Little Sulphur Bank furnished the supply of borax now practically exhausted, and that there will be no renewal of this supply unless the Little Sulphur Bank should again become a flowing spring. To bore wells in Borax Lake is useless. Possibly, however, a hole bored into the Little Sulphur Bank would bring about a renewed flow of dilute solution of borax, which by concentration under the hot summer sun in Borax Lake would yield the salt in profitable quantities.

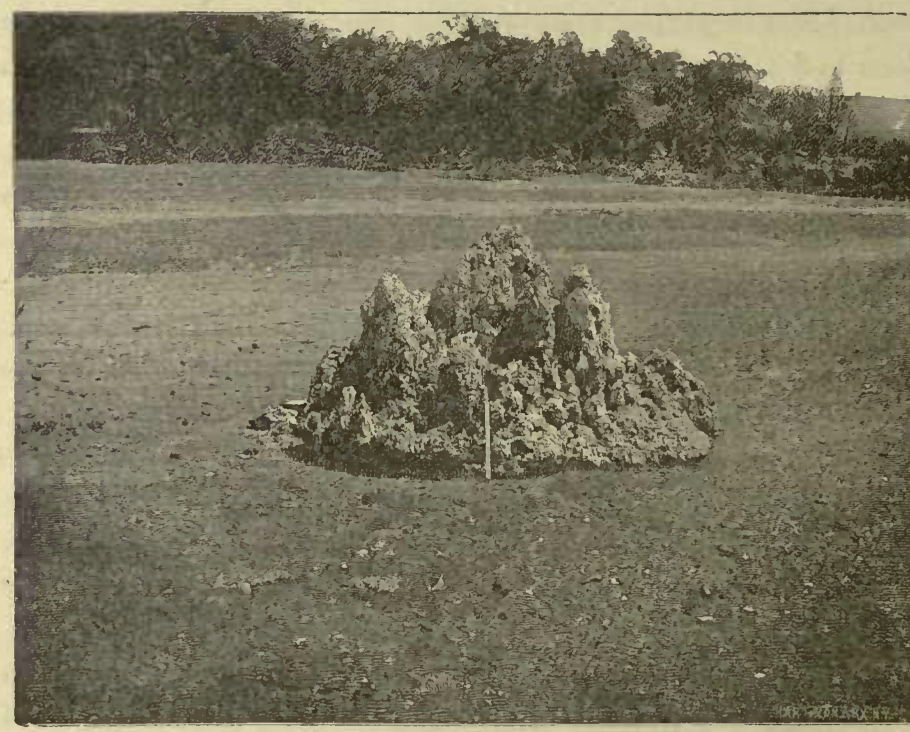

FIG. 6. Dendritic sinter on the shore of Borax Lake.

Dendritic sinter.—Along the shores of Borax Lake are numerous isolated masses of calcareous sinter (Fig. 6). They all grow from the surface of the lake bottom, but some of them are partially submerged and some stood at the time of examination many yards from the actual edge of the lake. They consist chiefly of calcium carbonate, with small quantities of all the sub-

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stances detected in the water (excepting manganese and bromine) and, in addition, traces of cobalt and lithium. They also contain some organic matter which evidently consists in part of the pupa cases of insects. These sinter masses grow to a maximum diameter of about four feet and a height of about three feet. The outlines assumed resemble those of an isolated clump of trees and bushes seen at a distance. They appear to grow laterally as well as vertically, and thus overhang the level, somewhat pebbly ground upon which they stand. Broken masses show a porous, sponge-like structure, but I detected no definite crystal forms. There appeared to be no opportunity to trace out the history of these masses, nor could I detect any definite nucleus. When once a small accretion of this sort has started, it would appear that the spongy mass draws up the brine from the moist ground and affords an opportunity for the evaporation of the fluid. Why the masses consist substantially only of calcium carbonate is not certain; but it seems not improbable that when first formed they contain a considerable excess of this rather insoluble compound, which separates out in a comparatively pure form, as is usual in cases of slow crystallization from mixed solutions, and that they are further purified by the winter rains. Though the inception of these masses has not been traced, it is easy to imagine how it might occur. Any small lump of pumice, fragment of wood, or other porous substance partially immersed or lying upon the wet mud near the edge of the lake would tend to accumulate a crust of salts upon its upper surface through capillary attraction and evaporation, and the spongy accumulation would then continue to absorb the fluid. These sinter masses appear to answer to some of the tufas associated with the thinolite studied by Messrs. King, Russell, and E. S. Dana. They are certainly still forming and are all of recent origin. If any substitution has taken place in these sinters it must have followed almost immediately upon deposition and probably accompanied dehydration. However this may be, it is an interesting and somewhat important fact that sinters composed substantially of calcium carbonate can grow directly from a fluid containing large quantities of sodium carbonates and borax and which holds only small amounts of calcium carbonate in solution.

Little Borax Lake, at the foot of Mt. Konocti, possesses a great deal of similarity to the larger body of mineral water near Sulphur Bank. It is small and shallow and frequently dries up entirely. The salts deposited are borates and carbonates of the alkalis, but no dendritic sinter is found along its shore. Evidences of the volcanic character of this basin were given in the preceding chapter, but no active solfatarism was observed. There seems no reason to doubt, however, that its origin is similar to that of the more important Borax Lake.

Maggots.—Borax Lake, like many similar pools, is infested by flies, the maggots of which appear to be the sole inhabitants of the brine. Specimens of these insects were sent to Professor Riley, who states that the larger part of the specimens are larvæ of *Ephydra californica* Packard. The same insect is abundant at Mono Lake, where the maggots are used by the Indians for food. Some larger maggots were also found in Borax Lake, which Professor Riley determined as belonging to the dipterous genus *Stratiomys.*

ADDENDUM TO CHAPTER VII.

SOLUBILITY OF CINNABAR IN AMMONIACAL SOLUTIONS.

As appears in part from the foregoing chapter, repeated efforts were made to detect mercury in the waters of Sulphur Bank, but without success. Consequently, although the deposit is of such a character as to suggest very strongly that cinnabar is still being formed, such a deposition could not be definitely asserted at the time when this memoir was transmitted. The absence of mercury from these waters was not a little perplexing, for, as will be described in Chapter XV, I had found cinnabar soluble to a very considerable extent in artificial solutions not dissimilar to the waters of Sulphur Bank, and everything pointed to the conclusion that the ore of this locality must have been deposited from waters like those which now flow from it. These waters, however, are ammoniacal, and experiments in my laboratory had proved that, under ordinary conditions, ammonium salts completely precipitate cinnabar from artificial solutions.

Consideration of all the circumstances showed it very improbable that the waters had recently become ammoniacal, and I therefore inferred, as was mentioned on page 260, that cinnabar was probably soluble at high temperatures and pressures in ammoniacal waters, seeing, also, in this hypothesis an explanation of the remarkable fact that cinnabar nowhere appeared at the original surface of the bank.

To test the matter I devised certain simple experiments, which were carried out after the transmission of this volume. A solution of mercuric sulphide was first made in a manner which will be described in detail in Chapter XV. The solvent is prepared by dividing a solution of sodic carbonate into two portions, saturating one of them with hydrogen sulphide and mixing the fluids. This liquid dissolves mercuric sulphide as a double sulphide of mercury and sodium. The solvent was charged with mercuric sulphide and filtered. Ammonium carbonate was then added till a large precipitate formed, and portions of the mixture were sealed in glass tubes, which were about half filled. These tubes were then heated to various temperatures above 100° C. At 120° the solutions still showed the dark tint due to the presence of undissolved sulphide, but at 145° and at 175° the mercuric sulphide was entirely dissolved in less than an hour. On cooling, the black color again appeared, and it was found by appropriate tests that this coloration was due to reprecipitated mercuric sulphide.

Ammonia in the presence of hydrosulphuric and carbonic acids thus does not completely precipitate mercuric sulphide at high temperatures and pressures, and waters similar to those of Sulphur Bank, though incapable of dissolving cinnabar under the physical conditions existing at the surface, would hold it in solution at higher temperatures and pressures. Such waters rising toward the surface would deposit the entire quantity of cinnabar held in solution before reaching the atmosphere.

This discovery seems to furnish an entirely satisfactory explanation of the absence of cinnabar from the original surface of the Sulphur Bank and of the failure to find mercury in the water. It also removes all reasonable doubt that the deposits of curdy, hydrous silica containing cinnabar are really as recent as they appear and that the ore is still accumulating at this interesting locality. The experiment furthermore affords an actual instance of the precipitation of an important ore by relief of temperature and pressure, a method of deposition the evidence of which is generally imperfect and indirect.

CHAPTER VIII.

DESCRIPTIVE GEOLOGY OF THE KNOXVILLE DISTRICT.

[Atlas Sheet V.]

General character.—This district includes the point at which Napa, Lake, and Yolo Counties meet. It presents the usual characteristics of the Coast Ranges: low, rocky ridges, partially covered by brush and a scanty growth of trees and divided by narrow valleys. Though some pleasing views are to be had from the higher points, the region is not a picturesque one. It possesses great geological interest, however, for it affords an admirable opportunity for the determination of the age of the metamorphic series and for a study of the processes of metamorphism. It also contains a series of quicksilver deposits which show instructive features and which bear significant relations to the metamorphic rocks and to basalt.

The Knoxville series.—The area embraced in the detailed map contains fossils at a number of points, and study of the district shows that all of the sedimentary beds are probably of the same age, belonging to one division, the lower, of the Shasta group of Messrs. Gabb and Whitney. As has been explained in Chapter V, it is advisable to consider this series as wholly distinct from the Shasta beds on Cottonwood Creek, in Shasta County. It is characteristically developed in the Knoxville district, where also it is the only series exposed, and Dr. White and I have therefore christened it the Knoxville group. The Knoxville beds form a very large part of the Coast Ranges and of the auriferous slates of the Sierra Nevada.

A considerable portion of the rocks in this district are nearly or quite unaltered and consist of predominant sandstones interbedded with shales and a little impure limestone. The beds stand at many angles, but their dip is usually very high, while the prevalent strike is in the direction of the ranges. Fossils are abundant at a few points, but are not very generally disseminated. By far the most frequent and the most important forms are two species or varieties of *Aucella*. These were not distinguished by Mr. Gabb, who collected specimens here and gave them the name *A. Piochii*, but Dr. White considers the more robust form as *A. concentrica* and the more slender as *A. mosquensis*. These and the accompanying fossils have been fully discussed in Chapter V, and the conclusion was there reached that the beds carrying them are close to the line of division between the Jurassic and Cretaceous formations, but are probably to be considered as the earliest Cretaceous, and therefore as belonging to the Neocomian period. The study of these fossils when first collected led me to the belief that the beds carrying them could not be separated from the slates of the gold belt, which also carry *Aucella*. This conclusion was afterwards fully confirmed by Dr. White.

Metamorphic rocks.—The Coast Ranges are so scantily supplied with fossils that the determination of these beds and their correlation with those of the Sierra Nevada are matters of much interest; but of no less interest is the fact that this district affords abundant opportunities of tracing the passage of these beds into the metamorphic rocks. The microscopical evidence of these transitions has been set forth at great length in an earlier portion of this memoir, but the structural relations have been only briefly referred to. These are of great importance for two distinct reasons. One of them is that eminent geologists deny that large areas of ordinary sediments are converted into crystalline rocks and serpentine by secondary processes; in other words, they deny the theory of regional metamorphism. The second reason for a minute description of the occurrence is that the results of mere microscopic examinations of collections are not altogether trustworthy. The phenomena which specimens and slides from complex areas present are so multifarious that it is nearly always possible to draw various plausible conclusions from them. Specimens may often be so arranged as to support arguments either for connecting the most diverse rocks by transitions or for separating varieties which are in reality closely allied. When due regard is paid to the occurrence in the field, on the other hand, the number of possible hypotheses is generally reduced to one.

There can be no question as to the regional character of the occurrence of crystalline rocks at Knoxville. A part of the area of the map, to be sure, is unaltered rock; but from the westerly edge of the map westward the crystalline rocks and serpentine form an unbroken mass many miles in width; indeed, it would probably be possible to proceed from Knoxville to the mouth of the Russian River, not in a perfectly straight line, but with no great deviations, without leaving this series.

The crystalline rocks not eruptive.—It is equally certain that these rocks are in fact neither of igneous origin nor crystalline precipitates from an ancient sea. No observer studying the rocks on the ground could fail to come to this conclusion; and, if conviction be not brought home to the reader, it will be due entirely to imperfect description. No area of more than a few yards can be examined without revealing evidence that the rocks are stratified. It is true that in a large proportion of cases there is entire discordance between the planes of stratification of different portions of a single cropping, but fractures may often be detected between adjoining masses which bear this relation, and sometimes distinct plication accompanied by a more or less elaborately developed fissure system is apparent. In the granular and serpentinoid series no masses are intercalated which exhibit the common characteristics of eruptive rocks: a lack of stratification and a tolerably persistent granular or porphyritic structure. The only rock in this district possessing this character is the basalt, which is manifestly far younger than the stratified rocks. It has frequently been maintained that certain rocks, like gneiss, which show distinct stratification, are of eruptive origin. That a gneissoid structure may be produced by igneous action, at least over small areas, is certain. I have myself seen such a case in New England. A dike of somewhat porphyritic diabase filled a fissure in unstratified granite, but at one point an irregularity in the fissure left a mass of granite projecting into the dike. This had been softened by the heat of the eruptive rock and molded by the pressure of the intrusive material. It had assumed a perfectly gneissoid structure without being separated from the wall of granular granite. But when an igneous origin is attributed to large areas of rock it must at least be shown that they possess a certain degree of uniformity; for, though there may be gradual changes from point to point in a mass which has been reduced to a pasty state by imperfect fusion and which has been extruded through vents, a certain degree of homogeneity, more easily appreciated than described, is inevitable. This is entirely lacking in the rocks at Knoxville, which often change from one structure to another in the most capricious manner and which frequently pass over into little altered, clastic rocks. Though there are single specimens and blocks of rock which might be supposed eruptive, the greater part of the rocks are not comparable with gneiss or with any eruptive rock and are manifestly closely allied to sandstones and slates such as no one would think of considering eruptive. As has already been remarked, no case of interbedded Pre-Tertiary eruptives has been met with in the investigations described in this volume nor any instance in which the serpentine is eruptive or traceable to the alteration of an eruptive rock.

These rocks not crystalline precipitates.—The supposition that the granular and serpentinoid rocks, though sedimentary in their origin, were originally deposited in approximately their present condition also requires careful consideration, particularly as this appears from the published evidence to be the most probable explanation of the genesis of some similar rocks in other parts of the world. Were this the case at Knoxville, two possibilities would present themselves: Either the conditions necessary to the deposition of the crystalline rocks must have been general, in which case the ordinary sedimentary strata of the district are of a different age, or, on the other hand, it might be that the ordinary sediments and the crystalline rocks are of the same age and that local influences produced the differences in lithological character.

The granular and serpentinoid rocks of the Knoxville district are of the same age as the ordinary soft, fossiliferous sandstones and shales, and this is shown independently by the structure of the country and by the transitions between the two classes. The structure can be particularly well studied in the neighborhood of the Reed mine, on the north branch of Davis Creek. To the northwest of the mine lies an area of unaltered rocks carrying *Aucella* and other fossils; another and larger area, also carrying *Aucella*, extends in a southwesterly direction from a point about one thousand feet south of the Reed mine. To the west of the mine, and again to the east of it, are large areas of serpentinoid rocks, which are connected by a neck a few hundred feet in width, cut by the creek near the mine. The strike of the unaltered strata in both areas is northwesterly, coinciding in general direction with the creek, and a large portion of these strata are inclined at high angles, most of those in the creek bed and a large part of those in the southern area being vertical or nearly so. Had the crystalline rock, including serpentine, been deposited before or after the ordinary sandstones and shales, and conformably with them, the two unaltered areas would be continuous, instead of being divided by an isthmus of crystalline rock. If the crystalline rocks had been first deposited, but disturbed prior to the deposition of the sandstones, so that the latter were unconformably deposited and afterwards folded up, it is difficult, but perhaps not impossible, to imagine relations such as those thus far described; but this hypothesis is entirely inconsistent with another structural feature. The north branch of Davis Creek, from below the Reed mine to the northwestern edge of the map, follows the axis of an anticlinal fold, so that the strata on each side dip into the hills. The same structure is traceable to the south also, particularly on Eticuera Creek below the Redington mine. If, therefore, there is any difference in age, the crystalline rocks are younger than the sandstones and overlie them. But this is also impossible; for, while the sandstones are comparatively little broken, the crystalline rocks show most abundant evidence of extremely violent disturbance, and evidently the upper portion of a series cannot be crushed while the lower portion remains intact.

Section on Davis Creek.—The following section on the north branch of Davis Creek was carefully worked out from numerous measured dips (Fig. 7). The evidence of anticlinal structure is clear, and, in view of the foregoing, it is certain that the southwestern side of the anticlinal fold consists of a crystalline mass, while the northeastern side is composed of fossiliferous sandstones, shales, and impure limestones. Nearer the Reed mine both sides of the anticlinal are crystalline and only the highly compressed portion close to the axis is arenaceous.

Transitions from ordinary sediments to crystalline rocks are not lacking at Knoxville. Some of these are much more striking under the microscope than in the field, for many rocks which were not suspected to be anything but somewhat indurated sandstones are shown by thin sections to be holocrystalline rocks, here called pseudodiabase and pseudodiorite. Usually, indeed, the transition is somewhat abrupt, and the rule is this: So far as evidence of crushing of the rock masses extends, these are more or less completely crystalline, while, where the rock preserves its continuity, it is generally an ordinary, more or less indurated sediment. The areas of crushed rock are naturally well defined; for, where the force exceeded the cohesion, the rock broke, but, where the cohesion exceeded the stress, the rock could only be bent or molded. There is no difficulty, however, in finding along the edges of these areas cases of partial conversion to crystalline material.

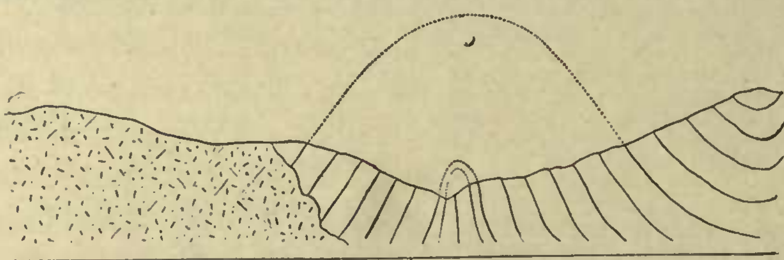

FIG. 7. Partly metamorphosed anticlinal, north fork of Davis Creek.

The relations of the crystalline rock to the anticlinal structure on the north branch and to the fissuring of the mass are so indicative that it is almost superfluous to consider the hypothesis of local crystalline precipitates. This theory would not exclude transitions, but it is difficult to imagine that areas of crystalline and uncrystalline sedimentation should be so intimately associated with each other. The absence of fossils in the crystalline rocks would also indicate an equally remarkable distribution of areas fitted for animal life. The intense dynamical action evinced wherever the rocks are crystalline and the absence of similar action in the ordinary beds appear to prove conclusively that the crushing and the crystallization were associated phenomena. The microscope finally shows, in connection with the field studies, that the crystallization was a secondary process, the progress of which can be followed in great detail.

Serpentine.—The granular and serpentinoid rocks cannot be sharply separated from the unaltered sedimentary rocks, as has been pointed out above.

Still less sharp is the distinction between the serpentine and the other altered rocks, though, so far as practicable, the areas covered by each are indicated on the map by different colors. There is nevertheless abundant evidence that serpentinization was a distinct process at Knoxville, from the formation of granular pseudodiabase, pseudodiorite, and glaucophane schist, all of which were formed under similar conditions and at the same time. The serpentine was formed in part from these granular rocks, but in part also from sandstone, and the microscopical evidence of this fact has been fully stated in Chapter III. This would be inferred from the occurrence in the field, but the difficulty of distinguishing partially altered sandstones from sandstones which have been converted into fine-grained, holocrystalline rocks is such that it would be impossible to make absolutely sure that a preliminary recrystallization did not invariably precede serpentinization. In a great number of occurrences at Knoxville serpentinization has evidently begun along cracks in rock retaining macroscopically the appearance of somewhat altered sandstone. When some progress has been made in the conversion, the structure may be illustrated by the following diagram prepared from sketches. Here the serpentine is represented by dark bands of nearly even width, but the corners of the intervening blocks are rounded, and it is evident that, were the serpentine removed, the remaining masses would no longer fit together as they originally did (Fig. 8). When the process has been carried further rounded balls are formed and in some cases these have weathered out and strew the ground like water-worn pebbles. The process is mechanically strictly analogous to the formation of balls of basalt in the Sulphur Bank, of which mention was made in the last chapter, and a theory of the process has been given on page 68.

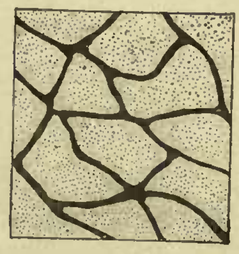

FIG. 8. Sandstone undergoing serpentinization from cracks in the mass.

The fibers of serpentine usually follow the direction of the veins separating the more or less rounded masses which they include, but in a few cases stand vertically to the surfaces of the unserpentinized nuclei, and the lines of division then clearly mark the exact position of the original crack, as shown in Fig. 9. One very fine case was found in which a subangular mass when broken

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open showed a rounded kernel of unserpentinized rock within a shell two inches or more in thickness composed of fibers of serpentine standing perpendicularly to the surfaces. These phenomena seem to demonstrate that the conversion of other rocks to serpentine has been effected by the instrumentality of solutions reacting on the material of the rocks. The latter are acid, and the solutions must have been magnesian. Partially serpentinized shales also occur, but I have nowhere seen any tendency to the formation of balls in this rock. This fact indicates that a portion of the constituents of the shale resisted serpentinization so that replacement of the rock as a whole could not take place, and only impregnation or the replacement of certain constituents was possible. Not a trace of any olivinitic rock could be found in Knoxville or its neighborhood, excepting the basalt, which is certainly far more recent than the formation of serpentine and has suffered little decomposition.

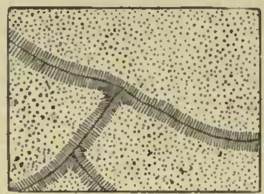

FIG. 9. Serpentine forming from sandstone and composed of fibers normal to the attacked surfaces.

Serpentine is attacked and removed by atmospheric agencies about as rapidly as partially altered sandstones. Where croppings of the latter are serpentinized in part, sometimes the sandstone and sometimes the serpentine may be seen standing in relief. On the whole, however, the serpentine appears to offer least resistance to weathering.

On the map serpentinized and unserpentinized metamorphic rocks are laid down in different colors. This division, however, must not be taken as absolute. Traces of serpentine are to be found in the unserpentinized area, and there are many small masses of other metamorphic rocks in the area colored as serpentinized. In the nature of the case an absolute division is impossible, but the colors represent the limits within which serpentine is the prevalent rock and serve to illustrate the approximate distribution of one phase of metamorphism.

Chromic iron is found in the serpentine here, as at many other places in the Coast Ranges. At one locality, not far from the Royal claim, it forms a series of nodules around which the serpentine has weathered away. The ore forms a belt or seam, and a considerable quantity of it might be obtained were the material in sufficient demand.

Redingtonite.—On the 150-foot level of the Redington, at a point where solfataric gases still issue, a hydrous chromium sulphate occurs in fissures in silicified serpentine. This substance is doubtless the result of the action of the gases upon chromic iron. Qualitative analysis showed that it is a hydrous sulphate of chromium, containing some aluminium and iron probably replacing chromium. The mineral is a finely fibrous mass, and sometimes the fibers are only just distinguishable under the microscope. The color is pale purple. The aggregates of parallel fibers sometimes appear white, excepting on the surface perpendicular to the fibers. Under the microscope the mineral is colorless, the fibers are extremely fine, and no crystal form is visible. The fibers possess double refraction and never extinguish parallel to the nicol planes. The angles of extinction vary between 13° and 38°. The crystals are therefore probably triclinic. It seems appropriate to give the name redingtonite to this hitherto unknown mineral.

When this mineral is heated it turns green without losing all its water, and coatings of this green sulphate occur upon the redingtonite. Under the microscope this green sulphate is found to be composed of rhombic tables with angles of 78° and 102°. The cleavage parallel to the base is excellent, and it also possesses good cleavages parallel to the prism faces and to the macropinacoid. It is somewhat pleochroitic, and the color is most intense when the short diagonal is parallel to the principal nicol plane. The refraction and the double refraction are of medium strength. The mineral seems to be isomorphous with copiapite. The tables are too small to show the emergence of the optical axes; but tests with the mica foil show that of the two axes of elasticity lying in the basal plane the one parallel to the brachyaxis is the larger. This agrees with copiapite, which is negative. The detection of these minerals is due to Mr. Lindgren.

Silicification.—There are two distinct periods of silicification traceable at Knoxville. One of these is represented by a fine net-work of quartzose veins intersecting a great proportion of the metamorphosed rocks. Silicified shales or phthanites are particularly prominent in this respect; but altered sandstones and granular metamorphics, as well as some of the serpentinized rocks, show a similar injection. The purer serpentines are seldom intersected by quartz veins, apparently only because this rock, though soft, is tough and not easily fissured. Where the net of quartz and more or less serpentinoid rock coexist, as is the case at many localities in this district, it seems certain that the silicification followed serpentinization; for, while the angular fragments surrounded by quartz veins are green, the veins themselves are not thus tinged. Had they existed prior to serpentinization they must have been attacked like the sandstones, and, since the quartz veins are permeable by solutions, they must have acquired a green tint. This silicification is a common characteristic of the metamorphosed rocks of the Knoxville group throughout the Coast Ranges. It is substantially coextensive with metamorphism and, as explained in a former chapter, seems to represent the last phase of that series of alteration processes. A more intense and different silicification occurs at Knoxville and elsewhere in the neighborhood of ore bodies, to which reference will be made in describing the deposits of the district.

Basalt.—The area to be mapped was selected in such a manner as to include all the ore deposits of the neighborhood and before anything was known of the distribution of volcanic rocks. It would almost seem, from an inspection of the map, as if the basalt area, which is the only one near Knoxville, had been purposely selected as the central feature. This coincidence is not meaningless. The basalt occupies portions of the crest and flanks of a low range of hills which forms the boundary between Napa and Yolo Counties. The range itself is composed of metamorphic rocks and it is evident from the topography that the basalt forms a thin sheet. It is altogether probable that the eruption of this small basalt sheet took place at two or more points along the crest of the ridge and flowed down on both sides. Not only does the disposition of the rock answer to this natural supposition, but a dike of the lava is said to have been met by a tunnel from the Lake mine run at right angles to the crest of the ridge from the spot called Johntown. Lithologically this basalt presents no peculiarities, excepting that it carries a rather small quantity of olivine. Near the basalt field is a small area of tufa, undoubtedly a portion of the basaltic eruption which furnished some of the building material for the reduction furnaces. It is well stratified and the beds are slightly inclined, showing a certain amount of movement in the country since its deposition. This tufa carries much brown opal in the vertical cracks which intersect it in some directions.

The Knoxville lava belongs to the older portion of the series of basaltic eruptions of this region. At one point it shows remnants of what was once probably a crater. This and the amount of erosion and weathering seem to refer it to a date indistinguishably near that of the earlier portion of the basalts near Clear Lake. Many bowlders have rolled from the more elevated portions of the basalt to lower ground, and the area mapped as basalt probably includes a fringe of such detritus, through which the underlying metamorphics were not visible. The basalt area is somewhat more than two miles long.

All but one of the quicksilver mines and prospects of the districts are separated from the edge of the basalt area by distances of less than half a mile. The exception is the Andalusia, which lies nearly in the strike of the Reed deposit and is probably on the same fissure.

Springs.—Near the edge of the basalt, particularly near the Redington and Manhattan mines, there are numerous strong mineral springs. These springs are not warm, but they carry so much mineral matter as to produce beds of sinter and to cement surface gravel into hard conglomerates. The sinters consist mainly of calcium carbonate. One of them showed, in addition to this substance, sodium, potassium, lithium, chlorine, boracic acid, and a very little sulphuric acid. The boracic acid is no doubt combined with sodium as borax, and it is evident that the water depositing this sinter is closely analogous to that of Sulphur Bank. This is an important fact when considered in connection with other phenomena and will be referred to again.

Deposits of the district.—Three properties in the district have produced important quantities of quicksilver. These are the Redington, the Manhattan, and the Reed mines. At the time of my visit the best days of these mines were either long past or reserved for a remote future and the greater part of the workings were entirely inaccessible. Only the somewhat extensive surface workings of the Manhattan were open, the deep mine being flooded and the tunnels caved in. At the Reed mine only trifling quantities of ore-bearing ground were to be seen at the surface. Even in the Redington, which was being worked, the upper levels were for the most part closed. The exposures nevertheless reveal many important facts. Before taking up the Redington such data as were procurable with reference to the other deposits may be recorded.

The Manhattan.—The Manhattan and Lake mines, which are contiguous claims, lie to the south of the basalt area. It is somewhat remarkable that scarcely a trace of serpentine exists near these mines. The surface soil here and also near the Redington mine contains cinnabar, resulting from the erosion of croppings, and accompanying the cinnabar is free gold, which may be found by panning the soil. There is no doubt that a part of this gold, if not the whole of it, was originally contained in pyrite. No considerable workings are accessible upon the Lake property. A tunnel was run from Johntown to the northeast underneath the basalt, but at the time of my visit it was unfortunately caved in. The watchman, an old miner, assured me that a dike of basalt crossed this tunnel and that cinnabar was found at the contact between the lava and the inclosing rock. There is no reason to doubt this interesting statement, for two deposits of precisely this kind exist in Pope Valley and will be described in Chapter XIII. Stibnite occurs on this claim near cinnabar. Mr. Goodyear also found these minerals associated on the Manhattan claim. It may be noted that the same association is found in the Stayton mines, in San Benito County, as well as on the Island of Corsica, at Smyrna, and elsewhere.

The surface workings of the Manhattan are quite extensive and are accessible, but the underground developments cannot now be inspected. This mine has yielded about 5,000 flasks of metal. The open cuts are in intensely silicified, thin-bedded, and considerably disturbed strata. There can be no doubt that a large portion of the silicification visible here attended the deposition of ore, but examination of the surrounding country shows that prior to the ore deposition the prevailing Post-Neocomian metamorphism was also of the siliceous type. It is not possible to distinguish in detail how much of the silica was deposited in each of the periods, but the opal at least, of which the open cut shows large quantities, is referable almost beyond a doubt to the period of ore formation. So far as I have observed, the silica deposited during the regional metamorphism is wholly crystalline.

The silicification, though very intense, has not obliterated stratification, and fine exposures of contorted strata converted into nearly pure silica may be seen. Vein-like seams often cross the strata, and in these, as well as in the partings between the strata, cinnabar has been deposited in brilliant contrast to the white background. It is easy to gather fine specimens of cinnabar on the exposed faces, but the average contents of the material exposed is certainly very low. Pyrite accompanies the ore, and copper stains were observed, no doubt resulting from the decomposition of chalcopyrite.

Prospects.—The Royal and the Grizzly claims are prospects upon which little work has been done. They belong to a type which is very prevalent in the quicksilver belt. The inclosing rock is highly metamorphic and very heterogeneous, but in the immediate neighborhood of the ore it is strongly silicified, and much of it is converted into a black chalcedony consisting chiefly of opal. In these claims the cinnabar occurs to some extent as impregnations in partially metamorphosed sandstone, but for the most part in threads and seams, either crossing or following the bedding, in short, wherever the disturbance preceding the deposition of ore left openings into which the solutions could penetrate. It is highly probable that deposits like these might become more regular below, but, so far as these particular deposits are concerned, the quantity of ore at the surface is not sufficient to justify the expectation of rich developments beneath. Pyrite, quartz, and bitumen accompany the ore.

The Reed mine.—The Reed mine, belonging to the California Quicksilver Mining Company, is on the north fork of Davis Creek and has produced, according to Mr. Randol's figures, 5,653 flasks of metal. It has not been worked for some years past. It lies close to the line which divides an area of serpentine from unaltered, fossiliferous rocks. Mr. T. J. Hall, the last superintendent, informs me that the ore was followed from the surface to the 300-foot level, the deepest in the mine. The trend of the deposit was the same as that of the strata in this neighborhood, nearly parallel to the course of the creek, and the dip was 30° to the southwest, which is somewhat less than the average dip of the disturbed strata hereabout. A very large part of the ore of this mine was metacinnabarite, as was the case in the upper portion of the Redington. Pyrite accompanied the cinnabar in a quartzose gangue and some bitumen occurred. The only accessible portion is an open cut at the croppings. Here are exposed both serpentine and the black opaline mass often called "quicksilver rock" in this region. The contact between the two is vertical and is pretty sharp, but the resemblance in general structure and the appearance along the dividing line led me to the belief that the opaline mass was an alteration product of the serpentine. Microscopical study has since shown that both in this district and elsewhere this transformation occurs, while other rocks as well as serpentine are, seemingly more rarely, converted into opal. The black, opaline mass at the Reed mine contains much pyrite, and the decomposition of this mineral appears to have yielded salts capable of attacking the opal superficially. The cut afforded no opportunity for the study of ore in place.

The Andalusia mine is in a similar position to the Reed and near the same contact. The rocks at this point have been very considerably decomposed, apparently as a consequence of the oxidation of pyrite. There are large quantities of black opal here, and some of this contains a considerable amount of microscopic millerite — nickel sulphide.

Vein of cinnabar.—Near the furnaces of the Redington Company a prospecting shaft was sunk for some distance upon a little seam of ore, which proved of no value, but of considerable interest. The deposit formed a vein an inch or two in width, cutting the strata of unaltered Neocomian sandstone. The fissure was filled with attrition material from the walls, cinnabar, and pyrite. This occurrence is in strong contrast with the other and more important deposits of the district, but is no doubt coeval with them and a consequence of the same set of causes.

THE REDINGTON.

Rocks and minerals.—This mine was discovered in making cuttings for a county road. It has been worked since 1862 and has produced nearly 100,000 flasks of metal, or more than any other mine in the State, excepting the New Almaden and the New Idria. The ore found at the surface was the superior portion of an immense, irregular ore body, which contained far the larger portion of all the ore which the mine has hitherto yielded; but downward continuations of this body of a much more regular character have been traced for several hundred feet. This change in the form of the deposit is an extremely interesting and important feature of the occurrence.

The rocks immediately inclosing the Redington mine are highly metamorphic and consist largely of serpentine, which is accompanied by siliceous rocks and shales, as well as by a great amount of dark, impure opal. Close to the deposit, however, and in contact with it at one point, is a considerable area of unaltered sandstone and shale. The strike of the deposit is also the trend of the contact. The metamorphic rocks surrounding the ore are far too much disturbed and altered to allow of any elucidation of their stratigraphical position.

In the upper and richer portion of this mine a large part of the mercury was in the form of metacinnabarite or black sulphide, which Dr. G. E. Moore first described from this locality. Metacinnabarite, as already mentioned, existed abundantly at the Reed mine. Mr. Goodyear also observed it at the Baker mine, between Knoxville and Lower Lake. It was found in large quantities at New Idria, and I have in Chapter II called attention to its occurrence in New Zealand, Mexico, and Rhenish Bavaria. So entirely had the accessible portions of the upper levels of the Redington mine been worked out at the time of my visit that I was unable to find any of this ore in place. Specimens show that it was accompanied by opal and marcasite and that it was in some cases coated with cinnabar, as if in process of conversion. It contains some iron. Dr. Moore's metacinnabarite was amorphous, but according to Mr. Goodyear it also occurred in a crystalline state. Dr. E. F. Durand describes crystals of this mineral which he regards as orthorhombic.[1] Onofrite has been reported from the Redington, but there is little doubt that the mineral supposed to be onofrite was in fact metacinnabarite. I was informed that more or less cinnabar always accompanied the black ore. The two were certainly mingled at New Idria.

[1] Proc. California Acad. Nat. Sci., vol. 4, 1872, p. 219.

Pyrite and marcasite accompany the ore of the Redington. The pyrite was tested for gold in my laboratory and unmistakable reactions for it were obtained. Millerite occurs in microscopic crystals in slides of the ore, but not, so far as known, in masses recognizable macroscopically. The gangue minerals are quartz and carbonates, and vast quantities of opal, usually dark brown or black, but sometimes of lighter colors, are closely associated with cinnabar. Microscopical examination shows that, while pyrite is frequently directly embedded in the opal, cinnabar is as a rule deposited with crystalline silica; indeed no case was found in which the cinnabar was directly embedded in opal.

The black opal, locally known as quicksilver rock, is manifestly a result of silicification, which formed a part of the series of chemical changes attending the deposition of ore. It was not a phase of the regional metamorphism of the country, but a local phenomenon. It seems here and elsewhere to have preceded ore deposition by a short interval. The opal was certainly not deposited in open cavities to any considerable extent, and for the most part has replaced constituents of rock masses particularly, but not exclusively, serpentine. In the Redington mine, ore is sometimes found with the quicksilver rock and sometimes at short distances from it, but the two substances are never far apart.

Although the occurrence of opal in this and other mines, as well as microscopical examinations of the material which will be described in Chapter XIV, shows that hydrated silica replaced rocks, cinnabar seemed to me to be confined to fissures, sometimes formed in opalized rocks and sometimes in other materials. Cinnabar occurs in contact with serpentine, but only where there has been disturbance prior to its deposition, and, so far as I know, never under conditions indicating replacement. The ore is not more usually found in contact with one rock than with another, but the larger ore bodies seem most often associated with brittle rocks.

Bituminous matter is not infrequent in this mine, and Dr. E. F. Durand has described a volatile substance which occurs here and at New Almaden as aragotite, a substance which he thinks allied to idrialite.[1]

[1] Proc. California Acad. Nat. Sci., vol. 4, 1872, p. 218.

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Solfataric gases.—At one point on the 150-foot level, in an old stope, the temperature is high and pungent sulphurous odors are very noticeable. At this place acicular sulphur crystals also form upon the timbers. I am unable to explain this occurrence except upon the supposition that sulphurous acid and hydrogen sulphide are escaping, and by their mutual decomposition yield sulphur. It is not infrequently the case in mines that hydrogen sulphide is produced by the reducing action of timber upon soluble sulphates, and the oxidation of this gas may then yield sulphur; but I do not know of any reaction by which sulphurous acid can be evolved at moderate temperatures from soluble sulphates in contact with organic matter. The presence of sulphites or hyposulphites among the mine deposits might lead to the evolution of sulphurous anhydride; but, while such salts appear to form near the surface at Steamboat Springs and Sulphur Bank, I have met with no evidence, there or elsewhere, of their deposition at depths such as to preclude the oxidizing action of the atmosphere upon alkaline sulphides. Hence it seems possible to account for the sulphurous anhydride which reaches the 150-foot level of the Redington only on the supposition that it represents a feeble remnant of solfataric action. The only other instance known to me in which sulphur is similarly crystallized on timber is at some of the workings of the Sulphur Bank which are now abandoned. In that case there is no question that the sulphur is produced by the mutual decomposition of sulphurous acid and hydrogen sulphide of solfataric origin. The high temperature of the spot where the sulphur crystals were found at Knoxville also strongly suggests volcanism. I have no record of this temperature, but I am certain that it considerably exceeded 100°F. No work was progressing near the spot, so that the abnormal temperature was not ascribable to candles and bad ventilation. The evolution of heat was tolerably rapid, for the locality was not closed off from the other workings. The high temperature must have been due either to volcanic emanations or to local chemical action. The heat of the Comstock mines has been hypothetically ascribed to local chemical action, but the hypothesis is not borne out for those mines either by observation or by experiment, and I know of no case in which such a temperature as that in the Redington, under similar conditions of ventilation, has been clearly traced to local decomposition of minerals. Were this a case of local chemical action, one would expect to find similar instances in other parts of this mine and in the other quicksilver mines of the slope, but, excepting at Sulphur Bank and at Steamboat Springs, no such temperature has been observed elsewhere. It is clear that this unusual temperature, together with the nature of the occurrence of the sulphur, points to the deposition of the ore from volcanic emanations and at a comparatively very recent period.

Structure.—The upper portion of the mine formed an immense ore body, or, more strictly, a confused group of ore bodies, each irregular in shape and divided from the rest by thin layers of poor or barren rock. The lower portion of this great ore body passed over into two parallel veins dipping at a high angle. These veins carried considerable quantities of ore, which did not indeed extend continuously along the fissures, but occurred in lenticular masses at the fissures. The veins also often showed thin seams of ore where there was no sufficient accumulation to permit of stoping. Slickensides and clays were abundant along the veins. They carried ore as far as explored, to the 600-foot level, but at that depth no valuable body of ore was found. The relations of the upper mass to the veins led me to believe that a third fissure must exist in the foot-wall, and at my suggestion a drift was run in to the position which the structure seemed to indicate as the probable position of such a third vein. A fissure was found, but at the point where it was struck it carried only pyrite. The ground was very hopeful in appearance, but the affairs of the mine were suffering greatly from the depression in the quicksilver market and the exploration was not pursued.

The following figure illustrates a cross-section of the Redington mine, showing the relation between the great ore deposit near the surface and the more deep-seated fissures (Fig. 10). An accident having unfortunately happened to the original, this figure is not drawn to scale, but is founded on a carefully prepared section to scale made from the mine maps, supplemented by data furnished by the foremen of the mine.

It is clear that faulting has taken place at the Redington under a compressive strain, the result at lower levels being the distribution of the movement over a series of parallel planes. This is a phenomenon which I have studied on former occasions.[1] In this case the movement has taken place close to the junction of two rock masses, one metamorphosed, the other unaltered, which offered different degrees of resistance. The motion also took place along a line upon which violent disturbance had occurred at the epoch of metamorphism long before the eruption of basalt. Thus the usual tendency to renewed motion along old lines of movement is once more illustrated.

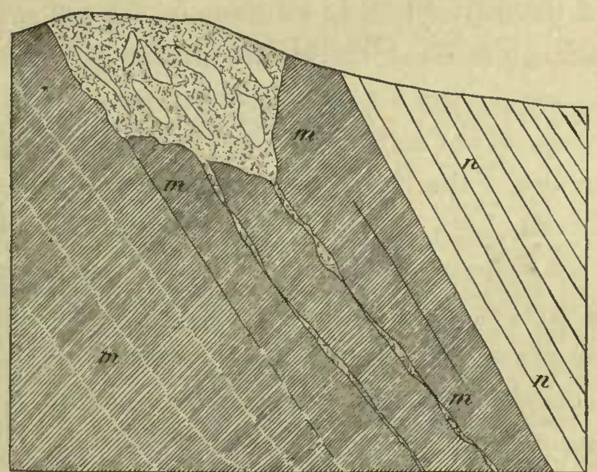

FIG. 10. Diagrammatic vertical cross-section of the Redington mine. *m*, metamorphic; *n*, unaltered Neocomian rocks.

In the upper part of the mine the disturbance broke the rock into a confused jumble of fragments. It is difficult to imagine how this difference of structure at different levels can have been produced, unless the present surface is but little beneath the surface as it existed when the fissures were formed. In other words, the lack of system in the fissures of the upper mine is an evidence that the fractures are comparatively recent and that the rock near the surface was thrown into confusion because it was not held in place by superincumbent masses.

Age and genesis.—The evidence as to the age and the mode of genesis of this important deposit consists in a number of facts, each of which, if taken singly, may be inconclusive, but all of which are concurrent. It may be well to mention them together. The deposits of the district are grouped

[1] Geology of the Comstock Lode, Mon. U. S. Geol. Survey No. 3, chap. 4; Am. Jour. Sci., 3d series, vol. 30, 1885, pp. 116, 194.

around the basalt area in a manner which indicates a relation between ore deposition and the eruption. At Mt. Amiata, in Tuscany, also, cinnabar deposits occur along the edges of a field of lava and are younger than the eruption. There is information, believed to be trustworthy, that cinnabar in the Lake mine was deposited at the contact between a basalt dike and the inclosing rock, and therefore later than the basalt. Mineral springs still issue close to the basalt and deposit sinter, the composition of which is similar to that of the matter held in solution by the hot springs at Sulphur Bank. The Redington, Reed, and Andalusia mines, with the fissure from which the basalt issued, form a nearly straight line. There can scarcely be a doubt of the escape of hot solfataric gases into the workings of the Redington, and the structure of the Redington ground is such as seems readily explicable if the ore has been deposited at a time so recent that little erosion has since taken place, but very difficult of comprehension on any other supposition. These facts seem to me to warrant the conclusion that the cinnabar deposits were consequences of the basalt eruption and that the course of deposition was entirely similar to that of Sulphur Bank.

This conclusion is particularly important because of the existence of most unmistakable veins at the Redington mine. The upper part of the deposit corresponds to and greatly resembles the underground developments of Sulphur Bank. The lower workings at Knoxville develop typical veins, which are continuous with the stockworks near the surface. The two forms of deposit, which are also associated at the great Austrian mine, were here formed at the same time and by the action of hot sulphur springs. True veins of ore may then be deposited from hot spring waters. It also follows that true veins probably underlie the Sulphur Bank.

Future prospects.—At the time of my examination the Redington showed little ore. This seemed to me very largely due to insufficient prospecting. I do not think a great ore body such as that at the surface will ever again be met in this mine, but I have no reason to suppose that it is exhausted or that important masses of ore are not still to be found at or near the principal fissures.

CHAPTER IX.

DESCRIPTIVE GEOLOGY OF THE NEW IDRIA DISTRICT.

[Atlas Sheet VI.]

Surroundings.—New Idria lies close to the line dividing Fresno and San Benito Counties, among the highest peaks of this portion of California. These form the southern end of the Mt. Diablo Range and divide the upper waters of the San Benito River from the drainage area of the San Joaquin. The scenery of this district is remarkable and wild. From its higher points the view is very extensive, embracing a large portion of the Coast Ranges, great areas of the San Joaquin Valley, and beyond it the southern portion of the snow-capped Sierra. To the southwest, the country visible from the New Idria peaks is fairly well watered, the ranges are wooded, and grassy meadows abound in the valleys. Near the crest of the range also there is a respectable growth of trees, but the comparatively lofty mountains of the district seem to extract the last available portion of moisture from the sea breezes, and the region to the east of New Idria is for the most part a wilderness, where the few springs are so alkaline, even in the wet season, that cattle will scarcely touch them and where a scanty growth of herbaceous plants among the almost naked rocks appears only for a few weeks in the spring.

This barren region extends as far as the San Joaquin Valley, which is fertile, at least in years of plentiful rain-fall, and early in the season is gorgeous with wild flowers. The eschscholtzia often grows in such masses in the valley that its fine orange tint is readily recognizable at a distance of 30 miles and stands out in pleasing contrast to the gleaming snows of the Sierra, which looms up in a somewhat unsubstantial fashion 125 miles away. Even within the small area embraced in the map the diversity of aspect is striking. The southwestern portion of the area surveyed is composed of highly metamorphosed rocks, crumpled and dislocated out of all semblance of regularity and weathered into more or less fantastic forms. Except where the surface is occupied by pure serpentine, this area supports fairly developed trees. To the northeast long and high sandstone bluffs succeed one another in endless succession and, being in large part utterly bare of vegetation, show to the most casual glance that they are composed of strata striking in a direction parallel to the trend of the range away from which they dip at large angles.

Questions presented.—New Idria has been a large producer of quicksilver, and was of course selected for study on that account. The geological interest, however, is not confined to the occurrence of ore, for the district happens to be admirably suited to the elucidation of two most important problems in the geology of the Pacific Coast These are the stratigraphical relations between the Lower and Upper Cretaceous and the true character of the famous Téjon beds. The last question has been a subject of controversy for a quarter of a century.

The metamorphic series.—The metamorphic belt, a part of which is included in the map of New Idria, is almost if not quite continuous from Mt. Diablo southward. The lithological and physical character of the metamorphic rocks at New Idria is identical with that of the altered strata at Mt. Diablo, at Knoxville, at San Luis Obispo and, in short, at all the points where members of this series have been found to contain characteristic fossils. Wherever determinable fossils have been found in the metamorphic series—and localities are known in nine counties—the age is the same, viz, the earliest portion of the Cretaceous period. No beds older than this are known to exist in the Coast Ranges. At New Idria organic remains are not altogether wanting in the rocks of this series, for plant remains are found in the New Idria mine, but the specimens are far too imperfect to admit of identification. Nevertheless the facts adduced above, together with other general considerations enlarged upon in Chapter V, make it almost certain that these rocks are members of the Knoxville series. There is a bare possibility, which no observed facts support, that they may be

Pre-Cretaceous; but, even if this could be shown, it is evident that they must have shared in the disturbance which accompanied the metamorphism of the Knoxville beds at Mt. Diablo to the northwest and at San Luis Obispo to the south.

An immense area of serpentine exists to the southwest of the New Idria district, only an edge of which is included in the map. In this, as in some other respects, there is a close analogy between New Idria and the area surrounding the Redington mine. Partially serpentinized rocks are common, and the descriptions of the transitions from sandstone to serpentine given in the chapter on the Knoxville district would apply without change to occurrences observed in this district. Professor Whitney here saw masses of serpentine consisting of radially arranged fibers in concentric layers, which he also considered as showing the unquestionably metamorphic origin of the mineral.

Shales are also largely represented here among the metamorphic rocks, and at Venado Peak argillaceous rocks of this description pass over by gradual transitions into phthanites. Some of the shales are so little altered that fossils might have been preserved in them, but prolonged and earnest search failed to reveal even a fragment of a shell. Similar rocks devoid of fossils are provokingly frequent in the Coast Ranges. *Aucella* was evidently a gregarious mollusk, and where specimens are found they are sometimes very abundant; but, though these animals lived on both sandy and muddy bottoms, the localities in which they flourished seem to have been few.

The metamorphic rocks have been dislocated in the most violent manner; indeed, the greater part of the mass was crushed at the time of the metamorphism to a small rubble. This is the case throughout the entire quicksilver belt and renders it utterly impossible to plot any sections of the metamorphic strata. I had hoped, by taking very numerous dips in the metamorphic area, to determine at least a prevailing system in the stratigraphical arrangement of the mass, for such a system might very well exist in spite of a large amount of comminution. Hundreds of dips were accordingly measured all over the metamorphic area, but without any result. No fortuitous distribution of directions could have been less accordant The position of the serpentine belt, however, and observations made elsewhere on the structure of the Coast Ranges, lead me to believe that the axis of upheaval at the close of the Neocomian coincided in direction with the present range, as was the case at later uplifts. In the area mapped the various classes of metamorphosed rocks are so mingled that it is not practicable, as at Knoxville and New Almaden, to lay down areas which are chiefly serpentinoid.

The serpentine near the county line contained a considerable quantity of chromic iron, which is said to have been mined at one time under the belief that it was a silver ore. The workings are now so nearly obliterated that nothing could be made out as to the character of the occurrence. As is pointed out in Chapter III, particles of chromic iron are very common in the serpentine of the Coast Ranges.

The Chico.—Resting against the metamorphic rocks are the Chico beds. These are thousands of feet in thickness and the exposures are very extensive, but the rocks are very poorly supplied with fossils. With much trouble, however, a small collection of fossils was gathered, and among these Dr. White recognized *Ammonites*, *Baculites*, *Inoceramus*, and *Lima* These genera are characteristic and the identifications are sufficient to establish the age of the beds beyond a doubt. The rocks of this series are for the most part soft, coarse, arcose sandstones of a reddish-gray tint; but small quantities of shale, conglomerate, and limestone are here and there intercalated between arenaceous beds. The prevalent rock is so soft that branches of manzanita bushes, growing across croppings and swayed by winds, sometimes wear channels inches deep in the rock without being killed. Near the mine, however, some induration has taken place, and cinnabar has been deposited in the Chico sandstone. Seams of gypsum, sometimes selenite, are common enough in these beds, as well as in the Téjon and Miocene strata. There are also at many points dark brownish-red, spherical concretions in this sandstone which are very firm. I do not doubt that the induration of these masses has been effected by the action of some substance which once existed at or near the centers. One of the concretions from this locality was found to contain a fossil at the center, and a few similar occurrences have been met with elsewhere. In Chapter III, I have given the results of an investigation of one of the concretions containing no fossil from the New Idria Chico beds, which seem to prove that the induration is due to the decomposition of an organic nucleus.

When the rock is of nearly uniform texture spherical concretions often extend over several laminæ, the regularity of which is undisturbed by the induration of the nodule. In other cases the concretions are flattened, and this form seems to be related to the unequal composition of adjoining beds. The shales of this formation are remarkable for nothing but their rarity. Conglomerates are still less frequently found, but such a bed is exposed on the road from the furnaces to the upper mine at a distance of a few hundred feet from the contact with the metamorphic mass.

Non-conformity.—This is an occurrence of much importance, for the pebbles which it contains are metamorphic and are composed of siliceous and serpentinoid rocks. Such rocks must therefore have been exposed to erosion at the time when the lower portion of the Chico was deposited, and probably at no great distance from the position now occupied by the conglomerate. There is no reason to suppose that the metamorphic rocks were other than those now exposed, and the metamorphism with the attendant upheaval must consequently have taken place prior to the deposition of the Chico, or, in other words, there must be a lack of conformity between the two.

Before the pebbles of this conglomerate had been studied under the microscope I had made out the existence of the non-conformity on structural grounds, as was described in Chapter V. It is unnecessary to repeat that argument at length here.

The Chico beds constitute a conformable series, inclined at an angle which is high close to the contact with the metamorphic rocks and diminishes as one proceeds northward. A result of the steepness of the contact is the absence of any single exposure by which a non-conformity can be proved beyond a doubt; but a study of the relations along the whole line leads at least as satisfactorily to the conclusion that there is a want of conformity. Over nearly the entire area mapped the Chico strata strike along gently undulating lines whose minimum radius of curvature is usually about one mile, and this regularity is persistent up to the contact. Only at the western edge of the map is there considerable disturbance among beds of the Chico series.

The line of contact, on the other hand, is marked by many irregularities. In the following diagram (Fig. 11) the line *a b* is the contact as it would appear were a horizontal plane passing through it at the mean elevation of 3,800 feet. The line *c d* shows the intersection of one of the Chico strata with the 3,300-foot level. The stratum for which this subterranean contour line was deduced was followed almost continuously for the entire distance shown, a closely adjacent stratum being sometimes substituted for a short distance. Other strata were mapped as far as they could be followed, in several cases for over half a mile. The curvature was in all cases similar and the conformity was absolute. In comparing this figure with the geological map it is of course to be remembered that the contact on the latter is laid down as it appears on the actual surface, while in the figure it is represented as it would appear were the country a horizontal plane. At one point the line of the figure is still further modified. The steep hill immediately south of the Hacienda or Bell tunnel is not wholly in place. A large landslide has begun here and an immense mass of metamorphic material has moved northward past the solid contact. For this movement allowance has been made in drawing the figure.

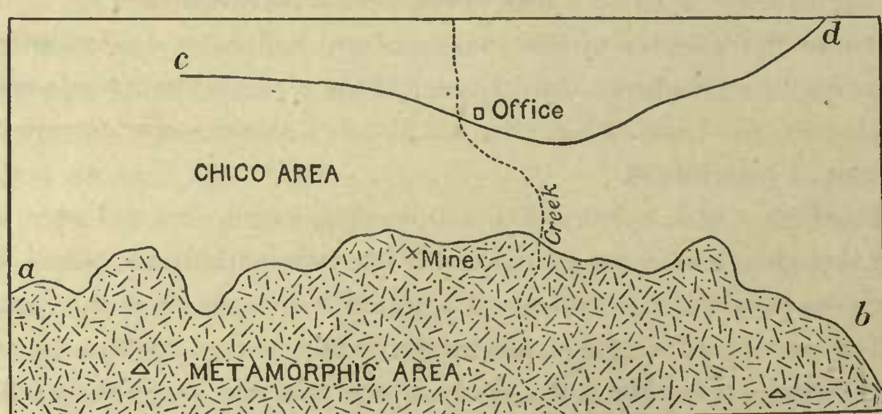

FIG. 11. *a b*, contact between metamorphic rocks and Chico beds reduced to intersection with a horizontal plane; *c d*, strike of a Chico stratum reduced to intersection with a horizontal plane.

The structure is evidently consistent with a non-conformity. It is also conceivable that the entire mass of strata was laid down conformably and that the disturbance and metamorphism ceased abruptly at the line represented by the contact. In that case, however, still greater irregularities in the line of contact would almost certainly exist, as well as outlying patches of metamorphic rock and transitions between metamorphosed and unaltered beds along the contact. The presence of siliceous and serpentinoid pebbles in the Chico conglomerate would also be very mysterious. The non-conformity above the metamorphic series is thus substantially certain from the observations at New Idria alone. Confirmatory evidence was obtained on the north fork of Cantua Creek, some five miles southeast of New Idria. At that locality the creek cuts through hills capped with heavy beds of Chico sandstone, which are inclined at an angle of approximately 30° and strike at right angles to the course of the creek; but this interval is only a few hundred feet in width and there can hardly be a doubt that, if the talus were removed, the Chico beds would be found resting on the upturned edges of the metamorphic rocks. Had the thin-bedded rocks been driven into their present position after the deposition of the Chico rocks, the latter could not, in my opinion, have been so little disturbed. The beds are not visibly flexed and form cliffs at their upper end. In the creek the metamorphic, thin-bedded sandstones are exposed in a nearly vertical position. The interval between the creek bed and the exposed sandstones is covered by detritus and vegetation.

The mine affords one important exposure of the contact below the Chico. This is in the Bell tunnel, the position and course of which are shown on the map. Its mouth is in the Chico strata, and it passes far into the metamorphic mass. The rocks near the entrance are thick beds of soft, tawny sandstones, with occasionally thin masses of shale. They are unbroken and dip north 30° east at angles of 65°, with some small variations. As the contact is approached breaks begin to appear in the sandstones, due to special disturbances in the region of the mine, which will be referred to in describing the deposit. While there are fractures and small faults along this part of the tunnel, the rock nowhere seems to be flexed and the beds recover their normal position at frequent intervals. The beds are neither silicified nor serpentinized, but, as at the surface, there are occasional stringers of calcite and gypsum. At a point 90 feet northward from the last station before the main cross-cut is reached, or at a distance of about twenty-four hundred feet from the mouth of the tunnel, a change takes place. Instead of the heavy sandstone beds with an occasional seam of shale, the thin, indurated strata so prevalent in the Knoxville series make their appearance. Instead of being flat like the sandstones or so little flexed that the curvature is insensible in the width of the tunnel, these thin-bedded rocks are almost everywhere greatly contorted, and for a considerable distance the tunnel is driven through an angle of flexure so sharp that the strata coming in at the roof in one direction pass out at the floor in another, differing from the first by 90°. This sudden transition from uncontorted to closely flexed strata and from soft sandstones to siliceous, thin-bedded rocks certainly suggests a non-conformity most forcibly. Indeed I know of no other theory which seems adequate to explain the circumstances; but along the actual contact motion has taken place and in regions of great disturbance the results of faulting sometimes closely simulate the aspect of non-conformity. From this exposure alone, therefore, I should be unwilling to pronounce upon the structure.

While there is no single exposure at New Idria from which a non-conformity can be demonstrated, there are many which are most satisfactorily explained by the supposition of a lack of conformity; indeed, when once the idea of a break in the continuity of sedimentation is suggested, a mere inspection of the country from any higher points affords the experienced geologist strong evidence in its favor. The transition from the crumpled, chaotic, metamorphic rocks to the gently undulating sandstone beds is too complete and too abrupt to fit easily into any other theory of structure.

There is much other structural evidence in the Coast Ranges, both direct and indirect, besides that obtained at New Idria, of this extremely important non-conformity. Its existence is also an inevitable concomitant of the time relations of the two sets of strata involved, for between the period of the Knoxville beds and that of the Chico there is a gap of hundreds of thousands of years.

It would have been nearly impossible to work out the extremely important structural geology of this district without a topographical map of great accuracy. The map prepared for this report by Mr. J. D. Hoffmann is entirely satisfactory in this respect. It may be depended upon for every detail and would bear enlargement to three times the scale on which it is published.

Eocene.—The Téjon formation is also represented at New Idria. Fossils were found in it by Mr. Gabb, and my party also collected a number of characteristic forms. For the reasons set forth in Chapter V it has been for many years a mooted point whether the Téjon series formed a portion of the Cretaceous or of the Tertiary. The fact is that it may be said to belong to both. There is neither fault nor unconformity between the Chico and the Téjon at New Idria; the deposition of sands went on uninterruptedly from the one period to the other, and Dr. White shows that there was a continuity of life also between the two. In short, in California there is no sharp distinction between the two series, though the Chico-Téjon beds are divisible paleontologically into an upper and a lower portion connected by transitions. The character of the faunas, however, proves that the Chico must be regarded as the concluding period of the Cretaceous era and the Téjon as the opening period of the Tertiary. Such a transition has been observed nowhere else in America or in Europe.

Even if the strata at New Idria were more abundantly supplied with fossils than they are, a hard and fast line could not be drawn between the Chico and Téjon. The demarkation indicated on the map, however, is not wholly arbitrary. The beds containing distinctly Téjon fossils both here and at Mt. Diablo differ physically from the Chico. The upper series is composed almost exclusively of sandstones which are remarkably light colored—often pure white—while the Chico sandstones are firmer and of a tawny color. These characteristics are so persistent that I have drawn the outline of the Téjon at the lowest of the white beds. The included area of course embraces all the known localities at which fossils referable to the upper series are found.

The line drawn between the Chico and the Téjon is rather irregular on the map and at its easterly end bends sharply northward. This suggests a non-conformity, but the suggestion is misleading. A portion of the irregularity of the outline is due to the unevenness of the surface. At many exposures the beds are shown in perfect conformity, but the soft, white beds have yielded to the stress accompanying upheaval more than the great

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mass of the Chico, and the dip is in some places reversed near the contact, giving this line greater irregularity than it would possess had the strata been more uniform in physical character. Towards the east end of the contact there has been a certain amount of disturbance, seemingly produced by a longitudinal stress. It has affected both series of beds, and here as elsewhere there is evidence of conformity. Near the western end of the contact a tongue of Chico rock is shown projecting into the Téjon area. This tongue is superficially composed of sandstone rubble, probably brought down from the more elevated area by floods. There is no reason to doubt that the contact of rock in place follows the dotted line drawn on the map across this tongue.

Although the greater part of the Téjon beds are nearly white, some of them contain dark, ferruginous concretions of a kind similar to those noted in the Chico. These nodules are less abundant and less regular in the Eocene. In passing it may be noted that Miocene rocks in the Vallecitos Cañon are thickly studded with spherical concretions of the same kind.

The Téjon is the coal-bearing formation at Mt. Diablo. At New Idria also there is a coal seam near the San Carlos Creek, just north of the limits of the map. Fuel was supplied to the mining company for the blacksmith-shop and other purposes for many years from this seam, but it was of purely local importance.

The thickness of the Chico-Téjon strata is very great. The thickness of the least-disturbed portion represented upon the map, when measured perpendicular to the stratification, is about seven thousand feet, but the entire series is not included in the area mapped. There cannot be less than ten thousand feet of the complete series. How such enormous accumulations, consisting almost exclusively of sandstone, can have been formed is a mystery. There are great thicknesses of Miocene beds also within a few miles of New Idria on both sides of the range, and these too are substantially composed of sandstone.

Absence of lavas.—No eruptive rocks are known to exist nearer to New Idria than about ten miles. There is a considerable area of basalt to the northwest of Vallecitos Cañon, or to the southeast of the Cerro Bonito mine. Pebbles of lava are also to be found along the lower portion of San Carlos

Creek. The absence of eruptive rocks close to the mines of New Idria, however, does not preclude the former existence of hot springs here. It simply leaves the question to be decided by analogy.

General description of the New Idria.—The deposits of the New Idria mine are substantially inclosed in rocks of the metamorphic series. Of these, serpentine is represented only to a small extent, the prevailing rocks being shales and sandstones in various stages of alteration. An important portion of the shales have been converted into phthanites, while some of the sandstone has almost escaped induration. The deposits are near the contact between the metamorphic rocks and the adjoining Chico sandstones; so also is the San Carlos mine to the east. At a distance of about three thousand feet westward from the New Idria, however, the limiting line of the metamorphic area bends in a southerly direction, and in the bay thus formed is a mass of somewhat indurated Chico sandstone, in which cinnabar has been found. This occurrence, known as the Washington croppings, shows at least that the period of ore deposition is later than the Chico, or that it is Post-Cretaceous.

The New Idria mine has disclosed important deposits of three distinct types: reticulated masses, or stockworks, impregnations, and true fissure veins—in short, all the principal classes of original ore deposits are represented. There is no question whatever as to the fact of a connection between these deposits and a system of fissures, but this system is unusually complex in some particulars which are of the greatest importance in relation to the economic value of the property. A portion only of the deposits was accessible at the time of my visit.

The upper part of the deposits, and particularly the northeastern portion, consisted of irregular stockworks. Only the excavations close to the croppings are now accessible. They show siliceous shales and phthanites, containing a few carbonized plant remains, with small seams and "paints" of cinnabar. The ore, accompanied by pyrite and quartz, has sometimes filled cracks across metamorphic strata and has frequently also followed the bedding exactly as it is observed in innumerable mines and prospects throughout the Coast Ranges. There is nowhere in these dense rocks any indication of impregnation. The descriptions of the great ore bodies of the northeast part of the upper mine by Mr. J. W. C. Maxwell, who was for many years superintendent, and the account published by Professor Whitney show that these ore bodies also consisted essentially of broken rock the interstitial spaces of which had been filled in with ore. The various bonanzas showed little evidence of systematic arrangement, though they were often connected by stringers or "hilos" of ore; but the plan of the workings proves that the prevailing strike was northeast and southwest. There are two well marked veins in this mine One of them, the New Hope lode, was enormously rich and was very remarkable for the fact that the ore was mainly composed of metacinnabarite with which a little cinnabar was mingled. This vein is in the eastern portion of the ore-bearing ground. It strikes approximately northwest and southeast. The other vein is at the southwestern portion of the ore-bearing ground and is known as the Elvan Streak vein. This is a misnomer, for elvan is quartz prophyry, while at New Idria neither this nor any other eruptive rock occurs. The Elván Streak is for long distances a clean-cut fissure, filled with decomposed attrition products which are impregnated with cinnabar. In contact with the vein are ore bodies, in part stockworks and in part impregnations. This vein strikes in about the same direction as the New Hope, and near it at one point were found some tons of metacinnabarite. To the southeast it is cut out by a clay seam. Ore-bearing ground has also been developed by the Bell tunnel, the deposit consisting of a very large but low-grade impregnation of cinnabar in sandstone.

Disposition of the ore bodies.—The disposition and form of the deposits as indicated by the above notes are sufficiently intricate, but the structure of the country is still further complicated by the presence of a clay wall running diagonally across the ore-bearing ground near the eastern end and dividing the New Hope vein from the remainder of the principal deposits. The presence of this wall renders plausible each of two distinct theories as to the fissure system of the mine, but leaves neither free from doubt.

The plan of the workings is so complex as to be very difficult to follow and the records of the mine contain no vertical section of the ground. Cross-sections were perhaps unnecessary to those thoroughly familiar with the workings, but it is impossible for others to obtain an accurate idea of the form of the stockworks from the mere projection on a horizontal plane. No purpose would therefore be answered by reproducing the plan of the mine in this volume, but an idea of the distribution of the deposits will be conveyed by the following sketch, in which some of the ore bodies and the position of the clay wall are shown in horizontal projection in a somewhat generalized manner (Fig. 12). Leaving the New Hope out of consider-

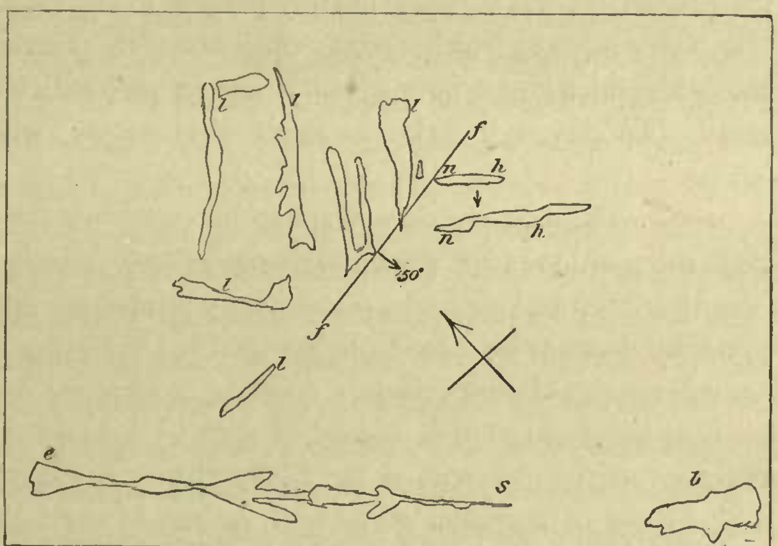

FIG. 12. *e s*, Elvan Streak. *n h*, New Hope. *l l l*, Stockworks. *b*, Bell tunnel ore chamber. *f f*, Strike of clay wall dividing the New Hope from the remaining ore bodies.

ation for a moment, it is evident that the remaining deposits may be divided into two groups, one including the Elvan Streak and contiguous bonanzas, together with the Bell tunnel ore body, while the other cluster comprises the stockworks. The former of these groups I have had good opportunities of examining. It is beyond question that north of the clay wall the Elvan Streak is a fairly regular, nearly vertical vein, which has afforded a passage for ore-bearing solutions. These have permeated the walls wherever they were permeable and ore chambers have been formed as adjuncts to the vein. The Bell tunnel body consists of very slightly modified sandstone of porous texture, impregnated with cinnabar, which also forms seams wherever cracks in the rocks permitted such deposition. It lies in the direction of the strike of the Elvan Streak, and the fissures through which the two were charged with ore must, I think, be very closely related.

They may be identical; but, if not, they are probably parallel, associated fissures. The developments accessible to me were insufficient to determine this point.[1]

With reference to the stockworks, my information is obtained at second hand and is very imperfect. I hesitate, therefore, to express decided opinions about them. It is noteworthy, however, that the most westerly of these deposits, the Florencio Diaz, is approximately parallel to the Elvan Streak, as is also the New Hope, to which further reference will be made below. Most of the other stockworks have a strike nearly perpendicular to the Elvan Streak. The clay wall makes an angle of about 45° with each of these directions.

The fissure system.—The most momentous question concerning the structure of this mine is the position of the principal fissures, those, namely, through which the ore-bearing solutions found access to the productive ground; for upon this question depends the plan to be adopted in developing the property. The main fissures almost certainly coincide in direction with one or other of the lines discussed above; indeed, it may be assumed with some confidence that either the clay wall or the Elvan Streak lies on the principal fissure or on one of a system of parallel fissures of nearly equal importance. The existence of the stockworks is susceptible of explanation as a subordinate structural phenomenon. The theory which was adopted in developing the mine is that the clay is the hanging wall of the ore-bearing ground. The Elvan Streak then represents a cross-course and the New Hope is an isolated deposit in the hanging wall. Great weight is to be given to this opinion, which was formed by the daily study of the exposures. It is evidently possible, however, that the main fissures may coincide in direction with the Elvan Streak and the New Hope and that the clay wall may represent a cross-course or a fault. I confess myself strongly inclined to this latter view.

Had the fault fissure been the channel of the ore solutions, one would expect to find the chief ore bodies in contiguity to it and coinciding with it in general direction. It is a common thing to find deposits of very

[1] Early in 1887 ore was struck in the Bell tunnel workings which resembled that of the Elvan Streak. This tends to confirm the above hypothesis.

irregular outlines and with ramifications extending into the walls along the fissures to which they owe their origin; but such deposits almost invariably follow the fissure to a certain extent and present a large contact surface with it. No better illustration of this usual relation could be given than the Elvan Streak, with its accompanying bonanzas. Nothing of the kind is apparent at the fault fissure. Where ore touches it at all, the surface common to both is small. As a rule the fissure containing this clay seam carries no ore whatever, while, had it been the channel of the ore-bearing solutions, one would expect to find at least small quantities of cinnabar nearly everywhere in it, as is actually the case in the Elvan Streak. It is very true that, in wide veins bounded by selvages of clay, the clay is often barren; but such cases are not comparable with the ore-bearing ground of the New Idria as a whole. The prevailing character and disposition of the rock, together with the absence of a defined foot-wall, show that the stockworks are not comparable to pockets in a vein, but to chambers adjacent to a vein and impregnated from it. They are not included in a fissure, but were charged with ore from a fissure. The stockworks stand to some fissures in relations similar to those which subsist between the Elvan Streak and the irregular, contiguous ore bodies, and do not correspond to bunches of cinnabar between the walls of the Elvan Streak. The term "pipe vein" is used by von Cotta to describe some deposits analogous to these; but this expression, having been employed in different senses, is now objectionable. A corresponding term is much needed to describe these adjuncts to fissures.

If the principal fissure of this mine be that at the clay wall, the clay, in my opinion, fills the fissure. In that case the absence of cinnabar in considerable quantity from this clay is very strange, and would be so even if the Elvan Streak and the New Hope did not exist. The fissures carrying these two veins, however, were most assuredly in existence at the time of ore deposition, showing that the physical character of the rock was not such as to preclude deposition in fissures. This makes the absence of ore from the clay wall inexplicable if it lies on the main fissure. On the other hand, if the clay marks the position of a fault which took place later than the deposition of ore, its own character and the relation which it bears to the deposits are exactly such as would be expected.

The clay wall, then, appears to me to mark a fault which has dislocated the ore-bearing ground. This fault has certainly not passed by the deposits, for it has cut off the New Hope lode from the other ore bodies. The hanging side of this clay wall has been little explored. I consider it the most hopeful portion of the property and believe that explorations should be made in it. I have no data tending to show the amount of the fault or even its direction, but, according to the general rule, ore bodies, if they exist and were once continuous with the stockworks, will be found at lower levels on the hanging side of the fault. The Elvan Streak and the New Hope appear to me to mark the direction of the main fissures of the mine. The disturbances which made room for the stockworks were probably contemporaneous with those which produced these veins. There is no evidence of a lapse of time between them and it is not difficult to understand how the two sets of ruptures may have been brought about simultaneously. Where a fracture is accompanied by torsion, two sets of fissures form at a large angle to each other. This has been demonstrated experimentally by Mr. Daubrée. The Coast Ranges are full of evidences of torsional fractures. At New Idria and elsewhere highly indurated shales are very common, which, even in small fragments, exhibit innumerable cracks, often filled with quartz, which are divisible into two systems nearly at right angles to each other. There is plenty of evidence, too, that fractures like those produced on a small scale are formed also on a large one. When a mass is broken under a torsional stress, the force will not in general be equally resolved in two directions perpendicular to each other and the intensity of the disturbance will be greater on one set of ruptures than on the other. The more violent a rupture in the rocks is, other things being equal, the cleaner will be the fissures produced, just as a rifle-bullet makes a round hole in a pane of glass, while a body moving at a low velocity crushes the whole pane to fragments. The ill defined zones of broken rock which led to the formation of stockworks resulted from disturbances less violent than those which produced the vein fissures; but the two sets of ruptures, in my opinion, were due to one cause, a torsional stress, and were produced at the same time. In searching for ore these vein fissures, and perhaps others parallel to them, should serve as guides. Other stockworks may very likely be found and the connection between them and the fissures striking northwest-southeast may sometimes be indirect, but is not likely to be entirely wanting. I can see no indication that the mine is exhausted, and I believe that more bonanzas exist to the south of the clay wall and perhaps also beneath the old group of stockworks, or on the lower portion of the Elvan Streak vein.

Age of the deposit.—The existence of cinnabar in the Washington croppings shows that the deposit is as late as the beginning of the Tertiary period. The deposit also seems to be later than the tilting of the Chico beds, which undoubtedly took place at the uplift shown by Professor Whitney to have occurred at the close of the Miocene. The eruption of lavas in the Coast Ranges seems to have begun early in the Pliocene, probably at its commencement. The period of ore deposition at New Idria thus seems to be within the volcanic epoch. It is probably much more recent than the Post-Miocene upheaval. The quantity of cinnabar found in the soil was small, tending to prove that no great erosion had taken place since its deposition. The ore bodies near the croppings are such as occur most frequently near the surface as it existed at the time of ore deposition. This relation will be found enlarged upon in several of the investigations recorded in this volume, particularly that of the Redington mine, where also stockworks and veins are associated. There is nothing at New Idria to suggest a considerably greater age than that of the Redington deposit. The latter is certainly Post-Pliocene.

In a drift near the stockworks on the lower tunnel level I met with what is at least a very curious and suggestive occurrence, which may have a bearing on the age of the deposit. The drift had not been used for years, and the walls were coated with epsom salts and other secondary minerals to the depth of nearly two inches. In this loose coating I found a tiny seam of cinnabar which had quite beyond question formed in this position since the drift had been abandoned. This proves that mercuric sulphide still exists in solution in the waters of the mine. It may be that the solution from which this little vein was deposited was a remnant of that from which the great ore bodies were precipitated. If so, the period of ore deposition is not even yet wholly past. But it is also not impossible that this cinnabar was leached from the stockworks by surface waters impregnated with sodium sulphide, this reagent resulting from the reduction of soluble sulphates by timber in the old workings. However this may be, the occurrence has a bearing upon the rarity of metacinnabarite in quicksilver mines, as will be shown in a subsequent chapter. Any solution capable of dissolving mercuric sulphide will tend to convert metacinnabarite into the red ore.

Origin of the deposits.—Had the New Idria mine alone been examined nothing could be affirmed concerning its origin further than that the ore was deposited from solutions which obtained access to the mine through a system of fissures. There is a sulphur spring in the district, but it is cold and may have nothing to do with volcanism. It is certain, however, that many deposits in California, similar in all essential respects to that of New Idria, have been precipitated from hot, fluid, volcanic emanations. It is also known that, in some cases, very hot sulphurous waters which rise at a distance of several miles from any known lava have deposited cinnabar. There is thus much reason to suppose that the New Idria deposits were formed by hot volcanic solutions, and no reason with which I am acquainted for suspecting any other origin.

Combustible gases escaped from the rock in great quantities during the running of the Bell tunnel and produced a disastrous explosion.[1] This gas was probably marsh gas, and it may or may not have been generated by volcanic action. In the Ætna mine also, the ore of which was certainly deposited from volcanic springs, as well as at Sulphur Bank, marsh gas escapes.

Other cinnabar deposits.—Besides the New Idria other less important deposits of cinnabar have been found within the limits of the map, though none of them was worked during my visit. The San Carlos mine, near the summit of San Carlos Peak, is in the rocks of the metamorphic series, consisting of thin, indurated shales, which have been whitened either by solfataric action or by leaching consequent upon the decomposition of pyrite. No exposures of special interest were accessible. The ore is said to have been

[1] After this explosion Mr. Maxwell employed a very ingenious method of lighting the tunnel without the use of fire. A mirror was placed at the mouth of the tunnel and was kept at such an angle as to reflect the sun's rays into it. This illumination, which was repeated for my benefit, was very satisfactory. The cloudless sky of California makes this method entirely practicable. A locomotive headlight might perhaps be used to advantage in a similar manner underground in certain cases. Possibly this device has been employed before, though I am not aware of it.

rich, and a considerable quantity was extracted and delivered at the New Idria furnaces. The deposits were very irregular and no considerable attempt seems to have been made to develop the property in depth. The Aurora or Morning Star mine, to the west of the San Carlos, also yielded ore. Beyond the fact that excavations were made here nothing is visible. Near the falls on San Carlos Creek, in a line connecting the New Idria and the Morning Star, a little cinnabar is said to have been found, and traces of ore have been detected at other points, all of which, except the Washington croppings, are within the metamorphic area.

Within a few miles of the area mapped and to the southwest, several mines have been opened and again abandoned. The Picacho is in the usual contorted, highly indurated rocks, partly silicified and partly converted into carbonates. The ore appeared to have occurred in cracks across the strata and along the partings.[1] It is said that the first continuous quicksilver furnace ever built in the State was erected here by Mr. John Roach. This structure was still in place at the time of my visit, in 1884, and substantially in the same condition as when it was examined by Mr. Goodyear thirteen years earlier. Several pounds of quicksilver still remained in the wooden condenser, showing how slowly quicksilver must volatilize, even at the high temperatures which prevail in this region during the summer. Near Clear Creek also are two mines, or prospects, at which ore associated with rocks of the same type as at the Picacho was extracted.

[1] In a prospectus of the company an assay is given according to which, besides mercury, the ore contains considerable amounts of both gold and silver. I did not have an opportunity of verifying this statement, which is not intrinsically improbable.

CHAPTER X.

DESCRIPTIVE GEOLOGY OF NEW ALMADEN DISTRICT.

[Atlas Sheets VII-XIII.]

Character of the district.—The New Almaden, Enriquita, and Guadalupe mines lie nearly south of San José, in a very attractive portion of the country. The fertile valley of Santa Clara is in full view from many parts of the region mapped, and the Santa Cruz Range, on the flanks of which the deposits occur, is picturesque. Forests, gorges, and brooks diversify the scenery, the character of which reminds one of portions of the Sierra Nevada rather than of the Coast Ranges. This district has been much more productive in quicksilver than any other in North America, and since 1850 it has yielded about four-fifths as much metal as the Almaden of Spain. The general geology of the district presents one special feature of interest in the occurrence of rhyolite, a lava not yet recognized at any other point in the Coast Ranges. Otherwise the general geology presents no novelty. The great opportunity which the district offers is for the study of structure disclosed by the very extensive workings of the New Almaden mine, which are said to measure 40 miles in length.

Metamorphic rocks.—The greater part of the surface is occupied by rocks of the metamorphic series. The age of these rocks is known, for Mr. Gabb found near the mines specimens of *Aucella*. He does not, indeed, describe the rock in which this characteristic shell was found, nor does he give the exact locality, but from the various other occurrences mentioned in this volume it is abundantly proved that the metamorphism was of later date than the period at which *Aucella* flourished. The metamorphic rocks of the district must therefore include beds containing this fossil and dating from the Neocomian. I did not succeed in finding *Aucella.*

The metamorphic rocks are for the most part identical with those so prevalent in the Coast Ranges. Pseudodiabase, pseudodiorite, phthanites, serpentine, and less altered rocks are abundant. There are also masses of limestone, one of which is quarried for the manufacture of quicklime. The occurrence of this rock, which is rather rare in the Coast Ranges, affords the observer an opportunity of estimating the intensity of the disturbance which attended the metamorphism. The mass of limestone from which the material for the limekiln is obtained must have formed a portion of a continuous stratum, but this has been so broken and dislocated that it now appears only as irregular patches scattered through the hills and it is quite impossible to restore the original configuration or to obtain from it any aid in elucidating the stratigraphy of the accompanying rocks. It was found possible to lay down the serpentinoid areas in this district, and they have received a separate color on the map. As on the other maps where this has been done, it must be understood that no sharp division really exists and that the purpose of the delineation is simply to indicate as nearly as may be the distribution of a certain phase of metamorphism. The general structure of the ridges of metamorphic rock seems to be synclinal, as it is at so many points in the Coast Ranges.

Granite.—There is no reason to doubt that granite underlies the region of New Almaden, though at a considerable depth. In the Gavilan Range and at Monterey, to the south, granite is exposed, and it appears also to the north, near Point San Pedro. The composition of the sandstones also indicates that the material of which they are composed is of granitic origin. As is shown in other portions of this report, there is evidence that the entire area of the Coast Ranges is underlain by granite, and the facts observed lead almost inevitably to the conclusion that the brush-covered hills, if examined with sufficient care, would show many outcrops of the rock which have hitherto escaped observation. It is far from improbable that granite is exposed in the somewhat inaccessible country southeast of New Almaden.

Olivine gabbro.—At various points in the district thoroughly rounded pebbles of a peculiar, coarse-grained, crystalline, gray rock of unusual hardness were found, which differ strikingly from any rock seen in place. They must have come from the higher mountains of the range to the southeast, but the croppings were not identified. This rock, when examined under the microscope, proved to be an olivinitic gabbro, the only rock of the kind known in the Coast Ranges and the only rock carrying even a trace of olivine detected during this investigation, excepting the lavas. The coarse grain and the general aspect of this gabbro suggest for it a very considerable age, but the olivines are very fresh and show only thin seams of serpentine along the cracks. Whether the rock is eruptive or metamorphic could not be determined from the material available. Olivine does not form a large proportion of the mass and decomposition would not yield a material to which the name of serpentine would apply unless other constituents besides olivine were serpentinized. As for the serpentine of the New Almaden area, the researches recorded in Chapter III show that they are derivative of sandstone, as is the case in all the districts examined.

Miocene.—Upon the metamorphic rocks lie some areas of Miocene sandstones. These are soft, yellowish strata, containing a considerable number of poorly preserved fossils (*Pecten*, *Ostrea*, *Balanus*), which, however, taken in connection with structural and lithological characteristics, are amply sufficient to fix the age of the beds. The Miocene rocks are considerably disturbed, though far less so than the metamorphic series. The structural relations indicate a non-conformity between the Tertiary and the metamorphic series, which is also demonstrated by the presence of fragments of the earlier strata in the Miocene beds. Professor Whitney observed sections exhibiting this non-conformity within a few miles of New Almaden. As is shown in Chapter V, the non-conformity displayed in an unequivocal manner here and elsewhere in the neighborhood, as well as in the San Benito Valley, is really between the Knoxville series and the Chico, or between the Neocomian and the Upper Cretaceous. Any upheaval between the Neocomian and the beginning of the Miocene would produce the relations existing at Almaden. But at New Idria and elsewhere the Chico and the Téjon are conformable, and in the Vallecitos Valley and at Mt. Diablo the

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Téjon and the Miocene are conformable. Hence there is no room for an extensive and violent disturbance of this region between the beginning of the Chico and the close of the Miocene, and the convulsions attending the metamorphism of the Neocomian beds must have preceded the Chico. The period is still more closely determined by the discovery of the Wallala beds, which are much earlier than the Chico and are referred by Dr. White to the Middle Cretaceous. These beds, described in Chapter V, also contain metamorphic pebbles and show that the metamorphism and upheaval which accompanied it occurred soon after the close of the Knoxville period.

Not all the areas laid down as Miocene on the map are fossiliferous, but the similarity in lithological character and in the disturbance which they exhibit is sufficient to justify their reference to the same series. The Miocene beds were raised and folded at the close of that period, as was shown by Professor Whitney from evidence in this part of the country. The axis of upheaval nearly coincided with that of the present range.

Besides the Tertiary rocks laid down there exists along the border of the Santa Clara Valley, at the northern edge of the map, a small quantity of conglomerate, composed of metamorphic pebbles embedded in an arenaceous matrix, which is similar to the Miocene sandstone. The surface here is covered with a Quaternary soil, and none of the conglomerate could be found in place, nor was any fragment of a fossil detected in it. The rock, which is of no great importance, may be a remnant of Miocene; but, were it so, it would be strange that portions of it should not have been found at greater altitudes, raised with the sandstones by the Post-Miocene upheaval. It more probably represents the Pliocene, but I do not dare to map it as such in the absence of positive evidence.

Rhyolite.—When the earliest examinations of this part of the country were made, now many years since, the serpentine was supposed to be eruptive, and at later dates some of the granular metamorphic rocks have been hastily classed as trappean; but at the time of my examination true eruptive rocks had not been detected near New Almaden. This is not so strange as it might seem, for it happens that the long and tolerably regular dike of rhyolite, which many observers must have crossed in visiting the district from San José, is for the most part a light-yellow, finely porous, tufa-like substance, which at a little distance is scarcely distinguishable from the ordinary Miocene sandstone. Only in a few small patches is it found in a dense state like ordinary andesitic lavas. The microscope and chemical tests show that it is quartzose, glass-bearing rhyolite. The importance of this dike with reference to the ore deposits is at once evident. It would be entirely unreasonable to suppose that this dike represents the whole of the lava of this species ejected in the Coast Ranges, though no other mass has yet been detected. If the physical character of other outbursts is similar to that of this dike, they may have been seen repeatedly at a distance without recognition, by myself as well as by others, in the course of reconnaissance trips, though they could certainly not escape detection in any area subjected to a detailed examination. This dike not only proves the former existence of volcanic activity in this district, but emphasizes a fundamental structural axis. The character of the metamorphic rocks shows that the line along which compression and upheaval took place in the early Cretaceous was about west by north, east by south The folding of the Tertiary rocks shows that compression was repeated in the same direction at the close of the Miocene. The position of the rhyolite dike proves that the dislocation which opened a passage for this lava again followed a similar course. As for the age of the rhyolite, it is certainly Post-Miocene, for had it been earlier it must have shown the effects of the Post-Miocene uplift. Had the lava been ejected at the time of that uplift, it would probably have been so eroded that the croppings would present a different appearance, for the tufaceous modification is probably superficial. It is possible, however, that its position has in great measure protected it and that during the Pliocene it was covered with sediments. As a rule, the rhyolites of the Pacific slope are younger than the andesites, as was pointed out by Baron von Richthofen, and if this rhyolite is younger than the andesites of Mt. Diablo and of Napa County it is Post-Pliocene; but there is no direct evidence that this is the case. On the whole, the probabilities are, then, that the rhyolite is recent or late Pliocene, but it is certainly known only that it is not older than the Pliocene.

Mine minerals and rocks.—The ores of this region are composed of the usual association of minerals: cinnabar (sometimes accompanied by a little native mercury), pyrite, quartz, calcite, and dolomite, and more or less closely associated masses of bituminous matter. Accompanying the deposits is a small amount of chalcedony or opal, usually black in color; but this substance is much less abundant here than in the greater part of the northern mines. Dolomite is more prevalent as a gangue mineral here than in most quicksilver districts, a fact probably not unconnected with the unusual quantity of limestone in the sedimentary rocks. The croppings of the deposits are to a large extent composed of dolomite in botryoidal masses, instantly seen to be secretions, and not sediments. Besides the minerals enumerated, Prof. W. P. Blake reported mispickel in the upper working of the New Almaden.[1] This mineral was extremely abundant in the great Peruvian mine and its existence at New Almaden is not at all improbable. No one seems to have observed it here since 1854, however; for Prof. B. Silliman[2] in 1864, Mr. Goodyear[3] in 1871, and my party in 1885 failed to meet with it. Neither is it mentioned by Mr. G. Rolland.[4] Professor Blake also states that gold has frequently been found in small quantities in this mine. This, too, is far from improbable, but it has not been verified

The rocks associated with cinnabar in this district include every variety of the metamorphic series. Where the rock happens to be a permeable sandstone, impregnations have resulted. Elsewhere the ore seems to occur exclusively in crevices in the rock, nor are the cracks invariably filled, so that quartz and carbonates frequently show surfaces covered with crystal faces. In some cases quartz reddened throughout by cinnabar occurs in this manner. I was unable to perceive any indication that ore had been deposited by substitution or that the rock had influenced the deposition of ore by its chemical properties. Ore is found with nearly equal frequency in contact with various rocks and the existence of fissures appears to have been the necessary and sufficient condition for the deposition of cinnabar and gangue minerals. The rock, then, influences the occurrence of ore mechanically, though indirectly. Where disturbance of the country resulted in the formation of open fissures or of ground present-

[1] Am. Jour. Sci., 2d series, vol. 17, 1854, p. 438.
[2] Ibid., vol. 38, 1864, p. 192.
[3] Geol. Survey California, Geology, vol. 2, appendix, p. 99.
[4] Annales des mines, vol. 14, 1878, p. 384.

ing a large amount of interstitial space, ore bodies were formed, but where the rock yielded to stress as a plastic mass no room was left for ore.

Altas.—The ore in the New Almaden mine seems never to occur except close to evidences of faulting. This evidence consists in the presence of layers of attrition products, so-called clays, full of slickensides and of fragments of rocks more or less rounded by attrition. These layers of clay usually occur on the hanging side of deposits and are known to the miners as altas, the Spanish term for hanging walls. The clays are impermeable to solutions and the ore usually forms on their lower side, as if the cinnabar had ascended and been arrested by the altas. That the solutions really took this course is clearly shown by the phenomena of other quicksilver districts, as well as by the relations observed in the New Almaden mine The miners very properly follow seams of alta in their search for ore. Sometimes, however, a second mass of ore exists on the hanging side of the clay and is again limited by a second layer of alta, as I have myself observed. Such occurrences are to be expected in a country so irregularly disturbed as this. The alta is not a definite substance, though it is usually a dark or black mass, readily distinguishable even in hand specimens from the country rock. It is simply triturated country rock and varies in composition with the material from which it has been produced. Its black color is in part due to the presence of manganese. These layers of clay correspond exactly to those which were met with in the upper portion of the Comstock lode and against which many bonanzas were found to rest. The evidence of movement in the New Almaden mine is not confined to clays. Where the opposing walls were so nearly parallel that no considerable quantity of trituration took place, polishing occurred, and some of the slickensides met with are as brilliantly polished as if the work had been done by a lapidary.

Form of the New Almaden ore bodies.—While the evidence of the existence of a fissure system is, if possible, more abundant in the New Almaden mine than in most other quicksilver deposits of the Pacific slope, the deposits themselves are of various types. The commonest is the reticulated mass, or stockwork, consisting of irregular bodies of broken rock into which solutions of cinnabar and gangue minerals have filtered, cementing the fragments together with ore. Where the disturbance has been less extensive and irregular, clean-cut fissures may sometimes be seen filled with ore, and these can only be classed as veins, though they are not persistent. As already mentioned, impregnations also exist where the ore-bearing solutions have encountered permeable sandstones.

The classification of the various portions of such a deposit under various names seems to me of very little interest, excepting as it serves to a certain extent as a basis of comparison between ore deposits of different regions. It is not long since it was customary to maintain that the deposits of cinnabar were very different in character from those of other ores and that the genesis of quicksilver deposits was essentially unlike that of other metals. I have taken some pains therefore to show that no distinction can be maintained as to form between the ore bodies of the quicksilver mines and well recognized types of gold, silver, and copper deposits. The only important mode of occurrence of ores which I have not encountered in the quicksilver mines is that of replacement. Lead ores have certainly in some cases replaced limestone molecule for molecule. According to Prof. von Groddeck, cinnabar ore at Mt. Avala, in Servia, has replaced serpentine in a similar manner. Others also have been led to suppose analogous substitutions at Almaden and at Idria, but I have not met with them at those mines or anywhere in California.

Existence of a fissure system.—While the reference of deposits to different heads of more or less artificial classifications is only of indirect interest, a comprehension of the fundamental structural relations of the ore bodies of a mine is of the utmost importance to its conduct. From any one accessible stope of the New Almaden mine it is evident that the country has been intersected by fissures, that energetic motion has taken place along these fissures, that the adjoining rock masses have been shattered more or less irregularly, and that solutions entering the ground have deposited ore in such spaces as were vacant. It is also apparent from the relations of the ore to the clay that the solutions have entered from below, and it is almost a necessary inference that the fissures served as channels of ingress for the solutions. These conclusions may be drawn in each of as many chambers as the observer can reach, and he will find nothing to conflict with them in any portion of the mine.

Certain features must be common to the ore bodies taken singly and to the ore-bearing ground as a whole. It would be impossible to suppose that each stockwork has an independent fissure system, and a mere glance at the mine maps shows that a connection between them exists. It is also a historical fact that the thin seams of ore (stringers or, as the Spanish miners call them, hilos) have led from one ore chamber to another. There must be a general fissure system, in subordination to which the various ore bodies are arranged, and this system must stand in the closest relations to the general geology of the country. Such a system can result only from a somewhat widespread disturbance and, it is superfluous to remark, must have been formed according to ordinary mechanical laws. If the rock of the country were thoroughly homogeneous and were level at the surface, a fissure caused by a simple disturbance would follow a straight line and would pass over at its extremities into a fold. Under a sufficient horizontal stress such a country would show a system of parallel fissures passing into a common fold at each end. Fissures thus tend to straight lines and parallel systems, but this tendency is modified by inequalities in the properties of the rock and in the configuration of the surface. It is often difficult to decipher the fundamental fissure system in a country of heterogeneous character, but this does not seem to be the case at New Almaden.

The distribution of serpentine, the average strike of the metamorphic strata, the compression of the Miocene beds, the position of the rhyolite dike, and the trend of the range, in short the whole structural geology of the region shows that the fundamental axis of disturbance must have a direction which is approximately northwest and southeast. It is along a fissure, or a system of parallel fissures, taking this general direction, but more or less deflected by local causes, that ore might be expected to occur in such a district. It is on such a line that the New Almaden, Enriquita, and Guadalupe deposits occur. In the New Almaden mine itself, also, there appear to me clear evidences of a fundamental fissure system.

Plans and sections of the New Almaden.—The surface and the workings of the New Almaden mine have been surveyed with the utmost care by the officers of the Quicksilver Mining Company, and data exist for the construction of any desired sections. A fine opportunity is thus afforded for a study of the structure of this very important deposit, and it has seemed to me worth while to illustrate the occurrence very fully by plans and sections. The mine maps and sections which I selected as best adapted to show the structure were prepared for me from plans and notes in the office of the company by Mr. Frank Reade, who was surveyor of the mine at the time of my examination and who formerly assisted me in studying the Comstock Lode.

The ore deposits being in my opinion comparatively recent, the relations between their distribution and the present topography of the surface are of interest. On Atlas Sheet VIII the plan of the known ore bodies is shown beneath a contour map of the surface. It will be at once remarked that these ore bodies are divisible into four groups. Two of them, reached respectively by the Washington and Cora Blanca shafts, seem to be isolated. The other two groups, upon which the main mine has been opened, are very closely connected. The more important group of the ore bodies of the main mine reaches from the top of the Mine Hill nearly to the Santa Isabel shaft and is substantially continuous for the entire distance. The croppings at which Castillero and others before him found cinnabar, as was narrated in Chapter I, were at the top of Mine Hill. A monument at this point is used as the datum to which the contours and mine levels are referred. The other group of ore bodies of the main mine lies to the east of the Randol shaft. I shall have frequent occasion to distinguish these two sets of ore bodies and shall refer to them as the north and south groups. This map is printed on a scale of 300 feet to the inch and the contours are drawn at vertical intervals of 10 feet. The plan of the workings is given on Atlas Sheet IX, this and the succeeding sheets being drawn on a scale of 150 feet to the inch, or double that of the topographical map on Sheet VIII. The highly complex structure of the separate ore bodies is very apparent from this plan as well as the existence of certain surfaces along which the ore bodies are grouped. The colors and figures make explanations needless. I have not tried to indicate on this plan or on the sections the character of the wall rocks, for nothing could result from such an effort. The entire mass of the country rocks consists of metamorphosed sediments. Every stage of metamorphism isrepresented, and pseudodiorite, pseudodiabase, phthanites, sandstone, shale, and serpentine are mingled in inextricable confusion.

Atlas Sheet X shows a section taken along the course of the south group of bonanzas. The line on which the section is made is shown on the mine map and was selected with a view of illustrating the continuity of ore from the surface at the top of Mine Hill to the lowest workings. The group of ore bodies thus intersected is for the most part distinct from that to the east of the Randol shaft. It is manifest from this section that a fissure extends from the lower workings to the top of Mine Hill, a vertical distance of about 2,000 feet, and that ore has been deposited almost continuously along its entire course. This fissure is remarkably sinuous in vertical section, and a long tongue of ground north of Mine Hill has manifestly moved northward sufficiently to leave space for the deposition of ore. If one considers the character of the disturbance to which the fissure must owe its origin, it appears almost certain that this tongue of country rock overlying the fissure cannot have remained intact. One would expect to find one or more fissures intersecting it in a direction more nearly vertical than the south ore channel, because the tenacity implied in the movement of the entire hanging country without fracture would be improbably great, even were the rock much firmer than the materials of which the Coast Ranges are chiefly composed. Such a fissure intersecting the hanging country really exists, and a trace of it may be perceived on this section from the 1,500-foot level downward, where the stopes show that the ore occurs on parallel lines. The line of the northerly stopes in this region if continued upward would reach the surface near the point at which the Randol shaft appears projected.

On Atlas Sheet XI two sections are shown, cutting the northern portion of the mine on parallel north and south planes. One of them is taken through the Randol shaft and the other 350 feet west of it. The two are to be considered together and as if they were superimposed. The western section shows the same group of bodies as is depicted upon Sheet X, but cut at a different angle. The relations of the section on Sheet XI are most easily appreciated by reference to their traces on the mine map (Sheet IX). The eastern section, through the shaft, on Sheet XI is very different. It shows only the edge of the south ore channel; or of that series of deposits which crops out on Mine Hill. To this series belong the various Santa Rita "labores" exhibited on the southern part of the section, and the series of winzes extending from the Santa Rita to the 1,400-foot level of the Randol shaft, showing here and there a small stope, was sunk along the course of the same fissure. The main stopes on this section are on the north fissure, which divides the great body of rock forming the hanging country of the south fissure from the region north of the mine.

Another view of the two fissures is shown on Atlas Sheet XII, where they are intersected by an east and west vertical plane. To the right appears the south ore channel, including the O'Brien, Don Federico, and other bodies; to the left is the north fissure.

Existence of two principal fissures.—The existence and position of the two fissures are not so evident and clear as would appear from the foregoing notes. The ore bodies lie upon complex curved surfaces. The result is that no vertical plane intersects both fissures at right angles throughout, and no single section affords indubitable evidence of two fissures. Views similar to those shown in the sections might be given of two channels along a single, doubly curved surface. Could one but represent the fissures by contours, the entire structure would be shown in three dimensions and would not be ambiguous. A certain approximation to this result can be reached. As was mentioned above, the fissures are marked by clay seams or altas. It occurred to me that if one could lay down all the alta seams followed in the explorations the result would closely resemble a contour map of the fissures. Mr Reade, with the assistance of other officers, has compiled all the information available regarding the occurrence of altas in the northern part of the mine, and they are shown on the same scale as the mine map on Atlas Sheet XIII. The result, however, requires some discussion because of the irregularity of the lines and the distance which sometimes intervenes between the two ore channels. At the northwest the fissures come nearly together, and on the 1,930, the 1,850, and the 1,735 foot levels it is plain from the position of the altas that there are at least two nearly parallel fissures. On the 1,650 the alta forks, probably indicating the existence of two fissures connected by a diagonal cross-course, for on the 1,540 and again at the 1,440 there are two altas nearly parallel and at a considerable distance from one another. On the 1,850 (1,832 to 1,847) it is the northerly alta which extends to the north group. The same is true of the clays on the 1,735, and on the 1,650 it is also the north fork of the alta which has been followed to the neighborhood of the Randol shaft. On the 1,550 (1,540 to 1,547) there are three lines of alta, two of which are to the southwest and one to the northeast. From the continuities just mentioned on the three levels below this it is evident that the northerly alta of the 1,540 in the southwest region answers to the alta in the north group of ore bodies, and to emphasize this relation I have connected the two altas by a straight dotted line. A precisely similar relation exists on the 1,440. Thus for a vertical interval of 500 feet there is abundant evidence of two fissures, the outer or more northerly of which leads into the north group of ore chambers. The inner or more southerly fissure is certainly that upon which ore has been followed from the top of Mine Hill, as may clearly be seen by reference to the section of this channel on Atlas Sheet X. The southerly or inner altas on the 1,540 and 1,440 levels form the hanging wall of ore body XLI, which appears on Atlas Sheet X, and this section shows that from this body to the top of Mine Hill the ore is substantially continuous. The outer or northerly alta appears on Atlas Sheet X as the hanging wall of the body XLVIII. These same altas in the north group overlie the bonanzas known as XXI, XLIV, XX, which appear on the section through the Randol shaft (Atlas Sheet XI), and from this section it is manifest that the fissure carrying these bonanzas is continuous up to the 900-foot level. Referring again to the plan of the altas (Atlas Sheet XIII), it is seen that the two groups of ore bodies are so far apart between the 1,440 and the 1,050 that from this plan alone no certain result could be reached as to the distinctness of the fissures within this interval. The lines of altas are very tortuous as well as distant, and without the aid of the sections it might seem quite possible that the altas of the same level were continuous in the two groups; but in the foregoing I have shown that each of these fissures for the interval between the 1,440 and the 1,050 continues in depth and that at lower levels the fissures are distinct. It is true that the fissures might come together above, though this would be an unusual structure. But on the 950 the altas of the two groups once more assume a position of approximate parallelism, which shows that they remain distinct throughout.

Another test of the distinctness of the fissures can be applied, and, indeed, one which is of no small importance for the mine. The average strike of the north group in its upper portion is on a line not far from S. 50° W. magnetic, and, as shown by the north and south section through the shaft, if the north fissure were continuous it would reach the surface about four hundred feet south of the Randol shaft. Having arrived at this conclusion, I examined the surface, and did in fact find a line of dolomitic, botryoidal croppings north of the road leading from the office to the Randol shaft above the Randol group of bonanzas, and which seemed to strike for other croppings on which a little tunnel has been opened about four hundred and fifty feet south magnetic from the shaft. These croppings thus strike very nearly in the same direction as the altas of the Randol group of ore bodies on the 1,050-foot level, and are very close to the position indicated for a cropping of this fissure. In my opinion they represent such a cropping and complete the proof that the New Almaden mine possesses two important fissures, along one of which the south group of bonanzas has been followed from the surface, while the north group lies upon the other. One fissure underlies the great tongue of hanging country, the other intersects it.

Ore in the inclosed wedge.—Between the two principal fissures a wedge of country rock exists. It is not uncommon for great masses of this description to be inclosed on both sides by ore-bearing fissures. Such was the case on the Comstock and also in the Ruby Hill mines at Eureka, Nev. Ground thus inclosed is seldom solid and subsidiary fissures leading into it are often ore bearing. In the New Almaden mine the ore is not confined to well defined fissures. It is true that ore can be followed from the top of Mine Hill downward to a depth of 1,600 feet practically without a break; but the sections show that at many points the fissures are systems of associated openings rather than simple ruptures. The north and south section through the Randol shaft shows a section of the Velasco, Theatre, and several of the Santa Rita bodies, which is especially illustrative of this structure. The section shows that the wedge of ground between the principal fissures is not a solid mass, but that subordinate fissures and ore channels exist in it. This would be still more evident were all the ore bodies represented. Those which have been exploited since systematic work was begun are, I believe, all accurately given, but in the early days there were many openings, resembling burrows rather than mines, excavated from the surface between the Randol shaft and the top of Mine Hill. Mr. Reade has shown many of the dumps of these old workings on Atlas Sheet VIII. They produced considerable quantities of ore. One of them, the Juan Vega, which appears on the plan but not on the sections, I was able to explore. The stopes were of considerable size and the ore appears to have been very rich. It was associated with masses of dolomite similar to those found at the surface as croppings, but which are not met with in the lower levels. Evidently fissures carrying ore in solution must have reached the Juan Vega and other similar deposits. These fissures must have connected with great ore channels, and must therefore intersect the wedge of country rock.

The wedge of rock between the two principal fissures has contained ore bodies and the fissures leading to them must penetrate the wedge through and through. The entire mass should be regarded as potentially ore bearing and should be explored. It is not in the least likely that all the ore which it contains is known and, if other bodies are encountered, they will be mined at a greater profit than similar bodies at lower levels. This mass and the lateral extensions of the main fissures constitute the promising ground in the mine. At the lowest levels reached there is little ore. There is no known reason why bodies of cinnabar should not be found at still greater depths, but I do not regard it as probable that the ore chambers beneath the 2,000-foot level will be as frequent as they were above. Some further comments on the fissure system of this mine will be made below.

Cora Blanca and Washington deposits.—The workings of the Washington shaft, which were formerly known as the San Francisco mine, are connected with the main mine of New Almaden, but the deposits were not being worked during my visit. The association of minerals and rocks is entirely similar to that of the main mine, and the deposits are also accompanied by clay seams or altas. The position of the deposits is shown on Atlas Sheets VIII, IX, and X. Ore has been followed in the workings to a depth of

850 feet below the summit of Mine Hill, but below that level no ore bodies have as yet been met with. The strike of these deposits is at an angle of over 70° to the deep fissure of the New Almaden, and both fissures stand at considerable angles to the main axis of uplift.

Near the New Almaden and the Washington is the Cora Blanca mine, the position of which, with a horizontal projection of the ore bodies, is shown on Atlas Sheet VIII. Portions of it were accessible to me, but no work was being done upon it. Though the rocks inclosing this deposit are members of the metamorphic series they are less modified than usual, and in part are but little contorted, though standing at a high angle. One of the strata, which is usually close to the ore, is a magnesian limestone. Some native quicksilver was found in the mine. The gangue minerals accompanying the cinnabar are almost exclusively carbonates. There are clays and evidences of disturbances in the Cora Blanca, but less marked than in the New Almaden. The ore-bearing solutions have followed the bedding for the most part, and in places the deposits can be classed only as a bedded vein; but not infrequently the ore crosses laminæ and often fills chambers adjacent to the main ore-bearing surface. These are in part reticulated masses and in part impregnations in sandstones. The ore was followed to a depth of 750 feet below the summit of Mine Hill. The strike of this deposit is about N. 18° W. magnetic, or very nearly true north and south. The direction has doubtless been influenced by the fact that the partings between the beds offered a comparatively slight resistance to rupture. The average dip is about 40° to the west.

The Enriquita.—The Enriquita mine is also on the property of the company which owns the deposits described above. It has long been abandoned and no part of the deposits is accessible. The ore-bearing ground was about five hundred feet in length and had an extreme width of about sixty feet, the dip being nearly vertical. From a manuscript report of Mr. Louis Janin, which he has kindly shown me, I see that the ore was found in limestone inclosed on both sides by serpentine. The ore formed rich pockets, connected by stringers, and the lowest body, the San José, was the richest of all. The mine possessed reduction works and in a short time yielded metal worth $350,000. It was producing in 1860 and is said to have yielded about nine thousand flasks.

The Guadalupe.—Over fifty thousand flasks of quicksilver have been produced from the Guadalupe, which was closed at the time of my visit, though it had been working in the preceding year. Cinnabar has been found at a great number of points on this property over an area of about a half a mile square. The only deposit of large size detected cropped out about one hundred and fifty feet north of the creek and has been followed downward for over seven hundred feet. The strike of the main body was about east and west magnetic; but to the east seams have been followed on a more northerly course which led to small bodies of ore. The dip is southerly and the greater part of the mine lies south of the creek. The ore and the associated substances are said to have resembled those of New Almaden, but I have been unable to obtain any particulars of interest. A small quantity of ore was obtained from the "Office mine," a small excavation on a cropping some two hundred and fifty feet north of that of the main mine. Some of the other numerous superficial workings have also yielded ore.

These excavations have obscured rather than revealed the structure of the country, and I was unable to make observations sufficiently definite to justify important conclusions. It certainly is improbable that the resources of the locality are exhausted. The most evident course to be pursued is further exploration along the fissures developed by the main mine. Were the old tunnels and superficial workings which dot the surface cleaned out, it is also possible that a careful study would reveal other fissures which might be ore bearing in depth; but there is no certainty that the search for ore bodies would prove successful. Quicksilver deposition in the Coast Ranges has been very irregular and study of the geological phenomena shows that this is an almost necessary consequence of the structure. The only way for quicksilver miners to keep up the value of their property is to study the fissure system with the most earnest attention from day to day and to do their prospecting while in bonanza. Prospecting when all the visible ore has been extracted and the old workings have become inaccessible is little better than guess-work and seldom meets with much reward. It is only under exceptional conditions that ore bodies can be foreseen in the quicksilver mines, and predictions as to the quantity of ore in these mines, excepting so far as the ore is in sight, are entirely valueless.

Minor deposits.—In addition to the mines upon which notes have been given above, there are a number of workings which have yielded cinnabar in quantities of little or no commercial importance, but which throw some light on the structure of the country through their position relatively to the more developed deposits. The America, to the westward of the New Almaden mine and a little south of the ridge, showed two small ore bodies. From the plan of the drifts it would appear that clays running to the northeast were followed. The Providentia, one quarter of a mile from the Enriquita, in the direction of the New Almaden, yielded ore of excellent quality, as I learn from Mr. Janin. The San Antonio mine was half a mile northwestward from the Enriquita, on the hillside northeast of Los Capitancillos Creek, and the San Mateo was a quarter of a mile farther in the same direction and in a similar topographical position.

A mass of black opal, such as is so often associated with cinnabar in California, exists about 6,400 feet north magnetic from the Enriquita, between the isolated patch of rhyolite and the continuous dike. I am not aware that cinnabar has been detected at this point, but it would not be surprising if search were to disclose at least a trace of ore.

Age and genesis of the deposits.—The croppings of Mine Hill have been exposed for a long time and there is a considerable quantity of cinnabar in the surface soil of the hill. The deposits have been formed since any violent disturbance of the country took place, however, for there are mere traces of dislocation in the ore bodies. The eruption of rhyolite must have been accompanied by very considerable movement of the country, and, had the deposits existed before the formation of the dike, they could hardly have escaped dislocation. There are no unquestionably Pliocene strata at New Almaden, but beds of this age have been considerably disturbed both to the north and to the south, though at distances of a number of miles. It is very probable, but not certain, therefore, that the deposits are Post-Pliocene, while it is certain that they are not Pre-Pliocene.

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Ore deposition followed the eruption of lava. The minerals deposited and the manner of their deposition are such as in the more northerly quicksilver districts were induced by volcanic springs. Though there are now no indubitable remnants of the volcanic activity which certainly prevailed here since the beginning of the Pliocene, the analogies of the deposit, together with the presence of lava of approximately the same age as the ore, make any theory of deposition excepting from hot sulphur springs improbable. The source of the ore will be discussed in a future chapter.

General fissure system.—The rhyolite dike, of course, represents a deep fissure. The length of this dike shown on the map is about twenty thousand feet, but I have followed it beyond the map limit for a considerable distance. The presence and the character of the range also indicate the existence of an axis of disturbance, though its direction is more or less obscured by irregularities in metamorphism and erosion. There can, further, be no doubt from the foregoing description that the cinnabar deposits occur along fissures. The question arises, what connection exists between the fissures upon which the various deposits are found? It is hardly possible to consider the relative position of the Guadalupe, San Mateo, San Antonio, Enriquita, Providentia, America, and Washington without coming to the conclusion that they form a substantially continuous series of deposits. If the strike of the Guadalupe, the Enriquita, and the Washington be taken into account this impression is strengthened, for it is easy to draw a continuous line through the deposits which will coincide with the strike of each. This series leaves out the New Almaden and the Cora Blanca. The deep fissures of the New Almaden to the northeast of the Randol shaft are nearly straight, approximately vertical, and strongly marked by slickensides, clays, and other evidences of motion. They must be very profound and persistent fissures. They strike nearly for the workings of the America. The fissures on the lower levels have been followed for about one thousand feet and to about twenty-two hundred feet in a horizontal direction from the America. I cannot believe that these strong fissures can die out within this distance or that they can greatly change in general direction. They might possibly be replaced by other fissures near to them and parallel with them, the two sets being connected by more or less indistinct cross-courses, but this would be substantial continuity. If I am right, the New Almaden deep fissures connect with the ore-bearing fissures south of the ridge and cross the ridge near the America. Considering the amount of disturbance on the New Almaden fissures they would seem to represent the main line of fracture, and in that case the crack leading to the Washington is in the nature of a cross-course. The apparent strike of the America accords with this view, which is strengthened by the relations to the dike to be mentioned presently. As for the Cora Blanca, the fact that the deposit is largely bedded or that it follows the stratification complicates its relations, for its strike is very likely to differ considerably from that which it would have if the structure of the country had not presented a local line of weakness. It may be that this mine is on a cross-course nearly parallel to the Washington, but the evidence is hardly sufficient to justify speculation. The following sketch shows the approximate positions of the several deposits of the ridge and of the dike. The strike of the main deposits is also indicated and a fine line is drawn through all except the Cora Blanca. The upper portion of the south fissure of the New Almaden is not represented on the sketch for lack of data. The croppings of this fissure probably curve rapidly toward those of its northerly companion, but the soil and artificial disturbances obscure the line (Fig. 13).

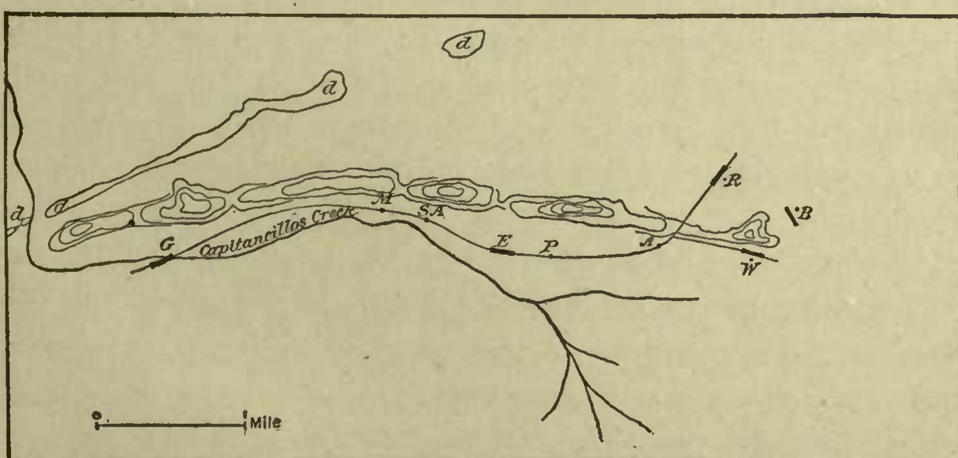

FIG. 13. *R*, deep fissures of the New Almaden near the Randol shaft; *W*, Washington deposit; *A*, America; *B*, Cora Blanca; *P*, Providentia; *E*, Enriquita; *SA*, San Antonio; *M*, San Mateo; *G*, Guadalupe; *dd*, rhyolite dike.

The straightness and persistence of the dike seem to show that its croppings have the same strike as the main fissure through which it reached the surface. I have shown that the deposits were probably induced by volcanic activity following the eruption of this lava, so that a not very remote connection exists between the ore-bearing fissures and that marked by rhyolite. At the time of the lava eruption the present range of hills existed much as it does to-day. Consequently the course of a fissure tending to assume a strike nearly parallel to that of the dike and which was formed near the range of the hills would be affected by their presence. The hills would act as a mass of considerable rigidity and would tend to deflect such a fissure, but if at any point this tendency were overcome the fissure would return more or less closely to the direction of the dike. Now, near the Guadalupe the line connecting the deposits is almost exactly parallel to the dike; as the ridge curves away from the dike the line of deposits follows the high ground. After the angle between the ridge and the dike becomes large the line of fissure seems to me to cross the high land and to approach the dike again in the New Almaden ground at an angle of about 30°. In crossing the ridge a branch fissure seems to have been formed leading to the Washington.

I cannot, of course, pretend to have demonstrated the above explanation of the relations of the deposits. For this the exposures are insufficient. I offer it, however, as a working hypothesis which possesses considerable probability and may serve as the basis for a more exact theory to be elaborated by the engineers in charge of the properties. It is probably needless to remark that if the hypothesis set forth above be true it shows where ore is to be sought, but ore will be found only at certain favored points or in certain channels at or near the fissures. If the Washington fissure actually meets that connecting the New Almaden and the America, great disturbances must have taken place at the junction and some ore will probably be found there.

CHAPTER XI.

DESCRIPTIVE GEOLOGY OF THE STEAMBOAT SPRINGS DISTRICT.

[Atlas Sheet XIV.]

Character of the district.—Steamboat Springs lies between the Sierra Nevada and the Virginia Range, at the western edge of the Great Basin. The forests and snows of the great Sierra are in sight a few miles away, but in the neighborhood of the springs only sage brush grows without irrigation. The soil in the lowlands, however, is fertile, and sufficient water is available to bring a considerable surface under cultivation. The hills are for the most part bare rock, as geologists love to see them. Many of the exposures are whitened or reddened by solfataric action, and on cool days tall columns of steam rise from the numerous hot springs, giving the locality a weird appearance. Steamboat Springs is only six miles from the Comstock lode and lies at the northwest base of Mt. Davidson, on the eastern flank of which is the great silver vein. The intervening space is for the most part covered with lavas, one of the sheets of which seems to be continuous for the entire distance. All the rocks which occur at Steamboat are also found in the immediate neighborhood of the Comstock, and the fissures of the two localities are approximately parallel cracks, with many points of resemblance. Steamboat affords fine opportunities for the investigation of massive rocks, and the occurrences here serve to throw much additional light on the rocks of the Washoe district, described by me in Vol. III of this series. The proximity of the areas permitted me to make direct comparisons during the present investigation. The spring deposits also have long been known to be of extraordinary interest, because they contain metallic compounds, including cinnabar and gold. So much cinnabar is found here in areas still emitting steam and sulphur gases that mining operations were undertaken some years since and a furnace was run for a time on the ore. That quicksilver was produced is certain, though I was unable to ascertain how many flasks. A considerable amount of ore is in sight, and there is no apparent reason to doubt that were the price of the metal to rise to a dollar a pound the deposit might be worked at some profit.

Here, if anywhere, the question of the mode of genesis of cinnabar deposits can be settled, and the study of the locality was undertaken on that account. The results of this study and of laboratory experiments suggested by it appear in this and succeeding chapters.

Granite.—The lithological character of the massive rocks of Steamboat has been described in Chapter IV, and the details do not require repetition here excepting in reference to the distribution of the rocks and their relations to field habit. The granite, which is exposed to a large extent, manifestly underlies the whole region. In external appearance it is thoroughly typical, and no geologist would doubt for a moment how to classify it. It is unstratified, much fissured, weathers irregularly, and sometimes crumbles to a coarse gravel, as granites often do. Some of it is coarse, and it displays considerable irregularities in texture and mineralogical composition, as if it had never been thoroughly fluid. Plagioclase is occasionally visible with the naked eye, but the predominant feldspar seems to be orthoclase. Under the microscope this granite appears less typical, inasmuch as the quantity of triclinic feldspar seems in the slides unusually large, and one might well doubt whether to class some of the rock as orthoclastic or plagioclastic. This is one of the cases in which the appearance is less truthful under the microscope than to the unaided vision, and this is doubtless due to the fact that the plagioclase is recognized by positive characters between crossed nicols, while the presence of orthoclase is evinced chiefly by the absence of polysynthetic structure. Separation by specific gravity shows that the more plagioclastic specimens of the rock contain about as much orthoclase as plagioclase. The granite of Steamboat Springs is substantially similar to that which appears near the southern end of the Comstock Lode. The superficial exposure there is very small, but the rock extends into the workings of the mines at American Flat. Similar granite is found near Washoe Lake, some miles south of Steamboat, and large exposures of it exist between these points and Lake Tahoe, in the Sierra.

The granite is intersected by distinct dikes of granite porphyry. So far as observed these dikes do not penetrate the sedimentary rocks and are probably older than the beds.

The metamorphic series.—Upon the granite lies a considerable area of sediments, which are in part very highly metamorphosed and in part but little altered. These beds are usually nearly vertical and strike with the trend of the Sierra. Attempts to make two series of them failed and only resulted in showing that the metamorphism was partial and irregular. The highly altered portions considerably resemble Archæan schists, but the partial character of the metamorphism seems to forbid their reference to a Pre-Cambrian age. They are certainly Pre-Tertiary, for there are Tertiary strata within a few miles both to the north and to the south which are far less disturbed and not at all metamorphosed. The only other sedimentary rocks known to exist near the eastern edge of the Great Basin in this latitude are those determined to be Jura-Trias by the paleontologists who discussed the fossils collected by the geologists of the Geological Exploration of the Fortieth Parallel. Dr. White, on reviewing the evidence on which the assignment was made, thinks it insufficient to justify any conclusion more definite than that the beds in question are Mesozoic. The descriptions of these Mesozoic rocks accord very well with the strata found at Steamboat. Their metamorphism is perhaps an evidence that they are not younger than the Neocomian, for no more recent alteration of any such intensity is known to have taken place later than the Post-Neocomian upheaval so often referred to in this volume. The upheaval is the same as that called the Post-Jurassic by Professor Whitney, and its existence was no doubt given due weight by the geologists of the fortieth parallel when they referred the Mesozoic beds of Nevada to the Jura-Trias. As this region is separated from the gold belt by a great range of mountains, however, it is not impossible that its metamorphism may have been subsequent to and independent of that of California, though no known fact lends this supposition probability. A prolonged, but wholly unsuccessful search was made for fossils, which are also very rare in the other Mesozoic rocks of Nevada.

A portion of these rocks are conglomerates. Among the pebbles of these conglomerates are some of diabase, identical with the porphyritic diabase which forms the hanging wall of the Comstock lode. There can be little doubt that these pebbles formed a portion of masses which were erupted simultaneously with that at Virginia, and it is possible that they came from that very mass, though this is not certain. I did not succeed in finding pebbles of the still older diorite of Mt. Davidson, which may perhaps have been buried under the diabase at the time when the conglomerates were laid down. The bearings of the occurrence of diabase pebbles at Steamboat on the geology of Washoe I have enlarged upon in another publication.[1]

Earlier hornblende-andesite.—The oldest of the lavas of the district is hornblende-andesite. It overlies the metamorphic beds in part and is distinctly more recent than the date of their upheaval. All this lava is very compact and of a bluish tint, but it is divisible into three varieties: one extremely fine-grained and often of a slaty texture; one a comparatively coarse-grained, porphyritic rock; the last glassy. Of these the first is most common. It is also found near the Ophir grade at Virginia, and the two occurrences are indistinguishably similar. The coarse-grained, somewhat grayish porphyry is best represented at Steamboat, near the eastern edge of the map. At Virginia this modification is perhaps the commonest. The glassy variety, associated with the others, is found at the western edge of the map of Steamboat Springs. In this area there also occurs a very small amount of a pyroxenic andesite which, after careful study, seems to me to represent a strictly local variation in mineralogical composition and to pass over into the hornblende rock by transitions. The fact that this andesite overlies the metamorphics seems to indicate that it is later than the early Cretaceous. The existence of glassy modifications forming a portion of the areas is evidence that it is much later than the Cretaceous. Indeed it is hard to understand how the glass can have failed to be removed if this andesite is older than the Pliocene.

[1] The Washoe rocks: Bull. California Acad. Sci. No. 6, vol. 2, 1887, p. 93.

Later andesites.—More recent than the hornblende-andesites described above are other andesitic rocks. These are divisible mineralogically into three varieties, and are so laid down upon the map. They appear, however, to have been ejected almost simultaneously. They are all so recent that extremely little erosion has taken place and only a few depressions are marked by water-courses. The difference in this respect between the areas of later andesites and the metamorphic areas is readily seen from the map where the amount of sculpturing corresponds to the geological colors.

All the later andesites are rough, soft rocks, in which the feldspars are much cracked. Some of them are laminated, the beds averaging perhaps an inch and a half in thickness, and this modification is physically indistinguishable from similar occurrences at Clear Lake. One variety of these rocks is highly pyroxenic; a second is hornblendic, though not free from pyroxene, and sometimes contains mica, while often lacking this constituent. Between the pyroxenic and hornblendic rocks are transitions of the most unmistakable kind, which I have designated by a separate color and have entitled for the purposes of this one map "transition andesite." In these areas the composition of the rock is curiously variable. Thus, in a little triangular patch nearly south of the mines and embracing considerably less than two acres, specimens can be collected which in the office might well be supposed to represent three distinct species: one a pyroxene-andesite, one a simple hornblende-andesite without mica, and the third a micaceous hornblende-andesite. But the whole area is thoroughly exposed and certainly represents only a simple eruption. The different varieties of rock were found here and elsewhere within a few inches of one another on the same blocks of lava. Such occurrences show how hopeless is the attempt to reconstruct the geology of an eruptive district from collections alone.

The area colored as later hornblende-andesite is covered with rock almost indistinguishable from the later hornblende-andesite near the Comstock; indeed, a very large proportion of the region intervening between the two districts is occupied by this rock and the lava field seems to be continuous from the northern end of the Comstock area to the eastern edge of the Steamboat Springs map. In both neighborhoods the quantity of mica is variable, but near Steamboat it is exceedingly capricious. Mica is sometimes present in most unusual quantities, forming a large percentage of the entire mass, and such flows appear to have been the latest of all. Elsewhere the rock is scantily supplied with mica and over considerable areas the most diligent search failed to reveal a single flake.

The non-micaceous portions of the later hornblende-andesites are distinguishable from the pyroxene-andesite only by the relative abundance of the bisilicates, texture and habitus being identical and both of them trachytic. The hornblendic and the pyroxenic modifications of this rock are in contact at the eastern portion of the map. Neither is eroded to any considerable extent, though both areas are more or less covered with loose fragments. I was unable to make sure whether the eruptions had been actually simultaneous or not. On the whole, the pyroxenic rock seemed a little earlier than the hornblendic lava. On comparing the occurrences here with those at Virginia I found that transitions occurred at the latter locality also, which I had overlooked when I mapped the geology of that region. The transition rocks in the Washoe district occur along the ridge of which Mt. Kate forms a part and near that peak, and are present in small quantities only.[1] At Virginia the pyroxenic portion of the later andesites is older than that which carries mica. On the other hand, Mr. Lindgren found near Mono Lake flows of pyroxenic andesites, entirely similar to that of Steamboat, overlying micaceous, hornblendic andesites. The order of succession is thus not a fixed one. At Steamboat the two are very nearly and perhaps absolutely contemporaneous. Both of them are later than the earlier dense hornblende-andesite and have overflowed it. The area of the older andesites at the east of the map is also intersected by dikes of the later rocks. These dikes are in part micaceous and in part free from mica. Those portions of them which carry no mica are sometimes highly charged with hornblende and sometimes carry comparatively large quantities of pyroxene.

[1] The occurrence of these transitions shows that the pyroxene-andesite of the Mt. Kate Range immediately preceded the later hornblende-andesite adjoining it. The pyroxene-andesite of the Washoe district (laid down on the map as augite-andesite) is divisible into two eruptions, one much older than the other, though without any intervening outburst. The Washoe district contains three pyroxenic rocks of different ages: diabase, which was followed by a hornblende-andesite, and two successive outflows of pyroxene-andesite, both later than this earlier hornblende-andesite. The pyroxene-andesites were again followed by later hornblende-andesite. Dr. Whitman Cross pointed out the prevalence of hypersthene in andesite after my discussion of the lithology of Washoe was completed. Compare my paper, "Washoe rocks," cited above.

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They are all of the trachytic type. Similar rocks occur abundantly in the surrounding region. Special mention may be made of the Hufaker Butte, which is an isolated volcanic mass about four miles north of Steamboat, in the valley. This seems clearly to represent a single eruption or a series of eruptions embraced within a short interval of time. The rock is all trachytic, in part highly micaceous and in part free from mica.

While it is quite possible to distinguish varieties among these later andesites, they pass over into one another in such a manner as to indicate that they form a natural group. The distinctions are, at least near Steamboat Springs, of little geological importance. As is pointed out in Chapter IV, similar rocks occur at Mt. Shasta and from Clear Lake to the Bay of San Francisco, but those of the latter area are remarkable because they usually contain mica and pyroxene, but no hornblende. All these andesites seem to be more recent than the close of the Pliocene and all have a similar physical character. Some contain pyroxene with a very little hornblende; some, pyroxene and mica, but no hornblende; some, hornblende with a little pyroxene and no mica; some, much mica, a little hornblende, and a trace of pyroxene. Every possible combination of these ferromagnesian silicates excepting those altogether excluding pyroxene is represented; there is no known difference in mode of occurrence and the order of succession is variable. This group of rocks is the same which, before the reference of lavas to the microscope became habitual, were regarded as trachytes. The name is indefensible, for the rocks are plagioclastic; but the thing to which it was given is a geological entity. I have therefore proposed for this natural group of rocks the name *asperites*, which is etymologically an equivalent of trachyte, but of Latin origin.

Basalt.—The basalt of Steamboat is in no respect remarkable. Though it covers a considerable area, the amount of the rock is by no means great, for it is evident from some exposures that the sheet is only a few yards in thickness. Doubtless, however, the depth of the lava is variable. Basaltic breccias form a portion of the mass. The basalt eruption antedates the deposition of ore, at least in part; for where it adjoins the mine it is solfatarically decomposed and cinnabar has been deposited in crevices in the lava. The spring deposits, including the cinnabar, have formed close to the edge of the basalt, and I can see no reason to doubt that they result from the volcanic action of which the lava eruption was one manifestation.

The springs.—The present vents of the springs lie along a series of fissures about a mile in length, shown on the map nearly parallel to the railroad. These cracks have formed in a mass of sinter deposited from earlier vents and are in part choked up by detritus, in part covered by recent deposits, but they are nevertheless traceable for long distances. The vents in many cases retain their fissure character and the water may be seen and heard boiling in openings, evidently of great depth, from an inch to two feet in width and many yards in length. At other points the cracks are closed, with the exception of pipe-like openings, through which the water reaches the surface. At vents of the latter class there often form smooth mounds of sinter, from the summit of which the water escapes continuously or fitfully. Some of the springs have a true geyser character, though on a very small scale, alternately disappearing from their basins and returning to them with noise and agitation at short intervals of time. It is said by the inhabitants that in some seasons the water returns to certain of the basins with sufficient violence to be thrown several feet into the air, but during my visits the maximum action did not exceed a plentiful overflow.

It is very clear that these springs are short-lived. In the most active area they are to be found in every approach to extinction. Some have completely covered their own vents with sinter, though when the crust is broken hot water is still found below, while other mounds and cracks are completely cold. Some very active vents are also manifestly extremely recent and have only lately begun to form new deposits. The extinction and subsequent formation of springs has certainly been in progress for a long time and the accumulation of sinter is large. The upper line of vents is about one hundred feet above the railroad, which runs along the base of the mass of sinter. The ground beneath the sinter, however, evidently slopes outward from the hills, and the maximum thickness of the deposits is probably about fifty feet. Active springs formerly existed at many other points. The map extends eastward to the foot of the Virginia Range. The rocks of this range a little farther eastward are greatly decomposed, apparently by solfataric action. There is also on the map east of the railroad one small area of sinter in which there is now no evidence of activity. Much of the main area of sinter is likewise cold and dry, but some three thousand feet due west of the active group of fissures is a second group, now nearly extinct, of which only one is shown on the map. From this small quantities of steam and other gases still escape at a few points. At the mine only small quantities of sinter exist and the fissures are not superficially defined as in the areas just mentioned, though it is clear that the lines of vent extended in a direction nearly north and south. In some of the excavations the ground is moist and still hot enough to be painful to the touch. Gases, too, still escape, but no water flows. The entire area of sinter and decomposed granite north and west of the basalt area is continuous and manifestly has a common origin. There can of course be no question that the thermal action of this locality is volcanic. The area of thermal activity is at the foot of a stream of comparatively recent basalt, which was the last rock ejected. The relations thus point very clearly to an immediate connection between the basalt eruption and hot springs.

In discussing the solfatarism of the Washoe district I inferred that it was probably of later date than the eruption of later hornblende-andesite, while of its time-relations to the basalt eruption there was no means of judging.[1] I was not then aware of the evidence that the activity at Steamboat was directly referable to the eruption of basalt. The thermal action on the Comstock has advanced somewhat farther towards extinction than that at Steamboat; for, while the water on the 3,000-foot level of the Comstock is charged with carbonic and sulphydric acids and has a temperature of 76.7° C., most of the vents at the surface at Steamboat show still higher temperatures and the water at a distance of half a mile below must be greatly superheated. Nevertheless the thermal action in each of the districts must be of approximately the same age, as are also the basalt eruptions of the two areas; and the fact that the origin of the spring in the one case is directly traceable to the eruption of basalt makes it extremely probable that in the other also the basalt eruption gave rise to the thermal activity. The relations of the lava to the springs at Steamboat are strikingly

[1] Geology of the Comstock Lode, p. 207.

similar to those studied by Dr. Hector near Lake Omapere, in New Zealand, where, too, the sinter contains cinnabar. (See page 50.)

Diversities.—The effects produced by the action of the heated waters and of the gases accompanying them in the various portions of the affected area differ very materially and in an interesting manner. The heavy masses of sinter near the railroad are to a considerable extent composed of carbonates and all effervesce with acids. Much of the mass is silica, however, in part crystalline and in part amorphous. The material is deposited in layers or bands, partly lining crevices and partly covering the adjacent country in more or less nearly horizontal sheets. The linings of the crevices have a ribbon structure precisely such as is found in veins and composed of substantially the materials most common in veins, excepting indeed the hydrated silica. In the northwestern part of the area carbonates occur only in small quantities. The deposits here are for the most part chalcedony, which also exhibits ribbon structure. In the neighborhood of the mine workings only small quantities of silica and carbonates have been deposited. Here, indeed, the quantity of material removed by the spring waters is greatly in excess of the deposits which they have formed. In the southern part of the ground, where mining has been carried on, an actual basin has been formed, with a low rim to the north, which, however, is not sufficiently high to be exhibited by the 20-foot contour lines. This basin, from which there is no drainage, is not artificial, and appears beyond question to have formed in consequence of the collapse of the decomposed granite, yet it contains not only cinnabar, but a thin layer of sinter composed of carbonates and silica.

There is no reason to suppose that the general character of the fluids and gases which have been active in the various portions of this area differed qualitatively; on the contrary, the entire character of the deposits and the distribution of decomposed granite indicate that the qualitative composition was the same. Variations in the quantitative composition of the waters thus seems to have been sufficient to bring about either the deposition of large masses of material or an actual subsidence of the surface. This important inference may seem doubtful when drawn from this locality alone; for, though there is no indication of a qualitative difference in the waters, the proof that the water which undermined the basin south of the furnaces was similar to that now issuing near the railway is negative. At Sulphur Bank, however, we have springs of similar qualitative composition which are not depositing sinter to any extent and which are actually removing material by their solvent action. The difference at the two localities appears to depend largely upon the quantity of sulphuric acid generated. At Steamboat, also, the depressed basin contains sulphates, which have been formed by the action of sulphuric acid on the rocks, and I can see no reason to doubt that the quantity of sulphuric acid generated has determined deposition of sinter or removal of constituents of the rocks.

The silica of the sinters.—As has been stated, one portion of the sinter area consists almost solely of a flinty or chalcedonic mass. This is by no means ancient, for scalding steam still issues at one point, nor does it show any signs of erosion. Under the microscope the sinter is found to be composed of ordinary quartz crystals and fibrous, crystalline silica. No opal was detected with certainty by the microscope. This rock is almost absolutely identical with some of the chalcedonic specimens from Knoxville, which contain, in addition, cinnabar. The sinters from the springs now most active are finer grained than that just described. They are composed of silica and carbonates. The silica is certainly in part crystalline and does not remain dark between crossed nicols.

To obtain further information about the existence of opal, water determinations were made of three specimens, care being taken to separate the water from other volatile constituents. One of the specimens was a milky-white, compact rock with dull luster; a second was a very dark slate-colored rock with a resinous luster; and the third, a pure-white sinter, earthy and friable in part. The water absorbed in a calcium chloride tube was in the order of the descriptions 0.72, 3.77, and 0.67 per cent. These experiments show that hydrous silica was present in three specimens and that they were true chalcedonies, if by that term is understood a mixture of crystalline and amorphous silica.[1] It is evident from these observations

[1] Some remarks will be made in Chapter XIV on another use of the word chalcedony.

that crystalline silica, both fibrous and granular, forms from thermal springs at the earth's surface.

Gases.—Besides steam, hydrogen sulphide, carbonic anhydride, and sulphurous anhydride escape from the springs and fissures. The quantitative composition of the gas manifestly varies from point to point, and therefore quantitative analyses were not made. In the qualitative analyses free hydrogen and hydrocarbons were looked for, but none was detected. Neither were oily hydrocarbons found here as they are at most quicksilver deposits, though low forms of vegetation flourish in the waters of the hot springs even at very high temperatures. The absence of hydrocarbons from the gases and deposits is a very important fact. The sinter rests upon granite, and through this rock the springs reach the surface. If the hydrogen sulphide were a result of the reduction of soluble sulphates by organic matter, hydrocarbons would almost certainly be present, as was pointed out by Bunsen in his great memoir on the geysers of Iceland. The composition of these gases, therefore, points to generation from inorganic material at the seat of volcanic activity far below the surface. Whether, under the unknown conditions there prevailing, hydrogen sulphide can be derived from sulphates without the intervention of organic matter by some reaction not yet discovered, or whether the sulphur comes from regions which have never been oxidized, is uncertain. The same gases are perceptible at the mine as at the more active springs; it is possible, however, that a portion of the sulphurous anhydride at the mine is due to the decomposition of hyposulphites.

The metalliferous deposits.—The springs now flowing emit no great quantity of water and many of the vents did not overflow at all during my visit; neither does the water seem to be impelled toward the surface with any violence and in most cases it is perfectly clear. The mass of sinter through which the water attains the surface is also many yards in thickness. The deposits formed in the vents, particularly when they are narrow cracks, consequently consist of substances which have been held in solution by the waters and which have been precipitated by cooling, evaporation, and, to some extent, by acidification. Large quantities of these deposits were collected at different points and were analyzed with the utmost care. In the waters themselves one could expect to find only those substances which were most abundant in the natural precipitates, because they represent the concentration of much larger quantities of water than it would be practicable to evaporate for analysis. The spring deposits were found to contain the following metallic substances arranged as nearly as may be in the order of their quantity: Sulphides of antimony and arsenic, ferric hydrate, lead sulphide, copper sulphide, mercuric sulphide, gold, and silver, together with traces of zinc, manganese, cobalt, and nickel. In the spring water itself only antimony, arsenic, and traces of mercury were detected. In considering the analyses, it must be remembered that the greater part of the metallic deposits are not at the vents of the living springs, but to the west at the mine, where no springs now exist, though steam and solfataric gases in small quantities still escape.

Metalliferous spring deposits.—Specimens I and II were from an old crevice in the plateau of sinter near the railroad. The crevice was sealed with sinter and the ground was entirely cold. When it was opened no water was found. The deposit was a true, simple fissure vein between walls composed of earlier sinters. It was brick-red in color, like almost all of the metalliferous deposits of the plateau, the tint being due to red, precipitated sulphide of antimony, a mineral which I believe has received no name.[1] The color of some of these deposits is such as to suggest impure cinnabar, but in none of those near the railway did we find enough mercuric sulphide to account for the tint Qualitative analysis showed the presence of mercury, gold, silver, copper, lead, arsenic, antimony, iron, aluminium, manganese, zinc in minute quantity, traces of cobalt and nickel, lime, magnesia, lithium, sodium and potassium, silica and sulphur. A minute quantity of sulphates appeared to be present. Quantitative separations were made with very large samples. The object was to obtain weighable amounts of the metals, in order that an idea might be obtained of their relative abundance. The precise estimation, however, has only a general value, because the deposit

[1] Dr. J. Sterry Hunt desiring to mention this mineral in his classification, I suggested *metastibnite* (Proc. Am. Philos. Soc., vol. 25, 1888, p. 168).

is manifestly of variable composition. The following figures give the results:

	I.	II.
	Grams.	*Grams.*
Weight of sample	1,021.0000	3,403.0000
Gold	0.0009	0.0034
Silver	0.0003	0.0012
Mercuric sulphide	0.0014	0.0070
Lead sulphide	0.0899	0.0720
Cupric sulphide	0.0064	0.0424
Antimonious and arsenious sulphides		78.0308
Ferric oxide		3.5924

Specimen III was taken from a crevice at some points of which hot water and gas still escape, but from a portion of the fissure no longer active. Qualitative examination showed the presence of mercury, gold, lead, copper, antimony, arsenic, iron, aluminium, manganese, traces of nickel, lime, traces of strontium, magnesium, sodium, potassium, lithium, cæsium, rubidium, free silica, and free sulphur. The bases were combined as silicates, carbonates, sulphates, sulphides, chlorides, borates, and phosphates, the last in small quantities. The color of the material showed that the greater part of the arsenic and antimony was in the form of sulphide. Special determinations of the mercury were made with portions of this deposit. After drying and pulverizing, the carbonates were extracted with dilute chlorhydric acid and the heavy metals were dissolved in aqua regia. The precipitate given by sulphureted hydrogen was leached with cold, yellow ammonium sulphide and the residual sulphides were weighed. A portion of this residue, heated in a closed tube with sodium carbonate and pure iron powder, gave a sublimate of metallic mercury. This sublimate was tested by uniting the globules to larger ones, by amalgamating gold, and by conversion into mercuric iodide in a closed tube. From another portion mercurous chloride and gold were precipitated by phosphorous acid. The gold produced the characteristic tint and a button of metallic gold in a pure state was finally extracted. Another portion of specimen III, examined quantitatively, gave the following result:

	Grams.
Weight taken	2,835.0000
Mercuric sulphide found	0.0024
Sulphides of arsenic and antimony	4.2725

Another sample (IV) from the same crevices which contained III, but from a point at which steam and sulphureted hydrogen bubbled through the hot water, showed an entirely similar composition; it contained mercury, lead, copper, arsenic, antimony, iron, aluminium, calcium, magnesium, sodium, potassium and lithium, free silica, and free sulphur. The bases were combined as silicates, sulphides, sulphates, carbonates, chlorides, borates, and to a small extent as phosphates.

Specimen V was from one of the springs which had formed a basin, through which occasional bubbles rise to the surface. The sediment consisted of layers of gray and yellow material, the latter being tinted by sulphide of arsenic. It contained mercury more abundantly than those previously mentioned, and also lead, copper, arsenic, antimony, iron, and aluminium, a trace of cobalt, magnesium, sodium, potassium, cæsium, lithium, free silica, and sulphur. The bases were combined as silicates, carbonates, sulphides, sulphates, chlorides, and phosphates.

At one point on the plateau a mud deposit is formed by deposition from streams issuing from two of the more active springs. Here mica scales exist, showing that in this case some material is brought up in suspension from the underlying granite, which must consequently be undergoing decomposition; for the feeble streams of water which rise through it are certainly incapable of wearing granite away at such a rate that the abraded portions would be visible to the naked eye. This mud must therefore contain products of decomposition of granite, as well as any substances which may have passed through the granite in solution. Qualitative analysis showed that it had nearly the same composition as the other deposits. The portion soluble in acid contained mercury, gold, silver, lead copper, arsenic, antimony, much iron, aluminium, a trace of cobalt, magnesium, calcium, and of course alkalis. The bases were combined as silicates, carbonates, sulphides, and to a small extent as phosphates.

A warm spring, which is known as the Chicken Soup Spring, issues at the base of the plateau close to the railway, the water of which is drunk by visitors to the locality. No mercury could be detected in the sediment; but sulphides of arsenic and antimony and free sulphur, as well as low vegetable forms, abound in it.

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Free sulphur occurs at many of the springs and also at tne mine. It is of course produced by the partial oxidation of hydrogen sulphides, either by atmospheric air or by sulphurous anhydride. The quantity is nowhere large, and I doubt whether more than a pound or two could be collected at any one spot. In this respect there is a great difference between this locality and Sulphur Bank, where a great quantity of sulphur was exploited. The sulphur is found chiefly at points to which the access of air is limited, as should be the case according to the thermochemical relations stated on page 255.

The water.—The water analyzed was taken from a spring at the eastern edge of the sinter plateau, which had formed a basin. The water in the basin seemed perfectly limpid and the overflow was gentle and nearly constant. The temperature of the spring was found to vary considerably, the extreme limits noted being 75° and 84.5° C. In order that the water might be free from solid impurities it was siphoned off from the basin into a covered funnel and was filtered directly into the demijohns used to transport it. In passing through the siphon the water was inevitably cooled, and it was found that the water on the filter paper had a temperature of from 30.5° to 33° C. In collecting the water in this manner a very interesting fact was observed. Near the lower end of the glass siphon a red precipitate formed. Since neither air nor any other foreign substance had access to the water at this point, the precipitation could hardly be attributed to any other cause than cooling. The precipitate consisted of sulphides of antimony and arsenic and silica, the last being deposited chiefly on the upper part of the coated portion of the tube. Here, then, ores and one of the most important of gangue minerals were deposited in an opening by natural means, and I had the pleasure of watching the actual progress of the formation of an ore deposit. On the filter paper also a similar precipitate formed, but here the organic matter of the paper and atmospheric influences were at work, and floating dust came in contact with the fluid. Even the water in the spring basin must have contained organic germs, for at all the springs, so soon as the water has somewhat cooled, low forms of vegetable life flourish and form red and green, pulpy sheets of slimy matter. The germs of these organisms are no doubt abundant in the atmosphere and fall into all the spring basins. On the inner walls of the siphon tube diatom-like structures were visible with the microscope. The cooling of the water was unquestionably necessary to the development of these organisms, and in the absence of air it seems impossible to suppose that they can have grown sufficiently to have influenced the precipitation of the sulphides.

An attempt was made to collect a considerable quantity of precipitate by simply cooling the water of this spring as described above, and for this purpose a number of long siphons were set in operation. But, though the precipitates in the tubes were very striking in appearance, the quantity of precipitate obtained in filtering 118 liters was only about nine milligrams. It was almost completely soluble in yellow ammonium sulphide, and, to my disappointment, not a trace of mercury could be detected. Perhaps this was to be expected in view of the proportion which cinnabar bears to the sulphides of antimony and arsenic in the other deposits.

The following results were obtained from analysis of the water:

Analysis of Steamboat Springs water.

[Contents of 10 liters in grams.]

Silica, SiO^2	3.1065
Carbon dioxide, CO^2	1.7759
Boric anhydride, B^2O^3	2.1741
Sulphuric anhydride, SO^3	1.0389
Hyposulphurous anhydride, S^2O^2	0.0307
Sulphur combined, S as RHS	0.0327
Hydrogen sulphide, H^2S	0.0055
Or sulphur, S	0.0052
Chlorine, Cl	9.5243
Antimonious anhydride, Sb^2O^3	0.0051
Arsenious anhydride, As^2O^3	0.0357
Phosphoric anhydride, P^2O^5	0.0063
Mercuric sulphide, HgS	Trace
Alumina, Al^2O^3	0.0025
Ferrous oxide, FeO	0.0018
Lime, CaO	0.0958
Magnesia, MgO	0.0047
Soda, Na^2O	9.1929
Lithia, Li^2O	0.1541
Potassa, K^2O	1.2460
Cæsium and rubidium oxides, Cs^2O, Rb^2O	Trace

The cæsium and rubidium in this analysis were detected by the spectroscope, but the quantity present was too small for determination. The mercury was precipitated by phosphorous acid under conditions precluding the precipitation of any other metal. A faint cloudiness indicated its presence, but no weighable quantity came down.

The basin from which this water was taken was small and contained perhaps no more than a cubic foot of water; but the overflow was also small, and a part of the water in it must have been exposed to the air at a high temperature for a considerable time. Some decomposition was therefore to be expected. If solutions of alkaline sulphides be allowed to oxidize, hyposulphites are well known to form. The analysis shows hyposulphurous acid, and this, I think, must be attributed to decomposition, for its formation at great depths appears hard to explain, nor am I aware that hyposulphites have ever been detected under conditions which suggest their existence in nature at points removed from oxidizing influences of the air. The hyposulphurous acid is undoubtedly combined with sodium, and probably represents a certain amount of oxidized sodium sulphydrate. The decomposition of sodium sulphydrate is well known to be attended by the formation of sodic hydrate. The antimony and arsenic were certainly in solution, and it is altogether probable that they were originally in the form of sulpharsenides and sulphantimonides of sodium. But in the presence of caustic soda these sulphides are partially decomposed with the formation of arsenites and antimonites The sum of the quantities of sulphur found in combination with metals and in the free state or in combination with hydrogen is just sufficient to form sulphantimonides and sulpharsenide of sodium, and the presence of hydrogen sulphide is explained if one supposes the sulphosalts partially decomposed, as suggested above. In the table given below I have supposed the arsenic and antimony to be entirely in the condition of sulphosalts and that the hyposulphite is represented by sodium sulphydrate. As has been mentioned, silica is precipitated when this water is cooled; but when the fluid reaches the surface there can be little doubt that it all exists in combination with the alkalis as an acid silicate. It is not improbable that this compound is the quadrisilicate of sodium It is computed as such.

Acid sodium carbonate is well known to be partially decomposed at high temperatures, and it is therefore by no means unreasonable to suppose that a part of the sodium salt was neutral. This supposition also accords with that made with reference to the silica. The alumina was probably present as an alkaline aluminate, but the quantity found was so small that it did not appear worth while to compute its hypothetical compounds. In Chapter XV it will be shown that the trace of mercury in this water is combined as a double sulphide with sodium, which is of the form HgS, $n Na^2S$. The value of n in this case is probably four. No comments seem needful on the state of combination of the other constituents of this water. The suppositions made lead to the following scheme of composition as the most probable prior to the action of the atmosphere upon the fluid:

Probable composition of the water prior to oxidation.

	Grams.
Ferrous carbonate, $FeCO^3$	0.0029
Magnesium carbonate, $MgCO^3$	0.0099
Calcic carbonate, $CaCO^3$	0.1577
Calcic phosphate, $Ca^3P^2O^8$	0.0137
Potassic chloride, KCl	1.9735
Lithic sulphate, Li^2SO^4	0.5650
Sodic chloride, NaCl	14.1475
Sodic sulphydrate, NaHS	0.0358
Sodic sulphate, Na^2SO^4	1.1147
Sodic bicarbonate, $NaHCO^3$	2.9023
Sodic monocarbonate, Na^2CO^3	0.4314
Sodic biborate, $Na^2B^4O^7$	3.1368
Sodic quadrisilicate, $Na^2Si^4O^9$	3.9090
Sodic sulphantimonide, Na^2SbS^3	0.0100
Sodic sulpharsenide, Na^3AsS^3	0.0866
Alumina, Al^2O^3	0.0025
Sodium-mercury sulphide, HgS, nNa^2S	Trace

Origin of the water.—Old residents informed me that the quantity of water flowing from the springs varies from year to year, being greater in years of heavy rain-fall than in dry seasons and greater in spring than in autumn. If these statements be accurate, the supply must come from the surface and no very long time can intervene between precipitation and return to the surface. It is natural to suppose the great snowy range to be the source of supply. The fissures underlying the range may afford a downward passage for the waters to the heated mass from which the basalt came, while the fissures associated with the channel through which the basalt was extruded furnish a shorter road back to the surface.[1] The water must be well filtered on its course, since there is no evidence that organic matter is carried to the source of heat.

The cinnabar deposit.—The quantity of mercuric sulphide in the deposits from the active springs is very minute, and there is in this district nothing which could be called quicksilver ore in a commercial sense, excepting near the mine workings and furnace on the northern central portion of the area mapped. Cinnabar is deposited in considerable abundance only in the decomposed granite, though a few paints and seams have penetrated into the basalt at the southern end of the basin-like depression. By no means all of the decomposed granite, however, even in this area, shows any ore, the cinnabar occurring only as impregnations in the decomposed area, apparently along the courses of half-obliterated fissures in the soft material. The underground workings are now almost wholly inaccessible, and some prospecting would be necessary to ascertain anything definite with regard to the amount of ore available. The mode of occurrence of cinnabar indicates that the deposition did not proceed pari passu with the decomposition of the granite, but followed it. Had it been otherwise, cinnabar would be found generally over the decomposed area and the impregnated granite would be tolerably firm, instead of forming a gravel-like, incoherent mass. It is very probable that at depths of a hundred feet, more or less, the character of the deposit would be found to differ markedly from that at the surface, for the phenomena here, as at Sulphur Bank, are complicated by the action of sulphuric acid due to the oxidation of sulphureted hydrogen.

Metals in the granite.—The present springs are certainly decomposing granite to some extent, and decomposition of this rock on a large scale has occurred within no long period. It seemed probable that at least a portion of the heavy metals found in the deposits were derived from the granite and possible that all of them had this origin. Rock from the area east of the railroad was selected because it was fresh and well removed from springs, active or extinct. Large quantities of granite, in one case 15.5 pounds, were finely pulverized and decomposed either by aqua regia, which does not

[1] Compare my suggestion as to the source of the water entering the mines on the Comstock (Geology of the Comstock Lode, p. 243).

decompose the mica, or by hydrofluoric and sulphuric acids. Both the resulting solutions were examined for heavy metals; and arsenic, antimony, lead, and copper were found in those prepared by each of the above methods, but neither mercury nor gold could be detected in either. Experiments made with 50 grams of hornblende and mica separated from the rock also failed to detect mercury or gold. Lead almost if not quite always contains silver, so that the presence of lead in the granite points to the existence of silver in that rock, although the tests available were not sufficiently delicate to reveal it. Professor Sandberger has actually found silver in the micas of German granites, as well as arsenic, lead, copper, and other metals. He has also detected zinc in the mica of gneiss.[1] Silver is rarely if ever found in nature unaccompanied by gold, and it is altogether probable that micas in which Professor Sandberger found silver also contained the sister metal. According to Mr. A. Simundi some of the Idaho granites, collected at long distances from any veins, carry determinable quantities of gold.[2]

The granite of Steamboat Springs exhibits considerable variations in texture and mineral composition, as do most other granites. This and other phenomena indicate, as Scheerer and others have pointed out, that granite has never been thoroughly fluid and is not uniform in composition. It is therefore far from impossible that specimens of this rock from other points in the region of Steamboat Springs might have shown gold, silver, and zinc.

Considering that the granite is certainly undergoing decomposition and partial solution by action of the springs and that the metals most abundant in the spring deposits are also found in the granite, it seems to me only reasonable to conclude that from the granite the springs derive the arsenic, antimony, lead, and copper which they bring to the surface. The other metals are found in the deposits in far smaller quantities than those just enumerated. Though not detected in the granite here, all of them excepting quicksilver are known to occur elsewhere in granite or gneiss. It is also worth noting that silver, gold, and zinc are very frequently associated in nature with arsenic, antimony, lead, and copper. The prevalence of this

[1] Untersuchungen über Erzgänge, p. 25.

[2] Emmons and Becker, Statistics and Technology of the Precious Metals, p. 54.

association seems to point to the supposition that these metals are often derived from the same source. It is therefore much more probable that the silver, gold, and zinc also were derived from the granite at Steamboat than that they came from the unknown regions beneath it or from some mass of lava crossing it. As for the quicksilver, I am not aware that it has ever been detected as a constituent of a massive rock; but it is found at very many points the world over in association with gold, copper, arsenic, and antimony, or some of them. All the circumstances at Steamboat seem to point to the granite as its probable source, and, so far as I know, nothing suggests a different origin.

Conclusions.—As Messrs. J. A. Phillips[1] and Laur[2] have pointed out, Steamboat affords instances of the formation of true fissure veins by hot springs at the present day. While it is quite probable that some veins are formed in a different manner, it is substantially certain that many deposits have been generated in this way. The composition of the waters, with special experiments devised for the purpose, also leads to definite conclusions concerning the soluble compounds of the metals contained in the waters, as will be shown in Chapter XV. Steamboat Springs, too, affords a striking illustration of lateral secretion. This term is sometimes limited to segregations affected by cold solutions, but quite improperly, for the extraction and deposition of ore from the rocks adjoining fissures by hot solutions are just as much lateral secretion as if the prevailing temperature were low. The term is used by von Cotta without any limitation as to temperature. As it has been employed by Mr. S. F. Emmons and myself also, a limitation as to temperature has never been implied.

Comparison with the Comstock.—There are noteworthy similarities and differences between the deposits of Steamboat and of the Comstock lode. At Steamboat gold is present in much larger quantities than silver, as it is in all the deposits of the gold belt of California. At the Comstock the proportion of gold to silver by weight is only about 1 to 20. At Steamboat arsenic and antimony, lead, copper, and mercury are the most abundant metals, while on the Comstock mercury is not found at all and the prevailing ore is auriferous argentite. As I showed in my memoir on the Com-

[1] Ore Deposits, 1884.

[2] Annales des mines, vol. 3, 1863, p. 423.

stock, it is probable that the ore was there leached from the diabase hanging wall by the action of ascending waters of very high temperatures, charged with alkaline solvents, and was not deposited by sublimation or distillation, as Baron von Richthofen surmised. The difference in origin of the two ore deposits sufficiently explains their difference in character. It is of course possible that a part of the ore of the Comstock may have been derived from granite, and it is noteworthy that the ore of the Justice mine, which is near the granite area, was much baser than and quite different from that of the mines of Gold Hill and Virginia. I shall be obliged to return to this subject in Chapter XVI.

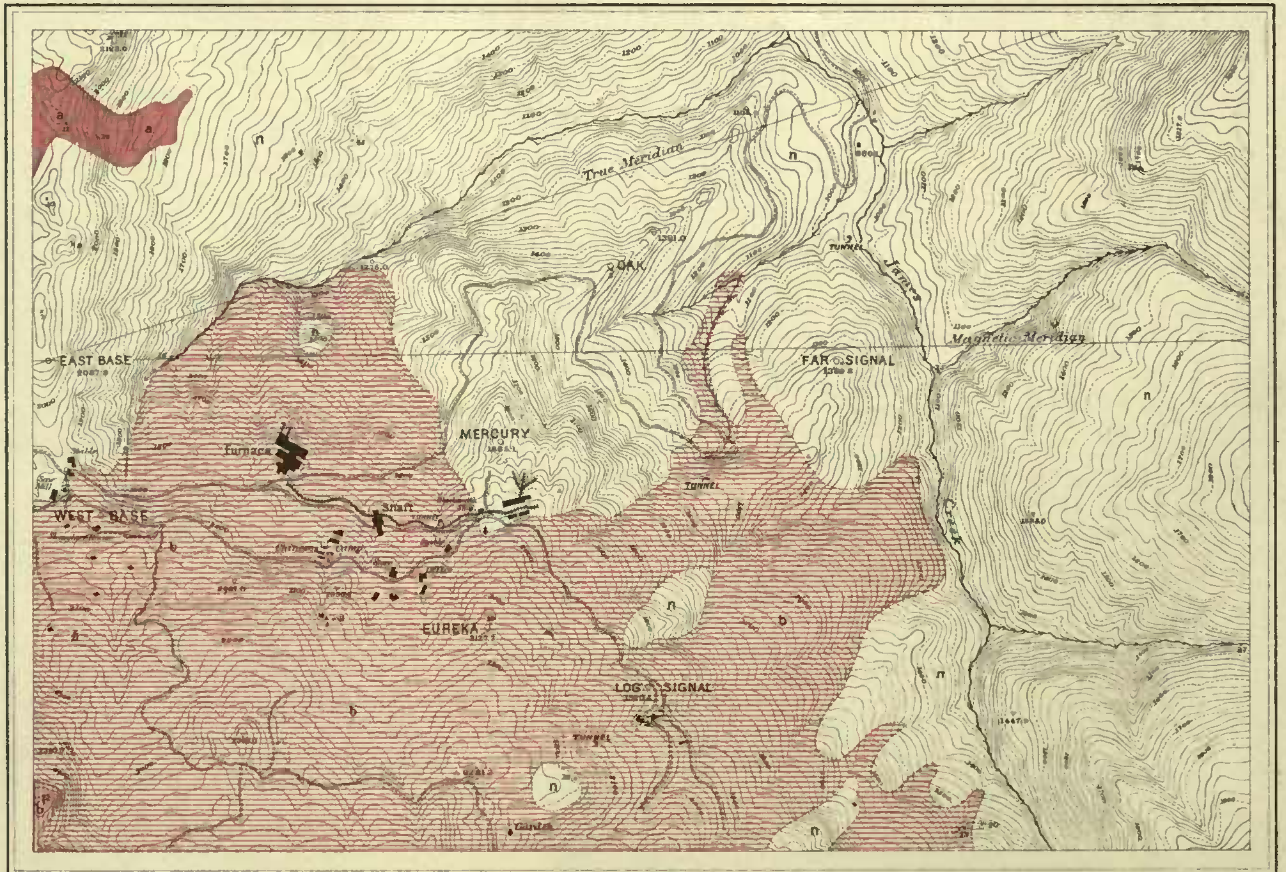
CHAPTER XII.

DESCRIPTIVE GEOLOGY OF THE OATHILL, GREAT WESTERN, AND GREAT EASTERN DISTRICTS.

In addition to the five districts described in the previous chapters, small areas surrounding the Napa Consolidated, Great Western, and Great Eastern mines were mapped. The topography of these maps was executed rapidly and without any effort to attain the degree of accuracy demanded in the larger maps. It is nevertheless very fairly done, and, excepting in some minute details, the localities are excellently represented. I intrusted the study of the geology of these districts to Mr. Turner. On going over the surface area and the mines with him, at the completion of his examinations, I could not see that anything had been omitted or misrepresented. This chapter is mainly prepared from his reports.

OATHILL.

The neighborhood of Oathill.—The region including Oathill, the Ætna mines, and the hot springs of Lidell, an area of, say, four miles by three, is one of the most interesting in the entire quicksilver belt, and, had its character been sufficiently understood at an earlier period, an atlas sheet would have been devoted to it. The deposits are numerous and differ very greatly from one another in external form and in the character of the inclosing rocks; some of them are also manifestly connected in the closest manner with volcanic phenomena. These circumstances lend the deposits special significance. The Ætna mines will be described in the next chapter, where also a sketch map showing the relative positions of the deposits will be found; but a few notes on these occurrences are needful to a proper appre-



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H. W. Turner Geologist

OAT HILL MINE, NAPA COUNTY, CAL.

Scale: 1250 ft. = 1 inch.

1000 0 1000 2000 3000 4000 5000 FT.

○ *Triangulation Points*
Roads

NEOCOMIAN n

PYROXENE ANDESITE a

BASALT
Thick mass b
Thin sheet. b

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ciation of the Oathill mines. Hot sulphur springs issue from an opening of the abandoned Valley mine at Lidell. The rock is highly metamorphic and shows small quantities of cinnabar associated with black opal. The Ætna Company's deposits are in part in metamorphic rocks, showing at present no evidence of volcanic action, unless the evolution of large quantities of inflammable gas is to be regarded as due to causes coming under this category. These metamorphic rocks, as well as the strata at Oathill, are members of the Knoxville series. Two of the ore deposits are in part impregnations and in part of the irregular, reticulated type. In two of the mines of the Ætna Company the deposits form veins or vein-like impregnations at the contact between the basalt dikes and sandstone, the ore occurring both in the decomposed basalt and in the adjacent sedimentary material. No hot water or gas now reaches these veins, though they must be of very recent origin. There is no reason whatever to suppose that the various deposits of this small district are due to essentially different causes, and the common cause seems beyond question the action of thermal springs.

Strata of Oathill.—The deposits of Oathill are inclosed in a gray, rather friable sandstone, which is comparatively little altered or disturbed in the neighborhood of the mines, but passes over into intensely metamorphosed rocks in all directions. Veinlets of quartz, however, intersect the sandstone in some places, indicating that the general metamorphism of the country was feebly felt even here. The sandstones are not fossiliferous, though *Aucella concentrica* occurs at no great distance and evidently in the same series of strata. A small amount of shale accompanies the sandstone. The area of unaltered rock is small, the ridge at the north end of the map (Plate V) being highly silicified, while the southern border is in serpentine, which forms a part of the belt of this rock, extending from the Ætna mine northwesterly to St. Helena Creek.

Lavas.—The hill in which the deposits occur is covered over with a thin layer of basalt. This sheet is cracked up into large bowlders, many of them weighing many tons each, and the underlying sandstone is exposed at a number of points. The basalt is for the most part gray and vesicular, but is found in the more usual dark, compact form at a few points. At the northwest corner of the map this thin sheet is in contact with a plateau of basalt, in which the rock is of much greater thickness. This mesa is about a mile square and is bounded on all sides by precipitous walls. To the north of the mines is a larger area of pyroxene-andesite, a tongue of which enters the region mapped.

Deposits of the Napa Consolidated.—The deposits of Oathill are the Mercury vein, the Manzanita vein, and the Accidental vein, which are the property of the Napa Consolidated Mining Company, and the Eureka claim, which contains a deposit similar to those of the Napa. The principal mine is upon the two veins first mentioned.

The Mercury and Manzanita deposits are on two nearly parallel fissures in the unaltered sandstones of Oathill. They strike northwest-southeast magnetic and dip at a high angle, usually more than 45°. The strata, both in the mine and outside of it, are nearly horizontal, excepting close to the fissures. Here the faulting which has taken place between the walls of the fissures has flexed the strata. Those of the hanging wall are bent upward toward the fissure and those on the foot-wall are flexed downward, thus indicating the direction of the movement. The walls of the fissures are almost everywhere well marked by slickensides and the interval between them is chiefly filled with products of their attrition, sometimes in the form of clay.[1] Often also fragments of sandstone and shale, showing the original stratification, are found between the walls. The attrition mixture is impregnated with silica, calcite, pyrite, and cinnabar. The silica is found mainly in stringers, which intersect the vein matter in surfaces parallel to the walls and sometimes give a cross-section of the vein a stratified appearance. A portion of the pyrite is oxidized, and iron oxide, ferrous sulphate, and magnesium sulphate have resulted from this process. The seams carrying most ore are often marked by iron stains.

At a number of points the cinnabar has followed the stratification of the inclosing sandstone away from the veins, forming horizontal chambers, which are sometimes 100 feet in length and 50 in height. In the Mercury several such chambers occur in the foot-wall. The only one accessible in

[1] It may be well to call attention to the fact that the clay of mines very frequently contains little or no kaolin. Any soft, tough mass is called clay by miners (see Geology of the Comstock Lode, p. 217).

the Manzanita was in the hanging wall. These chambers are true impregna tions in the soft sandstone. When the tenor of the rock is only 1 or 2 per cent. of quicksilver, the cinnabar is hardly visible on a fractured surface, but when such rock is bruised a red stain appears. The color in the pick-marks in such cases is regarded as a trustworthy guide to the value of the ore.

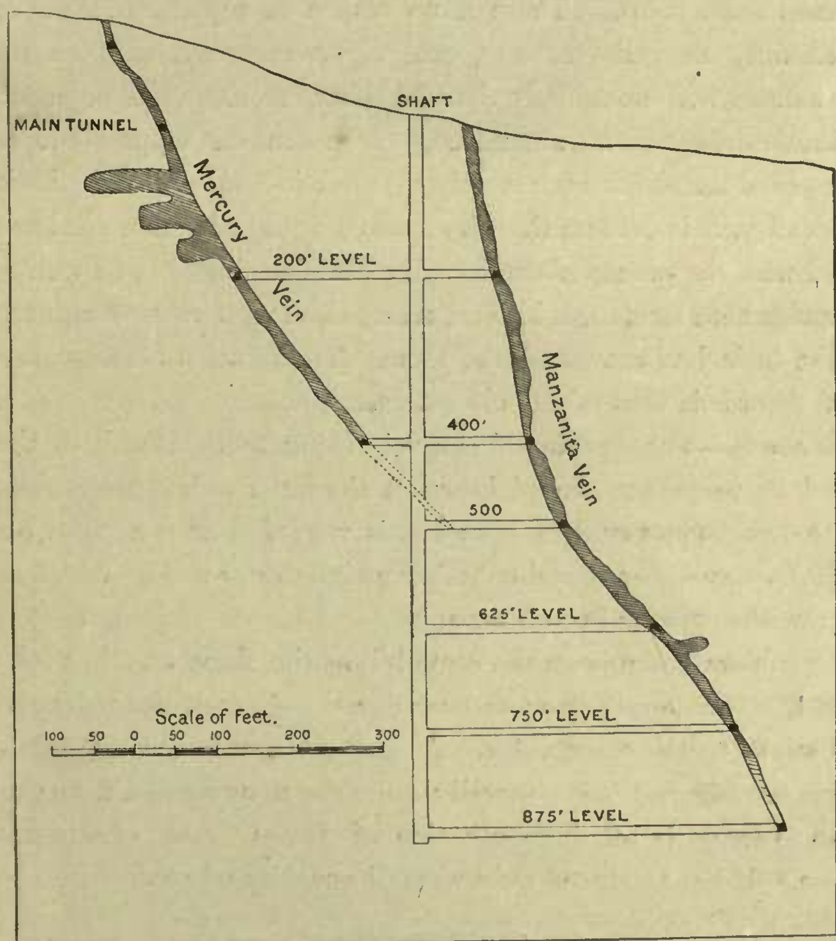


FIG. 14. Diagrammatic cross-section on magnetic northeast and southwest line through the main workings of the Napa Consolidated mine. Scale 400 feet to 1 inch.

The two veins of this mine answer to "rake veins," while the adjacent chambers correspond to "pipe veins," at least as these terms are defined by von Cotta. Pyrite as well as cinnabar impregnates the walls to some extent. No hot water or sulphur gases enter this mine.

Cross-section.—The accompanying diagram (Fig. 14) illustrates the character of these veins, but portions of the ground were inaccessible, and it does not profess to be perfectly accurate. The Mercury vein was barren below the 400-foot level and has not been traced below the 500. The Manzanita was followed to the 875-foot level, the deepest in the mine. This vein was richest between the 400 and 500 levels and was barren below the 750.

It is evident that the ore in this mine reached its present position along the fissures from below. There is no reason to suppose that the ore was deposited only near the surface, and vigorous prospecting on the well defined fissures will most likely disclose other ore chambers adjacent to the veins, unless the sandstone should become so dense as to preclude impregnations. Had the strata been nearly vertical, instead of almost horizontal, at this locality, it is evident that the fissures would have more or less nearly coincided with the planes of stratification and that, instead of a well marked vein, impregnated strata would have resulted, though everything except the dip of the beds had remained the same. The relation between those two forms of deposit is thus of the closest description.

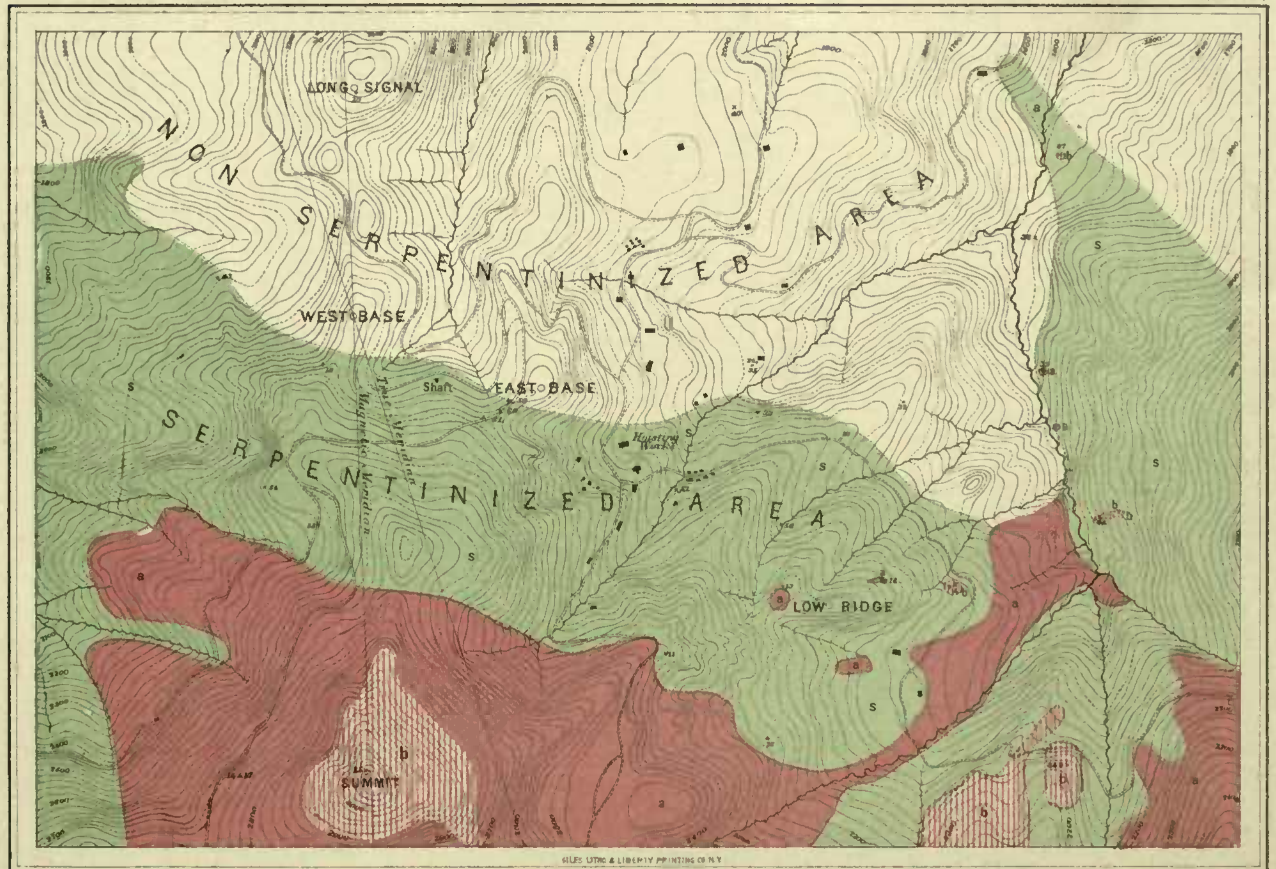
Minor deposits.—The Accidental is a vein lying to the south of the Mercury, and its projection would intersect the latter at a considerable angle. Cinnabar has been found in it and it is regarded as a hopeful prospect. Other faults have been found containing cinnabar, some of which are parallel to the Mercury and the Manzanita.

The Eureka claim is on the same hill as the Napa and in rock of the same kind. The deposit is on an irregular, though well defined fault nearly at right angles to the Napa veins. A part of the ore from this mine is in a sandstone breccia, but it is generally quite the same as that from the Napa.

The Ivanhoe is on the south side of James Creek, also in unaltered sandstone. It has produced only a small quantity of ore.

GREAT WESTERN.

Geological position.—The Great Western has been the largest producer among the mines of the Mayacmas belt. It has yielded over fifty thousand flasks of quicksilver and is by no means exhausted. The underlying sedimentary rocks of the district are for the most part highly metamorphosed. A little unaltered rock exists, but no fossils were found in it. The lithological and physical character of the beds so strongly resembles that of areas, not far



J. Ahern, Assist. Topog^r

H.W. Turner, Geologist

GREAT WESTERN QUICKSILVER MINE.

LAKE COUNTY, CAL.

NEOCOMIAN: Unaltered; Serpentinized. (s)

ANDESITE (a)

BASALT (b)

ROADS. TRIANGULATION POINTS. HOUSES.

Scale: 1250 ft. = 1 inch

1000 0 1000 2000 3000 4000 5000 FT.

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distant, which are known to belong to the Knoxville series (Neocomian), that they may fairly be ascribed to that series, especially as there is nothing to indicate the presence of any earlier rocks in this part of the country.

The metamorphic rocks include granular, phthanitic, and serpentinoid varieties. As is usual in the Coast Ranges, no definite lines can be drawn between these varieties; nevertheless serpentine prevails so greatly in one portion of the district that it seemed to me expedient to delineate it upon the map (Plate VI). The outline of the serpentinized area, however, here, as in the districts described in former chapters, is not to be regarded as representing a sharp and complete division, but only as indicating the prevalence of one phase of metamorphism in a part of the district. The unserpentinized area is chiefly occupied by silicified rocks. The dip of the strata is, as usual in such areas, very irregular, but the prevailing inclination is to the south, or toward Mt. St. Helena, at an angle approaching 45°.

Lavas.— Upon the sedimentary rocks lie lavas. The andesite seems to have once covered a larger area than it now does and to have been partially removed by erosion, leaving many patches of extremely small size. The andesite is pyroxenic, and the greater part of it is glassy, though asperitic modifications and tufa also occur. A portion of the asperite is laminated, as is so common near Clear Lake and at Steamboat Springs. More unusual is the occurrence of contorted beds in this asperite, as if plasticity had been retained after the structure was established. It is possible, however, that the original form of the laminæ was an undulating one. A portion of the andesite forms fine columns, which is somewhat unusual on the Coast Ranges, though common enough along the Sierra.

Basalt is also represented in this district. It crowns the highest elevation on the map, a hill composed of andesite, thus giving clear proof of the order of succession of the lavas, which indeed would not be questionable even in the absence of cases of direct superposition. A portion of the basalt is vesicular, and secondary crystals are sometimes found in the cavities.

Ore deposits.—The ore deposit of the Great Western consists of tabular masses of ore, situated at the contact between very slightly altered sandstone and a heavy body of serpentine. The serpentine is accompanied by a belt of black opaline material frequently known to the miners of northern California as quicksilver rock. This opaline layer, being firmer and less easily decomposed than the surrounding masses, projects from the adjoining rocks as a cropping. The ore bodies are in direct contact with the sandstone, but are for the most part inclosed on three sides by serpentine. In a few cases small bodies of the ore extend into the opaline zone, which is, as a rule, separated from the ore by a few feet of unaltered serpentine. These relations are best shown by the accompanying cross-section (Fig. 15).

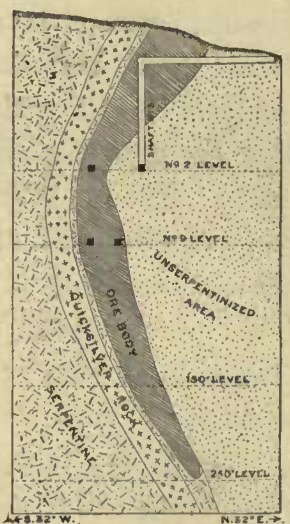


FIG. 15. Vertical cross-section through shaft No. 3, Great Western mine. Scale, 200 feet to 1 inch.

The distribution of ore in the direction of the strike is irregular, the ore bodies being divided from one another by barren ground, and, as has been the case in so many mines, they were richest near the surface. The following longitudinal section of the deposit shows the distribution of the chimneys of ore so far as they have been traced Fig. 16).

The ore has been for the most part cinnabar, but at one point a body of rock strongly impregnated with native quicksilver was found. Pyrite is abundant. Some of the cinnabar is so embedded in quartz as to show that the deposition of the two minerals was simultaneous. Bitumen occurs, particularly in cavities in the opaline belt. The new, seemingly very ill defined species of bitumen, posepnyte, was described from this mine by Schröckinger. This bitumen is said to consist of a mixture of ozocerite and a substance soluble in ether which has the formula $C^{22}H^{36}O^{4}$.

Specimens collected at the Great Western were examined by Dr. Melville with the following results:

The substance is reddish brown, resinous, soft, elastic, has a specific gravity of 0.985, and is highly electrified by friction in an agate mortar. On platinum foil it volatilizes partially at low temperatures with a rather suffocating, aromatic odor; at a higher temperature it becomes black and fuses and boils like rubber; at a dull-red heat an incombustible, light-brown ash remains. In a closed tube a yellow-brown oil distills off with an odor somewhat like burnt rubber, leaving a black, carbonaceous residue. Nothing volatilizes at 190° C., so far as could be determined. In the retort a light-colored, brownish-yellow liquid distills over considerably below red heat; at about low red heat a dark-brown liquid comes over and a black residue remains. Both liquids are heavy and viscous. The lighter-colored

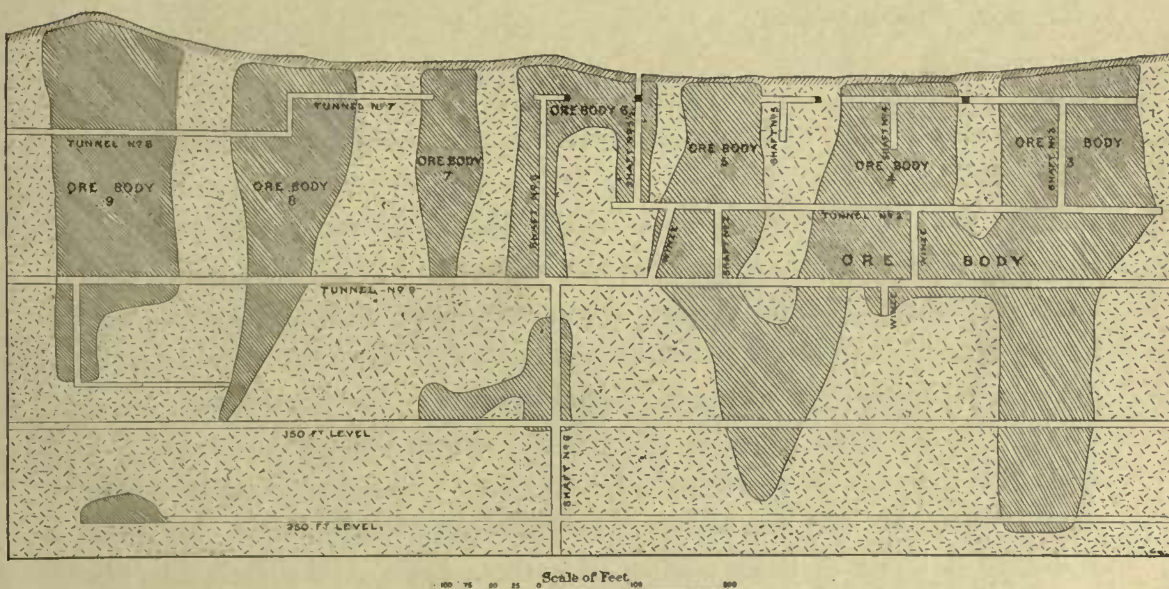


FIG. 16. Vertical longitudinal section of the Great Western quicksilver mine, N. 65° W. Scale, 200 feet to 1 inch.

liquid yields vapor at 140° C., rapidly at 190° C., the product smelling like coal-tar oils, while carbonaceous matter remains after complete distillation at temperatures gradually rising above 190° C. All these facts indicate decomposition by heat. Alcohol dissolves the substance partially. The alcoholic extract when evaporated yields an oil. Ether removes an olive-colored oil, the substance not wholly dissolving.

No nitrogen or sulphur was detected. Carbon, hydrogen, oxygen (by difference), and ash (silica and ferric oxide) were determined with the following result:

	Per cent.
Carbon	85.60
Hydrogen	10.71
Oxygen	3.22
Ash	.47
	100.00

This mineral is doubtless posepnyte, although many of its physical characteristics are not altogether like those ascribed to that mineral.

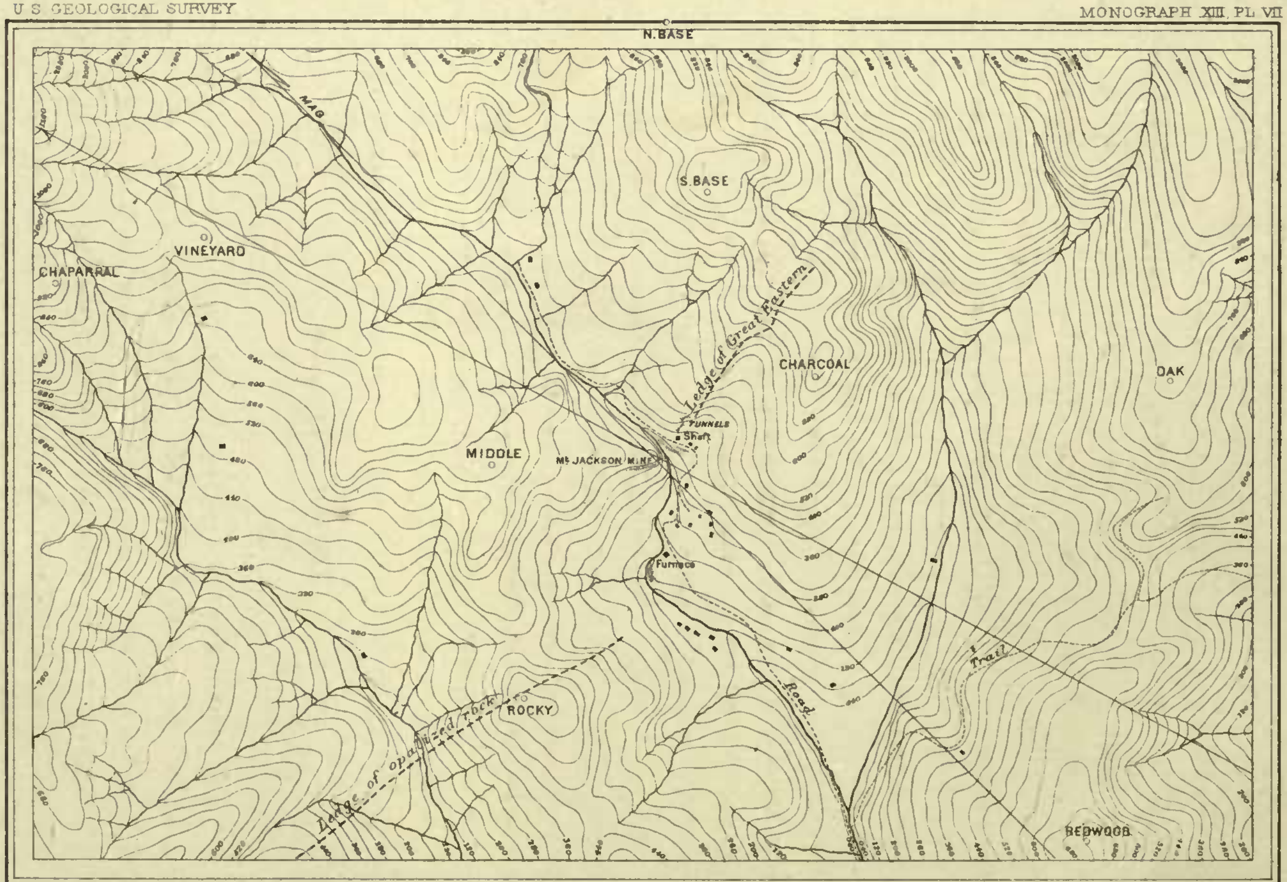
The deposit of the Great Western appeared to be a tabular, reticulated mass, connected with a fissure system. It was certainly precipitated from solutions, and these were probably dependent upon volcanic action which attended the eruption of the adjacent lavas. No hot waters or gases, however, now enter the mine.

THE GREAT EASTERN.

Importance and position.—This mine is in Sonoma County, about three miles north of Guerneville. There is another mine of the same name in Lake County, near the Great Western, which will be referred to in the next chapter. The Great Eastern of Sonoma County has a considerable economic importance, having yielded over eleven thousand flasks of metal and having been able to continue production in spite of the great depression in the price of quicksilver during the past few years. The Mt. Jackson mine, which is on the same ledge as the Great Eastern, has also produced 597 flasks, but has not been worked of late years. The deposit upon which these two mines are situated is somewhat remarkable for its isolation. Not only is it above twenty miles from the nearest quicksilver mine, but it lies away from the course of any line of deposits. It is also somewhat distant from manifestations of volcanic activity, the nearest known lavas being about six miles east of the Great Eastern.

General geology.—The district surveyed presents little interest from the point of view of general geology. The surface is exclusively occupied by the series of irregularly metamorphosed rocks so prevalent in the Coast Ranges. Slightly altered sandstones and shales, impure limestones, granular metamorphics, schists carrying glaucophane and garnet, phthanites, and serpentine are all represented. So thoroughly mingled are these various substances, however, and so numerous are the transitions that it would be entirely impracticable to represent the varieties by colors on the map (Plate VII).

Although a portion of the beds are so little altered that fossils might have been tolerably preserved in them, no organic remains could be detected.



J. Ahern, Assist. Topogr.

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GREAT EASTERN QUICKSILVER MINE,

SONOMA COUNTY, CAL.

○ TRIANGULATION POINTS
▪ HOUSES

Scale: 1250 ft. = 1 inch.

1000 0 1000 2000 3000 4000 5000 FT

[METAMORPHIC NEOCOMIAN.]

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Consequently their age is a matter of inference. The facts bearing on this question are as follows: Along the coast of Sonoma County, to the south of Ft. Ross and a little more than six miles from the Great Eastern, I found a series of unaltered sandstone beds lying unconformably upon the metamorphic series. The overlying strata are fossiliferous at some points and have been named the Wallala beds. Dr. White has determined the fossils which they contain as Middle Cretaceous. The underlying metamorphic series is older, and there can be little doubt that it is at least as old as the Knoxville series. It may possibly be older, but all the characteristics of the rock are absolutely identical with those of the material at numerous points from Colusa County to San Luis Obispo, in which *Aucella* has been found. There is, furthermore, nothing in this part of the country suggesting the presence of strata earlier than the Knoxville series. So far as there is any evidence as to the age of the rocks at the Great Eastern, therefore, they are to be regarded as Neocomian.

Quicksilver rock.—In this district there are numerous occurrences of opalized rocks. Of these many are small, seemingly isolated patches. In two cases this material forms defined ledges, standing up from the surface on account of the resistance which it offers to decomposition and erosion. These ledges strike nearly east and west magnetic, which seems to be the prevalent strike of the strata also. In one of these are the deposits of the two mines. At the surface the metalliferous ledge is nearly vertical, but at lower levels it dips to the north. It lies between a hanging wall of sandstone and a foot-wall of serpentine.

Ore deposits.—It will be remembered that at the Great Western also a layer of opalized rock lies between serpentine and sandstone. At the Great Eastern, however, the ore is inclosed in the dark, opaline mass, instead of being adjacent to it. The ore body was continuous from the surface to the lowest workings, a vertical distance of 450 feet. The ore does not form a nearly vein-like sheet in the ledge, but an irregular pipe, the axis of which is inclined to the horizon at an angle of about 50°. So far as it has been developed it is entirely embedded in the opalized rocks and does not touch either the sandstone or serpentine. The ore does not appear to have been deposited simultaneously with the amorphous silica, but in openings in the material. It is accompanied by pyrite and quartz. Bitumen is also found, especially in cavities in the opaline mass.

The deposit of the Mt. Jackson seems to have been similar to that of the Great Eastern, but of smaller extent. The explorations do not appear to have been sufficient to decide whether there are or are not other similar pipes of ore in this layer of rock.

The following cut (Fig. 17) represents a vertical cross-section of the ledge upon which the ore pipe is projected:

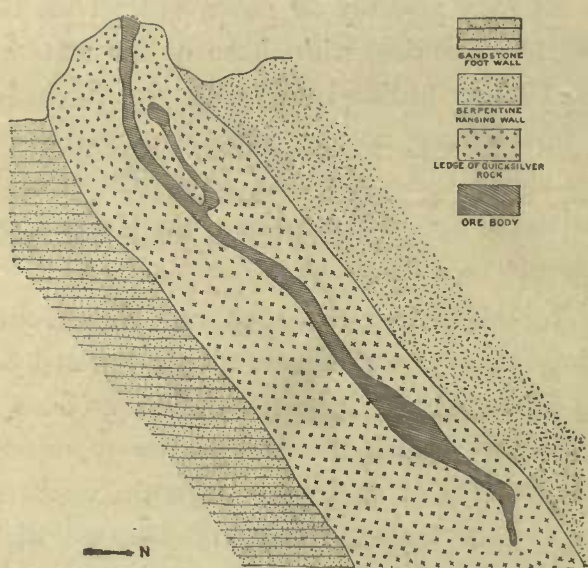

FIG. 17. Vertical cross-section of the Great Eastern mine. Scale, 150 feet to 1 inch.

Probable history.—The dark, opaline or chalcedonic "quicksilver rock" of this locality seems to have resulted from a silicification of several rocks, chiefly perhaps of serpentine. Both here and at the Great Western this silicification seems to have preceded the deposition of ore, though somewhat closely connected with it. The deposition of silica, in part amorphous, probably succeeded a movement attended by the development of hot springs. Renewed movements followed, dislocation taking place in the opalized beds at the Great Eastern, close to those at the Great Western, and these later movements were succeeded by the deposition of ore. This interpretation of the structure is supported by the existence of other ledges of the opalized material in which no cinnabar seems to occur.

CHAPTER XIII.

OTHER DEPOSITS OF THE PACIFIC SLOPE.

Besides the eight districts described in the foregoing chapter, there are many less important localities in which cinnabar has been found and from which more or less metal has been extracted. A considerable number of these have been visited by myself or by members of my party and others have been described by previous observers. Such notes on these occurrences as are available will be presented in this chapter. Many facts connected with these deposits are of great geological interest, but, on the other hand, a large number of the deposits are so similar that it is impossible to avoid monotony in their description.

The quicksilver belt.—The quicksilver belt of California cannot be said to be continuous to the north of Clear Lake, for between that sheet of water and the next deposit to the north there is a long stretch of country. It is possible, indeed, that cinnabar may yet be met with in this interval, which is very inaccessible and has been but little explored. The chances, however, seem against it, for the volcanic phenomena which are associated with so many of the deposits to the south seem to be absent between Clear Lake and the neighborhood of Mt. Shasta. There are cinnabar deposits at the northern end of the Coast Ranges, however, in the northeastern corner of Trinity County, and some fifteen miles from the edge of the volcanic rocks of the Mt. Shasta region. Cinnabar again appears in the Cascade Ranges of Oregon, which, as is pointed out in Chapter V, I regard as a northern continuation of the united Sierra Nevada and Coast Ranges of California. These occurrences to the north are thus on a continuation of the group of profound dislocations which are marked by the ranges and deposits to the south, and they show that the series of chemical phenomena leading to the deposition of cinnabar have been repeated at long geographical intervals. At the north, as to the south also, the deposits are formed at no great distance from lavas. The entire belt of country from the mines of Douglas County, Oregon, to Santa Barbara is thus structurally continuous and is marked by irregularly distributed volcanic phenomena and cinnabar deposits. In a broad sense the entire zone, six hundred miles in length, may be considered as a quicksilver belt. It will be convenient to take up the deposits not described in the foregoing chapters in the order of their latitude, beginning at the north.

North of Clear Lake.—The deposits of Douglas County, in Oregon, are situated on the western flank of the Cascade Range, the base of which is composed of granite and metamorphosed sandstones precisely similar to those at Knoxville and other points to the south which have been minutely described in Chapter III. The crest of the range is occupied by lavas. The New Idrian mine is said to be the principal deposit. It was visited in 1880 by Mr. H. W. Leavens and it is reported by him to be a vein in sandstone. The ore is cinnabar accompanied by iron oxides and, according to the report, by manganese oxide.[1] In 1882 fifty flasks of quicksilver are known to have been produced by the mines of this region.

Near the boundary between California and Oregon, in Del Norte County, Rockland district, in the neighborhood of the Diamond copper mine, cinnabar and native quicksilver were described as occurring in a whitish-gray rock in 1874.[2] I know of no second notice of this occurrence.

The quicksilver district of Trinity County, California, is in its northeastern corner. The rocks are mainly metamorphosed sediments, largely serpentinized, but volcanic rocks are said to occur at intervals, and there are mineral springs directly at the principal mine, the Altoona (formerly called the Trinity). The rocks immediately associated with cinnabar are serpentine and sandstone. The ore occurs in part as a tabular impregna-

[1] Statistics and Technology of the Precious Metals, by S. F. Emmons and G. F. Becker, pp. 27 and 28.

[2] Mining and Scientific Press, vol. 29, August 15, 1874.

tion several feet in thickness and in part as narrow seams of rich ore. One observer describes the deposit as a replacement vein between serpentine and sandstone. The vein matter is decomposed country rock and the gangue is quartz. The strike of the deposit is nearly north and south.[1]

Colusa County mines.—One of the most interesting deposits in the world is the Manzanita mine, on Sulphur Creek, close to the hot sulphur springs now known as Wilbur Springs, but formerly as Simmons's Springs. The rocks are highly metamorphosed beds of the Knoxville series. At a distance of about three-quarters of a mile from the mine is a bed of limestone, composed of shells of *Rhynchonella Whitneyi*, held together by a small amount of matrix. Within a few yards of the mine itself I collected perfectly recognizable specimens of *Aucella concentrica*. The age of the rocks is thus fully determined. The strata are thin-bedded, highly altered and contorted, shaly sandstones, a part of them somewhat serpentinized. The waters of the hot springs, which are only a few hundred feet from the mine, are highly charged with sulphureted hydrogen and are very salt. They also seem to contain borax. The surrounding country shows that, as is so usual with springs of this class, the position of the vents has repeatedly changed and much of the rock in the neighborhood has been leached by sulphuric acid. Hot sulphur waters once issued from the mine itself, for it contains a large amount of free sulphur. The ore consists of cinnabar and gold, which are sometimes in direct contact, and some metacinnabarite. These minerals are accompanied by pyrite and marcasite, chalcopyrite, stibnite, calcite, and quartz. The gold is often visible in feather-like, crystalline aggregates, sometimes in direct contact with cinnabar and sometimes deposited directly upon calcite, which is more prevalent in the ore than is quartz. The cinnabar and gold are often separated by a layer of calcite an eighth of an inch in thickness. Oily and resinous bitumens are also tolerably abundant in the workings.

The ores and gangue minerals do not form a regular deposit, but occur as thin seams, penetrating the rock sometimes along the partings between strata and sometimes cutting across the beds. It is evident on inspection

[1] This information is derived from an unpublished report of Mr. C. A. Luckhardt, Report of the Mining Commissioners, 1876, and from Statistics and Technology of the Precious Metals, by Emmons and Becker.

that the rock has been greatly disturbed and that wherever a fissure was produced the ore-bearing solutions penetrated.

The fact that native sulphur occurs in the mine in considerable quantities, taken in connection with the adjacent springs, is sufficient proof that the deposit is due to the action of hot sulphur waters. In mineralogical composition the ore is similar to that of most of the quicksilver mines, excepting in the fact that it carries gold in such quantities that the mine has been worked for this metal As has been seen in former chapters, gold occurs in much smaller quantities at Sulphur Bank, Knoxville, and Steamboat Springs. The Manzanita forms a link between cinnabar and gold mines and shows that both minerals may be deposited from the same solutions, not merely in traces, but in notable quantities. No volcanic rock is known to exist within several miles of the Manzanita, but the very hot sulphur springs seem ample evidence of volcanic agencies. It is important to note that this manifestation of volcanic activity with attendant ore deposition is found at a distance from lavas, so that, were the springs to dry up and the country to be somewhat eroded, no direct evidence would remain that any connection ever existed between this deposit and the eruptive phenomena.

The Buckeye and the Abbott's mines are near the Manzanita, and each of them has produced some quicksilver, the latter over two thousand flasks. Mr. W. A. Goodyear visited these mines. He describes the ore as consisting of cinnabar accompanied by pyrite, marcasite, and chalcedonic silica. The ore lines cracks and seams and impregnates earthy matter. Associated with the ore is a considerable quantity of the black oval so often referred to in the preceding pages.[1]

The Baker mine.—This mine lies about half-way between Lower Lake and Knoxville. It was visited by Mr. Goodyear, who found metacinnabarite in the ores. A specimen of marcasite which I collected at this mine was examined for gold and was found to contain it, the quantity being about one dollar per ton.

The Mayacmas district.—A very large part of the many cinnabar deposits north of the Bay of San Francisco are found along the Mayacmas Range, which extends in a northwesterly direction from Mt. St. Helena. Two

[1] Geol. Survey California, Geology, vol. 2, appendix, p. 124.

of the deposits of this district, the Great Western and the Napa Consolidated, have already been described. Mr. Turner was instructed to make a reconnaissance of this district as a whole, and the following information is chiefly derived from his report.

The underlying rock of the entire district appears to consist of metamorphic strata. At the southeastern end of the district some of these beds contain *Aucella concentrica*, and are certainly, therefore, members of the Knoxville series.[1] The lithological and physical character of the metamorphic rocks throughout the remainder of the region is identical with that of the rocks immediately associated with these fossils here, at Knoxville, and elsewhere, and there is no reason to suspect the presence of strata of other age than the Neocomian in the metamorphic series. To the north of the Oathill mines is a small area of unaltered rock carrying very imperfect fossils, the age of which is uncertain. Upon the metamorphic rocks lie great quantities of andesite and basalt. The andesite is for the most part glassy when fresh, though asperites are also found. This rock constitutes the greater part of the mass of Mt. St.

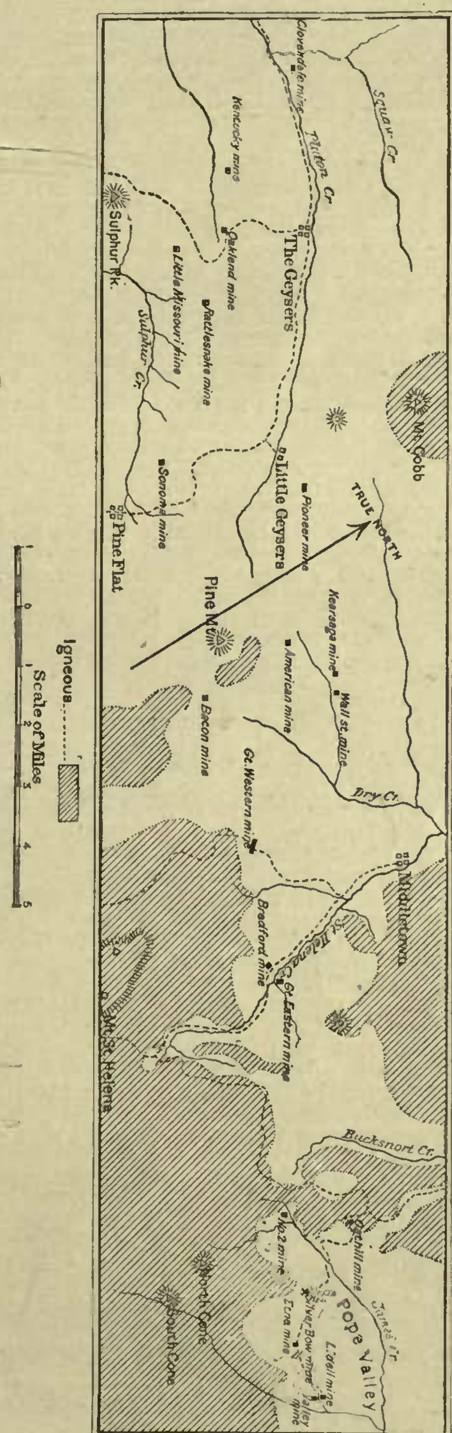

Fig. 18. Geological sketch map of the Mayacmas Range. Scale, 3 miles to 1 inch.

[1] The exact locality is on the east bank of Pope Creek, at the point at which the road from Lidell to Knoxville crosses it.

Helena and covers large areas to the north, east, and southeast of that mountain. The summit of Mt. Cobb is also andesitic. Tufaceous forms of andesite, usually much decomposed, are also abundant, especially to the south.

At the southern end of Mt. St. Helena there are argentiferous quartz veins in andesite from which a considerable amount of ore and, it is said, $90,000 of bullion have been extracted. About one and a half miles north of Calistoga, in King's Cañon and on a small ridge to the north of it, there are argentiferous quartz veins in andesite. Two of these strike northeast and southwest and two others cross them, striking nearly north and south. One of these latter is called the Elephant and carries ore of great interest, both cinnabar and pyrargyrite being visible in it, as well as pyrite. The cinnabar was chemically tested and the silver ore was analyzed. The latter contained antimony, with a mere trace of arsenic, sulphur, silver, copper, and a trace of lead. Here, then, is a true vein, carrying almost precisely the same ingredients as the deposits of Steamboat Springs. This is also the only case known as yet on the Pacific slope, excepting Steamboat Springs, where lead and quicksilver occur together. This vein is certainly a comparatively recent one, for the greater part of the andesites of the region are Post-Pliocene. In ore from one of the other veins (the Grigsby) cinnabar and pyrite were found together.

Large quantities of basalt were erupted at a much later period than that of the andesites. It occupies large areas to the north of Oathill and the igneous region east of Middletown is mostly basaltic. Some of the rock last mentioned produces a marked effect upon the needle and contains much magnetite. In some cases andesitic hills are capped by basalt. There are immense quantities of tufa to the southeast of Mt. St. Helena, and embedded in it are fragments of compact basalt, showing that the tufa belongs to the basaltic series of eruptions. The tufa is especially abundant in the neighborhood of the North Cone and South Cone and it often forms distinct beds, which are sometimes considerably inclined. It not infrequently includes great quantities of metamorphic pebbles.

The drainage and triangulation of the accompanying sketch map are mainly compiled from surveys by Mr. C. F. Hoffmann, but this material has been supplemented by observations by Mr. Turner. While the foregoing notes indicate in a general way the distribution of andesite and basalt, no attempt was made to map the two lavas separately. The areas marked as igneous are to be considered as only approximately correct, the cartographical base not being sufficiently good to permit of much detail. The area not occupied by igneous rocks is metamorphic.

The most southerly mine of this district is at Lidell and is known as the Valley claim. Lidell is resorted to by invalids for the sake of the hot sulphur baths, supplied by a spring which issues from the old workings of the Valley mine. Cinnabar may still be seen in the silicified and opaline rocks. The mine never paid for working, but is interesting for the direct association which it presents between cinnabar and hot springs.

The Ætna property is a mile distant from Lidell and comprises several claims between which are marked differences. The Phœnix, which has yielded large quantities of quicksilver—indeed, most of the product of Pope Valley—is entirely in sedimentary rocks consisting mainly of serpentine and other highly metamorphosed strata, though unaltered sandstones also appear in the workings and in parts of the mine are in direct contact with the metalliferous ground. The rock directly inclosing the ore from the surface downward was highly silicified slate and black, opaline chalcedony. The cinnabar occurred in stringers in this material and as impregnations in the softer rock and in the attrition products accompanying it. There are manifold evidences of the existence of a fissure system and of motion in the ground, so that in some places well defined walls exist. The ore was first found at the surface and was followed down for about one hundred and fifty feet. This upper ore body yielded about seventeen thousand flasks of quicksilver and then gave out completely. Vigorous prospecting below the old ore body of late years has disclosed the existence of more ore in depth. The Phœnix appears to belong to a group of deposits of cinnabar, instances of which are very numerous. The ore-bearing solutions have ascended along a fissure system, formed in very heterogeneous material, and have penetrated the wall rock with corresponding irregularity, producing irregular stockworks and impregnations tending to a tabular form. In the upper levels the ore contains some native quicksilver, which disappeared as depth increased. Besides the usual pyrite and marcasite, millerite is found in fine, bronze-colored needles on the 300-foot level. This mineral has been observed as microscopic crystals in the slides of ore from several of the mines in California, but not elsewhere in crystals visible to the naked eye, so far as I know.

Napalite.—The mine contains much yellow, bituminous matter, usually of a consistency similar to that of shoemaker's wax; indeed, it has actually been employed as a substitute for that useful material. It has been examined by Dr. Melville and turns out to be a new mineral.

The substance is dark reddish brown and shows green fluorescence by reflected light; by transmitted light, brilliant garnet red. It is interesting to note that the green fluorescence disappears in a great measure on exposure to the air, evidently with a loss of some very volatile constituent. The specimens from which the material was obtained for analysis had undergone this change, only a few smaller fragments exhibiting the original color. The ethereal solution is reddish brown, with green fluorescence, and both this solution and the solid resin are highly refracting. The luster is resinous and the hardness about 2. It is brittle, but by the warmth of the hand may easily be molded and drawn into long threads. It is not elastic. The fracture is conchoidal. It begins to fuse at 42° C. and becomes liquid at 46° C.; it boils above 300° C.; at 130° C. a heavy, colorless oil distills over, yielding an aromatic odor; then at a higher temperature yellow-brown vapors rise with a peculiar suffocating odor, and finally a heavy, dark-red oil condenses, much resembling coal-tar in smell. The boiling-point of this last product is not far below the temperature of 350° C. Many intermediate products were obtained by fractional distillation, but the yield was very small below 236° C., above which colored distillates were collected. At the temperature of softening of the glass boiling-flask a small amount of carbonaceous matter remains, showing that decomposition in part results Bromine attacks the resin with deposition of carbon. Ether dissolves it completely in the cold; so, also, does oil of turpentine, but not so readily; cold alcohol takes up but a small quantity. It is combustible and yields absolutely no residue. A small amount of sulphur was detected in one sample, but its absence in others proved that its origin was

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in the sulphurets sparingly disseminated throughout the rock specimen. It is associated with pyrite and millerite in vesicular quartz. The specific gravity is 1.02.

The following analyses were made on three different samples: (I) Pure material selected from that in the rock specimen; (II) material dissolved in ether filtered, and the filtrate allowed to solidify spontaneously; (III) material fused at a low temperature and allowed to flow away from small fragments of rock:

	I.	II.	III.
Carbon, C	89.84	89.54	89.35
Hydrogen, H	10.17	10.36	10.11
	100.01	99.90	99.46

The resin is therefore a hydrocarbon, and the analyses correspond closely to the formula C^3H^4, which would contain 90 per cent. of carbon. Since it is decomposed by heat its vapor density cannot be determined, and its structural formula could not be ascertained without a more elaborate investigation than was practicable. This mineral has not been described, and must therefore be named. The term *napalite* seems unobjectionable.

On the 150 and 300 foot levels inflammable gas issues from cracks. As shown by the following analyses by Dr. Melville, the chief component is marsh gas:

Carbonic anhydride	0.74
Marsh gas	61.49
Nitrogen	31.44
Oxygen	6.33
	100.00

The Starr deposit, belonging to the same company, is said to have produced five thousand flasks of quicksilver and is of peculiar geological interest. It occurs at the contact between a basalt dike and the sandstone through which the lava has broken. The ore occurs both in the sandstone and in the basalt along the contact. The workings extend to a depth of 400 feet from the surface and the ore is not yet exhausted.

Similar to the last and also on the property of the Ætna Company is the Silver Bow. So far as observed, the ore in this mine is wholly in the decomposed basalt close to its contact with the sandstone. This dike is typical, standing up as a ridge above the inclosing rocks and showing a double columnar structure, one set of columns being transversely arranged, while the other, at the croppings, is nearly vertical. The existence of these superficial vertical columns shows that little erosion can have taken place since the eruption of the rock.

The Ætna property also comprises two other claims: the Washington, containing alluvial deposits of cinnabar as well as native quicksilver along clay seams, and the Pope claim, which contains a deposit of cinnabar in contorted and silicified shales. The Ætna mine is included in a belt composed of serpentine, which can be followed almost without interruption as far as St. Helena Creek, a distance of about seven miles. In this belt croppings of opaline matter, which is largely opalized serpentine, form an almost continuous ledge, with traces of cinnabar at many points. At one point, the No. 2, or Phœnix No. 2, some work has been done. Mr. Luckhardt describes this mine as opened upon a layer of slate three to seven feet in width and carrying seams of ore of six to eight inches in width. The deposit seemed unusually regular, but ore appears not to have been sufficiently abundant to repay exploitation.

All of the deposits mentioned above, as well as the veins of cinnabar belonging to the Napa Consolidated Company, which have been described in a previous chapter, are within three miles of the hot springs at Lidell and within a triangular area measuring less than a square mile. Among them are deposits in unaltered sandstone, in highly metamorphosed strata, and in eruptive rocks. They embrace regular veins, impregnations, and reticulated masses. Three of the deposits show unquestionable connection with very recent volcanic activity, for one of them occurs in basalt, the second is in contact with the same lava, and a very hot mineral spring flows from the third. There is no reason to suppose that different genetic processes have been at work in this small area; on the contrary, there is every reason to suppose that the deposits, embracing all the principal types of occurrence, have been precipitated from waters heated by volcanic action, in a manner similar to that by which the ores of Sulphur Bank and Steamboat Springs have been produced.

The next deposit to the north of the Pope Valley group of mines is the Great Eastern, in Lake County, on St. Helena Creek.[1] This deposit was remarkable for the richness of its ores, but the quantity of quicksilver produced was small and the mine has been abandoned for several years. The specimens obtained from the dumps show that the ore was accompanied by opaline rock and that an oil was present, associated with dolomite. A large amount of unaltered sandstone on the dumps suggests a wall of this rock. Just northeast of this claim, on the opposite side of the creek, is Bradford's Prospect, in which also the cinnabar is associated with opal. Difficult drainage, due to the proximity of the creek, is said to have interfered with the development of this deposit. It is stated that since I visited this locality a shaft has been sunk and that a considerable ore body has been developed.

The next deposit to the northwest is the Great Western, described in detail in the preceding chapter. The district between the Great Western and Pine Mountain has been actively prospected, and many claims have been taken up and again abandoned. It is not possible to get much information about these deposits, none of which has been extensively developed and in none of which extensive ore bodies were found. The Wall Street is on a layer of opaline, metamorphic rock. Glaucophane schists occur in this mine and it was in specimens from this locality that glaucophane was first detected in California. Native quicksilver existed here as well as cinnabar. The American mine was located upon a ledge of indurated strata which form croppings of considerable height. The rock consisted of alternating beds of sandstone, siliceous slate, and partially serpentinized sandstone, and underlying the ore-bearing strata was dense serpentine. The cinnabar sometimes impregnated disintegrated and ocherous material, but was mostly found in seams and bunches in the siliceous rocks. Quicksilver, pyrite, and bitumen accompanied the cinnabar. The deposit appears to have been an impregnated series of strata and the ground must have been charged with ore after the metamorphism of the rock.[2] According to Mr. D. de Cortázar[3] specimens containing selenide of mercury were obtained from this mine.

[1] A more important mine of the same name in Sonoma County has been described in the preceding chapter.

[2] Unpublished report of L. Janin.

[3] British Reports on the Philadelphia International Exposition of 1876, vol. 3.

The Flagstaff is a claim adjoining the Pioneer and very similar to it. The ore-bearing ground is a stratum of argillaceous sandstone impregnated with metallic mercury, which is accompanied by a little cinnabar.[1] Professor Whitney visited the region in 1861, when some of the mines were being worked, and has published the following notes concerning them:[2]

The Cincinnati is on the hill-side near a steep cañon, northeast of Pine Mountain; from it Mt. St. Helena bears S. 32° E., and the mine was estimated to have an altitude of about two thousand five hundred feet. The prevailing rock is serpentine, filled with threads and veinlets of quartz, running through it in every direction, presenting a rather peculiar appearance, as some of the quartz is in a crystallized form. Both cinnabar and native mercury have been found here, but there was little appearance of regularity in the deposit and no large mass of ore had been discovered. * *

The Dead Broke lies about one mile west of the Cincinnati. The rock here consists of alternating layers of dark and light colored and partly decomposed quartzite; the strike is about N. 5° W.–S. 5° E., and their dip, which is to the west, about 45°. On the east side of the ridge imperfect serpentine was seen, and a level had been driven in it for 265 feet. The cinnabar, of which rich specimens had been procured, was contained in a stratum about four inches wide and parallel with the formation.

The Pittsburg claim is one-half a mile N. 15° W. from the Dead Broke, and some cinnabar has been found here in serpentine.

The Pioneer mine, which is south of Mt. Cobb and not far from the Little Geysers, was also visited by Professor Whitney, who says:

The rock most nearly associated with the ore is the same peculiar siliceous variety usually seen at the cinnabar mines of California, and it is inclosed on both sides by serpentine. The strike of the metalliferous lode or vein was nearly northwest and southeast. The metal exists here both in the form of the sulphuret, as cinnabar, and in the native state; indeed, so far as we know, it is one of the most remarkable localities of native mercury ever discovered. The metal occurs disseminated in fine globules through the vein-stone, or in larger quantities in the interior of quartz geodes or pockets. Over six pounds have been saved from a single pocket, and one of the first cavities broken into yielded four pounds three ounces of the metal, besides what was unavoidably lost in collecting. These facts are stated on the authority of Mr. B. C. Wattles, the superintendent. * * * Considerable bituminous matter occurs here, as in most of the other mercury mines of the State, and some of the quartz geodes contain bitumen.

From Pine Flat, in Sonoma County, a definite belt of deposits extends in a direction which is about 25° west of north. It is very noticeable on the sketch map that this belt of deposits occurs at a considerable distance from any volcanic rock, while, on the other hand, it passes within a mile of

[1] Unpublished report by L. Janin. [2] Geol. Survey California, Geology, vol. 1, p. 89.

the group of hot sulphur springs miscalled geysers. Some of these springs reach the boiling-point and emit steam. They are very numerous and active and are regarded as one of the sights of California. Their character is such as is almost universally attributed to volcanic activity. Their presence near the quicksilver mines therefore indicates that the remoteness of the deposits of cinnabar from the nearest lavas does not preclude a relation between volcanic activity and ore deposition. The mines of this group are the Sonoma, the Rattlesnake, the Little Missouri, the Oakland, the Kentucky, and the Cloverdale. The Rattlesnake produced only about sixty-five flasks of quicksilver, but it is a noteworthy fact that this product was obtained almost entirely from native quicksilver disseminated in a friable sandstone. An unusual quantity of oily bitumen accompanied this ore, and it is recorded that there were special arrangements to burn the hydrocarbons because of the quantity of soot which they formed in the condensers.[1] Though most of the ore was an impregnated unindurated sandstone, the usual opaline rock also occurred here and sometimes showed geodes containing oil. The Oakland mine, as stated in the table of production, Chapter I, produced 6,831 flasks, and may perhaps be reopened under favorable circumstances The product of the Cloverdale was 2,661 flasks, but the Kentucky only turned out 54 flasks. Another small mine, beyond the limits of the map, is the Livermore. It lies two miles west of the junction of Pluton Creek and Sulphur Creek.

Oakville and Bella Union.—Small quantities of cinnabar occur in the hills bounding Napa Valley on the west, about half way between Calistoga and Napa City. The principal deposits are on two adjoining claims, the Bella Union and the Oakville. The rock is siliceous slate, associated with serpentine. The slates strike north and south and dip at 60° or 70° westward toward the summit of the range. The ore is exclusively cinnabar, accompanied by pyrite and calcite. It forms seams in the slates and irregular bunches connected by narrow stringers of ore. The Bella Union has produced some metal.[2]

[1] T. Egleston, Trans. Am. Inst. Min. Eng., vol. 3, p. 273.

[2] The information concerning these mines is derived from an unpublished report of Mr. C. A. Luckhardt.

Solano County.—The most southerly of the mines north of the Bay of San Francisco is the St. John's, four miles northeast of Vallejo. It is situated in an isolated ridge of metamorphic rock trending from northwest to southeast and lying in Sulphur Spring Valley. The surrounding region is unaltered. In the metamorphic area also there are portions of little modified rock, and at two points on the ridge Mr. Turner found *Aucella mosquensis*. One of these localities is in the main tunnel of the St. John's mine, and the shales in which the fossils occur seem beyond doubt the same which, at a distance of 150 feet from the fossils, are indurated and contain cinnabar. The second *Aucella* locality is three-quarters of a mile southeast of the mine on the same ridge. At this point the shells occur in calcareous nodules in shale. These fossils of course determine the rocks as belonging to the Neocomian formation.

The ore was found at the croppings and is said to have been discovered as early as 1852. The ore body exposed at the croppings extended downward about four hundred feet and furnished most of the metal which this mine has produced. Much of this ore was inclosed in a white, greatly decomposed rock, which is probably a metamorphosed sediment, further altered by the action of sulphuric acid and other reagents. At one point it crosses the tunnel very like a dike. There is nothing suggesting the presence of eruptive rocks on the surface. According to Mr. Neate, the owner of the property, an open fissure exists in proximity to the main ore body, but the position of this fissure is now inaccessible. Like most of the quicksilver mines, the St. John's carried some bituminous matter. In the western mine workings cinnabar occurs in highly siliceous, apparently chalcedonic rocks, and close by is serpentine, forming a wall to the ore-bearing ground. As appears from the table of production, this mine has yielded 8,598 flasks of metal.

Mt. Diablo.—Cinnabar is found on the eastern slope of the north peak of Mt. Diablo, associated with the usual black opal and chromic iron ore. It is said that some thousands of dollars' worth of the metal was extracted from this locality. In the ravine just below the mine is a sulphur spring, and farther down the slope is another mineral spring which must formerly have been very active, for it has deposited a large quantity of calcareous sinter.

To the south of this spring deposit in a hill of asperite and at the contact between this lava and the unaltered shale Mr. Turner found cinnabar. It is associated with copper pyrites and calcite and in some cases is so intermingled with the latter as to show simultaneous deposition. There seems to be no quartz or opal at this point. This is the third locality in California at which cinnabar is found associated with andesite, and the circumstances are such as to leave little or no doubt that the deposition took place from hot sulphur springs, induced by volcanic action.

Traces of cinnabar.—The discovery of cinnabar at Point Reyes was reported in 1875.[1] There is no improbability in the statement, but I have heard of no confirmation of the report and hesitate to enter it on the map. Professor Whitney states that small quantities of cinnabar and mercury were found in early days near the Mission, in San Francisco, in rocks of the usual type.

Santa Clara County.—Besides the New Almaden, Enriquita, and Guadalupe, which form the subject for Chapter X, a small mine called the San Juan Bautista was worked in former years. It is in the northeastern portion of an isolated range or cluster of hills bearing the same name and is about four miles southeast of San José. The hills are composed of metamorphic rocks, largely serpentine. The ore deposits were irregular, but seemed in a general way to follow the stratification. Mr. Goodyear (loc. cit.) notes the presence of chalcedonic silica and of a hard, dark-gray, granular, crystalline rock, which was probably pseudodiabase. My party has not visited this deposit

Panoche district.—Panoche Pass, which is near the junction of Fresno, Merced, and San Benito Counties, leads from the area drained by the Pájaro River to that drained by the San Joaquin. The divide forms a portion of the somewhat irregular mountain system called by Professor Whitney the Mt. Diablo Range and is composed of rocks identical in character with the central metamorphic mass of Mt. Diablo. There is no reason for supposing these rocks to be of different age from those of Mt. Diablo and Knoxville, and there is considerable evidence that like them they are Neocomian, but no fossils were found in them. The surrounding country con-

[1] Mining and Scientific Press, February 27, 1875.

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tains Miocene sandstones and heavy gravels supposed to be Pliocene. Both of these formations have been greatly disturbed and often stand at high angles. The metamorphic rocks near Panoche Pass contain a number of deposits of quicksilver, some of which have yielded metal.

The Stayton mines was the name given to a group of fourteen prospects, which are remarkable because they contain stibnite in quantities equal to or greater than those of cinnabar. At one time quicksilver was reduced in a retort at this locality and at another the antimony ore was smelted. The mines have not been in operation for some years and little could be seen at the time of my visit, excepting that both minerals occurred in proximity, chiefly with quartz gangue, in siliceous and serpentinized rocks of the usual type. I saw no indications of a large or a regular deposit. The Wonder quicksilver mine was close to the Stayton and is said to have been similar.

About eleven miles west of Panoche post-office, near the main high road, is a prospect called the Cerro Gordo. It is remarkable for the presence of metacinnabarite in the ore, which contains, besides, cinnabar, pyrite, and bitumen, associated with opal and crystalline silica. The inclosing rocks are of the metamorphic series and contain titaniferous magnetite. The material on the dumps seemed to me of a promising character.

The Little Panoche mine is in a cañon at the north end of Little Panoche Valley. The workings were never large and are now for the most part inaccessible. The rock is metamorphic sandstone, highly silicified, but accompanied by only trifling quantities of serpentine. The ore, as shown by the dumps, consisted of cinnabar and pyrite in a quartz gangue, with metamorphic sandstone. I saw no evidence of a defined vein, though the workings may have disclosed something of the sort.

The Cerro Bonito, sometimes called the Panoche Grande, is about three miles by road from Panoche post-office, in the northwestern corner of Fresno County. It lies close to a basalt area of considerable size, the only one of the kind known to me in this part of the country. The mine is in metamorphic sandstone, accompanied by serpentine, and the ore is associated with quartz and calcite. Very little pyrite exists in the dumps and the ore was dull, unpromising-looking material. According to Mr. L. Janin, the ore followed the stratification. The most promising ore-bearing ground was a vein-like formation from two to five feet in width, consisting of earthy decomposed rock, in which occurred threads and bunches of cinnabar. Bowlders, too, were included in the matrix; they were impregnated with cinnabar to a greater or less extent.

San Luis Obispo.—The mines of the San Luis Obispo are on the Santa Lucia Range, which extends from near Monterey southward along the coast. This range is chiefly composed of metamorphic rocks and Miocene beds. The metamorphic rocks are lithologically identical with those farther north and are also of the same age. Five miles from the town of San Luis Obispo, on the road to Santa Margarita, in a patch of comparatively little altered shale inclosed in the metamorphic series, Mr. Turner found an excellent specimen of *Aucella mosquensis*. This is the most southerly locality at which this characteristic fossil of the Knoxville series has been encountered, and it is nearly three hundred miles in a direct line from the Manzanita mine, in Colusa County, where *Aucella* was also found. This interval is equal to three-fifths of the entire length of the Coast Ranges from Ft. Téjon to Shasta City.

There is a considerable extent of Miocene rocks in this region, as well as a volcanic range which trends in a westerly direction and ends, according to Professor Whitney, in the Moro rock off the coast. It seems to consist of asperites. Hot springs are said to exist in abundance in the quicksilver district of San Luis Obispo, and extinct springs, evidently similar to those now active, are stated to occur close to the most productive of the mines, the Oceanic. The hot sulphur springs of Paso Robles are not far from this group of mines.

The Rinconada mine is sunk on a deposit in metamorphic rocks among which is serpentine. These rocks are not distinguishable from those at New Almaden and other more northern districts. The deposit is partly in slaty material, accompanied by black opal, and partly in indurated sandstones. Pyrite, calcite, dolomite, quartz, and organic matter accompany the ore. It is to some extent disseminated, but usually occupies cracks in the rocks, which it often only partially fills. The crevices sometimes cross the beds and sometimes follow them. The deposit has not as yet proved of any commercial value. It is interesting because its general character is so like that of many deposits to the north in mineral association, in structure, and in the age of the inclosing rocks.

Judging from reports of Mr. Janin, the Ocean View, Keystone, Josephine (also called Sunderland and Luckhardt), and other mines seem to have been essentially similar in the mode of their occurrence to the Rinconada and to a great proportion of the other quicksilver deposits of California. The Oceanic was more exceptional, for its deposit consisted of a stratum of unaltered sandstone impregnated with cinnabar. The width of the stratum was several yards and at one time the entire body of rock paid for extraction and reduction. Specimens show that the cinnabar is associated with quartz as a gangue and that stringers of ore and gangue as well as impregnations occurred. A coarse conglomerate, said to form the "casing of the vein," contains metamorphic pebbles, showing that the rock is at least as late as the Chico and probably Miocene, but no fossils are known to have been found in it. There is nothing improbable in the hypothesis that this rock is Tertiary; for it has been shown in this report that in California cinnabar is associated with many rocks, both Pre-Miocene and Post-Miocene, and that it is known to exist in Tertiary strata in other parts of the world. The appearance of one specimen from the Oceanic suggests that the works have struck metamorphic rock beneath the sandstone. The Sulphur Spring claim adjoining the Oceanic on the west yields specimens of rich cinnabar. In the northwest portion of San Luis Obispo County good ore occurs at the Polar Star mine.

Santa Barbara.—The Los Prietos is on the northern flank of the Santa Inez Range, some five miles northerly from the town of Santa Barbara. A belt of quicksilver-bearing rock is said to extend from this point for about six miles on a course south 50° east, or approximately in the direction of the range, and upon it several claims have been located. The occurrence is of the usual kind — seams and bunches of cinnabar in metamorphic rocks, including serpentine and serpentinoid rocks. Specimens also show light-colored limestone with cinnabar. These mines have turned out a small quantity of ore, some of which has been reduced.[1] Hot springs occur at several points along this range of mountains.

[1] This information is derived from Mr. Janin.

Other traces of cinnabar.—The occurrence of traces of quicksilver has been reported a number of times near Lake Elizabeth, in Los Angeles County, and the report is credited by persons whose opinion is entitled to respect. Cinnabar also occurred near San Bernardino. A small deposit is said to have worked out long since, and new discoveries were announced in 1873.[1]

According to Mr. Schmitz, a mine superintendent, gold amalgam was found at many points on the gold belt in early days. He found one occurrence in stringers in "greenstone" five feet below the surface, which was analyzed by Sonnenschein[2] and gave the formula $AuHg^3$. The exact locality is not given.

Three extremely interesting occurrences on the gold belt of California are described by Professor Whitney. One of these is in Mariposa County, on the north bank of the Merced River, near Horseshoe Bend. Here an auriferous quartz vein six inches wide and resembling other such veins in most respects carried on its foot-wall a thin seam of quartz containing cinnabar in crystalline plates and bunches. The seam was about an inch wide and appeared to be continuous.[3]

Mr. C. L. Mast is now the owner of a ledge on the hillside east of the Merced River, near the mouth of Maxwell Creek, not far from Coulterville, which is probably the same vein referred to by Professor Whitney. The country rock is of the kind called by Professor Whitney greenstone and by Professor Wadsworth diabase tufa. The cinnabar occurs in crystals of unusually large size embedded in quartz and accompanied by very little pyrite. This ore was sold to the Chinese between 1850 and 1860. Mr. J. W. C. Maxwell informs me that many years ago extraordinarily well crystallized cinnabar in a quartz gangue used to be brought from the country back of the town of Merced and sold to the Chinese as vermilion at a high price per ounce. This cinnabar may have come from the vein just described or possibly from some similar locality now unknown. In Calaveras County, near Murphy's, a quartz vein assaying well for gold also carried cinnabar in small quantities, according to Professor Whitney, with traces of vitreous copper ore and copper carbonates. The same geologist has also seen speci-

[1] Mining and Scientific Press, vol. 27, 1873, p. 166.
[2] Zeitschr. Deutsch. geol. Gesell., vol. 6, 1854, p. 243.
[3] Geol. Survey California, Geology, vol. 1, p. 230.

mens of gravel from near Placerville, El Dorado County, containing gold and rounded grains of pure cinnabar.[1] This is probably at or near the locality, three miles south of Shingle Springs, from which not only float cinnabar, but a ledge carrying this ore, was reported some years since.[2]

Mr. Turner has visited this locality, which is at Cinnabar City. The deposit is a bedded vein in slates and quartzitic rocks. The cinnabar, accompanied by pyrite, occupies interstitial spaces. A furnace was built here and some quicksilver was produced. According to the county surveyor, Mr. G. W. Kemble, cinnabar also occurs in place in the ravine of Hastings Creek near its mouth and in the ravine of Clark's Creek about one mile from its mouth, the two localities being presumably on the same ledge. Hastings Creek empties into the south fork of the American River from the north about three miles from Coloma. Clark's Creek flows from the south into the same river about four miles northwest of Coloma.

Gold amalgam is reported from British Columbia.[3] Mr. H. G. Hanks has also analyzed arquerite (silver amalgam) from Vital Creek, British Columbia, in latitude 53° north.[4]

The only cinnabar deposit in British Columbia upon which any work has been done is at Kicking Horse Pass (lat. 51° 20′, long. 116° 30′), two and a half miles east of Garden City. It is called the Ebenezer and is described as a vein of calcite flecked with grains of cinnabar. The ore is accompanied by pyrite and contains traces of gold.[5] Dr. G. M. Dawson reports that float cinnabar has been found in the gold washings on the Fraser River, near Boston Bar. Rich specimens containing cinnabar and native metal are said to have come from the west side of the Fraser, near Clinton, and the silver ores from Hope, on the Fraser, are stated to contain mercury. A well defined lode containing rich cinnabar ore is also said to occur on the Homathco River.[6]

Mr. W. H. Dall informs me that in 1865 he saw a large piece of cinnabar in the Colonial Museum at Sitka, Alaska, which was said to have been

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[1] Auriferous Gravels, p. 367.
[2] Mining and Scientific Press, vol. 31, 1875, p. 118.
[3] Geol. Survey Canada, Geol. Canada, 1863, p. 518.
[4] Rept. State mineralogist California, vol. 4, 1884, p. 12.
[5] Ann. Rept. Geol. Survey Canada, 1886, pp. 9 T and 40 D.
[6] Rept. Progress Geol. Survey Canada, 1876–'77, p. 133.

brought in by the Indians from some portion of the Alexander Archipelago. It has since been reported as occurring on the Kuskokwim River. There seems to me no reason to doubt that cinnabar really does occur in Alaska, though more definite information is to be desired.

In the Great Basin quicksilver ores occur at several points besides Steamboat Springs. In Idaho considerable quantities of float cinnabar have been found in Stanley Basin, at the eastern extremity of Boisé County, and along the Salmon River between the mouth of Yankee Fork and the town of Sawtooth, but the ore has not been found in place.[1]

Prof. W. P. Blake wrote in 1867:[2]

> Cinnabar of a beautiful vermilion color is found in Idaho abundantly spread through a gangue of massive compact limestone or marble. No quartz or other minerals are visible in the specimens.

Professor Blake writes me that these specimens were water worn or rounded fragments about the size of one's fist, and he thinks it not improbable that they formed portions of a calcite vein in some other rock. Judging from the frequent occurrence of cinnabar with calcite in fissures in many parts of the world, this also appears to me probable. He cannot recollect ever having been informed as to the precise locality from which the specimens came, and they are most likely therefore to have been found in one or the other of the regions referred to above. Cinnabar, then, so far as known, has never been found in place in Idaho.

Mr. Janin informs me of a very interesting occurrence of cinnabar in the Belmont district, Nevada. Rich seams of nearly pure cinnabar were found here in the Barcelona silver mine, following along the vein of argentiferous ore. Cinnabar has also been reported from Humboldt County and from the southeastern corner of Nevada, but with no details as to occurrence.

In Utah the Lucky Boy claim, Mt. Baldy district, Piute County, contains bunches of tiemannite (mercuric selenide) in limestone.[3] In February, 1887, a mine was at work in the Lucky Boy claim upon a body of this rare ore about four feet in thickness. The ore sometimes contains 70 per cent. of mercury and is said to average 10 per cent. Three retorts were running and producing enough quicksilver to pay expenses. The

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[1] Emmons and Becker, op. cit., p. 55.

[2] Am. Jour. Sci., 2d series, vol. 43, 1867, p. 125.

[3] Emmons and Becker, loc. cit., p. 463.

product for the last quarter of 1886 was 87 flasks. A furnace was being built.[1] This is, I believe, the only case in which tiemannite has ever been mined and reduced on a commercial scale. A body of low-grade cinnabar is said to have been found near this mine. I also learned from Mr. J. E. Clayton, through Mr. D. T. Day, that cinnabar is found in the Camp Floyd district, near Lewiston, in the Oquirrh Range, about sixty miles southwest of Salt Lake City. The ore is said to occur in bunches and seams in calcareous shales of Carboniferous age and to be accompanied by heavy spar. The deposits at this locality can be followed for a mile or more, but the ore is of low grade and has not been worked.

Cinnabar has been reported from New Mexico, but I have seen no definite locality given and no particulars. Many years since, remarkable specimens of ore containing cinnabar with gold, silver, and copper ores were shown in San Francisco, which it was said came from Arizona.

[1] This information was obtained from Mr. F. Cope, general freight agent of the Utah Central Railway.

CHAPTER XIV.

DISCUSSION OF THE ORE DEPOSITS.

Purpose of the chapter.—The various cinnabar deposits of the Pacific slope have many features in common; indeed, it does not appear to me practicable to divide them into two or more groups. Each mine, however, affords special facilities for the study of particular characteristics and comparisons are essential. This chapter will be devoted to comparative descriptions of the deposits and I shall also endeavor to include in it such information with reference to the occurrences as seems likely to be welcome to readers who desire a general knowledge of the quicksilver deposits of the Pacific slope rather than full particulars of any one property. It will include studies of the ores, gangue minerals, and inclosing rocks, a discussion of the place which these ore bodies occupy in the general classification of deposits, and remarks on the relations which they bear to metamorphic areas and to volcanic rocks. The origin of the ores and the manner in which they were dissolved and precipitated will be discussed in separate chapters.

MINERALOGICAL CHARACTER OF THE DEPOSITS.

Ores.—Quicksilver is obtained on the Pacific slope from four minerals, cinnabar, metacinnabarite, native quicksilver, and tiemannite (mercuric selenide). The last occurs in quantity only near Marysville, Piute County, Utah. Reduction works are in operation, and, it is said, at a profit. Cinnabar is the chief ore in the United States, as it is elsewhere, and only a small portion of the metal is obtained from metacinnabarite or in the native state. In the Redington, Reed, and New Idria mines, however, large quantities of metacinnabarite were obtained from the higher levels, but large masses of this ore have not been seen in place during the present investigation. Native quicksilver in small and variable quantities is met in many of the mines. It is naturally oftener found in the lower portions of ore bodies than elsewhere, because of its fluidity and its high specific gravity, just as it permeates the earth far below the foundations of reduction furnaces when special means are not adopted to obviate its percolation. Hence miners do not welcome the appearance of native quicksilver.

Gangue minerals.—Dense masses of cinnabar, of considerable size, are found in most ore bodies, but the larger part of the ore is mingled with gangue minerals. These are few in number and are substantially the same in all the deposits. They are crystalline silica, opal, calcite, and dolomite. Associated with the cinnabar is also invariably pyrite or marcasite (sometimes slightly auriferous): millerite, too, in small quantities is common; and traces of copper as sulphide or carbonate are occasionally seen. Bituminous matter is present in all the mines examined excepting Steamboat Springs. This substance, though sometimes disseminated through ore, is usually found in spots in the country rock. Sulphur occurs at the surface of three of the most recent deposits, and in the Manzanita mine, Colusa County, native gold and cinnabar are mingled. Cinnabar is also met with in some of the gold quartz veins of the gold belt. Pyrargyrite and cinnabar are associated near Calistoga and this ore also contains arsenic and lead. At the Barcelona silver mine in Nevada cinnabar was found. A mixture of cinnabar with gold, silver, and copper ores is reported from Arizona, and at Steamboat the deposits contain gold, silver, lead, copper, and zinc. I know of no other case on the Pacific slope where zinc is found with quicksilver, but this association is not unknown in Europe. The bitumen posepnyte was recognized at the Great Western mine and a new bituminous mineral, christened *napalite*, was found at the Phœnix mine.

Other associated minerals.—Various other minerals have been identified in the mines, less important than the above or less closely associated with the ore. Gypsum is found with ore at Sulphur Bank. Magnesite occurs in the New Almaden, and perhaps elsewhere, with calcitic carbonates. Barite is found with cinnabar in the Oathill, and this is the only case known of the occurrence of barite with cinnabar in California.[1] Apophyllite in fine

[1] An erroneous statement with reference to an occurrence of barite in this State will be explained further along. It is also reported with cinnabar in Utah.

crystals occurs in the New Almaden, though at some distance from ore, in a geode, accompanied by bitumen. Specularite is found in hard crusts with pyrite and cinnabar in the Rinconada and limonite is naturally common near croppings. Melanterite often forms in the drifts of the mines. Copiapite occurs both at Redington and at Sulphur Bank, as was proved both by quantitative analysis and by crystallographic properties. Among the efflorescences in the mines are epsomite from the Redington mine, of which a quantitative analysis was made, ammonia-alum from Sulphur Bank, and borates from the same locality. Pyrolusite is found at the San Carlos and the alta of the New Almaden contains manganese. Morenosite coats one specimen of millerite, and nickel silicates are found at the St. John's and at the Phœnix, but no nickel carbonate has been observed. Stibnite occurred with cinnabar at the Manhattan, the Manzanita, and at the Stayton mines. The red sulphide of antimony, for which I have suggested the name metastibnite, and arsenic sulphides are abundant in the deposits of Steamboat Springs. Chromite is abundant in the serpentine of the Coast Ranges, and hence occurs also near cinnabar, though probably formed long before the ore. In the New Almaden some of the gangue is stained green with chromium silicates. The green stains were tested chemically; under the microscope they appear as greenish, cryptocrystalline grains. Two new hydrated chromium sulphates were found in the Redington mine at the point where solfataric gases issue, and they are doubtless the result of the action of these gases on chromite in the serpentinoid rocks. It is proposed to call the more highly hydrated compound redingtonite and that with less water knoxvillite. It is needless to point out that a considerable number of the minerals enumerated above are products of decomposition processes which have taken place since the original deposition of the ore and gangue.

Microscopical character.—Many thin sections of the ore from different mines have been cut, but under the microscope they give results so uniform that the information thus obtained can be very briefly stated. The cinnabar is transparent only when the section is unusually thin. It is ordinarily only faintly translucent, transmitting dark-red rays, and is much better observed by reflected than transmitted light. As a rule the cinnabar seen in slides forms aggregates with only occasional crystalline outlines, which are usually traces of prismatic faces. A few isolated and well developed crystals have been found showing, in addition to the prismatic faces, terminal rhombohedrons. Cinnabar is often met with in dust-like aggregates disseminated through quartz, and with high powers this dust often resolves itself into beautiful arborescent and capillary forms. In some hand specimens, too, quartz may be seen reddened throughout the mass by disseminated ore. These fibrous forms of the mineral are usually associated with concretionary structure and the ore is often deposited in concentric layers parallel to those of the accompanying quartz or at the centers of geodes. Good crystals visible with the naked eye are very uncommon. Some such occurred in the upper portions of the New Idria mine and were secured for the collection by the courtesy of Mr. J. W. C. Maxwell. These are tabular and present some remarkable characteristics, which will be discussed in a separate paper.

Vast quantities of silica occur with cinnabar at most of the California mines, and a large part of this material consists of mixtures of opal and crystalline silica. Such mixtures have long been known in geological literature as chalcedony, and the term is used in that sense in this volume. Professor Rosenbusch has shown, however, that the fibrous silica crystals so common in these mixtures possess negative double refraction and are distinct from quartz. He calls this mineral simply chalcedony.[1] It seems to me that the adoption of this name for this purpose will lead to much confusion, since chalcedony has been freely employed in literature in the other sense. A very slight modification of the term, however, would obviate this objection and would seem to escape any fresh ones. *Chalcedonite* at once suggests a mineral characteristic of chalcedony, yet not identical with it. So far as I know it has not hitherto been employed in any sense, and I venture to propose it for the anhydrous silica with negative double refraction described by Professor Rosenbusch.

In a great majority of cases the minerals immediately accompanying the cinnabar are quartz and chalcedonite, and no case has been observed in which the cinnabar particles were directly embedded in opal, although the greater part of the area of some slides is occupied by the last-named mineral. Minute cracks in the opal are often filled with crystals of cinna-

[1] Mik. Phys., vol. 1, 1885, p. 345.

bar and of silica, and these indicate that the deposition of opal preceded that of such cinnabar and the accompanying quartz and chalcedonite. The mixture, however, is sufficiently intimate to compel the conclusion that opal deposition cannot have been an independent process, but only an early stage of the same process by which cinnabar was ultimately deposited. It is possible that there may be cases in which cinnabar is directly embedded in opal, though this association is not represented among the slides, and it is certain from field observations that very little of the cinnabar can occur in this way. It seems more probable that the conditions attending the actual crystallization of the cinnabar were also favorable to the crystallization of the silica. Calcite and dolomite, especially the former, are found in a large proportion of the slides. The deposition or formation of more or less dolomitic carbonates appears from the slides to have preceded the deposition of opal, quartz, chalcedonite, and cinnabar in most cases, but in some instances the carbonates fill interstices in chalcedony, showing that carbonates were deposited at distinct periods. Cinnabar is sometimes deposited in direct contact with the carbonates, but occurs in this way much more rarely than in quartz. Field observations also show an irregularity corresponding to that observed under the microscope. In most of the mines silica predominates in some portions and carbonates in others. This variation is not only characteristic of the deep mines, but also of Steamboat Springs, where some areas of the spring deposits are almost pure chalcedony, while others consist largely of carbonates. The intimate association of cinnabar with opal and carbonates is of course sufficient to show that the ore is deposited from solutions.

Inclosing rocks.—The country rock of the cinnabar deposits is of the most varied character, and I am unable to see that, excepting from a mechanical point of view, the rock has exerted any influence on deposition. The oldest rock in which cinnabar occurs is granite, in which the main part of the deposit at Steamboat Springs is found. The ore occurs in every variety of the early Cretaceous rocks, in unaltered sandstones, and also in phthanite, pseudodiabase, pseudodiorite, glaucophane schists, and serpentine. The most important deposits occur in the metamorphosed rocks, but this seems to be due only to their hardness, as will be explained a little later. Chico sandstones not considerably altered contain cinnabar at New Idria. In San Luis Obispo County the ore is found in unaltered sandstones believed to be Miocene; at Sulphur Bank rich ore was found in modern lake beds; the andesite of Clear Lake contained deposits; so, also, does the andesite near Calistoga; and the same association occurs at Mt. Diablo; traces of cinnabar occur in the basalt of Steamboat, and a large part of the best ore of Sulphur Bank was found in this recent lava. On the Ætna property ore is also found in basalt.

Alteration of the rocks.—The rocks adjoining ore deposits have in many cases been greatly modified. Metamorphic rocks often appear to have been converted into or replaced by more or less dolomitic carbonates by the action of solutions. This is inferable both from field and laboratory observations; for, while limestone is extremely rare in the Coast Ranges as a whole, large masses of more or less impure carbonates appear in the mines. This is especially noticeable at New Almaden, where also the concretionary structure of a part of the material shows the foreign origin of the mineral. The metamorphic rocks converted into carbonates are usually stained brown by ferric oxide and ferrous carbonate and retain the general habitus of the associated metamorphic rocks which have not undergone this change; but it is often difficult to determine the exact character of the original material. The metamorphic rocks where they are unaffected by carbonate solutions vary so capriciously that the immediate association of pseudodiabase with carbonated rock does not prove that the latter is an altered form of the former. Under the microscope it is found, too, that the alteration by carbonate solutions so quickly obliterates the character of the rock modified that satisfactory transitions are comparatively rare. Both serpentine and the granular metamorphic rocks seem to be subject to this conversion.

Silicification.—In the third chapter I have referred to a widespread partial silicification of the Coast Ranges, which seems to have formed the latest phase of the Post-Neocomian metamorphism. In connection with the ore deposition there has also been localized silicification, sometimes on a large scale. The products of the two periods of silicification are ordinarily very distinct, though doubtless there are cases in the neighborhood of mines in which it might be impossible to refer the silica with certainty to one or the other period. The Post-Neocomian silicification altered a portion of the shales to jaspery masses or phthanite and formed in these and other rocks innumerable minute veins of quartz. The silicification attendant upon ore deposition at a much later date resulted in the formation of great quantities of opal, accompanied by a small amount of crystalline silica. The opal is usually colored, and, as seen in hand specimens, is often deep black, so that it considerably resembles some varieties of obsidian. It occurs in metamorphosed rocks sometimes as small spots and, again, near ore bodies in large quantities. It is much more frequent in the mines to the north of San Francisco than to the south, though few deposits are unaccompanied by small quantities of this material. I am not aware that it is found anywhere far from known traces of cinnabar and I look upon it as an indication of the probable presence of quicksilver wherever found. Its intimate relation with metalliferous solutions is shown by the fact that it is seldom if ever free from sulphides of iron or nickel, which may sometimes be seen under the microscope when they are macroscopically invisible. The opal is seldom absolutely free from quartz and chalcedonite, and sometimes a small amount of carbonates appears in it. The chalcedonite and quartz microlites in the opal are not infrequently radially arranged, forming globules which dot the entire field. Sometimes a perfect net of minute bands of quartz traverses the opal. This net has, however, nothing to do with serpentine, for, while net structure does not occur among the serpentines of the quicksilver belt, it is manifest under the microscope that this quartz net represents an infiltration into fissured opal. The opal usually carries a few fluid inclusions and microlites of an indeterminable character.

Some of the opal or opaline chalcedony has certainly been deposited in pre-existing openings, but a large part of it must have been deposited by substitution for rocks. This conclusion was drawn from observation in the mines, where the shape of the opaline masses and the manner in which it was mingled with country rock, particularly serpentine, forbade the supposition that it had filled cavities or fissures. Many slides present no evidence of pseudomorphism, being entirely occupied by opal, with trifling admixtures of quartz etc. Others, however, show clear transitions to serpentine and, in particular, distinct remnants of the grate structure so characteristic of the

California serpentine. This structure is also seen to be gradually effaced as the quantity of opal increases. The silica solutions seem clearly to have permeated more or less fractured serpentine, extracting the bases and depositing the opal, the course of decomposition being the same indicated for the silicified serpentine of the Böhmerwald by Schrauf[1] and for the rocks at Bilin by Doelter.[2] Remnants of hornblende have been detected in one of the opals and are probably explained on the supposition that pseudodiorite is subject to replacement by opal. In one case, from the Lake mine, glaucophane rocks have also undergone a similar change, glaucophane and distinct traces of the structure of the schist in which that mineral occurs remaining in a portion of the slide, but gradually passing over into microcrystalline quartz. There is similar evidence that chloritic sandstones have been impregnated with opal, and one such specimen from Knoxville contains perowskite. It forms small cubes of a violet-brown color, which refract light strongly. Twins formed by two cubes united according to the spinel law and one form similar to the pentagonal dodecahedron were also observed. It has been found in the Coast Ranges only in this one specimen, where it formed at the same time as the opal.

HYPOTHESIS OF SUBSTITUTION.

Substitution of ore for rock doubtful.—Almost from the beginning of the investigations described in this volume my attention has been directed to cases of replacement, including those by cinnabar; but I have entirely failed to find any valid evidence that this process has gone on to any considerable extent. On the contrary, careful study of much ore in place and under the microscope seems to show that the cinnabar and the gangue minerals immediately accompanying it have been deposited exclusively in pre-existing openings. These are usually fissures in the rocks, and most large bodies of ore seem to me to consist of crushed rock the interstices of which have been filled with cinnabar, quartz, and carbonates. I have never met with an instance in which the ore masses were bounded by rock the surface of which presented the peculiar pits and corrugations so characteristic of corrosion. Where compact rock is

[1] Tschermak's Mineral. Mittheil., 1873, p. 13.

[2] Zeitsch. für Krys. und Min., Groth, vol. 6, 1881, p. 321.

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in contact with cinnabar the ore does not penetrate it, but forms crusts; and the contact surface preserves the same geometrical character as freshly fractured rock of the same kind presents. Had an active process of replacement gone on, one would expect to find angular masses of ore containing rounded kernels of rock, just as in the partially serpentinized rocks globular masses of sandstone or pseudodiabase are found coated by less regular layers of serpentine. I have never met with cinnabar bearing this relation to serpentine or to other rocks. When the rocks are porous, or practically when they consist of sandstone of loose texture, the ore does, indeed, permeate them and the interstitial space is filled up with cinnabar and quartz; but neither in such specimens nor in the slides does any evidence present itself that replacement has occurred. So far as I know, the case most nearly simulating replacement is the deposit at Steamboat, where the cinnabar is chiefly found disseminated in decomposed granite. But here much of the granite is reduced to a loose, gravelly mass, in which there is no ore, and this material in every respect resembles that in which the ore is found. I can form no other conclusion than that the decomposition and impregnation with cinnabar were independent phenomena. The precipitation of cinnabar took place in the granite only after space was made to receive it, and the deposition of the ore was not a condition of the solution of the granite mass. So, also, in the basalt of Sulphur Bank cinnabar is found partially filling crevices, which have manifestly first been enlarged from mere fissures by sulphuric acid or by other means independent of the precipitation of cinnabar. Were the ore deposited by replacement, there would also be a closer relation than seems to exist between the chemical character of the rock and the richness of the deposits. In the metamorphic series phthanites, pseudodiabase, serpentine, and altered sandstone seem indifferently to limit rich ores, and such ores are also found in contact with basalt. The amount of disturbance (except in the case of porous sandstones), and not the quality of the rock, is approximately proportional to the amount of ore.

The absence of ore in the opal mysterious.—I cannot satisfactorily account for the fact that, while various rocks adjoining ore bodies become silicified, the cinnabar is either absolutely or substantially confined to fissures, in which it is usually associated with quartz. If the solutions which opalized the serpentine contained mercuric sulphide, it seems strange that it should not have crystallized out in the silicified mass from mere relief from pressure and diminution of temperature. Either, then, the silicification was effected before the solutions became charged with mercuric sulphide or the cinnabar was precipitated in the crevices before the solutions made their way into the rock. It seems fairly certain that a large part of the opalization took place before the main deposition of the ore; but, as the solutions at the actual time of ore deposition were certainly siliceous, a portion of the opalization was doubtless contemporaneous with the precipitation of cinnabar, and, although the earlier solutions may have been poor in mercury compared with the later ones, it does not seem to me probable that they were entirely barren at any time. I can only conclude that the cinnabar was separated from the solutions remaining in the fissures when the siliceous fluid permeated the rocks. Some mechanical process, more or less analogous to dialysis, seems to be the only natural explanation of such a separation. There are a number of phenomena in mineral chemistry which seem to require some such hypothesis as this for their adequate explanation; but I am not prepared to offer any positive evidence in favor of it and it is suggested only as a logical possibility.

Pseudomorphism and substitution.—The hypothesis that any ore has been deposited by substitution for country rock is equivalent to the hypothesis that the ore has replaced the mineral constituents of the rock molecule for molecule. The ore minerals must therefore be capable of forming pseudomorphs after such of the component minerals of the rock as are crystalline, and of replacing, without essential change of form, dense masses of these minerals or of components which are not crystalline. When it is known that any mineral, whether an ore or not, forms pseudomorphs after other substances, it is not unreasonable to assert that it may replace rock masses consisting of these substances. Thus talc is known to occur pseudomorphically after a great number of minerals, and to assert that it may replace whole masses of rocks, composed, for example, of pyroxene, dolomite, and quartz, is only to maintain that the physical conditions under which it may form pseudomorphs after all three of these minerals are the same. But when it is asserted that an ore replaces rocks composed of minerals after which the ore is not known to form pseudomorphs the hypothesis of substitution must be very carefully weighed.

Cinnabar is reported to occur as pseudomorphs after several metallic sulphides. At least one of these changes, the replacement of pyrite, appears to require confirmation, but they are of no importance here, since they have no bearing on the theory of the substitution of cinnabar for wall rock. Cinnabar is also known as a fossilizing mineral, indicating that it may replace organic matter. As has been stated in the description of Sulphur Bank, cinnabar is precipitated from solution by ammonia, though not at high temperatures and pressures. It is possible that herein lies the explanation of the fact that, while cinnabar is known to have replaced organisms, the presence of carbonaceous shale or of bituminous substances in the mines, whether of California or Europe, is not commonly of itself any indication of unusually rich or abundant ore. It may be, however, that such substances sometimes have an appreciable effect. "If quicksilver," says de Prado, "exhibits an affinity or, if you choose, a propensity for any other substance, it is for carbonaceous or bituminous matter."[1]

Cinnabar is also said to form pseudomorphs after two non-metallic minerals, dolomite and barite. Dr. E. F. Durand is the only authority cited for the statement that it replaces barite.[2] On reference to his paper it appears that this observer found in the Redington mine a tabular crystal of cinnabar which did not seem to him referable to the rhombohedral system; and he hence inferred that it must be an example of dimorphous cinnabar or a pseudomorph of cinnabar after some other mineral, very likely barite. This is a mere suggestion, and not an assertion. It was unsupported by measurements of angles or other evidence, and barite has never been found in the Redington mine. It is clearly incorrect to cite this crystal as a case of the otherwise unknown pseudomorphism of cinnabar after barite.

Of the pseudomorphism of cinnabar after dolomite also only one case seems to be recorded. It is said to have been reported by Blum[3] in 1863

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[1] Bull. Soc. géologique France, 2d series, vol. 12, 1855, p. 24.

[2] Proc. Cal. Acad. Nat. Sci., vol. 4, 1872, p. 211.

[3] Pseudomorphosen, Appendix III, cited in Allg. und chem. Geol., Roth., vol. 1, 1879, p. 184. This appendix is not at present accessible to me.

on the authority of Krantz as occurring in the Idria mine. Since that time Lipold has written two careful memoirs on the Idria deposit, but he does not refer to these pseudomorphs. On the contrary, he states that in the dolomite rock cinnabar occurs for the most part as mere paints or thin incrustations (zarte Anflüge), and mentions dolomite crystals and cinnabar as of simultaneous deposition from the ore-bearing solutions. In view of these facts and considering that dolomite and cinnabar each show a considerable variety of faces of the rhombohedral system, to which both belong, it appears to me nearly certain that Krantz was in error and that cinnabar has not been observed replacing dolomite

The substitution of a metallic sulphide for a sulphate or a carbonate of an alkaline earth seems strange, but there is no reason to doubt that such transformations occur. While it is extremely doubtful whether cinnabar has ever been found as pseudomorphs after non-metallic, inorganic minerals, there is good evidence that galena has replaced calcite, and probably also dolomite. Sillem found pseudomorphs after calcite at Andreasberg and at Přibram[1] and A. E. Reuss found at Rodnau, in Transylvania, transformations of calcite into a mixture of galena and pyrite.[2] Such replacements have also attracted attention in this country. In 1880 I suggested that there was evidence tending to prove that the lead ores of Eureka, which are galena and its derivatives, had replaced the more or less dolomitic limestone in which the deposits are inclosed.[3] Later Mr. J. S. Curtis made more observations on the same deposits, which seemed conclusive of this substitution,[4] and Mr. S. F. Emmons has shown that the same conclusion is to be drawn with reference to the lead deposits in limestone at Leadville.[5] In case of a real replacement the rock replaced will be represented in the resulting ore bodies only by residual kernels, and where action has been vigorous few such kernels will remain. Both Mr. Curtis and Mr. Emmons call attention to the rarity of calcium carbonate in the lead ores of the respective districts

[1] Neues Jahrbuch für Mineral., 1851, p. 397. Sillem's observations were not called in question by Reuss, as seems to have been supposed (Allg. Geol., Roth, vol. 1, p. 172), for, though the latter did not observe this change at Přibram, in speaking of the Rodnau occurrence he mentions the replacement as "already proved elsewhere," and he can have referred only to Sillem's observations.

[2] Sitzungsber. k. Akad. Wiss., Wien, vol. 10, 1853, p. 67.

[3] First Ann. Rept. U. S. Geol. Survey, 1880, p. 38.

[4] Silver-Lead Deposits of Eureka, Nevada, Mon. U. S. Geol. Survey No. 7, 1884, p. 104.

[5] Geology and Mining Industry of Leadville, Colorado, Mon. U. S. Geol. Survey No. 12, 1886, passim.

which they investigated. Had they been deceived as to the process of deposition and were the ores in reality deposited in interstitial spaces in the limestone or from solutions carrying large quantities of carbonates of calcium and magnesium, these would have been abundant in the ore.

Alleged cases of substitution.—The theory that cinnabar has been deposited by substitution for rock has often been maintained. So far as I know it was first suggested by de Prado, who believed that in the Almaden mine cinnabar had replaced a portion of the quartzite All the geological observers who have written on this deposit since de Prado have reached or adopted the same opinion, but the only proof given is that some of the impregnations are so rich as to preclude the supposition that cinnabar occupies only interstitial space. This is a statement which can be to some extent tested by computation. Quartz sand, well shaken down, weighs 120 pounds per cubic foot, while solid quartz weighs 165 pounds per cubic foot. The packed sand therefore contains 27 3 per cent. of interstitial space. Were this filled with cinnabar of a specific gravity of 9, the mass would contain almost exactly 56 per cent. by weight of cinnabar, or over 48 per cent. of quicksilver. No very definite idea is presented by "well shaken sand," but it at least represents an accepted experimental result comparable with the conditions to be expected in natural sand beds. Were the sand composed of spherical grains all of the same size and as closely packed as possible, so that every sphere was in contact with twelve others, the mass would contain 26 per cent. of interstitial space,[1] and were this filled with cinnabar the mass would contain nearly 47 per cent. of quicksilver. The richest impregnation which I was able to find in the Almaden mine or at the furnaces contained only 33 per cent. of metal and the average yield of the mine for the past twelve years has been only 9 per cent If one allows 1 per cent. for loss or assumes that the ore really contained 10 per cent., the volume occupied by the cinnabar was only 3.7 per cent., which is less than half of the interstitial space in some indurated sandstones employed for paving streets. The richness of the impregnations is thus certainly not such as to prove that replacement of quartz by cinnabar has

[1] Accurately, as I compute it, $1 - \frac{\pi}{3\sqrt{2}} = 25.95$ per cent.

taken place. Microscopical examinations of the ore are much more conclusive. I have twenty thin sections of the ores, and these show that, excepting in the rare cases in which the cinnabar is deposited with barite, the sulphide has crystallized simultaneously with quartz even in the interstices of the sandstones, themselves almost exclusively composed of quartz Macroscopically, too, it may be seen throughout this mine that veinlets of ore constantly contain quartz as a gangue mineral. This would be impossible were the cinnabar deposited by substitution for quartz, for, evidently, if solution of quartz be a condition of the precipitation of cinnabar, the simultaneous precipitation of the two minerals cannot occur. The two processes are mutually exclusive.

Lipold speaks of the replacement of constituents of the Lagerschiefer of Idria by cinnabar, but he attributes to this reaction only a subordinate part in the formation of the deposit and does not enlarge upon the theory. These slates are carbonaceous and may possibly have had some effect upon precipitation, but I saw no definite evidence of it and Lipold mentions none.

Professor von Groddeck, in his interesting memoir on the new Avala mine in Servia,[1] describes the deposits as consisting of vein-like zones of metamorphosed rocks impregnated with quicksilver ore. The wall rock which has been metamorphosed or altered is chiefly serpentine, and the process is one of silicification accompanied by the formation or deposition of carbonates. Most of the cinnabar occurs in stringers or impregnations which seem later than the silicification, but the silicified serpentine also contains cinnabar, deposited, in von Groddeck's opinion, at the time of the alteration of the serpentine. Though he speaks of the vein matter as pseudomorphic after serpentine and as consisting in part of cinnabar, he does not state explicitly that he regards the cinnabar as pseudomorphic after serpentine. It is evidently conceivable that while silicification of the serpentine was in progress cinnabar should have been deposited by relief of pressure and temperature, as was suggested in a preceding paragraph. Other explanations also seem possible, and I can see in this occurrence no sufficient proof that cinnabar has been substituted for serpentine molecule for molecule.

Professor von Groddeck also describes a specimen from New Almaden. He regards the ore as having replaced serpentine, because it shows the net

[1] See Zeitschr. für Berg-, Hütten- and Salinenwesen, vol. 33, 1885, p. 188.

structure so common in serpentine and from analogy with the Servian ores. The net structure in the California ores, however, is rather an evidence that it did not replace serpentine, because neither at New Almaden nor elsewhere in the Coast Ranges has the net structure been found in the serpentine.[1]

SIMILARITY OF THE DEPOSITS.

All the deposits similarly formed.—Everything seems to point to the hypothesis that all the quicksilver ores of the Pacific slope have been formed in a similar manner. The gangue minerals and their association are not identical at all the mines, but it will be found that the peculiarities offset one another. It is quite true that quicksilver ores the world over are strikingly similar in composition. The same minerals which are found abundantly with cinnabar in California are those most usually associated with it elsewhere. Though other minerals, such as sulphides of lead and copper, are also found with cinnabar both on the Pacific slope and in European mines, they are rare. These facts do not weaken the evidence given by this characteristic association of minerals that the deposits of the Pacific slope have all been formed in the same manner, but rather tend to show that conditions accompanying the genesis of European deposits were similar to those which attended the formation of the quicksilver ores of America.

Comparison of the various localities described in former chapters shows that a substantially complete series of transitions exists from deposits now forming to those in which there is every reason to suppose ore formation ceased long since. This is true both as to the method of genesis indicated and as to the form of the deposits; but it will be convenient to deal first with the former and then with the latter of these topics.

Evidence as to method of genesis.—There can, of course, be no possible doubt as to the manner in which the cinnabar deposits of Steamboat Springs and

[1] In my opinion much caution is necessary in using inferences from net structure. The system of fissures so well known to lithologists as forming in olivine does not appear to be characteristic of that mineral only, but of most substances which possess no distinct cleavage. In the rocks in which partially decomposed olivine is found, it is often the only substance without a pronounced cleavage, and under these circumstances such structure may of course be appealed to with confidence; but, when material is examined which has undergone at least two successive processes of radical alteration, it does not seem to me any longer safe to judge from this structure alone. Indeed, I have met with many very perfect examples of net structure in which it is certain that substances exhibiting it are not derived immediately or remotely from olivine.

Sulphur Bank have been produced. Both of these localities present at the surface very marked peculiarities, which might be thought to divide them sharply from the deep mines, such as New Almaden, and to permit of no inference from one to the other as to the genesis of ore, though, excepting for the occurrence of native sulphur at the active springs, the difference is physical rather than mineralogical. At Steamboat no considerable effort has been made to follow the deposit, none of the excavations, so far as I could learn, being over fifty feet deep. At Sulphur Bank, which is so closely similar to Steamboat Springs, one chimney of ore has been followed down for several hundred feet, and the ore found in the lower workings is entirely indistinguishable in any way from that in the cold, deep mines to the south. It is the same association of cinnabar, quartz, iron sulphides, and carbonates. It contains no free sulphur; it permeates very porous sandstone, but only fills the crevices of dense sandstones and shales, just as is the case at New Idria.

The Manzanita mine, in Colusa County, carries gold as well as cinnabar. The ores of Sulphur Bank and of Steamboat, as well as those of the Baker and Redington mines, are also auriferous. The Manzanita, further, contains a little stibnite (as did the Lake mine at Knoxville), pyrite, quartz, calcite, and considerable quantities of bitumen. The ore is irregularly deposited in the crevices of the rock. Close by issue strong, hot sulphur springs, and the surrounding country shows that similar waters have not long since issued from many other points now dry. Though this deposit has been somewhat eroded, large quantities of free sulphur still remain in portions of it. It thus exhibits the closest analogy to Sulphur Bank, though active springs no longer issue from it. It differs from Sulphur Bank, however, in the fact that no eruptive rock exists in the immediate neighborhood, nor, so far as is known, for a distance of several miles. This is an important peculiarity. Other small quicksilver mines occur within short distances of the Manzanita.

The neighborhood of Ætna Springs, in Napa County, is very instructive. Here within a circle of three miles in diameter lie numerous deposits belonging to the Napa Consolidated and the Ætna Companies. From one of these, the Valley mine, now abandoned, flow the hot sulphur springs used as medicinal baths. Cinnabar was obtained from the opening from which the spring flows. The other claims do not show especially elevated temperatures. At the Starr claim cinnabar occurs at the contact between a dike of basalt and the sandstone wall, the metal being found both in the decomposed lava and in the sedimentary rock. This mine has produced 5,000 flasks of quicksilver and is not exhausted. A second very similar claim is the Silver Bow, in which the greater part of the cinnabar is derived from the decomposed basalt near the sandstone wall. There is no reason to suppose that the eight productive deposits of this small area have been produced by different methods or at essentially different periods, and the association of those mentioned above with hot sulphur springs and basalt is sufficient evidence that the genesis of the deposits was substantially the same as at Sulphur Bank. The minerals associated with cinnabar in the district and the general characteristics of the ore are exactly the same as in the mines to the south of San Francisco.

Hot springs and cinnabar are also closely associated near Calistoga, and the hot sulphur springs, miscalled geysers, in Sonoma County, lie within a short distance of a number of small quicksilver mines. At Knoxville many strong mineral springs are still depositing calcareous sinter, which in some cases contains borax, but the water is no longer hot. In the Redington mine hot sulphurous gases are evolved at certain points and small amounts of crystallized sulphur are being deposited. It is barely possible that in this case some secondary action raises the temperature and induces the evolution of sulphurous and sulphydric acids, but I was unable to detect any sufficient cause for such action or any evidence that it was secondary. The pyrite of this mine does not decompose readily, and the phenomena are confined to a single portion of the mine, as they could scarcely be were this a case of decomposition. Were the heat due to the oxidation of pyrite, the sulphydric acid to the reduction of sulphates by timber, and the sulphurous acid to the decomposition of sulphites or hyposulphites, one would expect to find the phenomena repeated at other large mines, such as New Almaden and New Idria; but they do not occur in those mines. The probabilities are thus all in favor of the supposition that this is a veritable trace of a nearly extinct solfatara. On the Manhattan claim near Knoxville a tunnel was run into the hill under the basalt. At the time of my visit it was inaccessible, but I was assured by the watchman, an old miner, that a dike of the lava was encountered and that at its contact with the inclosing rock cinnabar occurred. Basalt does not elsewhere in this district come in contact with ore, but the Redington, Lake, Manhattan, and Reed mines and a number of prospects showing cinnabar, as well as the mineral springs, are grouped around the edges of the basalt area. Considering the occurrences near Knoxville in the light of the facts developed near the Ætna Springs and at Sulphur Bank, there appears to me to be no doubt whatever that all three localities have been charged with cinnabar in the same manner.

No two mines on the quicksilver belt possess a stronger similarity than the New Idria and the Redington. Each is close to the contact between a very large metamorphic area and unaltered rocks; each carried large quantities of metacinnabarite; each was very irregular in structure on the upper levels and developed well defined fissures below, and there is no difference in the association of minerals in the two mines. At New Idria, however, there are no direct means of determining the method of genesis. No sulphurous gases or hot water now enter the mines, and the nearest known basaltic area is 10 miles away. At the Manzanita also no eruptive rocks are found, though there is abundant evidence of the action of hot springs. There is nothing whatever to justify the supposition that the deposits of New Idria are due to different causes than those which led to the formation of ores at Knoxville and other localities north of San Francisco.

The New Almaden, Enriquita, and Guadalupe mines lie nearly in a straight line, along which quicksilver has been found at numerous points. No hot gases or water are found in the mines, but nearly parallel with them and at an average distance of about a mile is a rhyolite dike, which has been followed for several miles. This association of course suggests that heated waters of the volcanic type must at some time have reached the surface in the neighborhood, and probably along the line of the deposits.

The relations described in the foregoing paragraphs appear sufficient to establish the facts that no grounds exist for supposing the various cinnabar deposits to have been formed by different methods and that a considerable number of them are due to the action of hot sulphur springs. In the succeeding chapters other grounds will be stated for attributing all of them to this cause.

Partial absence of sinters.—Even if the ores of the Redington, New Almaden, and New Idria mines were not deposited from hot springs, like those of Sulphur Bank, the structure, as will be seen below, would lead to the conclusion that their present croppings were not far distant from the surface of the country at the time of their formation. No spring deposits, however, were found at the croppings, and the dissemination of cinnabar in the superficial soil at the first two localities shows that a certain amount of erosion has taken place. In this connection it is worth observing that the springs of Sulphur Bank have made practically no accumulation of material at the surface. They have indeed deposited sulphur, but they have also extracted a large amount of material from the basalt. Perhaps this is due to the sulphuric acid formed by oxidation of the hydrogen sulphide. This acid must convert the carbonates into soluble sulphates and precipitate the silica as particles which are carried off in suspension. Were the water to cease flowing and erosion to supervene, the disintegrated basalt and the sulphur overlying the cinnabar would quickly be swept away and no trace of surface action would be left. At Steamboat Springs, also, it is remarkable that, where the cinnabar is known to be tolerably abundant, there is no superficial layer of sinter. On the contrary, a basin has formed, seemingly by the collapse of the disintegrated granite. The deposits of calcareous and siliceous sinter are associated with the more recent springs, which carry but little quicksilver and do not form enough sulphuric acid to remove the lime. The lack of superficial sinters and native sulphur at New Almaden and other mines is therefore no indication that they were not deposited from hot springs.

Evidence from the mode of occurrence.—If the series of quicksilver deposits the genesis of which is discussed in the foregoing pages be considered from the point of view of the form and structure of the ore bodies, nothing inconsistent with asserted community of origin will be found; on the contrary, they form as perfect a series of transitions from a geometrical as from a chemical standpoint. That a close connection exists between the deposition of gold and that of quicksilver is certain, and it is more than probable that other ores sometimes form in large quantities under similar conditions; but no deposits in any part of the world offer such opportunities for the study of the real manner of deposition as those discussed in this memoir. They therefore constitute an exceedingly important example, and the question whether the quicksilver deposits of the Pacific slope include true veins of cinnabar is consequently one of great and general interest.

That fissure systems must underlie hot springs such as those of Steamboat and Sulphur Bank is evident, since otherwise the waters could not reach the surface. Some geologists, however, are of the opinion that hot springs deposit the minerals which they carry in solution only at their orifices, and not in the fissure systems which lead to the surface. So far as quicksilver and the accompanying characteristic minerals are concerned, deposition is not actually or substantially limited to the surface, as is shown conclusively by Sulphur Bank, where ore has deposited abundantly at considerable depths from ascending currents of water which are still intensely hot. This ore, too, as was pointed out above, is of precisely the same character as that met in other mines a thousand or more feet from the surface. The deposit of the deep mine at Sulphur Bank, however, is not a vein, though here and there stringers of ore were found which differed in no respect from small veins. Indeed, since, as was shown in the earlier portion of this chapter, the cinnabar is deposited in pre-existing openings, the form which the deposit takes is determined by that of the fissure system. Whether in a particular case a deposit assumes the form of a vein, an irregular body (stock), or a reticulated mass (stockwork) does not depend upon the direction or the temperature of the currents of the solution, but upon the character of the fissure system. This system, again, owes its character to the physical properties of the rock and the dynamical influences to which it has been subjected.

While in nearly all the quicksilver mines of the Pacific slope the portions of the deposits at short distances from the surface closely resembled the lower part of that at Sulphur Bank, say from the first level downward, several of the mines have exhibited a much more regular structure in the deeper workings than has been detected at Sulphur Bank. I have endeavored to discuss each of them without departing from recognized standards of description, but I have pointed out the inadequacy of the familiar terminology to express the relations of these deposits succinctly and clearly. Merely formal classification is of little value, but, since exhaustive descriptions of structure and form cannot be given on every occasion, deposits must in some way be referred to recognized types; and, unless such references are generally understood in the same sense, statements involving them will necessarily fail to convey the meaning intended. I am certain that the term vein as used by miners and geologists embraces types of structure which, though closely allied, differ greatly from one another, and I have found that many of the discussions which constantly arise as to whether a particular deposit is or is not a vein and as to the limits of veins owe their origin to the ambiguity of this term. My opinion as to the nature of the quicksilver deposits of the Pacific Slope will perhaps be more readily intelligible if a few paragraphs are devoted to the discussion of this subject.

NATURE AND NOMENCLATURE OF VEINS.

Fissures and cavities.—Excepting when ores are deposited in beds, like coal, or in placers, like gold gravels, the existence of open subterranean spaces of greater or less size is a necessary condition for the formation of ore bodies of any kind. The ore may be deposited in openings which existed before deposition began and which either were cracks between masses of rock broken asunder or were interstices in porous rock, like sandstone. Room for the ore may also be made by solution of the rock mass either before ore deposition or during that process. It is a mistake, however, to suppose that the masses stoped out in the exploitation of mines usually represent spaces which were empty before the deposition of ore in them. It is said that cases occur in which open caves in limestone have been filled with ore, but cavities of this kind appear to be confined to limestone and to have formed only above the water level of the district by the solvent action of surface waters charged with carbonic acid. Ore deposits, however, are by no means confined to limestones and are more often found in rocks of this class which have never been drained than in those which have been exposed under the conditions needful for the formation of caverns. It is also conceivable that yawning fissures should form in the earth's crust and that these should be filled up solely with ore and gangue minerals; but such cases, if they exist, are exceptional. All observations and theory point to the conclusion that most fissures are formed under a compressive stress of greater or less violence or that a tendency to compress the rocks into folds gives rise to fissures and faults when the applied force exceeds the tenacity of the rocks. It is also well known that in faulting the hanging wall commonly sinks relatively to the foot-wall. Fissures formed under such conditions cannot yawn. The walls must come together at intervals and the intervening spaces must be filled to a greater or less extent with the fragments of wall rock. Observation shows that veins very usually answer to this description and that the space really occupied by ore corresponds in great part to the interstices between fragments of wall rock which loosely filled the fissure before the ore was deposited. This is observed with particular frequency in large veins, while small ones are comparatively free from rock fragments. Irregular ore bodies connected with fissures still more often represent masses of rock fragments rather than caverns.

In some cases irregular chambers connected with fissures are solidly filled with ore and gangue minerals. Such bodies are found in limestones under conditions which preclude the supposition that they represent preexisting caverns, and they are usually accompanied by evidences of substitution of ore for carbonate of lime. The deposits of Eureka and of Leadville are of this type. In these cases broken rock seems originally to have filled the spaces in question, much as stopes in mines are often filled with rock by miners to prevent their collapse after the removal of the ore. Solutions of ore finding access to these spaces through the main fissures have come in contact with very extensive surfaces of limestone. The limestone has been dissolved and ore has replaced the rock molecule for molecule. Whether similar substitution occurs in other rocks than limestone and with other ores than those of lead has not been sufficiently investigated.

Fissures in the earth's mass would extend indefinitely both laterally and vertically if the rocks possessed neither plasticity nor elasticity. No rocks, however, are devoid of either of these properties. It is well known, accordingly, that fissures are not of indefinite length. They sometimes pass over into folds, as several geologists have pointed out; and even in granite areas dikes of eruptive rock may sometimes be observed which diminish gradually in width to a fine edge and disappear. There is every probability that fissures also die out in depth in a similar manner, though where considerable faults have occurred the depth of a fissure must be very great. Many fissures certainly penetrate from the surface of the earth to the foci of volcanic activity, a depth probably at least equal to that at which earthquake shocks originate, or several miles from the surface.

Simple veins, parallel veins, and linked veins.—When the term fissure vein is used without any qualification, it brings to mind a very simple and common form of deposit: a fissure with well defined walls usually nearly straight or curving gradually and including vein matter which is commonly composed of ore, gangue, and fragmentary masses of country rock. A vertical section of such a vein is shown below (see Fig. 20 *a*). It appears to me very desirable not only to call a deposit of this kind a simple fissure vein, but to limit the application of this term to deposits of this kind. It is not difficult to find natural designations for allied but less regular deposits.

Where the formation of a fissure is accompanied by a strong compressive stress groups of parallel fissures form, often passing over into a common fold at each end. The dislocation is then distributed over a number of parallel surfaces instead of a single surface, and this distribution takes place according to a definite law, which I have examined on other occasions.[1] In some cases such fissures form with great regularity and are distinct from one another as far as they can be traced. If ore-bearing solutions enter such ground, they deposit distinct, parallel veins. Such deposits are naturally described as groups of parallel veins.

In many cases a tendency to the formation of groups of parallel fissures is obstructed, perhaps by irregularities in the tenacity of the rock or by the action of complex forces. In such instances approximately parallel fissures form, which die out in the direction of their strike, being replaced by others to one side or the other. More or less diagonal stringers must then exist, connecting the principal crevices. Sometimes fissures of this

[1] Geology of the Comstock Lode Chapter IV; Impact, friction, and faulting: Am. Jour. Sci., 3d series, vol. 30, 1885.

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kind run together and separate again, without, however, diverging at any high angle.[1] Plans of such groups of veins are shown in Fig. 19.

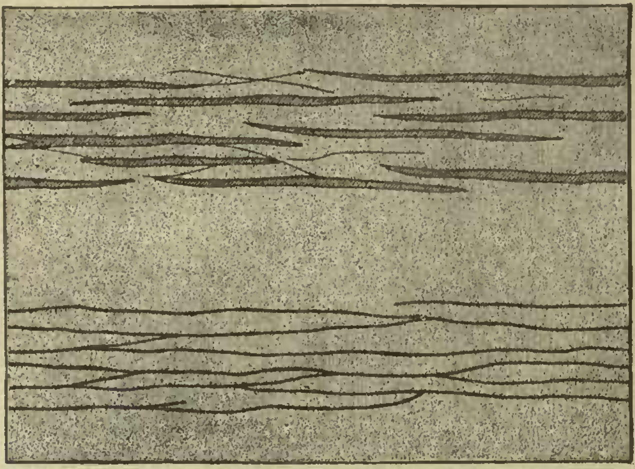

FIG. 19. Linked veins; horizontal section.

In all cases these veins are linked together by direct continuations of divergent strike or by small stringers intersecting the layers of rock which intervene between them. It appears to me convenient and natural to call such systems *linked veins*, to distinguish them from simple fissure veins and parallel systems of veins on the one hand and from netted (or reticulated) veins on the other.

There are still other less usual groupings of veins which do not need to be christened. No one would hesitate to speak of a system of veins which radiated from a central point as radiating veins or of a vein which sends off numerous stringers into the country rock as a branching vein, and such descriptive terms are clear and precise.

Chambered veins.—A slight degree of irregularity in the tenacity of the rocks or in the character of the rupturing force suffices to produce linked fissures instead of groups of parallel fissures. Greater variations in the rock or a torsional stress accompanying the dislocation will result in crushing portions of the country rock adjacent to the main fissure. This crush-

[1] Either a group of veins occupying fissures of this description or a system of parallel veins is called in German a Gangzug, but this word, though short and expressive, has no English equivalent and is not readily translated by any concise term. It means a procession or a flight of veins. It might be possible to introduce the term a *school* of veins, as we speak of a school of fish, but the metaphor does not seem particularly worth preserving.

ing will not as a rule be confined to a simple zone parallel with the fissure, but will reduce only occasional masses of rock along the fissure to fragments. When in such cases ore and gangue minerals are subsequently precipitated, the deposit will be confined to the main fissure where the adjoining country is unbroken, but it will spread into the neighboring rock where crushing has occurred, the excrescent ore bodies being nevertheless merely lateral extensions of the filling of the fissures. Miners then usually call the entire occurrence a fissure vein, and with no little reason, since the whole deposit is so evidently and closely dependent upon the existence of a fissure. In some of the simpler cases of this kind even formalists will grant the applicability of such a term as irregular vein or vein with irregular walls. "Pipe vein" has also sometimes been used to express structure of this kind, but this term has been employed in such various senses as to be objectionable. When the irregularity of the deposits is great, it has been usual for mining engineers and geologists to describe rather than to name them, to speak of stockworks and impregnations connected with veins, and the like. It does not seem expedient, however, to designate ore bodies so very closely related by different names unless the connection is also expressed by some appropriate term. The connection existing between the various portions of a deposit is at least as important as the form of the various parts, and, if miners err in giving a wrong impression as to form, the usual nomenclature of mining geologists ignores the close interdependence recognized in the language of the miners.

FIG. 20. Simple fissure vein and chambered vein.

The form of deposit under discussion is illustrated in the above diagram (Fig. 20 *b*).

It seems to me that deposits of this description may conveniently be called *chambered veins* and that the irregular, excrescent bodies of ore of such deposits may fitly be denominated *vein chambers*. I propose these terms to express the external form only and to embrace irregular ore bodies contiguous with a fissure, whether they consist of reticulated masses, of impregnations, or ore deposited by substitution. A chambered vein may then be defined as a deposit consisting of an ore-bearing fissure and of ore bodies contiguous with the fissure which extend into the country rock. The term is intended for use in contradistinction to the term fissure vein, or, more explicitly, simple fissure vein, which is thus restricted to those cases in which the occurrence of ore is limited to a single defined fissure. Transitions between the two forms are not infrequent, and such occurrences may be referred to conveniently as veins which are to some extent chambered or which show a tendency to chambering.[1]

Cap chambers.—In granites and gneisses it is not infrequently the case that simple fissure veins are found which from the cropping downward are very regular. I doubt, however, whether, if in these cases the surface still remained as it existed at the time when the fissure was formed, the superior portion of the deposits would be found to possess an equal degree of regularity. When a fissure is formed a fault almost or quite invariably accompanies it, for it is a force tending to elevate one portion of a region above another which usually produces the fissure. When a fault takes place, it is well known that the hanging country is commonly depressed relatively to the foot-wall and a projecting edge of the hanging ground must then press and scrape against the foot-wall. This wedge-like mass, not being supported at the surface by overlying rock, is greatly exposed to fracture, and will generally be more or less fissured, even when it is composed of firm material, such as granite. If ore deposition follows from solutions which reach the upper part of such a fissure, the irregular cracks in the lip of the hanging country will fill with vein matter and the simple vein will be surmounted by a chamber or a series of chambers close to the surface.

[1] "Chambered veins" seems to be as natural and as appropriate a term as the familiar "chambered shell;" indeed, the analogy between them is a close one, for the siphuncle which passes through the chambers of the nautilus and of other tetrabranchiata answers to the fissure of a chambered vein.

If a country be composed of rock of feeble and variable tenacity, the tendency of the ground near the surface to break up into irregular fragments will be much greater than where the country is firm and homogeneous, and the formation of chambers of ore close to the original surface is the more to be expected. The ore bodies which were found near the croppings of the Comstock Lode were of this description, and so are most of the more superficial cinnabar deposits of California.

I propose for these irregular bodies found at the croppings of veins the name *cap chambers*, to distinguish them from the lateral ore bodies of chambered veins. The term vein chamber then includes cap chambers as well as lateral chambers.

So far as we know anything of the mechanical conditions of ore deposition, it appears from the foregoing paragraphs that many deposits which now appear as simple fissure veins must once have included cap chambers, and must consequently have come under the definition which I have proposed of a chambered vein. The cap chambers in these cases must have been removed by erosion. Where ore deposition has continued until all available crevices were filled, as has sometimes but not always been the case, it is evident that cap chambers will contain a comparatively large amount of ore, often more than will be found within an equal vertical interval far from the surface, where the fissure system is more simple. Such was the case, for example, on the Comstock lode. Such also may have been the case on the gold belt of California, and the immense amount of auriferous gravel would then not represent the erosion of contracted quartz veins, such as are now being mined, but of the cap chambers of the veins. This hypothesis greatly reduces the amount of general erosion which the existence of these gravels would imply.

The terms simple fissure vein, group of parallel veins, linked veins, and chambered veins probably include nearly all species of deposits excepting sedimentary beds and placers. It is of course easy to imagine irregular bodies of ore unconnected with any fissure system, but it is doubtful whether such really occur in nature. If these terms should be adopted, the names impregnation, stockwork, pocket, etc. would be understood to refer only to the structural character of specific portions of deposits, and not to the form of any deposits as a whole.

Formation of fissures at great depths.—While it appears that even veins in firm, homogeneous rock must tend to irregularity near the original surface as it existed when the fissure formed, it is evident that at great depths fissures in irregular and weak rocks, such as those which form the greater part of the Coast Ranges, must tend to regularity and simplicity; for at great depths the walls of a fissure are so supported by the overlying masses that even if the country is composed of discrete fragments these will be held in place very much as if the material were continuous. Hence, at considerable depths distinct fissures are to be looked for even in the quicksilver mines; but it is evident that the mutual support of fragmentary rocks will act only so long as the fissures are very narrow. If considerable openings form, such as are suitable for the deposition of ore in large masses, irregular reticulated vein chambers will result in such material at any depth. In such rock as I have seen in the quicksilver mines of California, wide, simple fissure veins are not to be expected at any level and irregular chambers are not so likely to be met with at great depths as at small ones, though they may occasionally be found at any distance from the surface.

Fissure systems at the various mines.—Since fissure systems are almost necessarily more simple at considerable depths than near the surface, there is, a priori, a strong probability that veins underlie Sulphur Bank and Steamboat Springs. As to the extent of such probable veins one can now judge only from the amount of water which seems to have issued from them, and this is but a poor guide. They might or might not repay the expense of the explorations necessary to discover them. At Steamboat the springs rise in lines approximately parallel to the trend of the Sierra, and this is also the probable direction of the underlying fissures. At Sulphur Bank there is no certain indication of a prevailing strike, the local structure being very complex.

What seem inevitable conclusions from these very simple principles at these active springs are established certainties at other localities. The Redington mine has been shown in the foregoing discussion to be closely analogous to Sulphur Bank both in the method of genesis indicated and in its structural features. Near the surface lay the irregular bonanza, answering to the lower deposits of Sulphur Bank. A few hundred feet below the surface this cap chamber was connected with a system of three parallel fissures, two of them carrying ore and being in fact well developed and unmistakable chambered veins. Their contents varied in value from point to point, as that of all veins does, but they have yielded large quantities of ore. The third fissure has been proved to exist, but at the one point where it was intersected it carried only pyrite and no ore. In the main mine at New Almaden there exist two parallel fissures separated from each other by but a short distance. Ore is deposited in and near them, so that they are true chambered veins. From the lower levels they ascend on different courses and reach the surface at a considerable distance from each other. A great wedge of country rock is included between them, and fissures attended by ore penetrate this also, forming chambered branches of the main veins. But perhaps the finest and most interesting examples of vein structure are afforded by the group of mines near Ætna hot springs, which issue from one of them, while two others lie at the contact between basalt dikes and the inclosing sedimentary rocks. As was noted above, there is no reason to suppose that this group of adjoining deposits owes its origin to various causes; indeed, the supposition that they did so would be nothing less than extravagant. Here the bodies adjoining and in part penetrating the dikes are unquestionably chambered veins, but still more striking are those in the main workings of the Napa Consolidated mine at Oathill, called the Mercury vein and the Manzanita vein. These occupy nearly parallel fault fissures in nearly horizontal unaltered sandstones. The faulting was accompanied by compressive stress, as is proved by the flexure of the strata in opposite directions near the fissures, and the two principal fissures were doubtless produced at the same time. Parts of these veins are simple fissures filled with vein matter, which does not extend beyond the walls, but at a number of points impregnation of the adjacent sandstone has taken place. As a whole, therefore, these deposits, too, are to be classed as chambered veins. The upper portion of the Phœnix seems to have been a cap chamber, and this is the character of most of the smaller deposits in the State. The Great Eastern and the Great Western are both chambered veins, and no better example of this form of deposit could be given than the Elvan Streak of New Idria.

CONCLUSIONS.

Conclusion as to character of deposits.—The many analogies of the various ore deposits thus point to a common origin of the ores, viz, precipitation in fissures from ascending hot solutions. In the following chapters it will also be shown that the derivation of the ores is inexplicable except upon the supposition that the solutions ascended in a heated state. Portions of many of the deposits can only be described by themselves as simple fissure veins, and the existence of fissures is evident in all of them. The prevailing type of deposit in the deeper mines is the chambered vein, where the chambers are sometimes reticulated masses and sometimes impregnations. The ore often follows the bedding for a certain distance and such portions of the deposits are bedded veins.

Cap chambers are frequent and in many cases contain most of the ore. Stockworks without a known immediate connection with chambered veins have been met in some mines, but these are probably in every case chambered branches of veins. Of all the principal types of ore deposits, substituted masses alone seem to be absent. The quicksilver deposits of the Coast Ranges are on the whole more irregular than the deposits of average ores in other regions. This is due to the heterogeneity of the rocks in which they occur; but irregularities of precisely the same kind are found in veins of other metallic ores the world over and no fundamental distinction exists between deposits of cinnabar and deposits of other metals.

Age of inclosing rocks.—The greater number of the productive mines have extracted their ore from chambers in rocks of Neocomian age. This fact does not seem to be due to any precipitating influence of these rocks, which, when unaltered, are of exactly the same composition as the Tertiary beds. Still less does the association indicate great antiquity for the deposits. The main lines of disturbance in California, as elsewhere, are marked by ranges, and these are for the most part considerably eroded. In consequence, the older strata, where they have once been covered by Post-Neocomian rocks, have been re-exposed along the old axes of compression. Renewed movements always tend to follow the old lines, and thus the fissures and ore deposits, though of comparatively very recent date, are found most abundantly in the earliest sedimentary rocks of the region. The physical character of the rock often seems to influence the deposition of the ore. Cinnabar occurs along faulted surfaces in wholly unaltered Neocomian rocks, but this is rarely the case. Unchanged sandstones and shales are more likely to be distorted than to break, while the metamorphosed rocks are brittle and are intersected by innumerable partially cemented cracks. Adjoining masses of metamorphosed and unaltered rocks will present different amounts of resistance to dislocation, and a tendency to the formation of fissures is most likely to manifest itself near the junction of such areas. Knoxville and New Idria are excellent examples of this fact, which it is worth the while of prospectors to note. Of course it does not debar the formation of fissures in extensive metamorphosed areas.

Relations of deposits to volcanic rocks.—The relation of the quicksilver deposits to volcanic rocks is indirect, yet close. The ore deposition seems to have been immediately dependent upon the existence of hot sulphur springs, which were probably in all cases of volcanic origin. Such springs are most likely to occur at a very moderate distance from lava, but this is no invariable rule, several miles sometimes separating such springs from the nearest volcanic vents. So far as is known, basalt is the lava usually associated with the deposits, but the most important series of deposits in the State seems to have been induced by a rhyolite eruption. Some little deposits of cinnabar exist in andesite, and it is possible they are due to hot springs following the eruption of this rock. Some other deposits are also nearer to andesites than to basalts. I know of no reason to doubt that cinnabar deposits were formed by springs which owed their temperature and composition to volcanic activity of the andesitic period, but I have no unquestionable evidence that this was the case.

Age of the ore deposits.—So far as is known, volcanic activity in the Coast Ranges began in the Pliocene, and the main outbursts of the andesite seem to have closed that period. The age of the cinnabar deposits is, then, limited to Post-Miocene times, and there is little doubt that nearly all the ore has been deposited since the end of the Pliocene.

Future of quicksilver mining.—I cannot say that the future of the quicksilver industry on the Pacific slope seems to me very hopeful. The trouble is not in the lack of cinnabar, but in the mechanical disintegration of the country effected by the Post-Neocomian upheaval. To this are due the great irregularity of the deposits, the dissemination of cinnabar in minute fissures, or as "paints," in the language of miners, and the small average size of the deep-seated veins. Deposits may somewhere be found in firmer or less fissured rock, but there only can strong, simple fissure veins be expected to prevail in depth. Such deposits are exceptional everywhere. In the Almaden district ore is known to occur at over seventy points, but at only one of them was the accumulation great enough to supply the world with mercury for thousands of years. The Santa Barbara, at Huancavelica, too, was one of over forty known deposits in the same district. Systematic and intelligent prospecting is even more needful in mines on the Coast Ranges of California than elsewhere, and the special attention of superintendents should be directed to a study of the fissure system. This will almost invariably be very complex, and can be satisfactorily made out only by daily study as the work progresses. When a large part of the mine is abandoned and closed, it is often impossible to find the key to the true distribution of the fissures and of the ore chambers which accompany them. Helpless groping, discouragement, and often the abandonment of property which probably contains treasures often follow. An increase of geological skill in the management of quicksilver mines would do much to offset the unfortunately capricious distribution of ore. Good civil and mechanical engineering is necessary, but not sufficient, to make the best of a quicksilver mine, nor can occasional assistance supply the place of enlightened daily study of geological structure. There is nothing novel in this warning, nor is there any probability that so trite a piece of common sense will be heeded.

CHAPTER XV.

ON THE SOLUTION AND PRECIPITATION OF CINNABAR AND OTHER ORES.[1]

The waters of Steamboat Springs are now depositing gold, probably in the metallic state; sulphides of arsenic, antimony, and mercury; sulphides or sulphosalts of silver, lead, copper, and zinc; iron oxide and possibly also iron sulphides; and manganese, nickel, and cobalt compounds, with a variety of earthy minerals. The sulphides which are most abundant in the deposits are found in solution in the water itself, while the remaining metallic compounds occur in deposits from springs now active or which have been active within a few years. These springs are thus actually adding to the ore deposit of the locality, which has been worked for quicksilver in former years and would again be exploited were the price of this metal to return to the figure at which it stood a few years since. At Sulphur Bank also ore deposition is still in progress, but under conditions which differ somewhat from those presented at Steamboat Springs. The waters of the two localities are closely analogous. Both contain sodium carbonate, sodium chloride, sulphur in one or more forms, and borax as principal constituents, and both are extremely hot, those at Steamboat Springs in some cases reaching the boiling-point. The water of Sulphur Bank is ammoniacal. In attempting to determine in what forms the ores enumerated can be held in solution in such waters, it is manifestly expedient to begin by studying the simplest possible solutions of the sulphides, and particularly of cinnabar.

Previous investigations.—The solubility of mercuric sulphide in alkaline compounds containing sulphur has long been recognized by experimental and

[1] A digest of this chapter appeared in the Am. Jour. Sci., 3d series, vol. 33, 1887, p. 199.

industrial chemists. This fact is the foundation of the methods of preparation of vermilion in the wet way, first described by G. S. C. Kirchhoff in 1799.[1] In 1829 C. Brunner[2] discovered the double soluble salt HgS, K^2S+5H^2O. Later, Dr. Reinhardt Weber[3] re-examined the properties and formation of this salt, which he found could only exist in the presence of free caustic alkali. In opposition to Professor Stein, Dr. Weber is extremely positive in his statement that mercuric sulphide is entirely insoluble either in the simple sulphides of sodium and potassium or in the sulphydrates of these metals, excepting in the presence of free hydrates. In the light of facts definitely ascertained since this chemist's investigation, so general a statement does not seem to be borne out by his own observations; for he says that if potassic hydrate be added to the sulphydrate the mixture dissolves mercuric sulphide with the greatest ease. Now, excepting when extremely dilute, a mixture of the two alkaline solutions produces potassic protosulphide, K^2S, and, unless more caustic potash was added than would be sufficient to convert all the sulphydrate into the simple sulphide, Dr. Weber's solution was not, as he evidently supposes, a mixture of hydrate and sulphydrate, but of simple sulphide and sulphydrate.

In 1864 Mr. C. T. Barfoed[4] investigated the behavior of mercuric sulphide to sodium sulphides. He, like Dr. Weber, found the metallic sulphide wholly insoluble in the sulphydrate, but soluble in the simple sulphide, and in mixtures of the latter either with the sulphydrate or with the hydrate. He insists that the necessary and sufficient condition for the solubility of mercuric sulphide is the presence of sodic protosulphide.

The assertion is frequently made in chemical writings,[5] in spite of the results obtained by Weber and by Barfoed, that mercuric sulphide is soluble in sodium sulphydrate; but, though Professor Stein and the other chemists who have made this assertion may not have employed fully saturated sulphydrate, as will appear later, none of them can have failed to carry the saturation beyond 50 per cent, and none, therefore, can have dealt with

[1] Allg. Jour. der Chemie, Scherer, vol. 2, p. 290.
[2] Poggendorff, Annalen, vol. 15, p. 593.
[3] Ibid., 4th series, vol. 7, 1856, p. 76.
[4] Jour. prakt. Chemie, vol. 93, 1864, p. 230.
[5] For example, Graham-Otto, fifth edition, part 3, vol. 2, p. 1119.

mixtures containing free hydrate. A probable explanation of this apparent neglect of careful investigations will appear a little further on. In 1876 Mr. M. C. Méhu[1] examined the soluble, crystalline mercury-sodium salt corresponding to Brunner's potassium compound. He found mercuric sulphide insoluble in sodic hydrate or in the simple sulphide of sodium, but highly soluble in mixtures. One part of mercuric sulphide with two parts of the crystallized sulphide of sodium and two parts of a solution of sodic hydrate of specific gravity 1.33 form, he found, a perfect fluid, which absorbs carbonic acid and gradually precipitates at first sodium carbonate containing mercuric sulphide and later crystals of cinnabar.

Alkaline pentasulphides convert amorphous quicksilver sulphide digested with them into cinnabar,[2] and this process implies a certain degree of solubility. Mr. Barfoed, however, found mercuric sulphide insoluble at ordinary pressures in sodium sulphydrate to which sulphur had been added, and the solubility in the pentasulphide is probably slight. The conversion of the black into the red sulphide does not appear to imply more than a mere trace of solubility, for Messrs. H. Sainte-Claire Deville and Debray produced rhombohedral crystals of cinnabar by heating precipitated sulphide with chlorhydric acid to 100° C. in a closed tube.[3] No statement is made in the account of this experiment of any means being employed to produce any great pressure. Mr. S. B. Christy[4] found that at pressures of from 150 to 500 pounds per square inch and temperatures of from 180° to 200° various liquids heated with precipitated mercuric sulphide convert it into vermilion. He experimented with polysulphides of potassium, potassic sulphydrate, acid sodic carbonate charged with sulphydric acid, and a spring water containing acid sodic carbonate which he charged with sulphydric acid. He reached no conclusions as to the state of combination of the mercury in solution. The fact that glass is greatly attacked at high pressures and temperatures by alkaline solutions of course leaves many possibilities open. Prof. R. Wagner[5] has shown that mercuric sulphide is

[1] Russian Jour. of Pharm., reported in Jahresbericht der Chemie, 1876, p. 282.

[2] Gmelin-Krant: Handbuch der Chemie, Anorganische Chemie, vol. 3, p. 756, where many references may be found.

[3] Fouqué and Michel-Lévy: Synthèse des min. et des roches, p. 313.

[4] Am. Jour. Sci., 3d series, vol. 17, 1879, p. 453.

[5] Jour. prakt. Chemie, vol. 98, 1866, p. 23.

soluble in barium sulphide and Professor Roth[1] thinks it probable that calcium sulphide possesses a similar power.

Solubility of HgS in mixtures of Na^2S and NaOH.—A series of experiments was made in my laboratory with a view of testing the relative effect of the quantity of sodium sulphide and sodium hydrate on the quantity of mercuric sulphide which a given mixture of the solvents would take up. It is almost impossible to make experiments of this kind with the same accuracy which can easily be attained in precipitations, because, if one or more drops of either fluid reagent be added to a mass consisting of mercuric sulphide partially dissolved in the menstruum, it is not practicable to say how long a time will elapse before the additional drop will have become saturated. Approximate results are, however, readily obtained, and these appear in the present case to be sufficient.

It was found that, provided a small quantity of free hydrate exists in the mixture, the solubility of mercuric sulphide depends upon the quantity of sodium sulphide in the solution, or, in other words, that, if to a mixture of Na^2S and NaOH more sodic hydrate be added, the solvent power of the mixture is neither increased nor diminished thereby. For example, three solutions, containing, respectively, 0.95, 1.38, and 2.29 grams of sodic hydrate, and each containing almost the same quantity of sodic sulphide (about 0.7 gram), each dissolved the same quantity of mercuric sulphide. A very small quantity only of the hydrate is sufficient to secure to the alkaline sulphide its maximum solvent power over mercuric sulphide. The greater part of the experiments made to test the maximum solubility of HgS in Na^2S in the presence of NaHO shows that the relation of the weights of the two substances is very nearly in the proportion of one molecule of HgS to two molecules of Na^2S. The average of fourteen such experiments gives $1HgS$ to $2.03Na^2S$. From the nature of the experiments a slight excess in the quantity of the solvents employed is to be expected. One experiment was made by mixing mercuric and sodic sulphide in the proportion of two molecules of the latter to one of the former and adding a few drops of caustic soda. A mere trace of the metallic sulphide remained undissolved and

[1] Allg. und chem. Geol., vol. 1, 1879, p. 261.

this completely disappeared on the addition of a single drop of a solution of alkaline sulphide, so that less than one drop completed the solution.

Chemists, of course, regard cases of solution such as that under discussion as due to the genesis of soluble double salts, which are formed according to ordinary laws of composition. The above experiments show that this soluble double salt can be represented only by the formula HgS, $2Na^2S$ and that it is soluble in dilute caustic soda.

The soluble mixture given by Méhu appears to be intended to represent the maximum solubility of mercuric sulphide, for he states that sulphydric acid instantly produces a precipitate in it. As previously stated, it contains two parts of crystallized simple sodic sulphide (Na^2S, $9H^2O$) to one of HgS, which answers to $HgS + 2.07Na^2S$ and is thus, so far as it goes, confirmatory of the above experiments.

Solubility of HgS in Na^2S.—The most carefully prepared solutions of sodium sulphide dissolve mercuric sulphide freely. This statement is directly contrary to that which some of the chemists referred to have made, and it would be a rash one if the evidence to be adduced for it depended simply upon bringing solutions of sodic sulphide into contact with mercuric sulphide, for it is impossible to make certain that there is no trace of free caustic alkali or of sulphydrate in solutions of Na^2S, however closely its analysis may correspond to its theoretical composition. If, however, a solution of sodic hydrate be treated with sulphydric acid, it is gradually converted into sodic sulphydrate and passes through a point at which the only compound present is sodic protosulphide. If mercuric sulphide be dissolved in a mixture of sodic sulphide and sodic hydrate and the clear filtrate treated with hydrogen sulphide, the mercuric sulphide begins to be precipitated when very little free caustic alkali is left, and it is continuously precipitated until the entire amount of sodium present is converted into the sulphydrate. The purest preparations of sodic sulphide (Na^2S) which we have been able to make, dissolve mercuric sulphide less freely than mixtures of sodic sulphide and sodic hydrate, but more freely than mixtures of sodic sulphide and sodic sulphydrate. Different preparations, however, shown by most careful analysis to correspond very accurately to the formula Na^2S, give somewhat different results, possibly indicating a minute variation from absolute purity. It does not seem a priori improbable that the soluble salt when the sodic sulphide is absolutely pure is $HgS, 3Na^2S$, and one of our preparations gave almost exactly this result. It may also be that the mixtures of $HgS, 2Na^2S$ and $HgS, 4Na^2S$ are formed in proportions varying with other conditions than the purity of the sodium sulphide, such as temperature and concentration.

Insolubility of HgS in cold NaHS.—Repeated experiments and analyses undertaken during this investigation have shown that mercuric sulphide is totally insoluble in sodic sulphydrate at ordinary temperatures and that any preparation of this compound which will dissolve a trace of mercuric sulphide can be shown by analysis to fall short of complete saturation. A long time and an enormous quantity of hydrogen sulphide are required to completely saturate even a small amount of caustic soda with sulphur. As already mentioned, both Weber and Barfoed were aware of the insolubility of mercuric sulphide in sodic sulphydrate at ordinary temperatures. It will be seen later that the behavior of these compounds varies with the temperature. If mercuric sulphide be left in contact with cold sodium sulphydrate for twenty-four hours, just a trace of mercury goes into the solution. This is due to the spontaneous loss of hydrogen sulphide which the sulphydrate is well known to undergo.

The absolute want of power of a preparation of sodium sulphydrate to dissolve a trace of mercuric sulphide is perhaps the best known test of its freedom from the alkaline protosulphide. This test does not show the absence of polysulphides, however, for we have frequently found mercuric sulphide totally insoluble in solutions of sodic sulphydrate which possessed a yellow color and which were proved by analysis to contain an excess of sulphur. This corresponds to Barfoed's observation. The occurrence of alkaline polysulphides in nature, excepting near the surface of the earth, seems so improbable that I have undertaken no investigations of the conditions under which they dissolve mercuric sulphide.

Solubility of HgS in mixtures of Na^2S and Na^2S, H^2S.—For the purpose of determining the character of solutions of mercuric sulphide in mixtures of sodium sulphide and sulphydrate, clear solutions of mercuric sulphide in sodium sulphide and sodium hydrate were made, all of the reagents being carefully prepared for the purpose, and sulphureted hydrogen was passed through the solution until a large permanent precipitate of mercuric sulphide had formed The mass was then filtered, and of course the filtrate represented an absolutely saturated solution of mercuric sulphide in a mixture of sodic sulphide and sulphydrate. A portion of this solution was analyzed. The remainder was treated further with hydrogen sulphide, the precipitation being arrested before the separation of mercuric sulphide was complete, and the second filtrate—representing a second saturated solution of the metallic sulphide in a mixture of alkaline sulphide and sulphydrate, but one containing much less mercuric sulphide than the first—was also analyzed.

Two such analyses gave the following results per 100cm^3 of solution:

	A.	B.
	Grams.	*Grams.*
Mercury, Hg	1.4417	0.4076
Sodium, Na	4.7990	4.7790
Sulphur, S	5.9290	6.4220

It will readily be found that each of these analyses corresponds closely to the formula $HgS, 4Na^2S + nNa^2S, H^2S$.[1]

The degree of correspondence can best be seen by supposing all the errors of measuring, weighing, spontaneous decomposition, and of the analytical methods employed to be concentrated in the determination of the sulphur. Had the sulphur found been 5.9848 in A and 6.4102 in B the analyses would correspond accurately to the following:

$$\text{(A)}\ HgS + 4Na^2S + 10.473\ Na^2S, H^2S.$$
$$\text{(B)}\ HgS + 4Na^2S + 37.757\ Na^2S, H^2S.$$

The error here supposed in the sulphur determination of B is less than one-fifth of 1 per cent. of the entire sulphur found, and, considering the quantities actually weighed, it comes within the legitimate inaccuracies of analysis. The error supposed in A is somewhat less than 1 per cent. of the entire sulphur, and, when it is remembered that it really represents the

[1] The mercury is of course saturated with sulphur. The sodium may also be regarded as combined in the form of Na^2S. Deducting the corresponding quantities of sulphur, a remainder is left, which is the sulphur combined with hydrogen in the sulphydrate Na^2S, H^2S.

sum of all the errors of experiment and analysis,[1] the variation is not great.

In another analysis of this solution, devised for the purpose of determining separately the sulphur combined with the hydrogen and that directly united with sodium (an attempt which was only approximately successful), the total sulphur also actually came out somewhat higher than in that cited.

These analyses, which formed the conclusion of a tedious series of experiments, appear to me to show beyond any reasonable doubt that there is a compound HgS, $4Na^2S$ which is soluble in the presence of Na^2S, H^2S and which is decomposed by hydrogen sulphide in the presence of sulphydrate by the reaction HgS, $4Na^2S+4H^2S=HgS+4Na^2S$, H^2S.

Conclusions from the experiments.—It appears from the above that there are at least three double salts of the form HgS, nNa^2S where n may be 1, 2, or 4, and, judging from the analogy of the potassium compounds, there is probably also a compound of this group where n is $\frac{1}{2}$. The possibility of a case in which n is 3 has also been adverted to. Thus mercuric sulphide readily enters into combination with sodic sulphide in various proportions, while all the best known soluble compounds of mercuric sulphide and sodium have the same general formula. The presence of carbonates of the alkalis is also known, especially from Méhu's results, to be compatible with the existence of these compounds. The question therefore arises whether such double sulphides may not exist in natural waters.

Possible existence of Na^2S in natural waters.—This question resolves itself into two. It is to be considered whether sodic sulphide may exist in natural waters as such. In that case such waters must dissolve mercuric sulphide. It is also possible that alkaline monosulphides cannot exist as such in these waters, but that the affinity of the compounds Na^2S and HgS is sufficient to overcome the obstacles to the formation of sodic sulphide and that this compound will form when mercuric sulphide is present. The latter possibility is the more important, but the former is manifestly one of interest to chemical geology.

It seems commonly to be assumed that only the acid carbonate of sodium exists in natural waters. I know of no warrant for this assumption. The

[1] Among other sources of error in working with these compounds is the absorption of carbonic acid and the liberation of H^2S. The solutions never cease to smell of the latter.

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neutral carbonate and the sesquicarbonate are known to crystallize from many natural waters. It is even difficult to produce the acid carbonate free from the neutral salt, and the acid carbonate of commerce, though designed to be pure, invariably contains a considerable amount of the more basic compound. Hot solutions of acid carbonate lose carbonic acid rapidly and cold solutions evaporating in dry air also lose a large part of their acidity, so that the neutral carbonate and carbon dioxide may coexist. In my opinion it is only safe to regard natural waters as in general containing both carbonates.

When hydrogen sulphide is passed through waters containing neutral carbonate at ordinary temperatures the following reaction is known to take place: $Na^2CO^3+H^2S=NaHCO^3+NaHS$; so that, if the solution of the neutral carbonate be moderately strong, a portion of the less soluble acid carbonate is precipitated by hydrogen sulphide. If hydrogen sulphide be passed through the solution until it is only semi-saturated or if a saturated solution be added to a solution of the neutral carbonate, the composition will be $Na^2CO^3+NaHCO^3+NaHS$.

It is evidently conceivable that the neutral carbonate should react upon the sulphydrate, producing sodium sulphide and acid carbonate. This reaction cannot take place under ordinary conditions, however, for the thermal effect of $Na^2CO^3+NaHS=NaHCO^3+Na^2S$ is negative. It does not follow that this reaction may not take place at temperatures approaching 100°. Indeed, in connection with the known facts as to the solubility and hydration of sodium carbonate at different temperatures, it is a consequence of a somewhat complex train of reasoning on the thermal effects of the formation of the compounds involved that the following reaction must give a positive thermal effect when the temperature exceeds 80°:

$$2Na^2CO^3+2NaHCO^3+2NaHS=2NaHCO^3,$$
$$Na^2CO^3+NaHCO^3+NaHS+Na^2S.$$

If this reaction actually takes place, a mixture of the two carbonates with the sulphydrate, raised to a temperature of above 80°, yields a portion of the simple sulphide of sodium. This appears to give a greater thermal effect than any other reaction which can be devised between the ingredients. It does not of necessity follow that it takes place; for the salts may possibly present unknown resistances to combination similar to the resistance which prevents the combination of free hydrogen and oxygen at low temperatures. There is, however, nothing to indicate such anomalous resistances, and in any event the considerations adduced demonstrate a tendency to the formation of sodium sulphide. On the other hand, though many efforts have been made, neither Dr. Melville nor I have succeeded in devising an experimental method proving the presence of sodic sulphide, as such, in solutions of this kind. If it does exist, of course mercuric sulphide must immediately dissolve in the solution without the evolution of gas.

The theoretical results given in the last paragraph were worked out before a single one of the experiments described in this chapter was made, and, in fact, formed the basis of the entire investigation. When the attempt was made to dissolve mercuric sulphide in the mixture at the temperature indicated, in open vessels, it was found to go into solution without evolution of gas, thus behaving as if free sodic sulphide were present. This, however, in view of the facts afterwards ascertained, does not prove the actual presence of free sodic sulphide.

Formation of Na^2S in the presence of HgS.—When, in addition to the tendency towards formation of sodic sulphide discussed above, the affinity of mercuric sulphide for this compound is brought into play, it can be proved experimentally that sodic sulphide is formed. We found that at a temperature of about 90° a mixture of the two carbonates and the sulphydrate dissolves mercuric sulphide freely without a sensible evolution of gas. If the solvent does not contain sodic sulphide, it must contain the sulphydrate. Hence it becomes important to ascertain the behavior of mercuric sulphide to sodium sulphydrate at moderately elevated temperatures.

While sodic sulphydrate will not dissolve a trace of mercuric sulphide at ordinary temperatures, if mercuric sulphide be added to a solution of sodium sulphydrate which stands upon the water-bath, hydrogen sulphide is evolved and mercuric sulphide goes into solution. The fact that hydrogen sulphide is evolved demonstrates that sodic protosulphide must be formed. Cooling does not reprecipitate the mercuric sulphide, and the compound dissolved is therefore of the form HgS, nNa^2S. Though the solubility of mercuric sulphide in warm solutions of the alkaline sulphydrates at ordinary pressures has, so far as I know, never been explicitly stated, I have no doubt that chemists have observed it, and that, in consequence of this observation, the general statement of the solubility of mercuric sulphide in alkaline sulphydrates has remained in chemical literature in spite of the observations of Weber and Barfoed. The preparation in which I originally observed this important reaction was one from which mercury had already been removed by precipitation with hydrosulphuric acid. The experiment was afterwards repeated by Dr. Melville with several preparations of sulphydrate which had been accurately analyzed and had been tested in numerous ways.

Now, in a mixture of the carbonates and sulphides at the temperature of the water-bath, either sodic sulphide or sulphydrate is present, or, more probably, they coexist. If, then, mercuric sulphide be added to such a solution, either sodic sulphide combines directly with mercuric sulphide or sodic sulphydrate is decomposed by mercuric sulphide, setting free hydrogen sulphide, which must be immediately absorbed by sodium monocarbonate. Hence, in any case the salt dissolved in the solvent must be of the form HgS, nNa^{2}S.

Effects of dilution.—Laboratory experiments are usually made with solutions which are more concentrated than those found in nature. Hence the effect of dilutions on solutions of HgS, nNa^{2}S is important. Whether mercuric sulphide be dissolved in a mixture of sodium protosulphide and sodium hydrate or of the former and sulphydrate, dilution with cold water precipitates mercuric sulphide. The process is gradual, yet progresses in stages. Thus a mixture of solutions of sodic sulphide and sodic hydrate of a volume of 3.9cm^3 was nearly saturated with mercuric sulphide. The mixture was represented by the formula $HgS+2.04Na^2S+1.38NaHO+aq$ and contained 0.3349 gram of mercuric sulphide. Supposing no change of volume to have taken place, this is equivalent to 86 grams of mercuric sulphide per liter. On dilution no precipitate was observable until 25cm^3 of water had been added, or until the contents were reduced to 11.6 grams of mercuric sulphide per liter. Precipitation appeared to continue until about 100cm^3 of water had been added. There then remained in solution 0.0753 gram by weight, or 0.724 gram per liter. The filtrate remained clear until enough water had been added to reduce the strength of the solution to 0.29 gram per liter. Then the liquid began to grow darker and the color deepened, until the entire quantity of sulphide present was about 0.12 gram per liter. The precipitated material was so finely divided that it would not settle and could not be filtered out, and it was therefore impossible to say where, if at all, the precipitating effect of water ceases. Similar experiments yielding analogous but not numerically identical results were made with other solutions.

The cause of this precipitation is clear. It is known through the investigation of Messrs. Kolbe, Thomsen, and others that, while in moderately concentrated solutions $NaHS + NaHO = Na^2S + H^2O$, this reaction is partially reversed on dilution, or that in the presence of much water sodic sulphide is decomposed by water, the proportion of the sulphide undergoing this decomposition increasing gradually with the dilution. It is evident that the decomposition of HgS, nNa^2S is effected in the same way, more and more of the protosulphide in combination being converted into the sulphydrate as the dilution increases, probably without any limit. Since mercuric sulphide decomposes hot sodic sulphydrate, the effect of dilution in hot solvents will evidently be less than in cold ones.

Brunner found that dilution of solutions of such a salt precipitated a black mass, in which, on examination with the lens, minute globules of mercury were visible. The quantity of mercury was extremely small, so that the precipitate, on analysis, corresponded very closely indeed to the composition expressed by the formula HgS. Gmelin-Kraut[1] appear to have some independent confirmatory evidence on this point. If metallic mercury be precipitated in diluted solutions, of course sulphur is liberated, and, as shown above, alkaline hydrate must also be present. Now, when these two substances are brought in contact, sodic hyposulphite forms Accordingly Brunner found hyposulphite in solution forty years before the decomposition of alkaline sulphide in dilute solution had been elucidated.

As Brunner experimented with HgS, K^2S, I thought it best to compare the action of HgS, $4Na^2S$. A very concentrated, perfectly clear solution of freshly prepared mercuric sulphide in a mixture of sodic sulphy-

[1] Handbuch der Chemie, vol. 3, p. 851.

drate and sodic hydrate, containing very little of the latter, was suddenly diluted with cold water to two hundred times its volume and rapidly filtered. Minute globules of mercury could be seen with the black sulphide on the filter. On digestion (after thorough washing) with very dilute nitric acid, a solution was obtained from which sulphydric acid precipitated black sulphide. The decomposition thus appears to be the same in solutions of each of the compounds HgS, K^2S and HgS, $4Na^2S$.

Influence of foreign substances.—The fact that sodium carbonates do not prevent the solution of mercuric sulphide is evident both from Méhu's result and from our own. As was mentioned above, mercuric sulphide dissolves abundantly in a solution containing these carbonates and sodic sulphides. The chief constituents of the waters of Steamboat Springs and Sulphur Bank, besides alkaline carbonates and sulphides, are borax and salt. Experiments show that borax solutions precipitate a portion of the mercury from solution, but not the whole. The precipitation does not appear to be progressive, like that accompanying dilution, but to reach a sharp limit beyond which further additions produce no effect. A large amount of borax added to a concentrated solution of sodic sulphide and sodic sulphydrate does not rob it of the power to dissolve mercuric sulphide.

It is easy to imagine reactions by which borax may precipitate a portion of the mercuric sulphide. It seems possible, for example, that neutral borate is formed at the expense of the sodic sulphide combined with the mercuric sulphide. The sodic sulphide would then be converted to sulphydrate and mercuric sulphide would precipitate. But the behavior of solutions of borax to sulphydric acid and to alkaline sulphides is very peculiar, and, so far as I am aware, has not been thoroughly investigated.[1] Very concentrated solutions of sodium chloride do not precipitate mercuric sulphide from strong solutions in mixtures of sodic sulphide and sulphydrate, and they even appear to delay, but not to prevent, precipitation by dilution.

The waters of Steamboat Springs contain no ammonia and probably no organic matter. Those of Sulphur Bank carry ammonia, and all of the mines examined in California show more or less organic matter. It is highly probable, therefore, that during the period of ore-deposition more or less

[1] Gmelin-Kraut, loc. cit., vol. 2, p. 160.

ammonia was present in many cases. Very small quantities of ammonium carbonate precipitate all the mercury from the solutions discussed above at ordinary pressures and at temperatures not exceeding the boiling-point. At temperatures of 145° or more and corresponding pressures, however, mercuric sulphide dissolves freely in ammoniacal solutions, but it is reprecipitated on cooling. The entire absence of cinnabar from the original surface of Sulphur Bank shows how complete this precipitation must be and that a "quantitative" separation of mercuric sulphide has there taken place (see page 269).

Solubility of FeS^2.—The sulphide which is most frequently associated with cinnabar is pyrite or marcasite; indeed, these minerals in greater or smaller quantities are to be found in nearly every hand specimen of ore and occur very abundantly in most quicksilver mines. It seems impossible to avoid the conclusion that the iron sulphides are soluble in the same natural solutions which carry cinnabar. Pyrite, however, is a mineral which is so refractory to most chemical solvents that neither Dr. Melville nor I felt any confidence that sodium sulphide would attack it. On making the experiment I was accordingly surprised to find that pyrite, marcasite, or precipitated ferrous sulphide, when warmed with a solution of sodic sulphide, diminished in quantity, while the solution changed color. The filtrates gave strong reactions for iron.

Pyrite dissolves in cold solutions of sodium sulphide without any evolution of gas. Ten cubic centimeters of an irreproachable solution of sodic sulphide containing 1.0955 grams of the alkaline sulphide dissolved six-tenths of a milligram of pyrite at the ordinary temperature of the laboratory. Thus over eighteen hundred parts of sodic sulphide are required to dissolve one part of pyrite. The solvent power seems to increase with the temperature. Pyrite, like cinnabar, appears to be totally insoluble in cold sodium sulphydrate, and, like cinnabar, pyrite dissolves to some extent in hot solutions of the sulphydrate. Pyrite is also soluble in solutions of sodium carbonate partially saturated with hydrogen sulphide, both hot and cold. A solution of 407 parts of the neutral carbonate, after being semi-saturated with hydrogen sulphide, dissolved one part of pyrite at the ordinary temperature of the laboratory. The mineral dissolves more easily in hot solutions than in cold ones. Marcasite is more easily soluble than pyrite, and the simple precipitated sulphide goes into solution most readily of all. I think there can be no doubt that pyrite and marcasite form double salts with sodium sulphide entirely analogous to the soluble compounds of mercuric sulphide. Marcasite is more easily attacked than pyrite, just as metacinnabarite is more susceptible to the action of reagents than is cinnabar.

Solubility of gold.—The association of gold and pyrite is world-wide. According to Gahn[1] there is no pyrite which does not yield traces of gold when carefully tested. This, indeed, does not accord with my experience, for extremely careful tests of some pyrite in my laboratory have failed to reveal any indication of gold. Gold is associated with quicksilver, however, at Steamboat Springs, at some points on the gold belt of California, at the Manzanita mine, at the Redington mine, and some other localities. From these facts I concluded that gold should be soluble in sodic sulphide. On warming chemically pure precipitated gold dust with a solution of sodic sulphide the glittering scales of gold gradually disappeared. The filtrate after a proper manipulation yielded a purple precipitate with phosphorous acid.[2]

A solution containing 843 parts of sodic sulphide (Na^2S) by weight dissolves one part of gold at the ordinary temperature of the atmosphere. Gold also dissolves in sodic sulphydrate and in solutions of sodic carbonate partially saturated with sulphydric acid at ordinary temperatures. The solubility appears to be increased and facilitated by heat.

Solubility of CuS.—Cupric sulphide dissolves less readily than pyrite. Experiments were made by keeping CuS in contact with the solvents in bottles at about 20° C. for two weeks, the bottles being shaken from time to time. A little less than five thousand parts by weight of sodic sulphydrate are required to dissolve one part of copper sulphide. About eight thousand

[1] Bischof's Chem. und phys. Geol., vol. 3, 1866, p. 939.

[2] Bischof long since remarked that, were the existence of sulphide of gold in nature proved, the possibility of double sulphides of this metal, such as can be artificially produced, and of their deposition from aqueous solutions would be ascertained (ibid., p. 838). So, also, Prof. T. Egleston has found that gold kept in contact with alkaline sulphides produced solutions giving reactions for gold (Trans. Am. Inst. Min. Eng., vol. 9, 1881, p. 640). He did not show, however, how such sulphides or their equivalents could form or exist in nature, and seems to conclude that the compound existing in natural solutions is the chloride.

parts of sodic sulphide in the presence of caustic soda are required to produce the same effect. Cupric sulphide is also soluble at 20° in the solution of sodium carbonate to which sulphydric acid has been added. Over two thousand parts of neutral sodium carbonate which had been semi-saturated with hydrogen sulphide were required to dissolve one part of cupric sulphide at this temperature. Cupric sulphide is also soluble in each of these solutions when hot.

Solubility of ZnS.—The experiments on zinc sulphide were made in the same manner as on cupric sulphide. Zinc sulphide is more soluble in a mixture of sodic sulphide and caustic soda than in sodic sulphydrate. A solution containing a little less than a thousand parts of Na^2S and about one hundred parts of NaHO dissolved one part of ZnS at 20°. The sulphydrate dissolves only a very small quantity of zinc sulphide. Sodic carbonate partially saturated with sulphydric acid also dissolves zinc sulphide. Over one thousand parts of neutral sodium carbonate which had been semi-saturated with hydrogen sulphide were found necessary to dissolve one part of zinc sulphide at 20°.

Solubility of As^2S^3 and Sb^2S^3.—It is, of course, perfectly well known that the sulphides of arsenic and antimony dissolve freely in sodic sulphide without evolution of gas and in sodic sulphydrate with the evolution of hydrogen sulphide. In cold solutions of sodic carbonate partially saturated with sulphydric acid they dissolve freely without liberation of gas, because the hydrosulphuric acid set free immediately combines with sodic carbonate.

Insolubility of PbS and Ag^2S.—The sulphides of lead and silver seem to be entirely insoluble in solutions of sodic sulphide, of sodic sulphydrate, or in solutions of sodic carbonate partially saturated with hydrosulphuric acid. We have obtained no evidence of solution with these sulphides even when heated above 100° with the reagents in closed tubes. Galena is rarely found in quicksilver mines and distinct silver minerals are still more seldom found associated with cinnabar. Very little galena occurs in the gold mines of California, and lead deposits usually differ widely in character and mode of occurrence from either quicksilver or gold deposits. These facts seem to indicate that the best natural solvent for lead is different from that which is most effectual in dissolving cinnabar and gold. Mr. de Senarmont[1] produced

[1] Annales de chimie, Paris, vol. 32, 1851, pp. 168, 171.

galena by the solvent action of water supersaturated with sulphydric acid in closed tubes at high temperatures and pressures, and also obtained ruby silver, both arsenical and antimonial, by heating alkaline sulpharsenites with silver salts dissolved in solutions of acid sodic carbonate at temperatures of from 250° to 350°. There is, therefore, nothing strange in the fact that lead and silver accompany the other minerals at Steamboat Springs.

Natural solutions and precipitations.—The foregoing analyses and experiments show that there is a series of compounds of mercury of the form HgS, nNa^{2}S, one or the other of which is soluble in aqueous solutions of caustic soda, sodic sulphydrate, or sodic sulphide, and apparently also in pure water at various temperatures. These solutions subsist, or subsist to some extent, in the presence of sodic carbonates, borates, and chlorides. There is the strongest evidence that the waters of Steamboat Springs contain mercury in this form and that the waters of Sulphur Bank still carry it in solution. Sulphides of iron, gold, and zinc form double sulphides with sodium, which appear to be entirely analogous to those of mercury. Copper also forms a soluble double sulphide, but combines more readily with sodic sulphydrate than with the simple sulphide. All of these soluble sulphosalts may exist in the presence of sodic carbonates.

Mercuric sulphide is readily precipitated from these solutions. Any substance is more soluble in hot solutions than in cold ones, provided that increase of temperature does not resolve the fluid molecules into others which are less soluble, as happens with sodium chloride, neutral sodium carbonate, etc. Diminishing temperature is thus a cause of precipitation, and diminishing pressure appears to act in a similar way. At Sulphur Bank cinnabar is precipitated at a short distance from the surface, partly at least in consequence of the action of ammonium salts. There are also other methods of precipitation which may be carried out under natural conditions. If a natural solution of mercury comes in contact with a strong solution of borax, or with sulphydric acid or any stronger acid, it will lose a portion of the mercuric sulphide in solution, and, if the precipitation be a rapid one, the black sulphide will probably be thrown down. At Steamboat Springs and Sulphur Bank large quantities of sulphuric acid are found near the surface and, percolating downward, must precipitate mercury. The acid waters penetrate to a depth of at least twenty or thirty feet, and this helps to explain the fact that the water reaching the surface carries so little quicksilver. These same causes, or some of them, must also induce precipitation of the other ores and of gold from solutions.

Another method by which mercuric sulphide may be precipitated is, as has been seen, mere dilution. Now, ascending solutions of quicksilver must sometimes meet with springs, and, when they do so, metacinnabarite or black sulphide will be precipitated, and with it also a small amount of metallic quicksilver. In nearly all mines a small quantity of virgin quicksilver is found, and in most it constitutes a very small proportion of the entire ore.[1] Accompanying this precipitation is the formation of sodic hyposulphite, which actually occurs in the waters of Steamboat Springs. Dilution of solutions of quicksilver with extraneous spring waters thus affords one method of explaining the occurrence of metacinnabarite[2] found in at least five of the mines of California, and also that of native quicksilver. Native quicksilver, however, occurs in many mines in which no metacinnabarite has ever been seen. This does not preclude the supposition that the metal has been isolated by dilution, for black sulphide in the presence of solutions of mercury might readily be converted into the allotropic modification, and I know of no reason for denying that much of the cinnabar of the ore deposits may have been deposited in the amorphous state. Cinnabar and metacinnabarite are sometimes found mixed, as if a conversion to the red mineral were incomplete. In one of the abandoned drifts near the exhausted ore bodies of the New Idria mine the walls were covered with incrustations of secondary salts over an inch in thickness. In this mass, which had been deposited since the drift was opened, I found a tiny vein of cinnabar, about three inches in length and perhaps a quarter of a millimeter in thickness. The existence of this very recently formed veinlet evidently indicates the presence in the mine of solvents of mercuric sulphide in trifling quantities, which might be quite sufficient, however, to convert black ore into cinnabar. Professor Sandberger has described a series of

[1] It is a very curious fact that from ancient times to the beginning of the last century virgin quicksilver was supposed to possess qualities superior to that of the metal reduced from cinnabar (Brückmann, Magnalia Dei in Locis Subterraneis).

[2] The formation of metacinnabarite by dilution has already been suggested by Mr. S. B. Christy.

specimens from Huitzuco, in Mexico, which also seem to indicate a transformation of metacinnabarite into the red sulphide by the action of solvent fluids (see page 19). The mercury found at the Great Geyser of Iceland is also surrounded by black sulphide, which at a greater distance from the metallic globules passes over into the red modification.

While dilution will produce metallic mercury and a causa vera of its existence is thus detected, there may be other ways besides this in which it is produced in nature. Thus sulphydric acid precipitates a mixture of quicksilver and mercuric sulphide from mercurous salts. Whether soluble mercurous salts can occur in nature, excepting near the earth's surface, is another question. But even light is well known to decompose this feeble sulphide, and it is not impossible that the decomposition of organic matter associated in most cases with cinnabar deposits, and which seems to be especially abundant in those mines in which metallic mercury most prevails, may lead to the isolation of metallic mercury.

Conclusions.—The conditions of the solution and precipitation of ores traced in this chapter appear beyond doubt those mainly instrumental in forming the deposits of Steamboat Springs and Sulphur Bank. Most of the other quicksilver mines in California show ores and gangue minerals of similar composition to these, and many of them are accompanied more or less closely by warm springs containing much the same salts in solution. Some of the gold veins also appear to bear so considerable a resemblance in many particulars to these deposits as to lead to the belief that they too were formed by precipitation from solutions of soluble double sulphides.

That pyrite, gold, and other ores are sometimes produced in nature by other methods is absolutely certain, for some auriferous pyrite is known to have resulted from the reduction of iron sulphate by organic matter. This particular process is probably confined to short distances from the surface, for I know of no indication of the formation of iron sulphate far from the oxidizing influence of the atmosphere. But there may be other solvents yet for these and other minerals which can form at great depths, and, if such there be, I am convinced that there are cases in which these solvents, and not those which it has been my good fortune to trace in the foregoing pages, have been instrumental in the segregation of ores.

CHAPTER XVI.

ORIGIN OF THE ORE.

Solvents possibly due to reduction by carbon.—I have shown that cinnabar and some of the accompanying minerals are dissolved as sulphosalts. It is now desirable to consider how the alkaline sulphides essential to these solutions are formed. The alkalis found in thermal springs are easily explained, inasmuch as feldspathic rocks afford an inexhaustible supply of sodium and potassium. The source to which sulphur must be attributed is less clear. Many geological chemists, among them Bischof, maintain that sulphides and free sulphur are ultimately referable to the reduction of soluble sulphides by organic matter. That sulphides and sulphur are frequently produced in this way is entirely beyond question, for the reduction has been effected experimentally and has been observed many times under natural and artificial conditions. Gypsum, for example, in contact with water and carbon, yields hydrogen sulphide and acid calcium carbonate, or calcite and carbonic anhydride. If salts also be present which may be decomposed by sulphydric acid, sulphides will be formed.

Soluble sulphates exist in the greatest abundance in nature, being found in nearly all spring water and forming some of the principal constituents of sea water. There can also be no doubt that a very large part, if not the whole, of the water flowing from thermal springs and ejected by volcanoes is of superficial origin and must have carried soluble sulphates with it to the depths at which its temperature was raised to a maximum. Organic matter is also held in solution or mechanical suspension in many waters. Besides direct observations on this point, it is a well known fact that below the permanent water-level of a country reducing agencies are at work, so that the heavy metals occur as sulphides and the clays are commonly tinted blue from the presence of ferrous compounds. Of course sedimentary rocks of all ages also retain carbon, sometimes in large quantities, as graphite, coal, petroleum, etc, so that reducing matter is provided at all depths to which sedimentary strata extend. Organic matter is also said to be present in hot springs issuing from granite. In some cases granite undoubtedly overlies sedimentary rocks and some granites are beyond question metamorphic. It appears to me possible, however, that some hot springs issuing from granite and seeming to carry organic matter do not really bring such compounds to the surface; for at Steamboat Springs, in spite of the very high temperature of the water, living organisms of low forms are abundant and grow luxuriantly close to the vents. A description of the circumstances has been given in the chapter on that locality.

Solvents probably independent of carbon.—Since silicates of the alkalis and the earths are decomposed by carbonic acid and by hydrogen sulphide, the hypothesis that these reagents are due to the interaction of soluble sulphates and organic matter, more or less metamorphosed, affords a method of accounting for the existence of solvents for the ores. It is by no means certain, however, that the conditions are thus adequately explained. In his great memoir on the Icelandic geysers, Bunsen[1] called attention to the fact that in gases evolved by the help of organic matter, either in nature or by artificial processes, hydrocarbons are almost invariably present. In a very large part of the volcanic emanations, both gaseous and fluid, on the other hand, hydrocarbons are wholly wanting. Hence he concludes that in these cases the sulphur and hydrogen sulphide are in no way dependent upon organic matter. Prof. H. Credner[2] believes that most of the gases emanating from volcanoes, including sulphurous acid and hydrogen sulphide, are disengaged from the fluid interior of the earth in which they have existed since the original formation of the globe. Professors Tschermak[3] and E. Reyer[4] hold similar views. From the point of view of the nebular hy-

[1] Poggendorff, Annalen, vol. 83.
[2] Elemente der Geol., 1887, p. 170.
[3] Neues Jahrbuch für Mineral., 1877, p. 857.
[4] Fysik der Eruptionen, 1887.

pothesis it is certainly difficult to conceive that all the sulphur compounds should be confined to the surface of the earth or that all the sulphur compounds not occurring near the surface should be oxidized.

Borax is another component of the spring waters which it is difficult to account for, except on the hypothesis that the waters derive a portion of their mineral constituents from beneath the granite. Ordinary surface waters seldom, if ever, contain more than a mere trace of borax, so that it is highly improbable that currents descending toward the source of heat carry a large percentage of borax with them. The only boron mineral which is anywhere abundant in granite is tourmaline, but this mineral is so rare in the granites described in this memoir that not a single grain of it has been detected in the slides. It is somewhat improbable, therefore, that the waters ascending through the granite have derived the large quantities of borax which they contain from that rock. This improbability is strengthened by the well known fact that boric acid accompanies the direct sulphurous emanations of many volcanic vents It is indeed conceivable that the borax should be derived from sedimentary rocks, but on the one hand there is no reason to suppose that the granite of Steamboat Springs overlies any sediments and on the other hand it seems doubtful whether strata ever contain any considerable quantity of borax except where they have derived it from volcanic emanations in the neighborhood. It is usual, and appears rational, therefore, to ascribe the borax of hot springs to a volcanic source the character of which is unknown. The waters of Steamboat Springs and Sulphur Bank, it will be remembered, contain relatively large quantities of borax, which is also present in the Knoxville mineral springs.

Depths at which solvents are found.—Whether the hydrogen sulphide of those thermal springs which are associated with other volcanic phenomena is due to the reduction of soluble sulphates by organic matter by some unknown process not involving the production of hydrocarbons, or whether it is due to purely inorganic reactions not yet elucidated, as seems to me more probable, it is evident that this gas reaches the surface from considerable depths, at which the waters percolating from the surface meet with rocks of greatly elevated temperature. In cases like those of Steamboat Springs and Sulphur Bank, where the associated volcanic phenomena are of considerable age, probably thousands of years, the depths at which these heated rocks lie must be great. It is true that a body of lava covered with dry rock of a very moderate thickness would remain hot for a very long time; but, at the localities mentioned above, constant and copious streams of cold water from the surface are heated and returned to the surface. In both localities, also, this very effectual cooling process has been in operation for ages, and probably from the era of the latest volcanic outbursts. The rocks hot enough to heat rapid water currents to such an extent that they reach the surface with a temperature of nearly or quite 100° must therefore lie at great depths. On the Comstock lode the heat increment is 1° F. for every 33 feet. If the same increment obtain for Steamboat Springs and if the rock mass which heats its waters be at a very low red heat (about 500° C.), the depth of the mass below the surface is, in round numbers, five miles. The Sierra Nevada has been a land area from the Carboniferous onwards, and during a great portion of this immense interval it has been a mountain range undergoing rapid erosion. Its granitic surface must for the most part be extremely ancient, and at a depth of five miles from the surface it is very questionable whether there can be any rock which has ever been exposed to daylight.[1] The waters rising from a depth of five miles, and very possibly more, pass through granite which bears no evidence of metamorphic origin, and possibly through other rocks.

Relations of the deposits to various rocks.—Granite is the deep-seated rock beneath all the ore deposits mentioned in this volume. This has been alluded to in former chapters, in which it was shown that granite underlies the entire Coast Ranges and supplied the material of which the sedimentary rocks of that region are composed. The ore deposits themselves are found in various rocks: At Steamboat Springs, in granite and to a small extent in basalt; at Sulphur Bank, in basalt, in Neocomian sandstone, and in recent lake deposits; at Mt. Konocti, in andesite; at Knoxville and New Almaden, in metamorphosed Neocomian strata; at Oathill and to a slight extent in Knoxville, in unmetamorphosed Neocomian strata; at New Idria, in the meta-

[1] Compare "Origin of the massive rocks," Chapter IV, p. 164.

morphic series and in the Chico; and in San Luis Obispo County, apparently in Miocene sandstones.

Possible sources of the ores.—In the two cases just mentioned, in which cinnabar has been found in basalt, this lava forms a thin sheet covering earlier rocks, and in each case the ore is found below as well as in the basalt. The ore certainly is not derived from basalt. Leaving the interesting but very small deposits in andesite out of the question, it appears that all the other deposits must have been derived from granite, or from rocks composed of granitic detritus, or from some source below the granite. This is manifestly equivalent to the statement that quicksilver prior to its solution must either have formed a constituent of the granite or must have dissolved below the granite and have traversed the entire thickness of that rock without being precipitated.

Observation affords no clew to the material which underlies the granites of California. Professor Whitney is of the opinion that a portion of these granites is comparatively modern and I am by no means prepared to controvert this assertion, but it is certain that long before the Post-Neocomian upheaval granite formed the bed rock of a great part of that State and of western Nevada, as it still does. The fact that neither in California nor elsewhere do we know anything from observation of what underlies the granite on which the older strata rest shows that the massive rock is of enormous thickness, if indeed granite and granitoid rocks did not, as elder geologists supposed and as is maintained in Chapter IV, form the original crust of the earth. Before undertaking to consider whether it is more probable that the cinnabar and accompanying minerals were derived from the granite or that they came from a source inferior to it, it seems desirable to allude briefly to the general theories held by geologists with regard to the origin of ore deposits.

Brief statement of the theories of the genesis of ore deposits.—Five distinct theories have been maintained in geological memoirs respecting the methods by which the ores occurring in an unstratified condition (as veins, stocks, and the like) reached the positions in which they are found. These are known as the theories of simultaneous formation, descension, injection, ascension, and lateral secretion. The first two have been abandoned for many years, and the theory of injection, so far as ores are concerned, is limited to some very subordinate phenomena. Those remaining are variously subdivided as occasion may require. With appropriate modifications there is every reason to suppose that they include all important probable cases. It does not follow that they present the subject in the most advantageous manner. The least satisfactory form of the ascension theory asserts that the origin of the ores lies below the deposits in some unknown position from which translocation has been effected by unknown means. Lack of facilities for investigation may in some cases justify no more definite conclusion. In other instances the nature of the occurrence may point to the conclusion that the ores, though of unknown origin, have been deposited from solution or by distillation. The ascension theory also includes cases in which there is evidence, more or less satisfactory, as to the source whence the ore was derived. This may be the interior of the earth, as is maintained by many geologists, for some veins found in close connection with active volcanic phenomena, or the origin may be sought in deep-seated rocks, stratified or massive, but similar to those which are found at the surface. In either case there may or may not be sufficient evidence to justify conclusions as to whether the ores during their ascent were gaseous or in solution.

The lateral secretion theory, as usually defined, is that ores are segregated from rocks contiguous with the deposit. The statement that the lateral secretion theory is applicable to a certain case does not convey any implication as to the particular side from which the ore is derived. All ore deposits are finite and any finite space may be filled from any one of six directions. Neither does the lateral secretion theory, as such, involve any conclusion as to the temperature of the solutions from which the ore has been deposited. It is even possible that certain valuable minerals have been laterally secreted by means of distillation, though this is no doubt an exceptional and limited possibility.

The modifications of these two theories are best grasped in a tabular form.

Ore deposits are formed—
By ascension—
(1) From unknown sources:
(*a*) By unknown methods;
(*b*) By deposition from hot solutions;
(*c*) By distillation, with or without steam.
(2) From known sources:
(α) From the original interior of the earth: (*a*), (*b*), and (*c*), as above;
(β) From underlying rocks: (*a*), (*b*), and (*c*), as above.
By lateral secretion (from contiguous rocks on any side)—
(1) Due to heated waters rising from below, charged with reagents;
(2) Due to cold surface waters, which become charged with reagents in permeating the rocks;
(3) Due to distillation (a rare and unimportant case).

It will be observed that the difference between the lateral secretion theory and the ascension theory depends simply on contiguity, so that, as von Cotta pointed out, the ascension theory, as applied to rocks contiguous to an ore deposit, becomes a case of the lateral secretion theory. For the present purposes of economic geology the nomenclature of the theories is not well chosen. Many investigators are at present anxious to trace those cases in which ores are derived from rocks accessible from the surface, and the main question with mining geologists is now whether or not it is possible to prove the derivation of given ores from rocks existing in the neighborhood of the deposit, and, if so, how the solution and deposition have been effected. It is a matter of detail whether the ore deposit is actually in contact with the rock from which it has been derived or is separated from it by masses of rock which exert no sensible effect upon the solutions.

It is very easy to regroup the special forms of the lateral secretion and ascension theories with reference to this point, and the subject seems to gain considerably in simplicity by this step, as shown in the following statement:

Ores are derived—

From unknown subterranean sources:

(1) By unknown means;

(2) By distillation;

(3) By solution, hot or cold, and reprecipitation.

From rocks such as occur on the earth's surface:

(1) By unknown means, (*a*) source contiguous, (*b*) source remote;

(2) By distillation, (*a*) source contiguous, (*b*) source remote;

(3) By hot solutions, (*a*) source contiguous, (*b*) source remote;

(4) By cold solutions, (*a*) source contiguous, (*b*) source remote.

From the earth's interior:

(1) By unknown means;

(2) By distillation;

(3) By hot solutions.

Objections to an infragranitic origin.—As has been abundantly proved above, either the quicksilver deposits of the Pacific Slope are derived by means of hot solutions from the granite, which is contiguous to the deposit in the case of Steamboat Springs, but more or less remote in all other instances, or else they are derived as heated solutions from the earth's interior (the region below the granite). Of this region we know but little. It sends to the surface eruptive rocks and volcanic emanations, gaseous or in solution. These emanations almost invariably escape in large quantities from the same vents from which the lavas flow, but also often escape through fissures at considerable distances from craters. Eruptive rocks sometimes contain gold, silver, lead, and other metals, and it cannot be asserted that they may not also carry quicksilver. But, were the source of quicksilver nearly or quite identical with the source of the lavas, one would expect to find more or less quicksilver within the craters of the volcanic vents, from which sulphurous, boracic, and alkaline emanations must have issued. This is not the case. At Sulphur Bank are three unmistakable craters, none of them showing any trace of cinnabar, and there are very numerous eruptive masses throughout the quicksilver belt unassociated with quicksilver. Solutions of the heavy metals are also extremely unstable, their sulphides

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being soluble in a very limited class of solvents, and it is difficult to imagine a solution of cinnabar rising through several miles of rock at constantly diminishing temperatures and pressures without losing a large part of its contents. If high pressures and temperature have in this case anything like the effect which the theory of solutions and experiments on the solubility of substances at high pressures lead one to suppose, solutions which below the granite would be only partially saturated would become supersaturated long before they reached the surface, and cinnabar deposits thus formed, if they cropped out at all, would extend down into the granite, probably growing stronger with increasing depth for long distances. This is emphatically not the case with the deposits of the Pacific Slope.

Hypothesis of derivation from granite.—If, on the other hand, one supposes that the granite is the original habitat of the quicksilver, the observed relations become simple and natural. The solutions of sodium sulphide accompanied by carbonates, chlorides, etc., which followed the actual course of lava currents, would then have no opportunity to take up quicksilver; while similar solutions which diverged from the course of the lava into the surrounding country rock would decompose the metalliferous components of the granite, forming and dissolving mercuric and ferric sulphides and bringing them to the surface in greater or smaller quantities, according to the course of the currents and the composition of the granite. Deposits would then form, not in volcanic vents proper, but at the points where thermal springs due to volcanic action issue from the country rock. Such deposits would be of very variable size. Where the channels leading up to the springs were simple and of small extent, mere traces of ore would reach the surface; while, when a limited system of openings at the surface gave exit to waters which had flowed through extensive masses of shattered metalliferous granite, larger deposits would be produced. Now, in fact, the localities in which cinnabar is found on the Coast Ranges are numberless; they are characteristically associated with hot springs; they do not occur in volcanic vents, but are usually at no great distance from such vents. Of all the more important mines New Idria alone is not in the immediate neighborhood of lavas, the nearest mass of basalt known being some ten miles distant. But hot, alkaline springs, similar to those immediately associated with volcanic eruptions, are known in many cases to reach the surface at distances as great as this from lava vents. Though the cases in which cinnabar in greater or smaller quantities occurs close to hot springs in the Coast Ranges are numerous, not all such springs are known to be accompanied by quicksilver. If the granite be supposed to be the source of the metal, this may at first sight seem strange. But granite is by no means a homogeneous substance, and, as I have pointed out in Chapter IV and elsewhere, was probably never thoroughly fluid. With reference to the small quantities of heavy metals which this rock is known to contain in various European localities, the composition is known to be capricious. It is altogether probable, therefore, that some parts of the granite underlying the Coast Ranges may contain much more quicksilver than others, and this irregularity of diffusion, in combination with the want of uniformity in the amount of granite leached by different hot springs, would be sufficient to explain all the observed diversities in the deposits of cinnabar.

Evidence at Steamboat Springs.—At Steamboat Springs a variety of metals occur in the deposits from the active springs, and two concurrent quantitative analyses, together with many partial analyses, show that the relative quantities of the metals are as follows, beginning with the largest: antimony, arsenic, lead, copper, quicksilver, gold, and silver. The quantity of copper found was five times as great as that of quicksilver. If these same metals could be found in the granite it would establish the highest probability that the metals of the deposits were derived from the granite. Analyses of large quantities of very fresh granite, showing no effects of solfataric action and collected half a mile from any solfatarically decomposed material, failed to show all of these metals, but succeeded in revealing the presence of those most abundant in the deposits, viz: antimony, arsenic, lead, and copper. No mercury could be detected; yet the fact that four metals are common to the deposits and the granite and the coincidence that these metals are the most abundant in the spring deposits are highly suggestive of derivation from the granite. There is some evidence that the failure to find quicksilver in this granite was due to irregularity in the composition of the massive rock. The only portion of the solfatarically decomposed area of Steamboat in which cinnabar is abundant enough to be visible is at the extreme west ern edge of the deposits. The quantity of quicksilver at their eastern edge, where the principal active springs now exist, is very minute, and this may be due to the composition of the underlying granite. Now, the granite subjected to analysis was collected about half a mile still farther east than the active springs, and consequently a mile and a half from the mine. If the granite contains quicksilver, but in diminishing quantities as one proceeds to the east, it might well be that the quantity at this point would be imperceptible. On the other hand, it might be argued that the presence of antimony, arsenic, lead, and copper in both the granite and the spring deposits is a mere coincidence, that the infragranitic source of the ore has been gradually exhausted, and that consequently only the older deposits show considerable quantities of mercury. This argument would not, however, quite fit the facts, for, while steam and hot gases still issue in small quantities from the mine, there is a belt of solfataric matter at the very eastern edge of area mapped at Steamboat. The springs here were evidently a portion of the same system now active, but here neither water nor steam now issues. These eastern springs were the oldest of the group, yet no trace of quicksilver has ever been detected in the decomposed mass. If the quicksilver were derived from a limited infragranitic source, these eastern localities should show ore more abundantly than any other.

Comparison between Steamboat and the Comstock.—A comparison has been made on page 352 between the character of the deposit of Steamboat Springs and that of the Comstock lode, six miles distant, which is also significant in the present connection. The hanging wall of the Comstock is diabase,[1] and I have adduced much evidence going to prove that the main source of the ore in this lode is this Pre-Tertiary eruptive mass, from which it was extracted by intensely hot waters rising from great depths, charged with sulphides and carbonates of the alkalis.[2]

[1] See Geology of the Comstock Lode and Bull. California Acad. Sci. No. 6, 1886, p. 94.

[2] Prof. J. S. Newberry has made a curious criticism of my theory of the ore deposition on the Comstock (School of Mines Quarterly, vol. 5, 1884, p. 338). He says: "Richthofen, who first made a study of the Comstock lode, suggested that the mineral impregnation of the vein was the result of a process like that described, viz, the leaching of the deep-seated rocks, perhaps the same that inclose the vein above, by highly heated solutions, which deposited their load near the surface. On the other hand, Becker supposes the concentration to have been effected by surface waters flowing laterally through the igneous rocks, gathering the precious metals and depositing them in the fissure." The inaccuracy of this statement may be seen from the following quotations. Baron Richthofen writes (see The Comstock Lode: Its Character etc. or Mon. U. S. Geol. Survey No. 3, p. 19): "Fluorine and chlorine are the most power-

The water issuing from Steamboat undoubtedly comes from the Sierra Nevada, and this is also the probable origin of the water of the Comstock lode. In each case the water descends to great depths before rising to its point of issue. Now, if the ores of both localities came from infragranitic sources, these sources must be very near together, but of very different characters. For this difference it is not easy to account. But if only the solvents came from below the granite and the metals from the rocks comparatively near the surface, it is easy to see why the two deposits differ as they do.

Heavy metals in granite.—While in the granite investigated for this memoir only arsenic, antimony, copper, and lead have been found; lead is almost or quite always argentiferous and silver is rarely, if ever, free from gold. Silver has been detected by Professor Sandberger in the mica of German granites and Mr. Simundi has found gold in the granites of Idaho. Gold is always accompanied by silver. Zinc also has been found in gneiss-micas. Arsenic, antimony, lead, and copper are so frequently associated in nature with gold, silver, and zinc as to lead to the supposition that they often have a common source. Mercury is not yet known as a component of granite or gneiss, but all the metals associated with it have been detected in these rocks. The probability that the quicksilver alone is derived from an infragranitic source is exceedingly small and is not supported by a single known fact.

Conclusions.—The evidence is overwhelmingly in favor of the supposition that the cinnabar, pyrite, and gold of the quicksilver mines of the Pacific slope reached their present positions in hot solutions of double sulphides,

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ful volatilizers known, and form volatile combinations with almost every substance. Besides silicon, the metals have a great affinity with them. All those which occur in the Comstock vein could ascend in a gaseous state in combination with one or other of them. They must then be precipitated in the upper parts as metallic oxides or chlorides, and in the native state. Thus the fissure was gradually filled, from its upper portion downwards, with all the elements which we find chemically deposited in it." In my report, page 286, I wrote: "Floods of heated waters now rose from a depth of two or more miles, certainly carrying carbonic and sulphydric acids, and possibly other active reagents, in solution. The water followed the course of the main fissure as closely as circumstances permitted, but was deflected to a great extent into the fractured mass of the east country, where decomposition resulted. Silica and metallic salts were set free from the mineral constituents of the rock, and were carried into the comparatively open spaces near the main fissure, where they were redeposited" (see, also, ibid., pp. 226, 283, 386, 390). Professor Newberry attributes to von Richthofen and himself approves the very theory which I was at great pains to support. The hypothesis which von Richthofen advocates Newberry seems entirely to have overlooked (see, also, The genesis of certain ore deposits, by S. F. Emmons: Trans. Am. Inst. Min. Eng., vol. 15, 1887, p. 125).

which were leached out from masses underlying the granite or from the granite itself. No one fact or locality absolutely demonstrates whether the metals were originally components of the granite or came from beneath it, but the tendency of the evidence at all points is to show that granite yielded the metals to solvents produced by volcanic agencies, and, when all the evidence is considered together, it is found that this hypothesis explains all the known circumstances very simply, while the supposition of an infra-granitic origin leads to numerous difficulties. Though no one of these may be by itself fatal, when taken as a whole they appear to be so. As there is no known direct evidence pointing to an infragranitic origin of the quick-silver and the gold, I consider it tolerably well established that both were actually derived from the granite.

I regard many of the gold veins of California as having an origin entirely similar to that of the quicksilver deposits. I also have some reason to suppose that some of the gold deposits were formed by the leaching of their walls by surface waters. The auriferous area is now under examination, and the investigations on ore deposits described in this volume will be continued and extended in connection with my survey of the gold belt.

CHAPTER XVII.

SUMMARY OF RESULTS.

Purpose of this chapter.—A very large portion of the foregoing pages is necessarily occupied by detailed descriptions, written in order to enable readers to judge whether the facts warrant the opinions expressed, and by discussions of a somewhat technical character. There may be those, however, who will be interested to know in brief what conclusions have been reached, but who have no inclination to undertake the somewhat serious task of weighing the evidence adduced and of following the arguments in detail. For such readers this chapter is written; but it must be understood that for full and fully qualified statements reference must be made to the body of the report.

Statistics and history.—The commercial status of quicksilver is peculiar. It seems to be three or more times as abundant in nature as silver, and since 1850 the weight of silver extracted is about six-tenths that of quicksilver; but the total value of the latter is less than one-sixteenth that of the former metal. This is due to the limited demand for mercury, which is employed in large quantities only for amalgamating gold and silver ores and for the manufacture of vermilion. If it should prove practicable to extirpate phylloxera with mercury, this application will greatly benefit the quicksilver miners as well as the vine-growers.

Five regions in the world are yielding or have yielded great quantities of this metal. They are Almaden, in Spain; Idria, in Austria; Kwei-Chau, in China; Huancavelica, in Peru, and the Coast Ranges of California. Of the Chinese region little is known, except that it is extremely rich; in the opinion of a very competent judge, the richest of all. Almaden has produced more than any one of the other three. Idria, Huancavelica, and California have each yielded pretty nearly the same amount from the dates of discovery of the deposits to the present day, California taking the lowest rank. But considering only the period which has elapsed since the mines of the Pacific Slope were first opened the case is different. Peru produced nothing from 1850 to 1886; Idria, in round numbers, 300,000 flasks; Almaden, 1,140,000; and California, 1,400,000, or nearly half the entire product of the world. But California does not seem likely to maintain the same rank among quicksilver producers in the future.

Quicksilver was first recognized in California as occurring at the croppings of the New Almaden mine by Andreas Castillero in 1845. His means of testing the ore were quaint, but effectual, and he immediately began production on a small scale. A large number of other deposits were discovered at later dates, and some forty mines have produced metal, though from some of these the yield has been trifling. Half a dozen of them have yielded from 40,000 flasks upward and New Almaden has turned out over 853,000. The sketch map of California (see Plate I) shows the distribution of some of the mines.

Foreign occurrences of quicksilver.—The account given of deposits known to occur in foreign countries will not bear condensation, being in itself a brief digest. The rocks inclosing quicksilver deposits are of very diverse ages, ranging all the way from Archæan granites and schists to recent strata and lavas. The lithological variety of the inclosing rocks is equally great, including limestones, sandstones, and shales, many kinds of metamorphic strata, and massive rocks of acid, neutral, and basic types. Cinnabar does not even seem to exhibit any preference for one class of rocks rather than another. It is clear that the mere age of the surrounding material is without influence on the deposition of the ore and that the ore cannot in general be derived from the walls of the deposits, for it is scarcely supposable that this metal forms an original constituent of all sorts of rocks.

A glance at the map (Plate II) shows that the quicksilver deposits occur along the great axes of disturbance of the world. One of these is on the line of the principal mountain system of Eurasia, for which I suggest the name of Alpimalayan chain, because it includes the Alps and the Himalayas. The other coincides with the western ranges of the Cordillera system of America. In many parts of the world volcanic phenomena are intimately associated with these axes of disturbance and with the quicksilver deposits.

The minerals which occur in considerable quantities with quicksilver ores are few in number. Pyrite or marcasite is nearly or quite always present, arsenic and antimony are found at many localities, and copper ores sometimes accompany cinnabar. Other metalliferous minerals are comparatively rare. The principal gangue seems to be invariably either silica, sometimes hydrous, or carbonates, chiefly calcite. Cinnabar occurs in true, simple fissure veins, in impregnations, and stockworks. The forms which its deposits take do not apparently differ in any essential respect from those which deposits of other metals assume; but ore bodies precipitated by substitution do not appear from the descriptions to be common. In all cases a fissure system seems probably associated with the deposits.

The facts recorded point to the supposition that most of the quicksilver deposits, if not all of them, have been formed in a similar manner. They have all been deposited from solution, for the gangue minerals could have been formed in no other way. Cinnabar has certainly been deposited by thermal springs of very high temperature at Puzzuoli, in Italy, and at Lake Omapere, in New Zealand, and is most intimately associated with hot springs and other volcanic phenomena at a large number of other points. It has, perhaps, always been deposited by heated waters. It must be derived from some deep-seated substance of world-wide distribution, which has been exposed to the action of volcanic solvents by profound disturbance. The fundamental granitoid rocks answer this description, for they seem everywhere to underlie all other rocks; they are of great but unknown thickness, and they certainly in part overlie the centers of volcanic activity. Geological investigations have as yet revealed no other substance of similar distribution. There is no other rock from which it is equally probable that the quicksilver is derived.

The sedimentary rocks.—Excepting the light cream-colored schists of Miocene age, which occupy a narrow strip along the coast of California from the neighborhood of Santa Cruz southward, the rocks of the Coast Ranges where unaltered are mainly sandstones of Cretaceous and Tertiary age.

Sandstones often occur here in practically uninterrupted series of beds many thousands of feet in thickness. The unaltered sandstones of the Coast Ranges are very much alike, whatever their age. The Téjon (Eocene) beds, however, are of a much lighter color than the Chico (late Cretaceous) or the Miocene rocks. The Chico again is usually more indurated than the Miocene. While the Knoxville (Neocomian) sandstones where unaltered closely resemble those of later periods, no case is known in which unaltered Knoxville beds are not intimately associated with greatly disturbed and metamorphosed rocks of the same age, so that there is no difficulty in discrimination when once it is established that the epoch of violent upheaval and metamorphism followed soon after the close of the Knoxville.

Field study showed that the Coast Ranges are probably everywhere underlain by granite. The microscopical examinations have given this inference unexpectedly strong confirmation, for, though on structural grounds it appears certain that a portion of the later sandstones were formed at the expense of earlier arenaceous beds, they all exhibit unmistakable evidence of granitic origin. They are thus so similar that they may be discussed together lithologically. The microscope shows that the main constituents are quartz fragments (containing abundant fluid inclusions and in other respects resembling the quartzes of the underlying granite), orthoclase, the same plagioclases found in the granite, and biotite. Most of the less important constituents of the granite are also found in the sandstones. The proportion of quartz in the sandstones is, as a matter of course, greater than in the granite. The grains are commonly rounded like ordinary beach sand, but are sometimes extremely sharp. The cement is largely calcite. The sandstones are subject to the ordinary decomposition known as weathering, by which the ferromagnesian silicates are in part converted to chlorite and in part to a ferruginous cement

The unmetamorphosed late Cretaceous and Miocene sandstones show numerous concretions. These in rare instances contain fossils as nuclei. A representative concretion in which no organic remains existed was investigated. It was found that the cementing matrix contained a considerable amount of phosphoric acid, but was chiefly composed of a mixture of calcium carbonate and a hydrous subsilicate of iron. It is shown that this composition points to the action of organic acids, especially the humus acids, and that the class of concretions of which this is a type must have contained nuclei of organic matter which have decomposed and disappeared.

Rounded nodules resulting from the action of decomposition processes on angular masses are discussed, and it is shown that the rapidity of attack must be in an inverse ratio to the radius of curvature of the mass. This explains the fact that such nodules tend to a spherical form. The rounding of pebbles and of sand grains is shown to depend on the same mathematical law.

Sharply defined limits cannot be drawn between the various early Cretaceous metamorphosed rocks of the Coast Ranges; they pass over into one another by degrees. For purposes of description, however, it is desirable to consider certain types as distinct. The divisions which appear to satisfy best both their field occurrence and their microscopical character are as follows: *Partially metamorphosed sandstones*, in which, although a process of recrystallization has begun, the clastic structure as seen under the microscope is not obliterated, but is often more or less obscured. This class will be referred to hereafter for the sake of brevity as altered sandstones. *Granular metamorphics*, in which metasomatic recrystallization of sandstones has transformed the mass into a holocrystalline aggregate, form another group. The third class embraces the *glaucophane schists*, derived from certain shales, much as the granular metamorphics are produced from sandstone. The *phthanites* are a series of more or less calcareous, schistose rocks which have been subjected to a process of silicification, resulting in chert-like masses, which retain schistoid structure and are intersected by innumerable quartz veins. They usually carry more or less zoisite. Finally the *serpentines*, which have resulted in part from the direct action of solutions on sandstones and in part from alteration of the granular metamorphics.

A considerable number of minerals have been generated in these rocks by metasomatic processes and weathering. These are biotite, muscovite, augite, hornblende, glaucophane, labradorite, andesine (probably), oligoclase, albite, orthoclase, quartz, zoisite, rutile, ilmenite, titanite, apatite, garnet, nacrite, chlorite, epidote, serpentine, and chromite. The most interesting and in some respects the most important mineral found is zoisite, which has been repeatedly analyzed and tested.

All the more important processes of metasomatic recrystallization can be traced in the altered sandstones, rocks whose clastic origin could not be doubted for a moment. In many cases one of the first stages in the process is the resolution of the clastic grains into crystalline aggregates from which new minerals are again built up. Augite, hornblende, and plagioclase have been observed which had formed in this manner. The feldspars also crystallize along tiny veins in the slides. A frequent occurrence is the resolution of quartz grains into plagioclase microlites. The reaction begins on the surface of the quartz grains and produces a fringe of twinned feldspar microlites in positions approximately normal to the surface of the residual kernel. The microlites do not merely abut against the kernel, but penetrate it for a sensible distance like closely set pins in a cushion. Zoisite is present in nearly all the altered sandstones. It forms in the aggregates which result from the clastic grains, and its microlites sometimes pierce quartz grains from the outside. It is abundant in the granular as well as in the prismatic form. This hydrous mineral forms simultaneously with the other products of metasomatic recrystallization, and does not here represent a decomposition process in rocks already recrystallized.

It is only necessary to suppose the processes indicated above carried further to obtain a product in which the clastic character of the rocks would cease to be evident. The altered sandstones thus form under the microscope, as they do in the field, transitions from the clastic series to the holocrystalline rocks.

The granular metamorphic rocks of the Coast Ranges are separable under the microscope into several groups, but this is not practicable by unaided vision; indeed, there are many cases in which specimens which appear to the naked eye to be not greatly altered sandstones prove under the microscope to be holocrystalline rocks, with none of the microstructure of a sandstone. The most important class of the granular rocks is chiefly composed of plagioclase and augite. It sometimes resembles true diabase, and may conveniently be called *pseudodiabase.* The pyroxene sometimes assumes the form of diallage. Another class contains amphibole instead of pyroxene, and I call this rock *pseudodiorite.* No metamorphic rocks have been found in place which carry olivine. Glaucophane occurs in both the pseudodiabase and the pseudodiorite. The quantity of zoisite in these rocks is very variable and in some cases is so great that with feldspar it forms almost the entire mass. The schistose metamorphics, not including phthanites, are all characterized by the presence of glaucophane. In every case but one, zoisite is associated with the glaucophane in this group and either muscovite or biotite is usually present.

The phthanites or silicified shales form a very distinct group readily distinguishable from the granular metamorphics. They are usually green or brown and are intersected by innumerable quartz veins. They contain microscopic organic remains, and embedded in the quartz veins or projecting from their walls are often numerous zoisite crystals. All of these rocks are best represented by detailed descriptions of special examples, for which there is no space here.

Serpentine in a comparatively pure state occurs throughout the quicksilver belt in irregular areas. As nearly as can be estimated these areas amount to somewhat over one thousand square miles between Clear Lake and New Idria. Serpentine is also one of the mineral constituents of many of the altered sandstones and of the granular metamorphic rocks. It is a biaxial variety, often just perceptibly dichroitic, and rarely shows differences of tint as great as those characteristic of chlorite. It might be called antigorite if it seemed needful to separate the biaxial serpentines. The net structure so usual, though not invariable, in serpentine formed from olivine has nowhere been detected. Where any considerable quantity of serpentine is present it usually shows the now well known grate structure.

No considerable portion of the serpentine of the Coast Ranges has resulted from the decomposition of olivine. Only in one district have pebbles of olivine gabbro have been found, and these contain a mere trace of serpentine, while the origin of the serpentine has been traced in a great number of cases to rocks containing no olivine.

Field observations show most conclusively that the great mass of the serpentine of this area is derived from the sandstones, either immediately or through an intermediate granular metamorphic rock.

Under the microscope it can be shown, as I think beyond question, that all of the principal components of the sandstones and granular metamorphic rocks are subject to serpentinization. Not only are the augite and hornblende subject to this kind of decomposition, but feldspar, quartz, apatite, and probably other minerals are also converted into serpentine.

In the present state of opinion it is not superfluous to insist upon the derivative character of the holocrystalline metamorphic rocks and the serpentine of the quicksilver belt. There are in fact two independent lines of evidence leading to this conclusion, for the known occurrences of zoisite and its composition indicate that rocks containing it otherwise than as a product of decomposition are metamorphic, while, even if zoisite were a common constituent of undecomposed lavas, the proof of the metamorphic character of these rocks would still be ample.

The depth at which the rocks now exposed were buried at the epoch of metamorphism, soon after the close of the Neocomian, was probably a moderate one, perhaps two thousand or three thousand feet. At a sufficient pressure rocks appear to be molded by dynamic action rather than crushed, and Dr. Lehmann has shown that under such conditions even crystals may be bent. In the Coast Ranges no such phenomenon has been observed. On the contrary, the amount of fracturing is really astonishing. The recrystallization of the sandstones and the serpentinization and silicification are regarded as due to the action of solutions rising from the underlying granite; and these solutions were heated, charged with mineral matter, and driven to the surface as a result of the same dynamical causes which produced the uplift.

In conclusion it may be noted that all the more important minerals of the Archæan schists are found in the metamorphosed rocks of the Coast Ranges The quantitative relations indeed are different, especially those of the feldspars; for, while orthoclase predominates in the Archæan, plagioclase is much more common in the Coast Ranges; but it is evident that, under conditions not greatly dissimilar to those which prevailed in California at the close of the Neocomian, rocks not distinguishable from those of Archæan areas might have been formed.

The massive rocks.—The massive rocks met with in this investigation are granite, diabase, diorite, andesites, rhyolite, and basalt. The granites seem to underlie the entire Coast Ranges and to form the lower and central portion of the Sierra Nevada. They are on the whole pretty uniform and present no known peculiarity. Diabase occurs in the Mesozoic conglomerates of Steamboat Springs and seems to be identical with the diabase which forms the hanging wall of the Comstock lode. Diorite is represented chiefly by pebbles in the Neocomian conglomerates of the Coast Ranges.

The andesites are divisible into two groups, an older and a younger. The younger group is found at Steamboat Springs and elsewhere in and near the Sierra Nevada, at Mt. Shasta, and from Clear Lake to Mt. Diablo. It presents several varieties: one containing pyroxene, a mere trace of hornblende, and no mica; a second containing pyroxene and mica, but no hornblende; a third containing hornblende, with very small quantities of pyroxene, together with mica in quantities ranging from nil to a very large percentage. All of these pass over into one another, sometimes within a few feet, and in masses evidently not due to separate eruptions. Nearly or quite all of them are rough, soft rocks, such as were formerly supposed to be trachyte. They form a natural group, which should be recognized. I have proposed the name *asperite* to suggest their resemblance to trachyte. Asperites, then, are a group of andesites with external characteristics similar to those of trachyte.

Both the asperites and the basalts near Clear Lake pass by transitions into enormous masses of obsidian. The transitions have been traced in the field, in the chemical laboratory, and under the microscope. The glasses are more acid than the crystalline rocks into which they pass, but they contain much more alkali and much less lime and magnesia; their specific gravity is also much smaller. They have cooled as glasses, instead of as crystalline aggregates, because of their peculiar composition, and not because they have been subjected to different physical conditions from the associated, sensibly holocrystalline lavas.

The origin of the massive rocks of California is discussed in Chapter IV. It is shown to be probable that portions of the granitic rocks represent parts of the original crust of the earth, or that they are primeval rocks.

That the primeval rocks must underlie all others is self-evident and the lowest rocks we know of are granitic. It has never been shown how the original crust could be wholly buried beneath its own ruins, and simple arguments are adduced to show this utterly improbable. It follows that a part of the granite must be Azoic and that the lavas which have broken through the granite cannot be remelted sediments.

Historical geology.—The following outline states in the briefest terms the main events in the geological history of the Coast Ranges, so far as they have been elucidated by former observers and by myself.

Prior to the opening of the Cretaceous the region of the Coast Ranges seems to have been chiefly occupied by granite. During the first period of the Cretaceous—the Neocomian—great quantities of sediments derived from the granite were deposited on the quicksilver belt. These were chiefly sands, though shales and calcium carbonate were also found. The sea must have been shallow and many islands must have existed in it. The most characteristic animals of the period were *Aucella concentrica* and *Aucella mosquensis*, of which a description, with illustrations, by Dr. C. A. White, is given in Chapter V. At the close of the Neocomian an upheaval took place with extraordinary violence, folding and crushing the rocks and producing the first ranges along the coast of California of which any record remains. It is probable enough that earlier ranges existed, but had been obliterated. The same upheaval affected the Sierra Nevada and added to its western side, along a part of the gold belt, an immense mass of Neocomian rocks, which were driven into a nearly vertical position. Accompanying this upheaval was a vast expenditure of energy. The heat into which this energy was converted brought about the solution of some components of the underlying granite, particularly of magnesia and soda. These solutions, acting on the Neocomian rocks, converted them into the metamorphic product mentioned in preceding paragraphs.

During the Middle Cretaceous (the Turonian) the shore of California seems to have been nearly in the same position as it now is, and a series of beds discovered during this investigation, the Wallala group, was deposited. They are composed of granitic detritus and fragments of metamorphosed Neocomian beds and certain fossils.

Late in the Cretaceous a great part of the Coast Ranges was again under water and the sea once more reached the flanks of the Sierra Nevada. The sediments laid down at that time, and now known as the Chico series, were of course deposited unconformably upon the metamorphosed and eroded Neocomian rocks. There was no disturbance at the close of the Cretaceous, and sedimentation and the gradual development of the marine fauna went on undisturbed through the Eocene, which, in California, is represented by the Téjon series. The non-conformity between the Chico and the underlying rocks and the continuity of the Chico and Téjon were first established in this investigation.

Between the Eocene and Miocene there is a sharp faunal distinction, but there is no general corresponding non-conformity. At the close of the Miocene an important upheaval took place, though one which was much less violent than the earlier uplift. Professor Whitney first studied this Post-Miocene disturbance. Only a small amount of Pliocene territory exists in this region, and part of it consists of lake deposits. It is of course unconformable with the Miocene.

After the close of the Jurassic no eruptions seem to have taken place in the Coast Ranges until the close of the Miocene, or possibly a little later. Andesites were then ejected and outbursts of these rocks recurred at intervals to the close of the Pliocene. The asperites of Clear Lake and of Mt. Shasta date from the end of the Pliocene. Only one dike of rhyolite is known to exist in the Coast Ranges. It is close to the New Almaden mine. It is probably later than the andesites, but its date is not certain. During the Quaternary and down to very recent times there have been many basalt eruptions.

The formation of cinnabar deposits was confined to the period of volcanic eruptions with which they are most intimately connected. Almost all the massive and sedimentary rocks of the region inclose bodies of cinnabar, and the age and the chemical character of the rocks are without apparent influence on the ore.

Clear Lake district.—The region of Clear Lake is a picturesque one, lying at the northwestern extermity of a belt of lavas which extend southward as far as the Bay of San Francisco. Extinct volcanic cones, borax lakes, hot mineral springs, and deposits of sulphur and cinnabar form its most noteworthy features.

Metamorphic rocks of the Neocomian series underlie the whole country so far as known, though the existence of granite pebbles in the stream which drains the lake suggests that this rock is exposed at no great distance. Upon a part of the metamorphic area about Lower Lake the Chico-Téjon occurs. The latter series is comparatively little disturbed and not metamorphosed.

The earliest eruptions in the district seem to have been that of Chalk Mountain, on the north fork of Cache Creek, and some of the rock near Thurston Lake. This lava was a dense pyroxene-andesite and the eruption seems to have occurred about the beginning of the Pliocene. Soon, and perhaps immediately afterward, a large body of fresh water formed, which I have called Cache Lake. It lay mostly to the east of Clear Lake and continued in existence up to the end of the Pliocene. At this period fresh eruptions of andesites took place. They are the asperites of Mt. Konocti (or Uncle Sam) and the neighborhood. A part of the lava flowed over a portion of the bed of Cache Lake, and the orography was so modified as to shift the position of the water to the new Clear Lake, which overlaps part of the more ancient bed. The change must have been somewhat gradual, for the same mollusks which lived in the earlier body of water also flourished in the new one and the forms are lacustrine.

The asperitic andesites of Mt. Konocti are interesting because they contain pyroxene and mica, but no hornblende, which is unusual, and because they pass over into acid glasses. The asperite is often almost wholly crystalline, though it has been subjected to substantially the same physical conditions as the glass, and the latter has remained vitreous because of its divergent chemical composition. The mountain nearly coincides in form with the theoretical shape of a volcanic cone and its highest point is 2,936 feet above the lake at high water. The lake is 1,310 feet above sea-level.

Much later than the andesite came basalt eruptions, which extended to modern times. A part of this rock also is glassy. All the springs which now issue at a high temperature are probably due to the basalt eruptions, and the borax, sulphur, and cinnabar are referable to the same source.

X Sulphur Bank.—The general geology of the Sulphur Bank is indicated in the notes on Clear Lake. The bank itself is a small basalt area, through which hot solfataric springs reach the surface, owing their heat to the volcanic action of which the lava eruption was an earlier manifestation. The springs contain much sulphydric acid, which, oxidizing more or less fully at and near the surface, has yielded native sulphur and sulphuric acid. The latter has attacked the basalt in part, extracting the basis and leaving a mass of more or less pure silica, in which rounded nodules of undecomposed rock remain. The rounded form of these nuclei is certainly due to the more rapid corrosion of the edges and corners of the basalt blocks, not to any structural peculiarity of the rock. The lava is bleached to an average depth of about twenty feet.

In the lower portion of the decomposed layer of rock the sulphur is mixed with cinnabar. Near the bottom of this rock layer the sulphur disappears and the ore is richer, while the most extensive bodies are found at depths beyond the limits of the action of acid. The ores at one portion of the ground continued down for several hundred feet into the underlying recent lake beds and the metamorphic sandstones. Quartz, chalcedony, calcite, pyrite, and marcasite are the usual gangue minerals, but many other minerals are found in small quantities. The marcasite contains minute quantities of gold and copper. Bituminous matter is widely disseminated. The ore has been deposited exclusively in cavities, and not by substitution. The ore of the lower workings is exactly like that of most other quicksilver mines.

The gases escaping from the waters are carbon dioxide, hydrogen sulphide, sulphur dioxide, and marsh gas. The waters contain chiefly carbonates, borates, and chlorides of sodium, potassium, and ammonium; but alkaline sulphides are also present. At the ordinary pressure the water does not dissolve cinnabar, on account of the presence of ammonia, but I have proved that at somewhat higher pressures it would effect solution. It is beyond question that the cinnabar has been deposited from waters of almost exactly the same composition as those now issuing from the mine and that the formation of ore is still in progress. Deposition of the ore seems to have been effected chiefly by relief of temperature and pressure in the presence of ammonia, not by acidification of the solutions.

Very large quantities of quicksilver have been taken from this property, but it has not been worked with system and has been insufficiently prospected below the basalt. There is no reason to suppose, however, that it is nearly exhausted.

Close to Borax Lake lies a very interesting area of glassy basalts, ranging all the way from a nearly normal olivinitic rock to a pure glass. As is the case with the andesites across the lake, the glass is very acid and contains little lime, but much alkali.

Borax Lake is a shallow pond, without an outlet, into which springs similar to those now flowing from Sulphur Bank once drained. These springs came from the obsidian area, and to them the borax contents of the lake is due. They issued at the point called Little Sulphur Bank, which is still hot and moist and shows native sulphur. It is stated on excellent authority that cinnabar in small quantities was found here. Maggots of *Ephydra californica* and of a species of *Stratiomys* live in the lake.

The Knoxville district.—The region about Knoxville consists of metamorphosed and unaltered rocks of Neocomian age, through which a small basalt eruption has broken, and contains a number of quicksilver mines and prospects. I know of no other district so favorable as this for the determination of the age of the metamorphic rocks and for a study of their character, excepting Mt. Diablo. Rocks occur in all stages of metamorphism, and the transitions, together with the structural relations, show that even the serpentine is not of eruptive origin. The metamorphosed and unaltered rocks are also so related as to preclude the supposition that the former are crystalline sediments. One side of an eroded anticlinal is metamorphosed, while the other is unchanged and fossiliferous. Fossiliferous strata in a nearly vertical position pass over into metamorphic rocks in the direction of their strike, and patches of unchanged rocks remain in metamorphosed masses. The fossils of the unaltered strata are of Neocomian age and the principal species are *Aucella concentrica* and *A. mosquensis*. The series carrying these shells are called the Knoxville group from the name of this locality.

Excellent opportunities are here afforded for studying the passage of sandstone into pseudodiabase and pseudodiorite and the alteration of these rocks to serpentine. The direct change of slightly altered sandstones to

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serpentine may also be seen in a very striking manner. Serpentinization takes place from cracks in the sandstone just as it does in olivines, excepting for the difference of scale. The meshes of the net in sandstone croppings are often about a foot across, while those in olivine are microscopic.

The ore deposits occur at half a dozen points in the district, all of them near the basalt area, which is as nearly as possible in the center of the group of ore bodies. Ore is stated on good authority to have been found also in the Lake claim, at the contact of a basalt dike with the inclosing metamorphic rocks. Many mineral springs exist around the basalt area close to the mines and some of them carry borax. Solfataric gases still issue in small quantities at one point in the Redington mine and the upper portions of the ore deposits are of such a character as to indicate that they were deposited near an original surface. All of these facts indicate that the deposits are indirectly due to the basalt eruption and that the nature of the process was similar to that at Sulphur Bank.

The upper part of the famous Redington mine was an extremely rich bonanza of great size and irregular form. It carried much metacinnabarite. Leading up to this mass from below were three regular fissures, and two of them were filled with ore, forming well defined fissure veins. This is particularly interesting as a proof that true, simple fissure veins may be formed by hot solfataric springs, which has been doubted by some geologists.

The California or Reed mine, the Manhattan, the Lake, the Andalusia, and several prospects, as well as the Redington, lie in this district, but of late years only the last has been worked. Metacinnabarite was the principal ore of the California Stibnite occurs on the Lake and Manhattan claims and is said to have been found in contact with cinnabar.

New Idria.—The New Idria mining district lies among some of the highest peaks of the Coast Ranges, at the southern end of the Mt. Diablo Range. The views are very extensive and the scenery is picturesque, but it is in part very forbidding, the portion of the Coast Ranges lying to the northeast of the district being a mountainous desert.

The higher portion of the Mt. Diablo Range is here, as for the greater part of its length, composed of highly metamorphosed rocks of the Knoxville series. No fossils are known to occur in it here, but at the northern end of the range they are abundant, and they are found again at San Luis Obispo, to the south, in precisely similar rocks.

On the northeastern flank of the range lie the rocks of the Chico-Téjon series. These are tilted at angles averaging about 45°, but are only slightly flexed. The lower part of the series lies unconformably upon the metamorphic beds, as is proved by the structure and by the presence of metamorphic pebbles in Chico conglomerates.

The Chico and Téjon are absolutely conformable at New Idria and sedimentation went on continuously from one period to the other. Fossils are not numerous, but are present in sufficient number fully to identify the age of the rocks. Both portions of the series show many of the concretions mentioned above as due to induration by decomposing organic matter. The Téjon beds contain coal seams which were exploited on a small scale for many years.

No lava exists in the district, but there is a considerable area of basalt just north of Vallecitos Cañon, about ten miles from the mine. There are cold sulphur springs, but no hot ones.

Next to the New Almaden, the New Idria has been much the most productive quicksilver mine in North America. The ore contains the usual mixture of cinnabar, pyrite, and quartz, accompanied by some bitumen; metacinnabarite also was found in the New Hope lode in very large quantities and in less abundance at another point in the mine. The structure is extremely complex, but typically developed stockworks, veins, and impregnations all occur. Faults and cross-courses make successful explorations very difficult and uncertain.

The ore is almost entirely deposited in Neocomian rocks, but to a small extent also in the Chico beds. The deposition has taken place since the Post-Miocene upheaval and is seemingly referable to about the same period as the other deposits. The analogies point to the action of hot springs, but there is no direct proof that the solutions were of high temperature.

The San Carlos, Aurora, Picacho, and other mines which have yielded small quantities of ore lie at no great distance. In all of them the ore has been deposited in shattered rock masses of the metamorphic series. Nowhere in this region is there any evidence of the substitution of ore for rock.

New Almaden district.—The first discovered and the most productive of the quicksilver mines of North America is the New Almaden, and in the same district the Guadalupe, Enriquita, and other mines have yielded quicksilver. The district is well watered and wooded and is more attractive than any other of the quicksilver camps.

Upon highly metamorphosed rocks lie Miocene sandstones, which were sharply folded at the Post-Miocene upheaval. They are not conformable with the lower series and contain pebbles from these older beds. In the older rocks near New Almaden Mr. Gabb found *Aucella*, proving the presence of the Knoxville series.

In this district is the only mass of rhyolite thus far found in the Coast Ranges. It forms a dike nearly parallel to the line connecting the New Almaden and the Guadalupe. It is almost continuous, and I have followed it for a distance of several miles. It is certainly Post-Miocene and probably Post-Pliocene.

The New Almaden is a very extensive mine, said to contain as much as 40 miles of galleries. Much of this length is open, and admirable opportunities are afforded for study of the ore and structure. The ore is cinnabar, with occasional traces of native quicksilver, accompanied by pyrite and marcasite, with rare crystals of chalcopyrite. The gangue is quartz, calcite, dolomite, and magnesite. These materials are deposited in shattered masses of pseudodiabase, pseudodiorite, serpentine, and sandstone. There is no deposition by substitution and impregnations are very subordinate. Considered in detail, the ore bodies are stockworks; but they are arranged along definite fissures and the deposits as a whole have a vein-like character and answer to the "chambered veins" defined in a subsequent paragraph. The workings have developed two main fissures. One of these dips from the surface at a high angle and in a nearly straight line. The other strikes in nearly the same direction as the first, dips steeply from the surface, then flattens and approaches the first fissure rapidly, again becomes very steep, and in the lowest workings almost coincides with the first. In vertical cross-section the two fissures form a figure resembling a *V*. The great ore bodies are distributed along these two fissures, making irregularly into the walls. The wedge between the fissures also contains ore bodies. They are always accompanied by evidences of motion and by a mass of attrition products of various rocks—*clay* in a mining but not in a mineralogical sense. This clay is usually on the hanging wall and is called *alta*.

The other mines of the district contained similar ores in similar rocks. The Guadalupe was the most productive, but was not at work and was full of water during my visit.

All the deposits of the district appear to occur along a rather simple fissure system. The main fissure is nearly parallel to the rhyolite dike at the Guadalupe. It follows the direction of the hills, the axis of which curves gradually away from the dike for a certain distance. Passing through or near the San Antonio and Enriquita, it seems to break across the ridge at the America and enters the Almaden on the strike of its two great fissures. It is near this fissure that new ore bodies are most likely to be found. The Washington seems to be on a branch of the main fissure.

This fissure was probably formed at the time of the rhyolite eruption, to which also I ascribe the genesis of the ore.

Steamboat Springs.—This curious thermal area lies just within the desert Great Basin, in full sight of the forests and snows of the Sierra Nevada. It is only six miles in a straight line from the Comstock lode.

Granite underlies the district and much of the area exposed is of this rock. Upon it lie metamorphosed rocks of the Jura-Trias series and lavas. Older andesites and younger asperites, described in a former paragraph, cover a large space, and there is a considerable area of basalt, which represents the last eruption.

The springs are numerous and some of them reach the boiling-point. They are unquestionably of volcanic origin and due to the basalt eruption. They reach the surface in the granite area. The flowing springs are confined at present to a small group of fissures, but steam in small quantities issues at many points in the region marked by evidences of solfataric action, and this region is substantially a continuous one. In some portions of it the sinters are chalcedony, in others they consist to a considerable extent of carbonates, and in one portion (at the mine) the deposits of sinter are insignificant in extent, the chief effect having been decomposition of granite and the precipitation of sulphur and cinnabar. In this part of the area also steam and gas still issue in small quantities.

The amount of cinnabar is considerable. The ore was mined and reduced a few years since, but mining would not pay at present prices.

Quicksilver in very small amounts is being deposited by the springs now active, together with gold and several other metals. They are dissolved as alkaline sulphosalts, as will be explained in a subsequent paragraph. The waters and gases are similar to those of Sulphur Bank, excepting that ammonia and organic compounds are absent.

The four metals most abundant in the present spring deposits, antimony, arsenic, lead, and copper, exist in the granite, but I was unable to detect quicksilver. This may be due to the small quantity of quicksilver in the average granite or, as I think more probable, to irregularity in the composition of that rock. The granite is the probable source of the mercury.

The Oathill, Great Eastern, and Great Western districts.—The neighborhood of Oathill is a most interesting one and contains many quicksilver deposits within a small area. The underlying rock is of the Knoxville series, identified by the presence of *Aucella*. It is in part metamorphosed and serpentinized and in part unaltered. Andesite and basalt have broken through it.

The basalt eruption gave rise to hot springs, one of which still exists at Lidell, issuing from the workings of a now abandoned quicksilver mine. In two cases also cinnabar deposits occur at the contact between basalt dikes and the adjoining rock, forming veins. Irregular stockworks of the more usual type also occur.

The Oathill mine is the principal one of the mines belonging to the Napa Consolidated Company. It is in unaltered sandstone, the strata of which are nearly horizontal. The deposits are true veins, cutting the strata at an angle of 45°. From these veins ore bodies sometimes make out into the country, following the stratification. These are impregnations. The ore is the usual mixture of cinnabar, pyrite, silica, and calcite, and bitumen also occurs. Small quantities of barite are also found, and this is the only case in which this mineral is known to accompany cinnabar in California. It is also found at Almaden.

The Great Western lies near the extinct andesitic volcano called Mt. St. Helena. The country rock is of the metamorphic series, and both andesite and basalt have broken through it. A layer of opalized serpentine accompanies the ore-bearing ground. The ore is chiefly cinnabar, but at one point rock impregnated with native mercury was found. The cinnabar was deposited simultaneously with pyrite and quartz. The bitumen posepnyte was first described from this mine. The deposit consists of a tabular, reticulated mass connected with a fissure system and it lies at the contact between serpentine and nearly unaltered sandstone. If it does not come under the common definition of a vein, it is closely related to that class of ore bodies.

The Great Eastern lies in Sonoma County, far from other quicksilver deposits and six miles from lava. The rock is the ordinary metamorphosed material of the Coast Ranges The ore occurs in black, opalized serpentine, which here forms a definite ledge. The ore seems, as usual, to be of somewhat later date than the formation of opal and is accompanied by pyrite, quartz, and bitumen. The ore seems to form a pipe, which is continuous from the surface to a depth of 450 feet. This pipe I believe to lie on a continuous fissure.

All of the above mines have produced important quantities of quicksilver.

Other quicksilver deposits.— So far as I know, the most northerly cinnabar deposits on the west coast south of British Columbia are in Douglas County, Oregon. In the northern part of Trinity County, California, there is also a mine. These widely separated deposits both lie on the northerly continuation of the middle Coast Ranges, where most of the deposits occur. From Clear Lake to Santa Barbara, as is shown on the map of California accompanying this report, the deposits are thickly scattered.

Of the very many deposits briefly described in Chapter XIII, only a few can be mentioned here. The Manzanita mine, Colusa County, is very remarkable for the association with cinnabar of free gold, often in feathery crystals. Pyrite accompanies the ore and the gangue is chiefly quartz. There is free sulphur also, as well as other evidence that the ore was deposited by hot sulphur springs, such as still issue within a few hundred feet of the mine. There is no lava in the neighborhood. In the Stayton mines, San Benito County, large quantities of stibnite were associated with cinnabar. The Oceanic, in San Luis Obispo County, is in unaltered sandstone, supposed to be Miocene. Most of the other deposits occur in shattered rock masses of the Knoxville group, forming stockworks. In some cases they seem to be accompanied by true veins, and sufficient exploration would doubtless show a fissure system connected with each of them. The usual mineral association is the same so often described above.

On the gold belt of California cinnabar occurs in pebbles, in auriferous gravels, and in true gold quartz veins, so that there are mercuriferous gold veins as well as auriferous deposits of cinnabar. In the Barcelona silver mine, Belmont, Nev., cinnabar was found with silver ore in the vein. Cinnabar also occurs in a silver vein near Calistoga, Cal. In Idaho float cinnabar has several times been found, in some cases with a calcite matrix. A statement repeatedly made in the literature reads as if this ore had been found in place in Idaho, but this is not the case. In Utah, near Marysville, a deposit of the selenide of mercury, tiemannite, was being mined and reduced early in 1887. So far as I know this is the only case in which this mineral has been found in sufficient quantities to form the basis of commercial exploitation. None of the other deposits requires special mention in this abstract.

Discussion of the ore deposits.—The general results of the observations on the various mines are discussed in Chapter XIV. Microscopical examination of the ores shows that cinnabar is usually deposited in immediate contact with quartz, and that, though opal and chalcedony are frequently found very near the particles of cinnabar, there is seldom, if ever, actual contact. More rarely the cinnabar is directly embedded in calcite. The evidence of the microscope also goes to prove that the ore is always deposited in fissures in in dense rocks or in the interstitial spaces of porous sandstones. Macroscopically the same conclusion had been reached. The assertion often made that cinnabar has been deposited by substitution for wall rock at Almaden in Spain is certainly incorrect, and, in my opinion, no such case has been adequately proved to exist. The only substance, excepting metallic sulphides, which cinnabar is known to replace is organic matter, and this seems to be very exceptional.

The usual mineral association consists of cinnabar and traces of native mercury, with pyrite and marcasite, silica and carbonates; but sulphur occurs at three mines, chalcopyrite is not very uncommon, stibnite is found (though rarely), gold or auriferous pyrite occurs in a few cases, millerite in a number of instances, and barite in one. These substances and their decomposition-products are rare. Excepting in Steamboat Springs, at Calistoga, and in the Barcelona mine, I do not know of silver, lead, or zinc minerals accompanying cinnabar in the western United States. A new bitumen, two new chromium minerals, and a red antimony sulphide have been detected with cinnabar in this investigation.

The great similarity of the deposits points to a common history for them all. The evidence is strong in many cases that they have been deposited from hot sulphur springs and the remainder have probably been produced in the same way. The inclosing rocks have been without effect upon the deposits, for nearly all the rocks in the Coast Ranges inclose ore bodies. These facts point to a common, deep-seated origin.

It has often been asserted that quicksilver ores do not form deposits similar to those of the ores of other metals, but I can find no evidence of this Stockworks, impregnations, and regular veins all occur, and no other or peculiar form of deposit is known to me. Many of the discussions as to whether or not deposits are veins depend on the various uses of this word. To miners it usually means deposits along, or directly connected with, a distinct fissure; to a geologist a vein means a deposit between well defined, nearly parallel walls which have once been in contact. Irregular bodies of ore, even those connected with distinct fissures, are known to him as stocks, stockworks, or by some similar name. I propose to call the contents of distinct fissures with very irregular walls *chambered veins* and the irregular openings or ore bodies connected with a main fissure *vein chambers*. A chambered vein may then be defined as a deposit consisting of an ore-bearing fissure and of ore bodies contiguous with the fissure, but extending into the country rock. The greater part of the cinnabar deposits would come under this definition, which would also apply to many deposits of other ores. If this term were adopted, simple fissure vein would still describe the form of deposits now known to mining geologists as veins.

Solution and precipitation of cinnabar and other ores.—The waters of Steamboat Springs are now depositing gold, probably in the metallic state; sulphides of arsenic, antimony, and mercury; sulphides or sulphosalts of silver, lead, copper, and zinc; iron oxide and possibly also iron sulphides; and manganese, nickel, and cobalt compounds, with a variety of earthy minerals. The sulphides which are most abundant in the deposits are found in solution in the water itself, while the remaining metallic compounds occur in deposits from springs now active or which have been active within a few years. These springs are thus actually adding to the ore deposit of the locality, which has been worked for quicksilver in former years and would again be exploited were the price of this metal to return to the figure at which it stood a few years since. At Sulphur Bank ore deposition is still in progress. The waters of the two localities are closely analogous. Both contain sodium carbonate, sodium chloride, sulphur in one or more forms, and borax as principal constituents, and both are extremely hot, those at Steamboat Springs in some cases reaching the boiling-point. In attempting to determine in what forms the ores enumerated can be held in solution in such waters, it is manifestly expedient to begin by studying the simplest possible solutions of the sulphides, and particularly of cinnabar.

The statements in the previous literature of this subject are incomplete and in part discordant, so that the subject required reinvestigation, particularly as to the sodic solvents. It was found that, provided a small quantity of sodic hydrate be present, one molecule of mercuric sulphide unites with two molecules of sodic sulphide to form a freely soluble sulphosalt and that an excess of sodic hydrate is without effect upon the solubility. Even when sodic hydrate is entirely absent, mercuric sulphide is freely soluble in aqueous solutions of sodic sulphide, though the contrary has repeatedly been asserted; but either one molecule of mercuric sulphide then unites with three of sodic sulphide, instead of two, or a mixture of sulphosalts nearly corresponding to this compound is formed.

Sodic sulphydrate when cold is absolutely without effect upon mercuric sulphide, but when the mixture is heated on the water-bath the sulphydrate is decomposed and sodic sulphide is formed; it unites with the mercuric sulphide in the proportion of four molecules of the former to one of the latter. A perfectly limpid solution results. The same compound is produced when mixtures of sodic sulphide and sodic sulphydrate are brought in contact with mercuric sulphide. The presence of sodic carbonates diminishes the solubility of mercuric sulphide, but does not prevent solution. Ammonium carbonate completely prevents solution at temperatures below the boiling-point, but not at 145° C.

These facts suffice to lead to important conclusions with reference to spring waters, such as those mentioned above. When neutral sodic carbonate is treated with sulphydric acid at ordinary temperatures, sodic sulphydrate forms. At temperatures approaching the boiling-point, it is probable that a certain quantity of sodic sulphide is also produced. At these higher temperatures either of these sulphur compounds will dissolve cinnabar, and the presence of sodic carbonates will not prevent solution. These conclusions were amply verified by direct experiments.

Mercuric sulphide may be wholly or partly precipitated from solutions of the sulphosalts in many ways: by excess of sulphydric acid or of other acids, by borax and other mineral salts, by cooling (especially in the presence of ammonia), and by dilution. In the last case a certain quantity of metallic quicksilver, as well as mercuric sulphide, is formed, and this is very probably one of the methods by which native quicksilver has been produced in nature.

Metallic gold, iron pyrites, cupric sulphide, and zincblende were found to be soluble in solutions of sodic sulphide and in solutions of the carbonates to which sulphydric acid had been added. All of them appear to form sulphosalts with the alkaline compound. It has long been known that sulphides of arsenic and antimony are soluble in sodic sulphide. They also dissolve in mixtures of the carbonates and sulphides of sodium.

Natural solutions of sodic carbonates and sulphides, which are common components of hot spring waters, are thus capable of dissolving at least five of the principal metals, as well as sulphur, arsenic, and antimony. Combinations of these elements form a large part of the minerals found in mines. There is little or no doubt that the cinnabar of the California deposits has been dissolved and precipitated as indicated above and that at least a part of the gold of that State has been produced in a similar manner, but I by no means assert that natural deposits of cinnabar and of gold have never been produced in any other way.

Origin of the ore.—There is the strongest evidence for the supposition that the cinnabar, pyrite, and gold of the quicksilver mines of the Pacific slope reached their present positions in hot solutions of double sulphides. Either the metals must have been leached from the granite or they were derived from an infragranitic source, for examination of the conditions of occurrence shows it utterly improbable that they were extracted from any volcanic rock at or near the surface, while the sedimentary strata of the region are composed of granitic detritus. No one fact or locality absolutely demonstrates whether the metals were originally components of the granite or came from beneath it, but the tendency of the evidence at all points is to the supposition that the granite yielded the metals to solvents produced by volcanic agencies, and when all the evidence is considered together it is found that this hypothesis explains all the known circumstances very simply, while the supposition of an infragranitic origin leads to numerous difficulties. Though no one of these may be in itself inexplicable, when taken as a whole they appear to me to be so. Had solutions of quicksilver been formed in company with other products at the foci of volcanic activity, cinnabar would often be met with in craters. Though it is often found associated with volcanic effects, it perhaps never occurs in craters. Were the solutions formed below the granite, ore deposition would also almost certainly take place in part within the granite, and most ore deposits would continue down into that rock, probably growing richer with increasing depth. On the other hand, the distribution of the deposits relatively to volcanic vents is such as would be anticipated if the ore were known to be leached from the granite by hot waters of volcanic origin. The varying richness of the different deposits also corresponds to the irregularity in the composition of the granite and in the extent of surface exposed along the underground passages through which the waters must have reached the surface. Finally, at Steamboat Springs, at least, the composition of the granite answers to that of the deposits of springs which are still depositing small quantities of quicksilver. It thus seems fairly certain that the quicksilver and gold are derived from the granite. I entertain little doubt that many of the gold veins of California have a similar origin, while others have probably been produced by the action of cold surface waters.

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