6.

# PRESTWICH

ON THE

# CONSTRUCTION OF A TUNNEL

BETWEEN

# ENGLAND AND FRANCE.

# ON THE GEOLOGICAL CONDITIONS AFFECTING THE CONSTRUCTION OF A TUNNEL

BETWEEN

# ENGLAND AND FRANCE.

BY

JOSEPH PRESTWICH, F.R.S., V.P.G.S., Assoc. Inst. C.E.

WITH AN ABSTRACT OF THE DISCUSSION UPON THE PAPER.

EDITED BY

JAMES FORREST, Assoc. Inst. C.E.,

*SECRETARY.*

By permission of the Council.

Excerpt Minutes of Proceedings of The Institution of Civil Engineers.

Vol. XXXVII. Session 1873-74.



LONDON: PRINTED BY WILLIAM CLOWES AND SONS,

STAMFORD STREET AND CHARING CROSS.

1874.

## ADVERTISEMENT.

The Institution is not, as a body, responsible for the facts and opinions advanced in the following pages.

# THE INSTITUTION OF CIVIL ENGINEERS.

December 9, 1873.

T. HAWKSLEY, President,
in the Chair.

No. 1358.—"On the Geological Conditions affecting the Construction of a Tunnel between England and France." By JOSEPH PRESTWICH, F.R.S., V.P.G.S., Assoc. Inst. C.E.[1]

THE object of this Paper is to review the geological conditions of the several formations in the south-east of England and north-west of France, and to give certain facts bearing on the possible construction of a submarine tunnel, with the view of serving as data for any future projects or operations. In this case, many supplementary investigations would be necessary, and these pages, while they show the extent of present knowledge, may serve to indicate in what direction those inquiries should be made. The observations on the Palæozoic rocks made during the last few years by the Author in the north of France and south of England, in connection with the Reports of the Royal Coal Commission, have also suggested an entirely new course of action, which, whatever may be its drawbacks—and they are not inconsiderable—offers, there is reason to believe, the one material advantage of security against the irruption of the Channel waters.

On the geological structure depend the primary conditions of such a work. These ascertained, the not less important mechanical and engineering questions remain to be considered. Granting the possibility of the work in a geological point of view, there are great and formidable engineering difficulties; but the vast progress made in engineering science during the last half century leads the Author to imagine that they would not prove insurmountable, if the necessity for such a work were to arise, and the cost were not a bar.

In considering the geological question, the points first to be considered are the lithological characters, dimensions, range, and probable depth of the several formations; and it is proposed to notice, on this side of the Channel, all those from the estuary of

[1] The discussion upon this Paper occupied portions of two evenings, but an abstract of the whole is given consecutively.

the Thames on the north to the coast of Sussex on the south; and on the other side, all those ranging from French Flanders to the Bas Boulonnais and the coast of Normandy. This is done, irrespective of their relative merits in any other than a geological point of view.

The several formations are taken successively in descending order. The Cretaceous and Wealden series are touched on but briefly, as they have been treated at length in reference to this question by Mr. Topley in his "Geology of the Straits of Dover."[1] The Lower Cretaceous and Jurassic series have also been the object of similar researches on the part of M. Thomé de Gamond.[2]

THE LONDON CLAY.—This formation attains in the lower part of the Thames valley a thickness of not less than from 450 feet to 500 feet, and its equivalent on the Continent, the 'Système Ypresien' of Dumont, has in French Flanders dimensions little, or if any, less than in England. It consists, as is well known, of a tenacious and homogeneous clay,[3] extending on the English coast, uninterruptedly, from the mouth of the Thames to Harwich. It has been proved by wells to be 293 feet thick at Sheerness.[4] On the opposite shore, at Southend,[4] it attains a thickness of 413 feet; at Foulness Island, of about 350 feet (but is there covered by 60 feet to 80 feet of sand and gravel); and opposite Mersea Island to about 250 feet, thinning off to 23 feet at Harwich. Inland, at Chelmsford, the London clay is 186 feet thick, at Maldon 234 feet, and at Colchester a little more than 100 feet. (See Appendix, page 30).

On the French coast the London clay comes to the surface in a line from Bergues, near Dunkirk, to Watten, near Calais, whence it passes seaward beneath the alluvial sands and shingle which extend to the coast. At Calais[5] these alluvial beds are 86 feet thick, and overlie 161 feet of Tertiary clays, sands, and pebble beds. The upper of these tertiary beds may probably be referred to the London clay; but it is there only a few feet thick. At Dunkirk the London clay has been sunk into, but not traversed, to a thickness of 264 feet,[6] and over it there are 118 feet of shelly sands and

---

[1] Quart. Journ. of Science, April, 1872.

[2] Étude pour l'avant-projet d'un Tunnel sous-marin entre l'Angleterre et la France, Paris, 1857. Also a further account published in 1867, and a translation published, London, 1870.

[3] In France and Belgium it is in places more sandy, but it is not until it reaches the neighbourhood of Mons that any material difference is perceptible.

[4] Whitaker, "Mem. of the Geological Survey," vol. iv., pp. 468 and 441.

[5] "The Waterbearing Strata of London," p. 208.

[6] M. Meugy, taking the dip from a point in the interior, gives a depth to the Lower Tertiaries which would be equivalent to a thickness of 728 feet to the

shingle; while at Ostend its exact thickness has been ascertained by a well-boring to be 448 feet, and it is capped by 110 feet of the shelly sands and shingle. From the coast the London clay ranges inland, and is 322 feet thick at Hazebruck, and 300 feet or more at Cassel. The lithological character of the London clay in French Flanders is very similar to that which it has in England—a tenacious blue and grey clay—brown, where weathered near the surface. M. Meugy [1] says that it is "une argile compacte, de couleur gris bleuâtre ou gris jaunâtre et à texture souvent feuilletée. Elle est imperméable à l'eau." MM. Ortlieb and Chellonneux [2] also remark, "Cette argile est aussi remarquable par sa masse que par son homogénéité" . . . "cette roche est imperméable à l'eau." [3]

The rise of the Chalk in the Isle of Thanet breaks the continuity of the London clay in its range eastward beyond Sheppey and Herne Bay, and thus the direct communication through this formation between Kent and the French coast is intercepted. Mr. Whitaker [4] has, however, shown that the Chalk in the Isle of Thanet forms an arch or dome, dipping to the north at Margate, and to the eastward at the North Foreland. It is probable, therefore, that the outcrop of the Lower Tertiaries is very near the coast, and that the London clay sets in at a distance of from 2 to 3 miles from the shore,[5] dipping northward towards the Essex coast, and eastward towards the coast of French Flanders—the intermediate sea-bed forming a trough of London clay, capped, possibly, in its northern position by the thin sandy Upper Tertiary beds, which set in in North Essex and the coast of Belgium.[6]

This trough of London clay is not less than from 300 feet to 400 feet thick at the Essex end, and from 350 feet to 450 feet thick

---

London clay at Dunkirk. This is hardly probable: it is more likely to be between 400 feet and 500 feet. The dip is subject to variation.

[1] "Essai de Géologie pratique sur la Flandre Française." Lille, 1852. P. 142.

[2] "Étude Géologique des Collines Tertiaires du Département du Nord." Lille, 1870. Pp. 15, 16.

[3] The few subordinate seams of sand and pebbles which the London clay contains both here and in French Flanders, give little or no water, and are rarely persistent. They are, in fact, generally merely local seams, without any persistent range.

[4] "Quarterly Journal Geological Society," vol. xxi., p. 395, and op. cit., p. 35.

[5] According to this view the outcrop of the London clay would pass by the Margate Sands and the Goodwin Sands. Can these shoals be in any way due to central unremoved portions of the London clay? It appears by the MS. in the Author's possession that the same idea had occurred to the late Dr. Mitchell on independent grounds.

[6] The presence of certain extraneous fossils in the Crag of Suffolk renders this probable.

at the French end; and as the dip seaward is equal at least to the dip of the sea-bed between the two coasts, it is probable that in the intermediate area but little of the London clay has been removed by the Channel denudation.[1]

Supposing there are no faults of importance between the Essex and the French coasts (and there is no reason to suspect that there are any of magnitude), there would be a continuous mass, 400 feet, or more, in thickness, of this tenacious and impermeable clay, extending the whole distance between the two countries, and presenting every condition favourable for the execution of submarine tunnelling. On a small scale, its adaptability to tunnelling under water was proved in the case of the Tower Subway, where a passage under the Thames, 1,320 feet long and 7½ feet in diameter, was successfully made, without a single obstruction or mishap, in the course of five and a half months; and although in one part not more than 20 feet from the bottom of the river, there was no leakage and no water in any part of the work.

The nearest points, however, between the two coasts where the London clay is thus largely developed are 80 miles apart; and it is probable that, taking into consideration the approaches, and the necessity, in order to avoid the overlying alluvial beds, of not taking a straight line, a submarine tunnel in the London clay could not be much under 100 miles in length. Two alternative and possibly equally formidable lines offer,—one starting from St. Osyth, where the London clay is about 250 feet thick, and the other from Southend, where the clay is above 400 feet thick, both running in a straight line to a point on the Falls Shoal; and thence straight by Dunkirk to, or beyond Bergues (6 miles inland), where the London clay comes to the surface from under the great fringing belt of alluvial sands and shingle. (See Map, Pl. 8., and Sec. 1, Pl. 9.)

Under the London clay are the Lower Tertiary beds, which are together about 100 feet thick. They consist of quartzose sands, pebble beds, and subordinate mottled clays, all too irregular, too unimportant, or too permeable for tunnel work.

Chalk.—This formation, which everywhere in the south-east of England and north-west of France underlies the Tertiary series,

---

[1] Had the small trough of Lower Tertiary strata which passes inland at Pegwell Bay included the London clay, the passage from the French coast at Gravelines, or Dunkirk, to Pegwell Bay, would have been easy. The continuity is broken at or near the Goodwin Sands, so that thence to the English shore the only possible connecting link, and that a very poor and dangerous one, would be the lower part of the Thanet Sands (base of Lower Tertiaries), which are there more argillaceous than usual.

has a maximum thickness of from 1,000 feet to 1,300 feet; but, as much of it has in this area been worn away or denuded before the deposition of the tertiary strata, its actual thickness in the district under notice varies from 300 or 400 feet, to 800 or 1,000 feet.

The upper beds consist of almost pure carbonate of lime, easily worn by water, and, being also soft and fissured, they are readily permeable. But the Lower Chalk or Chalk Marl contains so large a proportion of argillaceous matter and silica in a state of fine division that some beds pass almost into a clay, and when unbroken and compact, very little water can pass through them, and then only with extreme slowness, though this will increase under pressure. But, although a small bore-hole, or even a shaft, may often be carried through a considerable thickness of Lower Chalk, and no water obtained, the occurrence of fissures is too uncertain to render it a reliable medium over a larger area.[1] In some cases, when the Lower Chalk comes to the surface, and is more broken and fissured, the quantity of water it yields is very large, as in the instance of the Tring cutting, described by Robert Stephenson, where the discharge was at the rate of 1,000,000 gallons per day; or at Folkestone, where the town water supply is obtained from the Lower Chalk of the adjacent downs. On the other hand, the Chalk Marl in France and Belgium acts as an impermeable stratum in stopping the passage of water from the very permeable Upper Chalk into the underlying Coal Measures; and no water was found in it either at Kentish Town, Harwich, Southampton, or Calais; but the diameter of the bore-holes, by which they were traversed, were very small. At Calais one spring was met with at a depth of 70 feet in the Upper Chalk, and the water was brackish, showing communication with the sea.

Nor must it be forgotten that wells in the Chalk under London have to be carried or bored to depths of from 10 to 300 feet, before meeting with water-bearing fissures, or else headings have to be driven in search of one. Again, the escarpment of the North Downs, and that of the chalk hills of Wiltshire, Oxfordshire, and Buckinghamshire, are fringed with numerous springs, which issue at their base. These springs, although thrown out generally by the Chalk Marl, are apparently, not always, on the top of it, but often low down in the deposit, and they constantly wear their point of issue from a higher to a lower level. Whatever the level of the spring, the water of course passes through all the superincumbent portion of the Chalk Marl.

[1] The Author's opinion on the Chalk is expressed at length in the "Water-bearing Strata of London."

It would be instructive to determine the levels of these various springs.

This very commonly impermeable character of the Chalk Marl has given rise to the hope that it might prove compact enough for a submarine tunnel under the Channel between Cape Blanc-Nez and the South Foreland; but when it is considered that such a work would have to face the risks arising from the lateral passage of the inland springs,[1] and from the chance fissures, so common to calcareous rocks communicating with the sea, it is feared that the difficulties would prove to be of a very formidable nature. It is to be observed that in the Channel the chalk is frequently bare, besides being unprotected by any overlying strata.

THE UPPER GREENSAND is here too thin (1 to 3 feet) to require notice. It is a chalk marl, mixed with green grains.

THE GAULT.—This formation consists of a bluish-grey clay, very tenacious and impermeable. As it is, however, only 130 feet thick on the English coast, and as this is reduced to about 40 feet on the French coast, the attempt to carry a tunnel through it under the Channel would hardly be feasible.

THE LOWER GREENSANDS are composed, 1st, of the Folkestone beds, which consist of extremely permeable sands; 2nd and 3rd, of the Sandgate and Hythe beds of mixed grey clays, sands, and ragstone; 4th, of the Atherfield clay. The latter alone is impermeable; but although these beds form on the English coast a mass of strata together, 260 feet in thickness,[2] they thin off so much to the eastward, that on the French coast they are reduced to 30 or 40 feet, exclusive of the Atherfield clay,[3] which is, however, only 30 feet thick at Hythe.

THE WEALDEN STRATA, largely developed in England, where they attain a thickness of not less than 1,200 feet, are reduced to a thickness not exceeding 40 feet or 50 feet in the Boulogne district,[4] and,

---

[1] Although it might be possible to overcome many of the inland springs, there would be the danger that, owing to the ramifications of the fissures through which they pass, some may communicate with the sea-bed, so that draining of these lesser waters would only leave channels for the more dangerous influx of the sea waters through the very fissures by which the inland waters now find vent as submarine springs.

[2] Dr. Fitton, "Trans. Geol. Soc.," 2nd Series, vol. iv., p. 319, and Drew, "Mem. Geol. Survey," Sheet 4.

[3] There are specimens in the Boulogne Museum of the *Ostrea Leymerii*, from Wissant, indicating probably the presence there of the Atherfield clay, which is, however, only occasionally exposed on the shore.

[4] For a description of these and the underlying rocks of the Boulonnais, see M. Rozet's "Description Géognostique du Bassin du Bas Boulonnais," Paris, 1828;

instead of presenting large masses of soft permeable sandstones, and impermeable grey and mottled clays, they consist of permeable rubbly ironstones and grits, with thin subordinate beds of clay and sand. These beds cap the cliffs and hills in the interior of the Boulonnais, and their continuity between these points and our coast is broken by the rise of the Kimmeridge clay. If, however, the sandy beds on the coast south of Wissant should prove to be Wealden, and to cover more argillaceous Wealden strata, then possibly the latter might deserve inquiry; but this is very problematical, as is also the line which such Wealden strata may take from this point to the English coast. They may form a narrow band wrapping round the north end of the Varne. There is a possibility of this, owing to the break in geological sequence between the Wealden and Jurassic strata, the former of which covers, in the neighbourhood of Boulogne, unconformably and at different levels, a denuded surface of the Kimmeridge and Portland beds, and passes transgressively on to the Oolites, and then to the Palæozoic rocks in the neighbourhood of Marquise and Ferques. This point has an important bearing, which we shall have occasion to refer to again.

Under the Wealden commences the series of Jurassic strata, the uppermost of which consists, in the Boulonnais, mostly of loose and very permeable beds of sand, with layers and detached blocks of massive concretionary sandstone, constituting,—

The Portland Beds.—It would be impossible to traverse these sands and sandstones under the Channel, as water would pass through them as through a quicksand. They are from 60 feet to 100 feet thick and repose upon,—

The Kimmeridge Clay.—This argillaceous formation is largely developed in the north-west of France, though it rarely appears on the surface. It underlies the chalk at Rouen,[1] and was there found, by a boring for coal, to be about 1,000 feet thick. It crops out from beneath the Cretaceous rocks for a short space in the Pays de Bray, where it was proved many years since, to the depth of about 600 feet. It reappears again in the Boulonnais with a greatly reduced thickness. From a boring just made at Montalaire, 2 miles inland from Boulogne, it may be inferred to be there at least 364 feet

---

M. E. Rigaux's "Notice Stratigraphique sur le Bas Boulonnais" (Bulletin No. 4, année 1865 de la Société Académique de Boulogne), and Mr. Topley's Paper before cited, and that "On the Lower Cretaceous Beds of the Bas Boulonnais" (Quart. Journ. Geol. Soc., vol. xxiv., p. 472); see also the large geological map of the Boulonnais, by M. de Souich.

[1] Guide du sondeur. Par MM. Degoussé et Laurent. 2nd edit. Vol. ii., p. 484.

thick, while in the neighbourhood of Marquise it is reduced to about 230 feet or 240 feet.[1] On the English coast it forms the cliffs at Kimmeridge in the Isle of Purbeck, where it is not less than 550 feet thick. It then passes eastward, and is lost under the Cretaceous rocks. There is reason to believe, however, that, as it exists in the Boulonnais and reappears from under the Cretaceous series in Bedfordshire and Buckinghamshire, it passes underneath the Wealden area.[2]

In the Boulonnais, the general dip of the Kimmeridge clay is southward under the Cretaceous series, and westward under the Channel, across half of which on the French side it probably extends; for midway between the two coasts is the Varne Shoal, which, from trials made by M. Thomé de Gamond, is formed, there is little doubt, of the hard concretionary blocks of sandstone, characteristic of the Portland series at Gris-nez and Mont Lambert. This shoal probably marks the boundary of the Kimmeridge clay, which there passes with these overlying Portland beds under the Weald clay, specimens of which latter are stated by M. Thomé de Gamond to have been brought up by him between the Varne and the English coast, in depths of 16 fathoms.

The Kimmeridge clay in the Boulonnais consists essentially of massive clays, indurated marls, and thin-bedded argillaceous limestones, with one subordinate central bed of sands and sandstone 12 to 15 feet thick. As a whole this series is impermeable, but still the sandstone and limestone bands give rise to small springs. In the Pays de Bray, three unimportant water levels were found in it. At Sotteville, near Rouen, a strong brine spring was met with at a depth of 670 feet.

It is possible, therefore, that if a tunnel were driven into the upper clays at Andrecelles, between Boulogne and Gris-nez, or else in the lower beds near Boulogne, it might, by following the dip seaward of the Kimmeridge clay, be carried in that formation half-way across the Channel; but the presence of the Portland beds in mid-channel, and of the Weald clay further on, must there give

---

[1] M. Thomé de Gamond makes it 183 feet thick at Cape Gris-nez.—Op. cit p. 23, and Table, pl. III.

[2] The Kimmeridge clay (and some of the underlying secondary strata) may be more or less reduced under the Wealden area. For, as mentioned above, the superposition of the Wealden on those strata, shows, in the Boulonnais, a considerable amount of preliminary denudation; so that, looking at the much greater volume and depth of the Wealden in the English area, it is possible that it may have been deposited in a channel or basin denuded partly out of the Portland, Kimmeridge and Oolitic strata, and that a portion of these formations may be removed from under the Wealden area.

rise to one of two conditions of structure. It may be supposed either that the Kimmeridge clay dips thence to Hythe and passes intact, together with the Portland beds, under the several divisions of the Wealden, of which the uppermost there comes to the surface; or else, from the unconformable superposition of the Wealden to the Jurassic strata apparent in the Boulonnais, and the great development of the Wealden strata in Kent, it may be supposed the Portland beds and some of the Kimmeridge clay are denuded and replaced by Wealden strata. In the former case, the tunnel would have to follow in the line of the Kimmeridge clay across the Channel, and to be brought to the surface through the Portland and Kimmeridge clay beds, succeeded by one or all of the divisions of the Wealden,[1] according as they may or may not have thinned out against the Palæozoic ridge. In the other case (Section 5, Plate 2), the Portland beds would be gradually replaced on the same level by some member of the Wealden, possibly the Upper Weald clay,—like the Permian beds overlap the scarped edges or slope of the Coal Measures, on the east side of the Coalbrookdale coalfield,—so that a tunnel would pass directly from the one impermeable stratum, to another equally or more impermeable, and in such a case the work might not be impracticable.

Between Boulogne and Ambleteuse the strata are considerably disturbed.

The Oolites.—The freestone and rubble beds, whether of the Coral Rag[2] or of the Great Oolite, are too permeable, while the Oxford clay, lying deeper and being therefore more inaccessible than the Kimmeridge clay, presents in consequence greater difficulties. They outcrop 3 miles eastward of Boulogne, near which town their thickness has recently been proved, by a well-boring, to be 425 feet. These are the lowest members of the Secondary series, which are known to exist in the Boulonnais. M. Thomé de Gamond introduces the Lias, but it is not known that that formation ranges so far to the north-west of France. Its last appearance is in the Department of the Ardennes. The Sub-Wealden boring

[1] The prolongation of the Palæozoic axis of old rocks of the Boulonnais under our Wealden area, renders the presence and the thickness not only of the Jurassic but also of the Wealden strata at Hythe very uncertain. The upper and lower division of the Wealden need present no difficulties, but if the Hastings sands extend there in any importance, they would offer serious obstacles to the passage of a tunnel in its ascent to the surface.

[2] The Coral Rag containing some argillaceous beds, might not, for a short distance, present any insuperable difficulties, but the Great Oolite, and associated beds, would doubtlessly be perfectly impassable. A very large quantity of water was given out by the lower beds of the latter at the Montalaire boring.

now making near Battle will throw important light upon the succession of the Jurassic strata under the Wealden.

It may be remarked that, a few years since, it was proposed to make a tunnel commencing on the French side of the Channel in the Great Oolite near Marquise, emerging from which it would enter the Oxford clay, and so pass on in succession through the Coral Rag, Kimmeridge clay, Portland Sands, Wealden strata, and issue on the English side through the Lower Greensands, thus intersecting all the Lower Cretaceous and the Jurassic strata, regardless of their lithological structure. The proceeding is of so bold a nature, that it is hard to imagine that the energetic author of it could have been aware of the difficulty, and, in some cases, the impracticability, of carrying merely vertical shafts beneath the line of water-level through some of these strata.

The Palæozoic Series.—Thus far all the strata have followed in a regular order of succession, underlying and cropping out from beneath one another in consecutive order. But this regularity suffers a remarkable interruption on a line running in an E.S.E. and W.N.W. direction, passing immediately north of the Boulonnais. There the Lower Greensand, Wealden strata, and the Jurassic series, instead of being prolonged northward under the Chalk, are interrupted in their course, and thin out against a ridge of older rocks, which, with the exception of a slight exposition above ground in the Haut Boulonnais, runs underground from Belgium to the south-west of England, only the Chalk and Gault passing northward on to and over the crest of this underground ridge (Sections, Plate 9).

This ridge is part of a great range extending from Westphalia to the south of Ireland, and forming a tract about 800 miles in length, with a breadth varying from 20 miles to 60 miles, whilst the main ridge is subtended to the north by a lower, but still a raised underground tract of the same old rocks (Sections 6 and 7). These form the fundamental rocks or rock floor, over which the Tertiary and Secondary strata are spread in the south-east of England, Belgium, and Northern France. They were raised into mountain chains, possessing a similar definite strike and direction, and into continental areas with intervening seas, before the deposition of any of the Secondary strata, the accumulation of which then commenced in those seas, and gradually spread transgressively over all the Palæozoic rocks as the old continental areas were submerged.

These two sets of rocks are therefore perfectly independent one of the other; and the direction, range, and depth of the underlying Palæozoic rocks, could no more be inferred from the bearing of the overlying Secondary rocks, than could the direction and levels of the old Roman roads be known by an inspection of existing railways.

These Palæozoic rocks consist in the Ardennes, where they are best known, of a central axis of Silurian strata, flanked by Devonian rocks, and then by Carboniferous strata. These are contorted and tilted at every possible angle, but the strike is always in one given direction, and they thus form a series of narrow parallel anticlinal ridges and synclinal troughs, having each only a small breadth from north to south, but a great length from east to west. Thus the rich coal basin of Belgium and the north of France consists of about 7,000 feet to 8,000 feet of Coal Measures crushed up into a trough, which is only 3 to 6 miles wide from north to south, but which ranges east and west for a distance of 164 miles. When these Palæozoic rocks pass beneath the surrounding newer formations, the horizontal beds of the latter repose on the upturned edges of the former. Similar features prevail where they emerge again from beneath the secondary rocks in the west of England.

With regard to that portion of this great axis which passes underground beneath the Channel, reference has been made to its more distant sections for the purpose of showing how permanent are its characters, and how persistent its range; and that its exhibition in the Boulonnais is not a mere local disturbance, but part of one great and general phenomenon affecting the same class of rocks along a given line over a very wide area. At the same time it is to be remarked that, although the strike of the axis is, as a whole, from east to west, yet it has local deflections, which, for certain distances, give it a direction E.S.E. and W.N.W. This is important to note.

The extent of area of these old rocks in the Boulonnais is small. They emerge at Caffiers and Hardinghen from beneath the Chalk and Gault, and disappear at Marquise and Réty beneath Jurassic strata. They are, as in Belgium, tilted at high angles, and thrown also into a series of anticlinal and synclinal lines. The strike, however, has here a more north-westerly direction than in Belgium. M. du Souich, who has mapped the Palæozoic rocks of the Boulonnais with great accuracy, makes the several bands of Devonian and Carboniferous Limestone with the associated coal beds strike persistently W. 30° N. and W. 30° S. over the whole area exposed, which has a length of 5 miles, with a width of 4½ miles. Mr. Godwin-Austen's and the Author's observations confirm this, and also the existence of a similar line of strike in the small tract of Palæozoic rocks cropping out in the bottom of a chalk valley at Matringhen, 20 miles to the S.E. of this district.

Of the Silurian rocks in this area little is known; they consist of hard quartzites, slates and grits. The Devonian rocks, on the contrary, are well exposed. They consist of alternations of purple and grey shales, schists, and fissile sandstones, with hard compact limestones and dolomites, together, probably, not less than 2,000 feet thick. These are succeeded by the Carboniferous series, composed of fissile sandstones, dolomites, hard compact limestones, with a subordinate series of coal beds, sandstone, and shales, together, possibly, about 2,200 feet to 2,500 feet thick. The true Coal Measures are higher in the series, and pass further to the north.[1] The trough in which they lie thins out between Bethune and Calais, and there is reason to suppose that it sets in again in the neighbourhood of the latter town.

The Palæozoic rocks of the Boulonnais pass on the southward under the Jurassic formations already described. To the north, the Devonian rocks, after passing under the Chalk and Gault in the cutting between Beaulieu and Caffiers, at an elevation of 250 to 300 feet above the sea-level, have been met with again at Hames-Bucres, near Guines, 4 miles further north, under 635 feet of Chalk and 33 feet of Gault; at 10 miles to the north, beneath Calais, at a depth of 1,032 feet under the same strata; and again at Ostend 56 miles distant under 985 feet of similar strata (Sections 2, 3, and 7, Plate 2).

The question now arises what is the trend and depth of the Palæozoic rocks westwards under the Channel? The only place between Calais and the West of England where the Chalk has been traversed and the Palæozoic rocks found beneath them is at Kentish Town, which is situated nearly on the main line of strike of the Palæozoic axis. Red sandstones, probably of Devonian age, were there met with at a depth of 934 feet below the sea-level, and under a thickness of 1,114 feet of Tertiary strata, Chalk, and Gault. At Harwich, which is 80 miles north eastward of Calais, Lower Carboniferous rocks have been proved to lie immediately under the similar strata at a depth of 1,026 feet. It is known from trials made by Sir John Hawkshaw, the particulars of which he has obligingly supplied, that, on the coast about 3 miles westward of Calais, a boring, 551 feet deep, passed through 197 feet of White Chalk

[1] Some of the French geologists now consider that the Hardinghen coalfield is a prolongation of that of Belgium and Valenciennes; but this, so far as the 'massif' of old rocks is concerned, is immaterial to the question.

with flints, and 284 feet of Grey Chalk. Add to this, the 64 feet extra of Lower Chalk existing at Calais, and it will there give to the base of the Chalk a depth of about 615 feet beneath the sea-level, or 410 feet higher than at Calais; on the English coast, another boring Sir John Hawkshaw had made at St. Margaret's Bay—about 4 miles eastward of Dover—after traversing 240 feet of White Chalk and 296 feet of Grey Chalk, reached the Gault at a depth of 554 feet (Appendix, p. 32).

With a persistent trend of so wide a range, and with a strike subject to so little variation, there is reason to believe that the main axis of the Palæozoic rocks, after their exhibition in the Boulonnais, passes under the Channel, and that the crest of the same ridge would probably be found underground somewhere near Folkestone. The elements of greater uncertainty are—1st. The depth at which the older rocks lie; 2nd. The line along which the Wealden and Lower Cretaceous strata thin out against the older rocks.

The Lower Greensand, and the Wealden strata have at Folkestone and Hythe dimensions far in excess of the same beds at Wissant. Still there is some evidence of their thinning out: for, on the western side of the Weald, the Lower Greensand has a thickness of as much as 500 feet, which is diminished to 260 feet at Folkestone. Of the thickness of the Wealden series in the Hythe district there is no positive information. We have assigned to it a thickness of 600 to 800 feet; but there are no borings or wells to give exact measure, and the only guide in this case has been the dip and range of the beds between that town and Appledore—a fallacious guide in a case like this, where the beds are very obscure and where the lower divisions may be affected without the upper or surface beds showing it.

Any estimate, therefore, of the dimensions of the Wealden and Jurassic series under Folkestone must be conjectural. Looking at the tolerably certain range of the Palæozoic rocks westward from the Boulonnais, and the partial thinning out of the Lower Greensand at Folkestone, the Author would be disposed to expect a somewhat like thinning out of the underlying Wealden and Jurassic formations in the English as in the French area; and that further northward, at Dover or St. Margaret's, the Gault may overlie almost directly the Palæozoic rocks.[1] If such should be the case,

[1] Fragments of mica slate have been found in the Lower Chalk near Folkestone. "Mem. Geol. Survey," vol. iv., p. 33. These all tend to show the proximity of an old land surface of Palæozoic rocks. In the Lower Greensand at Maidstone, pebbles (some of large size) of Palæozoic rocks are occasionally found, and in one part of the Wealden series they are not uncommon.

then the boring at St. Margaret's would give about 650 to 700 feet as the depth to those rocks at that spot. (See map and Section 6.) In the Boulonnais, at a distance of 10 miles south from the exposed older rocks, the Jurassic series have already attained a development of 1,000 to 1,100 feet. If to this is added the thickness of the Wealden and Greensands, there will be an additional 100 feet, making the dimensions of the Secondary rocks 1,100 to 1,200 feet; while in the neighbourhood of Marquise it seems probable that they do not attain much more than half those dimensions. Again, as the Palæozoic rocks are not less than 750 feet below the sea-level at Boulogne, and as they rise to a height of 378 feet above the sea beyond Marquise, the difference of level exceeds 1,100 feet in these 10 miles; so if the main axis of the Palæozoic rocks underlies the Gault at Dover and has a similar slope southward, the older rocks might be 1,600 feet deep at Hythe; but if the axis maintains the direction it has in the Boulonnais it must pass under the Greensand near Folkestone, and the older rocks may then be more than 600 feet to 800 feet deep at Hythe. The Author has, in the sections, taken as a possible approximation the depth at Hythe to be about 800 feet, and at Folkestone 300 to 400 feet. (Sections 4, 5, 6.)

Assuming hypothetically these conditions of range and depth of the Palæozoic rocks, we will now examine the lithological structure of their several divisions with reference to their water-bearing characters—first, where exposed on the surface, and then when covered by newer rocks.

With regard to the Silurian and Devonian series, M. Laurent[1] states that rocks of this age rarely contain any levels of water, and that it is only encountered in fissures. The Silurian strata in this area are not exposed. They are generally impermeable.

The Devonian series is largely developed, and contains a large proportion of impermeable schists and shales. The railway section between Caffiers and Beaulieu cuts through Lower Devonian strata, dipping at an angle of 27° to 32° southward, and measuring about 2,000 feet across their outcropping edges. In this distance there occur about 70 feet of fissile and compact sandstones, and solid limestone, and 380 feet of impermeable schists and shales, while about 1,300 feet of sloped surfaces probably indicates the presence of soft strata,—such as shales. Higher in the series are thick beds of compact limestones and dolomites, possibly 500 feet to 600 feet thick, the whole capped with by 200 feet to 300 feet more of impermeable grey and purple shales.

[1] Op. cit., p. 333.

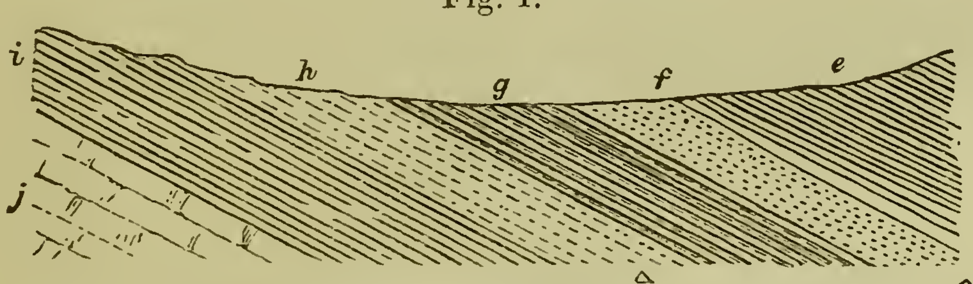
THE MOUNTAIN LIMESTONE series, which next succeeds, consists of compact limestones with subordinate dolomites, and with an intercalated series of coal strata, formed, as usual, of alternating beds of permeable sandstones and impermeable shales, altogether probably 2,200 feet to 2,500 feet, or more, thick. As these crop out at a high angle, and the surface is traversed by several small streams, the permeable beds of the coal series give admission to much water, the transmission of which is, however, localised by the large faults which traverse the measures. The coal mines at Hardinghen, which are worked in these beds, suffer so much from water, that it was a question, a few years since, whether they would not have to be abandoned in consequence. The water is now kept under by powerful engines.

The great limestone bands of the Carboniferous series, as well as those of the underlying Devonian series, also hold large quantities of water in their fissures and cavities, when they are below the line of water-level, and their surfaces are exposed.

The conditions, however, that obtain when these rocks pass under great masses of superincumbent strata are extremely different.

Permeable strata, *f*, *h*, Fig. 1, cropping out on a nexposed surface, or exposed in the bed of a stream, or in the sea channel, serve, as is well known, as vehicles to conduct the rain, river or sea-water underground along the line of their passage, the current being kept in defined bounds by the impermeable strata *e*, *g*, *i*; and any works executed at Δ on the prolongation of *f*, *h* must be subject

Fig. 1.




to the drainage of the whole section of *f* or *h* above those points. A fault throwing *f* against *e*, or *h* against *g*, might serve to stop the transit of the water, but its effect would be uncertain, and would depend on the relative dimensions of *f* and *h*, to *e* and *g*.

The section Fig. 1 may, in fact, be taken as representing the outcrop of the Portland Sands *f* from beneath the Wealden *e*, and of the Coral Rag *h* from beneath the Kimmeridge clay *g*, while from beneath the Oxford clay *i*, the Great Oolite *j* crops out. With such a structure, the influx of the surface waters into the Oolites along their line of outcrop near Marquise, and of the sea-water into the

Portland Sands, and other permeable strata at their outcrop in the Channel is inevitable. As the tunnel before referred to was to pass first through the Great Oolite from its outcrop to near Griz-nez, then through the overlying beds, as they are brought by their dip to the level of the tunnel, to the Portland beds at the Varne, from which it would pass to the Weald clay and into the Lower Greensands on the English coast, there can be no doubt that any such attempt would have proved futile, owing to the unavoidably great influx of water both from the land and from the sea. It is true it did not escape the notice of the projector that these several strata are water-bearing, but he does not seem to have attached sufficient importance to the difference between the water discharge in that portion of the strata above the level of the permanent water line, which only deals with the annual rainfall and surplus quantities, and the formidable underground reservoirs constantly stored in such strata below that line; nor to the fact, that although the sea-water may not infiltrate in a vertical line, it would follow the oblique line of bedding, however long, whenever the strata crop out in the bed of the Channel.

It is this which constitutes the great danger in dealing with the Secondary strata under the Channel, where these conditions prevail. It is an imminent risk, even should it be desired to keep the work within the impermeable beds only. If the dips of these strata were uniform, and it were certain that no faults existed, then a tunnel might be carried with safety in the centre of an impermeable deposit, by adopting, if possible, a gradient coincident with the angle of outcrop; but although the dip of the strata may have on the whole a general and given direction to a certain point or line, it is liable to constant minor variations and accidents. It is only requisite to look at the coast sections, to see how common faults are. Small ones would be unimportant, but larger ones might offer serious obstacles, less only in proportion as the strata are thicker. This must be taken into consideration, and allowed for in all preceding observations on the Tertiary and Secondary strata. It is a qualification important to bear in mind, not as a certainty, but as a certain contingency. It must also be remembered that these faults must all pass through the underlying Palæozoic strata, which suffer in addition from other faults of older date,[1] but the mass of these rocks is so great, that the faults are of less importance, especially on the line of strike.

---

[1] The old faults of the Palæozoic series were all levelled and planed down before the deposition of the Secondary strata.

With respect to the Palæozoic formations, where they are overlain by newer formations, other conditions come into play than those of outcrop and permeability—conditions by which, whatever may be the permeability of certain strata, its consequences are generally nullified and rendered inoperative. This gives to these rocks in such cases a peculiar value for submarine work.

The Palæozoic strata of this part of Europe were, as before mentioned, upraised, contorted, and formed into continental areas at the end of the Permian period, and consequently all the Secondary strata which were subsequently deposited, overlie the former unconformably, and in masses in accordance with the depth of the sea basins intersecting these old continental areas, and their thickness increases with the distance from the old shores; whilst over the continents themselves, either the Secondary strata were not deposited, or only such members of them as were formed at a later period when those continents were submerged.

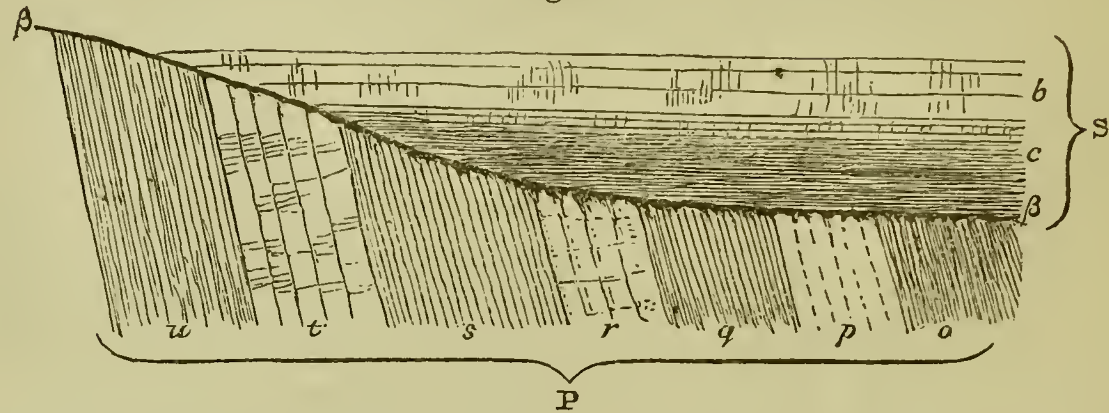
In this way the Silurian, Devonian, and Carboniferous strata, forming the Ardennes, and stretching from Central Europe to the south-west of England, were first squeezed and elevated into their numerous parallel anticlinal and synclinal lines; and then, whilst the central raised tract, or, at all events, the higher portions of it, remained above water during all the earlier Secondary period, certain portions to the south of the main axis were gradually submerged; and finally the lower parts of the main axis, and the tract to the north of it, were also submerged.

Thus to the south of the Palæozoic area in the Boulonnais, the Jurassic and Wealden strata are largely developed, but they thin off against this axis of old rocks; while the crest of the Palæozoic ridge, and the tract immediately north of it, are covered only by the Gault and Chalk. In the same way the Palæozoic rocks of Belgium are covered only by Cretaceous and Tertiary strata, whilst as they trend and deepen southward into France, all the Oolitic series gradually set in over them, showing the original existence of a depressed area to the south of the old Palæozoic ridge.

It follows from this, that the Secondary strata S were spread gradually and transgressively over the upturned and denuded edges of the older rocks P, as shown in Fig. 2; and therefore the actual water-bearing condition of these Palæozoic rocks depends on the characters of *c*, *b*. If the Palæozoic rocks P contain permeable strata, their action would depend not upon their own lithological structure, but rather on that of the over-lying Secondary strata; for if S is formed of impermeable strata, they would effectually prevent the influx of rain, river, or sea water into P.

In Fig. 2 let *p*, *r*, and *t* represent the more or less permeable strata

Fig. 2.




of the Palæozoic rocks P, and *c* an impermeable deposit of the Secondary formations S. Here the outcropping edges of *p r* are efficiently protected by the overlying strata *c*, while laterally *r p* are protected by their associated beds *o*, *q*, *s*, and although *t* is exposed to communication with *b*, that communication is restricted in its operation by causes next to be mentioned. Supposing *b* to represent highly aquiferous strata, or a body of water whatsoever, no water could pass from it into *p* or *r*.

In addition to these circumstances, the action first—of the air, during the exposure of the old Palæozoic surface *β*, *β*, led to the decomposition of the surface of the rocks, converting the shales and schists into clays,—and subsequently the action of the water when the tract was submerged caused these argillaceous materials to become mixed with the first sedimentary deposit, and washing this basement bed into all the irregularities of the surface, and filling all its fissures, puddled as it were with a liquid grouting the edges of the old rocks, and still more effectually prevented communication from the overlying deposits.

The Author has dwelt thus long on these points because he believes they offer a solution to the problem of driving a tunnel safe from the irruption of water under the Channel. In the tract between the Boulonnais and Calais, the conditions just described especially prevail, as the Palæozoic rocks on the northern border of the Boulonnais axis are directly overlain by the Gault clay, succeeded by the great mass of Chalk Marl—an order of superposition which has been shown to be continued to Calais and Ostend, and most probably extends westward across the Channel. Neither in the borings at the towns last named, nor in the analogous ones at Kentish Town and Harwich, was any water found in the underlying older rocks. The same remark applies to the numerous borings for coal in the district between the Boulonnais and Bethune, where the Devonian or the Silurian rocks were met with.

There is, however, an important exception to this rule. At Lille and Roubaix, Artesian wells have been carried successfully through the Lower Chalk into the Mountain Limestone, and in the fissures of the latter large quantities of water were at once found which rose to the surface; but M. Laurent[1] considers these to be exceptional cases, due to local causes.

But besides these instances relating to shafts and borings, to which, as beforesaid, some uncertainty always attaches, other evidence enables a judgment to be formed with much greater certainty of the extent to which Palæozoic strata, more permeable than the Devonian, can actually be worked under highly aquiferous deposits, of a depth exceeding the depth of the Channel, and at a level even lower than that at which the Palæozoic strata lie at Calais.

In the great coal basin of Mons, the Coal Measures are covered by variable and often great masses of Tertiary and Upper Secondary strata, some beds of which are impermeable, whilst others, on the contrary, are extremely permeable and full of water. These overlying strata are from 100 feet to 1,200 feet thick; and as the surface of the ground does not average more than 200 to 300 feet above the sea level, the top of the Coal Measures is in places as much as 900 to 1,000 feet below that level. In no part of the Channel under consideration does the depth exceed 186 feet, and it rarely is more than 150 feet.[2]

The Lower Tertiary strata of Belgium (the Laudenian Sands) consist of light greenish sands, forming beds about 100 feet thick. When below the water line of the country, the sands contain so much water that they are like a quicksand. The Upper Chalk, which attains in places a thickness of 1,000 feet, is very friable and broken, and its fissures are everywhere full of water, so that

---

[1] Op. cit., vol. ii., p. 380.

[2] The height of the river at Mons, above the sea level, is 102 feet, and the general height of the country, which is slightly undulating, may be 200 feet to 300 feet more. The depth which the Thalweg of the basin of Cretaceous and Tertiary strata, filling the depression in the Coal Measures, attains in various parts of its course, will show the importance of this overlying mass of more or less aquiferous strata, and the great depth at which the Coal Measures are worked under them.

| | | feet. |
|---|---|---|
| Approximate depths of the Thalweg below the level of the sea at the various places here named. | St. Vaast . . . . . . . | 331 |
| | Near Nimy . . . . . . . | 1,033 |
| | South of Ghlin . . . . . | 721 |
| | Douvrain . . . . . . . | 787 |
| | Pommeræul . . . . . . . | 1,040 |
| | South of Harchies . . . . | 820 |

*See* Cornet and Briart's "Terrain Crétacé de la Province de Hainaut."—Mons, 1866, p. 6.

extreme difficulty is experienced in sinking shafts through it. Under these beds is the Lower Chalk, or Chalk Marl, which is from 30 feet to 250 feet thick, and comparatively impermeable; and at the base of it is a thin, compact conglomerate, called Tourtia. Beneath these are 60 feet to 600 feet of Greensand (Meule de Bracquegnies), and then 20 feet to 500 feet of the Aachenian beds. These two latter formations present difficulties even more formidable than the Upper Chalk. The sands of both are so loose and moveable, and the pressure of water at the great depth at which they lie is so great, that in many districts it was, until lately, found to be impossible to sink shafts through them.

Nevertheless, notwithstanding the great volume of water held in these beds, the Coal Measures underneath are comparatively dry.

M. Cornet and M. Briart, Civil Engineers, and managers of some of the largest works in the Hainaut Coalfield, state, in a communication to the Author, that as the result of their experience, it is only when the Tertiary sands, the lower Greensand and the Aachenian sands repose directly on the Coal Measures that these are invaded by water; and M. Briart says, "that in this case it is generally in those works which cut across the strata, or, in fact, work at right angles to the strike; but that when they follow the vein the mine is generally dry. In any case, it is excessively rare that the water in the coal mines offers any serious obstruction to their working. It is only when the works approach too near to the water-bearing strata that irruptions of water occur." M. Cornet writes, "that when the works are conducted with prudence, they can approach very near to the Cretaceous strata. In one case coal seams are worked at from 30 mètres to 40 mètres beneath those strata in places where the latter were 250 mètres thick, and contained a body of water 220 mètres high."

M. Cornet concludes by stating, that "when the Coal Measures are covered by the Chalk Marl (Dièves), which is generally the case, they are found altogether free from water coming in from the overlying strata. Just now, at a depth of 25 mètres in the Coal Measures at Maurage (see p. 25), there is no water. In those places where the Coal Measures are covered by the Greensands and the Aachenian sands water sometimes passes; but more commonly none passes, for the shales are altered, and converted into a sort of clay (which stops the water). Sometimes, however, when the Tertiary sands directly cover the coal strata, much water passes when the works come near to them. Nevertheless, I am of opinion, and experience proves that I am right, that they can always mine under great thicknesses of water (water-bearing strata), without its penetrating into the works. At the Grand Hornu, near Mons, they are at present working under 300 mètres of water, at a distance only of 40 mètres from the base of the Morts-terrains (unproductive overlying strata)." [1]

Mr. Warington Smyth, also, in a Paper communicated to the North of England Mining Institute,[2] remarks that "the northern coalfield of France is covered by Cretaceous strata, which, down to 100 yards or 120 yards deep, are some of the most troublesome a miner can meet with." Of the beds overlying the Belgian coalfield he says, they "consist in great part of sands, marl, and Chalk, with occasional bands of massive flints and loose or running sand, and with water extremely abundant;" and he alludes to several failures in sinking shafts, in consequence of the difficulties thus presented, until the new method of sinking in water was introduced by Messrs. Kind and Chaudron.

Mr. Smyth goes on to observe, after speaking of the difficulties of passing through the overlying beds, that when "the excavations reach certain of the more solid lower beds of the Cretaceous series, the so-called Dièves or the Tourtia, or have penetrated to the Coal Measures themselves, scarcely any addition to the water is expected."

Applying these considerations to the Palæozoic rocks as they pass under the Channel to England, it is evident, from the great dimen-

[1] Some of the other particulars given by these gentlemen are too pertinent to the subject to be omitted. The following are extracts from M. Briart's communication:—

"The strata most charged with water are—

"1. The Lower Tertiary sands of the east of Hainaut.

"2. The thick mass of the White Chalk.

"3. The bed of sandy chalk marl with large irregular concretions of flint.

"4. The Greensand of Bracquegnies.

"5. The sands of the Aachenian system.

"The quantity of water in these beds is often very considerable. It is the flinty bed, No. 3, called Rabots, which contains most. With respect to the Aachenian sands, they may be said to be impregnated with it, and it is useless to think of passing through any thickness of them by the ordinary methods of sinking. In sinking through the White Chalk and the rabots, the discharge of water in bad cases amounts to from 4,000 to 6,000 cubic mètres in 24 hours, but generally it does not exceed 1,500 to 3,000 cubic mètres. In one instance, in a pit at the Couchant du Flénu, the discharge amounted to 12,240 cubic mètres.

"The White Chalk and the rabots are never in direct contact with the Chalk. They are generally separated from it by other beds more or less argillaceous and impermeable (Fortes-toises, Dièves), which act as a barrier between the water held in the water-bearing strata and the underground works, so that these workings

[2] *Vide* Transactions of the Inst., vol. xx., pp. 196 and 189.

sions and general impermeability of these strata, their persistent rectilinear strike,—and their security against the influx of water, in consequence of the continuous overlie of the impermeable Gault and of the Chalk Marl,—that these old rocks are likely to offer the surest and safest means of submarine communication

---

can be extended beneath the aquiferous beds without meeting any large quantity of water, and requiring only a comparatively restricted drainage.

" But it is different when the tertiary sands which lie on the east of the basin, or the Greensands and Aachenian sands which occur on its northern edge, repose directly on the Coal Measures. In those cases the beds of sandstone intercalated in the Coal Measures, and which are always more or less fissured, allow readily the influx of the water from the overlying strata (*morts-terrains*). The pits, when the use of powerful engines is much required, are mostly those which work across the beds (*à travers-bancs*), or across the strike of the strata. The works, on the contrary, which follow the vein (or along the strike) rarely yield any water, except where there is a bed of sandstone in close proximity, or a fault intervenes."

M. Cornet gives the following particulars of the strata in descending order :—

" Chalk A.—White Chalk, generally greatly fissured, and giving much water. Thickness, 0 to 346 mètres.

" Chalk B.—Rabots. This is a bed formed of numerous seams of massive and single flints in a grey chalk. It is fissured, and gives a great quantity of water. Thickness, 3 to 40 mètres.

" Chalk C.—Chalk Marl. More or less argillaceous, and containing in its upper part siliceous concretions. It bears the name of *Fortes-toises* when it contains these concretions. The lower beds are simply a very clayey marl, to which is given the name of *Dièves*. At the bottom is a thin bed of green chloritic marl, with pebbles called *Tourtia*. The division C is impermeable, and prevents the waters of A and B descending lower. On the south of the basin it is only 7 to 10 mètres thick; but on the north it is sometimes as much as 80 to 100 mètres thick.

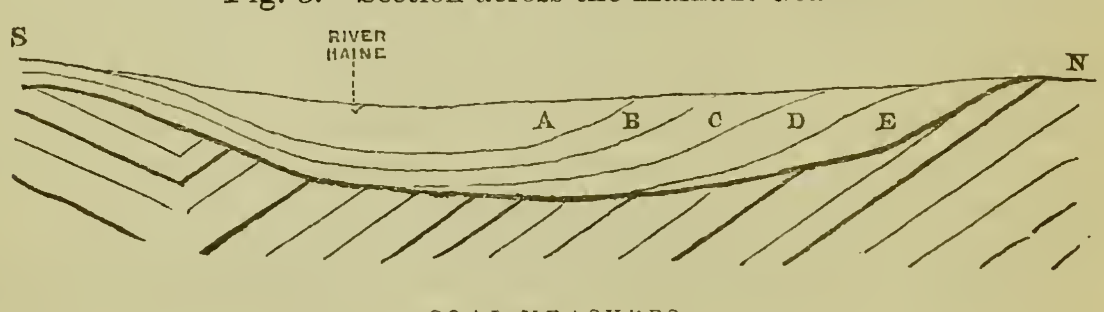
" Greensand D.—A greenish sandstone, very hard and very much fissured, containing much water. Thickness, 20 to 180 mètres.

" Aachenian Strata E. — An irregular series of sandstones, pebble-beds, sands and clays, with lignites. They contain much water, and the sands which are there met with are shifting sands. Thickness, 5 to 150 mètres.

" The formations D and E exist only on the northern side of the coal basin."

He illustrates the range of these beds by the following section, Fig. 3.

Fig. 3.—Section across the Hainaut Coalfield.




M. Cornet then proceeds to give some special and extreme cases of the discharge of water in strata overlying the Coal Measures, in sinking certain pits near Mons.

between the two countries; but as distance seems an insurmountable objection in the case of the London clay, so depth may here also render the other conditions nugatory. If the trend of the Carboniferous rocks were followed from near Calais (Section 2,

| | 1. Pit at Quaregnon. | 2. Pit at Harmignies. | 3. Pit at Couchant du Flénu. |
|---|---|---|---|
| | Mètres. | Mètres. | Mètres. |
| Drift beds . . . . . | 4·5 | 6·20 | 4·5 |
| Tertiary sands . . . | ·0 | 7·80 | 13·1 |
| Strata A . . . . . | 17·3 | 117·50 | 108·3 |
| ,, B . . . . . | 3· | 5·35 | 4·7 |
| ,, C . . . . . | 6· | 3·15 | 10· |
| | 30·8 | 140· | 140·6 |

Pit 1. Water stood at 1·5 m. from surface; discharge in B 22,000 cubic mètres per 24 hours.

,, 2. Water stood at 53 m. from surface; discharge in B 7,000 cubic mètres per 24 hours.

,, 3. Water stood at 18 m. from surface; maximum discharge 11,000 cubic mètres per 24 hours.

"The discharge of A is not given in 1 and 2. It is merely stated to be very large.

"The quantity of water in the aquiferous strata, where they were thicker, is so great, that in places it was impossible to sink through them until the introduction of the system *Kind-Chaudron*. By means of this machinery they have now succeeded in sinking through very great depths of this water-logged strata. The following are the most remarkable and successful instances in places where all ordinary means had failed:—

| | 1. Pit at Maurage. | 2. Pit at Harré.[1] | 3. Pit at Bracquegnies. |
|---|---|---|---|
| | Mètres. | Mètres. | Mètres. |
| Drift beds . . . . . | 3·64 | 14·20 | 11·50 |
| Tertiary sands . . . | 3·18 | ·0 | 1·0 |
| Strata A . . . . . | 117·0 | 126·98 | ·0 |
| ,, B . . . . . | 30·30 | 60·52 | 15·23 |
| ,, C . . . . . | 39·71 | 63·09 | 19· |
| ,, E . . . . . | ·0 | ·0 | 20·17[2] |
| | 193·83 | 214·89 | 66·90 |

"In pit 1 the water stood at 35 mètres from the surface.

" ,, 2 ,, ,, 2 mètres ,,

" ,, 3 the pressure in the lower part of E was equal to 35 mètres of water.

"There are pits in this district in which the coal is worked at depths of 610 mètres, 730 mètres, and 800 mètres below the level of the sea."

[1] Not yet finished. [2] Complete quicksands.

Plate 9), the line would probably reach our coast somewhere between the South Foreland and Ramsgate; but the depth would be not less than 1,000 feet to 1,100 feet. If, on the other hand, the prolongation of the Devonian rocks were followed (Section 3, Plate 9) from Guines or Sangatte to the neighbourhood of Dover, they may possibly be found to range at a depth of from 700 feet to 800 feet; or if the Lower Carboniferous or the Devonian rocks could be followed from their outcrop at Leulinghen and Rocthun, near Marquise, they might probably be found to pass under somewhere near Folkestone, at a depth of 300 feet to 400 feet.[1] But in all these cases it must not be forgotten that although the estimates of depth on the French side are tolerably certain, their correctness has to be proved on the English side. They are merely offered as tentative and approximate, and require confirmation by trials, which could, however, be made without much difficulty.

Nor is evidence wanting of the possibility of carrying galleries in Palæozoic strata under the sea, and of ventilating such galleries to a considerable distance from the shafts. On the Durham coast coal pits are worked several hundred yards under the sea, and at great depths; and on the Cumberland coast Mr. G. B. Forster, who drew up the Report on the Coals of the Northern Counties for the Royal Commission, informs the Author that "At Whitehaven we have workings under the sea which are at a distance of nearly 4 miles from the shaft. They are about 2 miles from low water mark, but, of course, under the same conditions as to ventilation as if they had been driven directly seawards. In these workings we have no difficulty with the ventilation, though only produced by a furnace of moderate size. It is intended to put a powerful fan on this pit, and we then expect to carry the workings much further on. These workings are about 200 yards below the sea. All the water met with is salt; but there has been no indication of the sea making a breach, even where the cover is only half that thickness." And, in further explanation, Mr. Forster adds:—

"1. The depth of the sea at the point to which the coal workings are carried is 60 feet.

"2. The Coal Measures (at Whitehaven) are *not* covered by any newer rocks or by boulder clay where they pass under the sea.

"3. The *least* distance between the bed of the sea and the working galleries is 180 feet.

[1] A trial boring recently made near the coast, about 2 miles south of Wissant, ended in Jurassic strata at a depth of about 200 feet, but the Author could not obtain exact particulars.

"4. The shaft is within a few yards of the beach, and the workings actually extend nearly 4 miles under the sea. They are, however, not driven at right angles to the line of coast, and therefore at the extremity they are little more than 2 miles beyond high water mark. There is no communication with the surface except the main shafts, so that the workings are, in this respect, in the same position as if they had been driven nearly 4 miles right out to sea."

It is evident, therefore, that it is quite possible to work the Coal Measures in safety, both under the sea at places where they are dependent only upon the protection afforded by intercalated impermeable strata and by faults, and also under great masses of strata charged with water, from which they are protected by intervening and unconformable overlying formations. It should be noted, also, that in all these cases the works are carried on as usual in open galleries, without the protection of brickwork. If the Coal Measures, with their subordinate permeable sandstones, can be so worked, it follows, with little doubt, that the other Palæozoic strata, which consist of more entirely impermeable rocks, and which are under the same conditions of dip, strike, and overlie, may be expected to offer conditions equally, or even more favourable, for similar submarine work. Briefly to resume :—

In the London clay there exists a perfectly impermeable bed of sufficient thickness, but nowhere continuous between the two countries, except probably at points where the distance presents apparently insuperable difficulties. The Lower Chalk or Chalk Marl affords a comparatively impermeable deposit, also of sufficient dimensions; but from its having a calcareous base, and from the possibility of fissures, with the absence of a protecting overlie, it has great uncertainty. In the Gault there is another impermeable stratum, but of dimensions too small. The Lower Greensand contains no beds sufficiently continuous and impermeable. The Weald clay ranges about half-way across the Channel; and if a belt of it should possibly pass round at the north end of the Varne and range to Wissant, it might prove to be worth further inquiries. In the Kimmeridge clay there is again a deposit of sufficient dimensions, but with subordinate bands which may be sufficiently permeable to present difficulties, whilst, though it comes to the surface on the French coast, its depth on the English coast must be very considerable. There is, however, just a chance that the Kimmeridge clay may in mid-channel be overlapped unconformably, and at a slight angle, by the Weald clay, and in that case they might for all purposes be considered as continuous strata. The

Oxford clay presents similar difficulties, in addition to its greater depth and inaccessibility. In the Secondary strata the irregular lie of the strata, and the presence of faults, are contingencies important to be considered.

On the other hand, the great mass of the Palæozoic rocks so protected by impermeable overlying strata, is of such great dimensions, and so compact, and holds its range so independently of the more irregular range of the Secondary strata, that it offers the conditions most favourable for the secure construction of a submarine tunnel; and that such strata can be worked in safety, and for considerable distances, under great bodies of water, has been proved at Whitehaven and Mons. But, on the other hand, the depth of these old rocks below the surface is very great, and they are much more dense and harder than the overlying formations.

There is another important problem in connection with the Palæozoic rocks which such an undertaking might help to solve. The great question of the range of the Coal Measures under the South of England has lately come prominently into notice; and it was, in fact, in inquiries connected with that question that the foregoing considerations presented themselves to the Author. The rich coal basin of Mons and the North of France has been traced to within 30 miles of Calais, where it thins out; but, like the coal basins of Liege, Aix, and Westphalia, which form separate sections of the same great trough, to the eastward, so there is reason to suppose that other sections of the trough set in on the westward, forming other coal basins, which possibly range to the west of England (Somersetshire), passing under the north-eastern part of Kent and the Thames. Any such work, therefore, as a submarine tunnel in these Palæozoic rocks could not fail to throw much light on the subject; while, in case it were to hit upon the line of strike of the Coal Measures, and could be carried on along that line, the work might prove otherwise remunerative, and tend to solve the great problem which interests so largely both geologists and the general public.

Such, briefly, are the conditions which bear on the construction of a submarine tunnel between France and England. The Author is satisfied that, considered on geological grounds alone, it is in one case perfectly practicable, and in one or two others it is possibly so; but there are other considerations besides those of a geological nature, and whether or not they admit of so favourable a solution is questionable. In any case, the Author would suggest that, the one favourable solution admitted, it may be desirable, in a question involving so many and such great interests, not to accept an adverse verdict without giving all those other considerations the attention and deliberation which the importance of the subject deserves.

Under any circumstances, the difficulties are formidable. Whether or not they are insuperable are questions which may safely be left to Civil Engineers. The many and great obstacles overcome by engineering science in late years lead the Author to expect that, should the occasion arise, and the attempt be considered worth the cost, the ability to carry it out would not be wanting. Various preliminary trials are, however, indispensable, in order to clear up some of the geological questions before a balance of the comparative advantages presented by the different formations could be satisfactorily settled, and before the grounds for action could be accepted.

The Paper is illustrated by a series of coloured maps and sections, from which Plates 8 and 9 have been compiled and reduced.

---

# APPENDIX.

*Particulars of Sections giving details of the several formations referred to in the foregoing pages. The right hand column is in most cases added by the Author.*

## The London Clay and Lower Tertiary Beds.[1]

### SHEERNESS.—Artesian Well.

(Abridged from Mr. Whitaker's "Geology of the London Basin" in the "Memoirs of the Geological Survey," vol. iv., p. 468.)

| | Feet. | |
|---|---|---|
| Clay | 9 | Alluvial beds. |
| Shingle | 3 | |
| Black mud | 35 | |
| *London clay*, with beds of Septaria in the lower part | 293 | Tertiary strata. |
| Loam and sand full of water | 10 | |
| Pebbly beds | 1½ | |
| Dark green sand with pebbles | 7½ | |
| Black loam | 1 | |
| Marl with a seam of lignite | 3 | |
| White and brown sands | 7½ | |
| Quick green sand | 10½ | |
| Hard green sand | 3 | |
| Total | 384 | |

### SOUTHEND.—Artesian Well.

(Ibid, vol. iv., p. 441.)

| | Feet. | |
|---|---|---|
| Surface soil | 3 | |
| *London clay* yellow clay | 30 | Tertiary strata. |
| *London clay* blue clay | 384 | |
| Bored through (in adjacent well) running sand, clay, sand and pebbles | 181 (?) | |
| Chalk | 302 | |
| Total | 900 | |

[1] See also the Harwich, Calais, and Ostend Sections, pp. 34, 35, and 37.

### FOULNESS ISLAND.—Artesian Wells.

(Abridged from Mr. Whitaker's "Geology of the London Basin" in the "Memoirs of the Geological Survey," vol. iv., p. 435.)

| | Ft. Ft. | |
|---|---|---|
| Soil | 3 to 5 | Alluvial and drift beds. |
| Sand and shingle | 40 to 60 | |
| *London clay* | 307 to 335 | |

Water from greenish sand at bottom.
The total depths of the wells vary from 350 ft. to 400 ft.

### MERSEA ISLAND.—Artesian Well at Little Wilsborough.

(MSS. of the late Dr. Mitchell.)

*London clay* and lower tertiary strata to the chalk, about 300 feet.

### DUNKIRK.—Boring for Water.

(From Meugy's "Essai de Géologie pratique sur la Flandre Francaise," p. 225.)

| | Mètres. | |
|---|---|---|
| 1. Made soil | 6·66 | |
| 2. Quicksand | 6·66 | Alluvial beds. |
| 3. Sand with shells, and with very thin beds of silt | 7·66 | |
| 4. Quicksand of a blackish colour | 5 | |
| 5. Yellowish quicksand, with broken shells | 5·66 | |
| 6. Blackish sand, mixed with shells | 4·33 | |
| 7. Tenacious clay, with a few small pebbles at a depth of from 314 to 320 feet (not traversed) | 80·66 | *London clay.* |
| Total | 116·63 | |

### The Chalk.

### MARGATE.—Well Shaft and Boring for Water.

(Abridged from Mr. Whitaker's Paper in "Memoirs of the Geological Survey," vol. iv., p. 467.)

| | Feet. | |
|---|---|---|
| Chalk | 31 | *Upper chalk.* |
| Chalk with flints | 265 | |
| Chalk without flints | 19 | |
| Grey clayey chalk | 3 | |
| Beds of grey and marly chalk | 56 | |
| Total | 374 | |

ST. MARGARET'S, NEAR DOVER.—TRIAL BORING.[1]

(Communicated by SIR JOHN HAWKSHAW, Past President, Inst. C.E.)

| | Feet. | Inches. | |
|---|---|---|---|
| Shingle | 9 | 0 | |
| White chalk | 209 | 0 | Upper or White Chalk. |
| Yellow chalk | 4 | 0 | |
| White chalk | 4 | 0 | |
| Fissure (salt water) | 3 | 0 | |
| White chalk | 20 | 0 | |
| Grey chalk | 30 | 0 | Lower or Grey Chalk. |
| White chalk | 10 | 0 | |
| Blue marl | 11 | 0 | |
| Pipe clay | 42 | 0 | |
| Light blue clay | 158 | 0 | |
| Light stone | 1 | 9 | |
| Light clay | 1 | 6 | |
| Stone | 1 | 3 | |
| Clay | 2 | 6 | |
| Stone | 1 | 6 | |
| Clay | 3 | 0 | |
| Stone | 1 | 9 | |
| Clay | 10 | 0 | |
| Stone | 1 | 3 | |
| Clay | 10 | 0 | |
| Stone | 0 | 6 | |
| Clay | 10 | 0 | |
| Green sand | 3 | 0 | |
| Gault clay | 19 | 0 | |
| (Boring still in gault clay) Feet | 567 | 0 | |

BORING ON THE FRENCH COAST, ABOUT 3 MILES WEST FROM CALAIS.

(Communicated by SIR JOHN HAWKSHAW, Past President, Inst. C.E.)

| | Feet. | Inches. | |
|---|---|---|---|
| Loam, light clay, and black peat | 3 | 0 | |
| Grey sand (with water) | 48 | 0 | |
| Grey sand (with black pebbles) | 5 | 0 | |
| Light brown clay | 2 | 0 | |
| Loose gravel | 9 | 0 | |
| Light sand | 1 | 0 | |
| Flints | 2 | 0 | |
| Loose chalk | 5 | 0 | Upper or White Chalk. |
| Hard chalk (white) and flints | 3 | 0 | |
| White chalk | 180 | 0 | |

[1] "Clay" is probably used in this section in the sense of "marl."

| | Feet. | Inches. | |
|---|---|---|---|
| Grey chalk | 60 | 0 | Lower or Grey Chalk. |
| Soft chalk (a lightish blue colour) | 124 | 0 | |
| Soft chalk (whitish) | 2 | 0 | |
| Soft chalk (dark blue) | 41 | 0 | |
| Soft chalk (lightish and sandy) | 20 | 0 | |
| Hard grey chalk | 37 | 0 | |
| Total | 551 | 0 | |

**The Jurassic and Oolitic Series.**

BOULOGNE.—Boring at Montalaire in the Valley of the Liane two Miles above Boulogne.

(From particulars given to the Author by M. E. Rigaux, of Boulogne).

| | Mètres. | |
|---|---|---|
| Detritus fallen down from the side of the hill. At 23 mètres the water flowed up to the superficial level | 23·0 | *Lower Kimmeridge Clay.*[1] |
| Alternations of marl and calcareous sandstone | 10·0 | |
| Alternations of marl and marly limestone | 9·0 | |
| White lithographic marly limestone which is worked for lime at Val St. Martin, near Boulogne | 4·65 | |
| Calcareous sandstone with traces of fossils | 0·45 | *Coral Rag.* |
| Oolitic limestone with marl. Second water level | 5·0 | |
| Calcareous sandstone and sandy marl | 4·90 | |
| Clay, the upper part blue, becoming black in going down | 13·0 | |
| Beds of limestone and blue marl | 3·85 | |
| Clay with foraminifera | 0·30 | |
| Hard oolite with fossils | 6·60 | |
| Very sandy clay with beds of schistose stone full of pyrites | 6·75 | *Oxford Clay.* |
| Clays and limestone, alternating by beds of 1·50 to 2·00 thickness | 13·00 | |
| Blue clay and grey marl | 9·20 | |
| Hard limestone | 3·65 | |
| Clays and marls | 16·90 | |
| Limestone | 2·00 | |
| Marl | 0·90 | |
| Limestone | 1·00 | |
| Clay and marls | 10·40 | |
| Limestone, 20 per cent. iron | ·50 | |
| Clays and marls, full of the characteristic fossils of the upper part of the Lower Oxford Clay | 18·10 | |
| Very hard limestone | 0·40 | |
| Clays and marls, with the same fossils as before, but scarcer (lower part of Lower Oxford Clay). This and the upper bed are worked for drains and tiles at Le Wast | 23·00 | |

[1] Above this division is a bed of loose sand and sandstone 12 to 15 feet thick, succeeded by a series of dark clays with septaria and calcareous bands.

| | Mètres. | |
|---|---|---|
| Oolite . . . . . . . . . . . . . . . . . . | 2·30 | *Cornbrash.* |
| Marl and white limestone alternating—is probably our Forest marble . . . . . . . . . . . | 5·00 | *Great Oolite.* |
| Oolite. The thickness is greater by half than I (Mr. R.) thought to find it; but some of it probably belongs to fuller's earth . . . . | 22·00 | |
| Limestone with fossils, not oolitic (fuller's) . . . | 3·65 | |
| Oolitic and siliceous limestone . . . . . . . . | 1·70 | |
| Blue marl, with black oolites and limestone . . . | 1·35 | |
| Rock . . . . . . . . . . . . . . . . . | 4·00 | |
| | 231·25 | |

"At 228·15 mètres the water rose rapidly and violently, and overflowed the boring;[1] it has since gone down to the ordinary level. At 231·25 mètres the rock (*Palæozoic?*) was very hard; and they tried during seventeen days to get a specimen, but the diameter of the last tubing was too small to allow it. During those attempts they got to 237 mètres. A very small bit was got up and analysed, and was found quite pure limestone, with a faint trace of magnesia and 2 per cent. residuum."

**Position of the Palæozoic Strata under the overlying Secondary formations.**

KENTISH TOWN, LONDON.—Boring for Water.

(Abstract from a Paper by the Author in "Quarterly Journal of the Geological Society" for February 1856.)

| | Feet | Inches. | |
|---|---|---|---|
| London clay . . . . . . . . . . . . . . | 236 | | Tertiary strata. |
| Lower tertiary strata . . . . . . . . . . | 88 | 6 | |
| Middle chalk. . . . . . . . . . . . . . | 244 | 6 | Cretaceous strata. |
| Lower chalk and chalk marl . . . . . . . . | 400 | 3 | |
| Upper greensand . . . . . . . . . . . . | 13 | 9 | |
| Gault . . . . . . . . . . . . . . . . . | 130 | 6 | |
| Red and grey sandstones . . . . . . . . . | 188 | 6[1] | *Palæozoic strata.* |
| Total . . . . . . . . . . | 1302 | 0 | |

HARWICH.—Boring for Water.

(Ibid, "Quarterly Journal of the Geological Society," vol. xiv., p. 250.)

| | Feet. | |
|---|---|---|
| Earth . . . . . . . . . . . . . . . . . . | 10 | Alluvial beds. |
| Red gravel . . . . . . . . . . . . . . . . | 25 | |
| London clay . . . . . . . . . . . . . . . | 23 | Tertiary strata. |
| Coarse dark gravel . . . . . . . . . . . . | 10 | |
| Plastic clay . . . . . . . . . . . . . . . | 7 | |
| Bluish clay with green sand . . . . . . . . | $3\frac{1}{2}$ | |
| Green and red sand . . . . . . . . . . . . | 5 | |
| Blue clay . . . . . . . . . . . . . . . . | 3 | |

[1] The water rose to 9 m. 54 c. above low water.

| | Feet. | |
|---|---|---|
| Chalk with flints | 690 | Cretaceous strata. |
| Chalk (lower) without flints | 160 | |
| Chalk, rocky, in thin layers | 38 | |
| Greensand (upper) | 22 | |
| Gault | 39 | |
| Black slaty rock | 44½ | *Palæozoic rocks.* |
| Total | 1070 | |

CALAIS ARTESIAN WELL.—BORING FOR WATER.[1]

(From the "Almanach de la Ville et du Canton de Calais pour 1845," p. 112–13, with additions from letters of Mr. E. Blakewary, and by the Author from inspection of specimens in the Calais Museum.)

| | Mètres. | |
|---|---|---|
| 1. Made soil and gravel | 3·00 | Alluvial beds. |
| 2. Grey and yellow quicksand, with shells | 8·50 | |
| 3. Grey and bluish quicksand, with shells and vegetable remains | 11·80 | |
| 4. Brown sandy clay | 0·50 | |
| 5. Rolled pebbles with veins of clay (some pebbles being found ·20 c. in diameter) | 2·65 | |
| 6. Brown clay | 6·05 | London clay. |
| 7. Sandy clay | 0·20 | Lower Tertiary strata. (Lower Landinian or Thanet Sands.) |
| 8. Greenish argillaceous sand | 0·35 | |
| 9. Green sand, with iron pyrites and shells | 2·70 | |
| 10. Very large rolled pebbles. (These two beds were very slowly traversed. An effort was made for the tube to penetrate with a weight of 900 kilos., but without success) | 1·10 | |
| 11. Greenish grey sand, with traces of shells | 10·00 | |
| 12. Very fine grey sand—lighter coloured and shells | 5·20 | |
| 13. Light brown sandy clay | 0·55 | |
| 14. Sandy conglomerate, with iron pyrites | 0·30 | |
| 15. Argillaceous sand, and with shells | 1·80 | |
| 16. Compact sandy clay, with iron pyrites | 3·30 | |
| 17. Very compact clay, brown, and with shells | 7·00 | |
| 18. Hard sandy clay and green sand | 2·00 | |
| 19. Greenish argillaceous sand | 1·10 | |
| 20. Argillaceous grey sand | 2·20 | |
| 21. Brown sandy clay | 2·40 | |
| 22. Brown clay with flints (*green coated*) | 0·25 | |
| 23. Friable white chalk | 8·05 | Upper and middle chalk. |
| 24. White chalk, with a few black flints | 83·45 | |
| 25. Grey chalk, with cherty flints | 4·15 | |
| 26. Marly chalk | 0·05 | |
| 27. Hard chalk (tufaceous), with a few flints | 33·25 | |

[1] This and the preceding two borings were unsuccessful in procuring water.

| | Mètres. | |
|---|---|---|
| 28. Very hard chalk marl . . . . . . . . . . | 1·40 | Lower chalk and chalk marl. |
| 29. Very hard chalk . . . . . . . . . . . . | 9·60 | |
| 30. Ditto marly chalk . . . . . . . . . | 9·40 | |
| 31. Grey chalk (*craie siliceuse*), with iron pyrites . . | 2·15 | |
| 32. Bluish grey chalk, very hard . . . . . . . | 1·15 | |
| 33. Very hard chalk marl . . . . . . . . . . | 0·75 | |
| 34. Grey chalk (*craie siliceuse*), very hard . . . . | 4·50 | |
| 35. Grey chalk (*craie siliceuse*), with iron pyrites . | 7·50 | |
| 36. Very hard chalk . . . . . . . . . . . . | 26·55 | |
| 37. Grey chalk (*craie siliceuse*) . . . . . . . . | 12·55 | |
| 38. Very hard grey chalk (*craie siliceuse*) . . . . | 13·45 | |
| 39. Hard chalk, marl . . . . . . . . . . . . | 8·30 | |
| 40. Very hard grey chalk (*craie siliceuse*) . . . . | 6·99 | |
| 41. Very hard grey chalk, with green grains—glauconite . . . . . . . . . . . . . . | 0·90 | Upper Greensand. |
| 42. Compact grey micaceous clay . . . . . . . | 1·30 | Gault. |
| 43. Ditto, ditto, ditto, darker, with iron pyrites | 3·65 | |
| 44. Sandy clay, with green grain and iron pyrites . | 1·15 | |
| 45. Brown clay, with coarse grains of quartz and iron pyrites . . . . . . . . . . . . . . | 1·70 | |
| 46. Sandstone, with green grains, very hard . . . | 5·31 | Lower Greensand. |
| 47. Ditto, less compact . . . . . . . . . . | 14·50(?) | |
| Calcareous and shaly beds (carboniferous) . . | 10·36(?) | *Palæozoic strata.* |
| Total . . . . . . . | 346·86 | |

A spring of water was met with at a depth of 160 mètres; but, as it was brackish and did not rise to the surface, it proved useless.

## HAMES-BUCRE, NEAR GUINES.—Boring for Coal.

(From Degoussé's and Laurent's "Guide du Sondeur," Pl. XLIX.)

| | Mètres. | |
|---|---|---|
| Vegetable earth . . . . . . . . . . . . . | 2·0 | |
| White chalk with flints . . . . . . . . . . . | 106·0 | Middle chalk. |
| Bluish chalk marl . . . . . . . . . . . . | 4·0 | Lower chalk. |
| Greenish grey chalk . . . . . . . . . . . | 4·0 | |
| Greenish chalk . . . . . . . . . . . . . | 28·0 | |
| Dark grey chalk . . . . . . . . . . . . . | 50·0 | |
| Clayey greensand . . . . . . . . . . . . | 0·20 | Upper Greensand. |
| Black clay . . . . . . . . . . . . . . | 9·80 | Gault. |
| Red schists (Devonian rocks) . . . . . . . . | 2·0 | *Palæozoic strata.* |
| Total . . . . . . . | 204·0 | |

### Borings in the Boulonnais.

(Communicated to the Author by M. E. Rigaux, of Boulogne.)

" A boring was made (two years ago) at Le Bail, 1½ mile north-west from Marquise.

" They found there 90 feet Oxford clay inferior,
100 feet Kelloway and Great Oolite,
under these the red *Devonian* dolomite of Beaulieu; they could recognise that this bed and the red and grey shales underneath had a dip of 45°, but they could not determine on what side the dip was.

" We have in our museum (of Boulogne) specimens of some old borings, two of which are near Loquingoio. One at Fouquesolles has gone through 300 feet of violaceous shales and greenish grit and got to Devonian limestone. The second one at Rebergues was in the white sands and sandstone, which overlie the red shales (*Devonian strata*).

" At a boring at Houllefort 3 miles south of Hardinghen they found grey shales which they looked upon as the same as the *Silurian* shales found at the boring at Caffiers."

At the following places the older rocks were reached under overlying cretaceous strata, but no particulars of depth are given:—

" Leubringhem.—Reddish shales }
" Landrethun.—Grey or whitish shales } *Devonian strata.*
" Caffiers, 1837.—Slaty shales—(*Silurian strata*).
" Celles (near Desvres).—Greyish or light blue shales.

### OSTEND.—Artesian Well.

(From the " Proceedings of the Société Paléontologique de Belgique about 1863.")

| | | Mètres. | |
|---|---|---|---|
| 1. | Vegetable earth | 0·25 | Alluvial beds. |
| 2. | Fine grey sand | 1·15 | |
| 3. | Very sandy greyish yellow clay | 0·50 | |
| 4. | Ditto grey ditto | 0·80 | |
| 5. | Grey sand mixed with shells, and a little peat | 2·40 | |
| 6. | Peat | 1·55 | |
| 7. | Sandy, bluish grey clay | 2·71 | |
| 8. | Bluish grey quicksand | 6·08 | |
| 9. | Sand, with a considerable number of shells | 2·36 | |
| 10. | Dark grey clay | 4·85 | |
| 11. | Bluish grey quicksand with shells | 3·55 | |
| 12. | Fragments of shells | 0·50 | |
| 13. | Fragments of shells with rolled pebbles | 5·00 | |
| 14. | Rolled pebbles | 1·60 | |
| 15. | Greenish grey sand | 0·45 | |
| 16. | Bluish grey clay, very tenacious | 136·50 | London clay. |

| | | Mètres. | |
|---|---|---|---|
| 17. | Argillaceous sand with some pyrites | 3·00 | Lower Tertiary strata. |
| 18. | Greenish grey sand, full of shells, rolled pebbles, and pyrites | 5·00 | |
| 19. | Indurated clay (Argile petrifiée) with shells | 4·00 | |
| 20. | Grey sand with shells | 3·00 | |
| 21. | Grey sand with fragments of shells | 4·00 | |
| 22. | Greenish grey clay containing but little sand | 1·50 | |
| 23. | Ditto ,, ,, with shells and fossils | 1·25 | |
| 24. | Dark grey ,, with shells | 3·75 | |
| 25. | Lighter coloured clay | 4·90 | |
| 26. | Sandy clay | 4·30 | |
| 27. | Clay with a larger proportion of sand | 3·30 | |
| 28. | Pure white chalk | 64·00 | Cretaceous strata. |
| 29. | Marly or greenish grey chalk | 2·20 | |
| 30. | Red calcareous marl | 15·80 | |
| 31. | Fawn-coloured ,, | 9·00 | |
| 32. | White sand | 1·40 | |
| 33. | Dark coloured slaty rock | | *Palæozoic strata.* |
| | Total | 300·65 | |

A first spring was met with at a depth of 173 mètres.
And a second spring at ,, 185 ,,

Mr. Henry Willett remarked, through the Secretary, that Sir John Hawkshaw's borings proved the similarity of the strata on both sides of the Channel, and the last discovery of the Sub-Wealden exploration, viz., the existence of the Kimmeridge clay of the same character as that in the cliffs in the Boulonnais district, seemed to assert the ancient continuity of strata. He thought it was also satisfactorily proved that the same horizontal bedding, observable in the cliffs at Fairlight, was continuous as far as Netherfield, distant about 10 miles in a north-westerly direction. As one fact was worth a dozen theories, it was important that the Netherfield boring should be prosecuted until the Palæozoic strata were reached.

He thought the following questions might be put to the Author with advantage:—

1st. Was there any evidence to show what were the natural causes in operation which effected the separation between England and France?

2ndly. While, as was well known, the destruction of the cliffs by marine erosion was slowly but surely widening the Channel, was there any evidence that the same denuding forces, viz., of storm and tidal currents, were deepening the Straits in any portion of the Channel? This must be the case if the current at the bottom was swift, and if the bottom itself was not protected by marine growth, or by deposit of sand.

3rdly. Did any data exist as to the rate at which this increase of depth proceeded? He could not admit that the Lower Chalk and the Chalk Marl were unsuitable for tunnelling; on the contrary, he thought they were more suitable than any other strata likely to be found in the district. The Wealden strata were notoriously unfit for engineering purposes, first, from the frequency and uncertainty of their faulting, and secondly, from their alternating character of clay and sand. The Kimmeridge clay, if it extended in a horizontal bedding across the narrowest portion of the Channel, and if it were of the same dense structure as the lower beds discovered at Netherfield, would perhaps prove more desirable for tunnelling. There was, however, much virtue in *if*, and the fact that at Bexhill, distant from Fairlight about 3 miles to the eastward, the faulting was so serious, as to suggest the possibility of the strata being actually reversed, did not augur well for an unbroken continuity, unless in the direct line of the anticlinal axis.

Mr. Edward Hull observed, through the Secretary, that no one was better qualified than the Author to advise the eminent engineers who had projected the scheme of the Straits Tunnel regarding the nature and position of the strata liable to be encountered. Mr. Prestwich's proposal was at once bold and original; and if the question of water were the only one to be considered might be said to solve the problem. But as the depth at which a tunnel in the Palæozoic rocks would have to be driven was admittedly great, questions of gradients, increased cost, &c., here came in, and imposed other problems. Without venturing to pronounce an opinion in the present stage of the inquiry, he had an impression that a line taken in the central or lower portion of the Chalk, from the neighbourhood of the South Foreland to Calais, would present the least number of difficulties. The great thickness, persistency, and uniform mineral character of the Chalk formation, together with the facilities it presented for tunnelling, offered strong inducements in its favour; and should water-bearing fissures be encountered, which would doubtless be the case, they could be dealt with by strong iron tubing.

Mr. WILLIAM LOW stated, through the Secretary, that he could corroborate the importance and value of the Paper, from the geological investigations he made in 1867, previous to fixing the direction of a proposed tunnel under the Channel, for uniting the railway systems of England with those of France. The line of the proposed preliminary driftways, preparatory to the construction of a double tunnel, without sinking a shaft in the Channel, and with the object of obtaining ventilation, both during construction and after completion, started from the English shore at the South Foreland, and was continued in a straight line until it reached the French shore, at a point ½ mile north-east of Sangatte. In that line he expected the bottom of the lower bed of Chalk would lay at a uniform depth of about 450 feet under the level of the sea. And, as near as he could judge, it coincided with the line of strike of the Chalk, which dipped in a north-east direction. There was a difficulty in fixing upon this exactly, as uniformity in the dip of the Chalk beds was uncertain, the dip being probably less steep as it approached the outcrop. He found that, on the English coast, whilst the dip of the Chalk was about 520 feet in 8½ miles, on the French coast it was upwards of 1,000 feet in the same distance. It was doubtful whether this great fall on the French side was uniform, or whether a fault intervened between Sangatte and Calais. The true line of strike of the Chalk at the outcrop and at the level of the sea was found in a straight line between Folkestone, in England, and Wissant, in France. It was the difference in the dip of the Chalk beds in both countries that induced him to suggest to drive the tunnel along the centre of the lower bed of Chalk. Mr. Prestwich referred to a tunnel proposed by M. Thomé de Gamond to be carried through the Great Oolite and other measures lying under the Chalk, between Cape Gris-nez and East Ware Bay. This was abandoned by M. de Gamond many years ago; and another engineer and himself signed plans on February 7th, 1868, to be submitted to the French Government, upon which the tunnel was laid down as passing in the lower bed of Chalk from the South Foreland to Sangatte. He was still of opinion that the only practicable line for executing a tunnel between England and France was in the lower bed of Chalk. The difficulties to be overcome in constructing a Channel tunnel appeared insurmountable to those who had not investigated the subject. The geologist was satisfied that, on geological grounds alone, it was in one case perfectly practicable, and in one or two others possibly so. It now lay with the civil and mining engineers to determine whether the difficulties of constructing such a work were, or were not, insurmountable.

Mr. John Evans, F.R.S., wished to express the satisfaction he was sure all must feel at the extremely able manner in which the geological questions involved in the matter under consideration had been brought before the Meeting. Mr. Prestwich admitted the impossibility of a tunnel being constructed through the London clay, or through the lower beds, such as the Kimmeridge clay, overlaid as it might be by the Wealden. His preference was for the Palæozoic rocks, but even in regard to these he admitted that there were important elements of uncertainty. The distance beneath the surface and the position of the Palæozoic rocks on the French side of the Channel were known; but with regard to England there was not sufficient information to enable a definite opinion to be formed. Even if the borings on the English side of the Channel, say in the neighbourhood of Dover, were to meet the Palæozoic rocks at some not inaccessible distance, the existence of any comparatively level ridge between that point and Boulogne or Sangatte would be doubtful. In contorted beds, such as these were known to be, there would, in all probability, be considerable unevenness in the surface against which the Secondary deposits were laid. He imagined that the level of the central part of the proposed tunnel should be the highest, so as to allow of drainage to either end; and at such a depth as 1,000 feet below the sea there must of necessity be a considerable addition to the length of the slanting passages leading into the main or central tunnel, which would add enormously to the expense and difficulty of the work. One geological point had (no doubt accidentally) been omitted, viz., the probable presence of the Upper Greensand between the Gault and the Lower Chalk. It was a permeable stratum, and would materially interfere with the water-tightness of a tunnel coming in contact with it. If, however, the Lower Chalk rested in almost immediate contact with the Gault clay, there would be a considerable thickness of impervious strata, which would conduce materially to the convenience of the engineer who might undertake the work. With regard to the Chalk, in the neighbourhood of Dover, where unfissured, it was more impervious to water, *i.e.*, the angle of friction of the water passing through it was greater, than in many other parts of England. In some parts, as in Hertfordshire, the incline might be represented by 12 feet 6 inches to the mile; but in the neighbourhood of Dover it required a hydrostatic pressure equal to 40 feet to the mile to enable water to pass through the Chalk, as was shown by the inclination of the stream from Buckland to Dover.

Mr. Homersham thought Mr. Prestwich had passed over the Gault clay too lightly. The reason assigned was its insufficient thickness. He had dealt with that formation in many places, and had ascertained that it was not so thin as was generally supposed by geologists. At Caterham, having first sunk a shaft through the Chalk, he found a thickness of 343 feet of Gault clay before reaching the Lower Greensand. He was not aware that near Folkestone or Dover any borings had been made through the Gault clay where the Chalk was immediately superposed. In sinking a well in Gault clay where it cropped out at the surface of the ground, as at the southern side of the chalk hills known as the North Downs, the Lower Greensand would probably be reached after 20 feet; a little further north it would be 60 feet, and further north still 100 feet. It was not until the Chalk itself had been penetrated, and the Gault clay thus reached, that the full thickness of the formation was encountered, owing to its having been thinned off at places where it appeared at the surface as at Wissant. At Arlesey, where the Upper Greensand was pierced before coming to the Gault clay, the thickness of this formation was 204 feet. He did not know of any borings or wells sunk through the Chalk into and through the Gault that would warrant the Author's confidence as to the extreme thinness of the formation between Folkestone and Dover, and between Cape Gris-nez and Calais. If the Gault was of sufficient thickness for a tunnel, he believed there was no formation through which it could be so successfully carried. It did not swell like the London clay. It was homogeneous, easy to work in, and impermeable to water. There was this advantage in going through it, that the depth below the surface might be chosen. It dipped down from north to south, or from Folkestone to under Dover and the Thames, and as it crossed the Channel it still dipped in nearly the same direction; therefore by going more to the north or the south, and sinking through the Chalk, the Gault clay could be reached at almost any level desired.

Mr. Warrington Smyth said the Author had referred to several cases in the North of England in which a considerable amount of work had been carried on beneath the sea. Being familiar with those works, he desired to state a few additional facts in connection with them. He wished especially to refer to the importance of carrying out works of exploration for the purpose of selecting the most suitable formation through which to pass. He agreed in the selection of certain beds of an argillaceous character in preference to any other kind of material, especially one likely to contain limestone or chalk. The mines at Whitehaven, belonging to Lord Lonsdale, had been worked to a distance, if followed by the regular roads taken by the colliers, of about 4 miles from the nearest shaft, but considerably less in a straight line. But the principal point to be gained from the experience of those submarine collieries was, that although the Coal Measures were exposed at the bottom of the sea, and in some parts lay bare over considerable areas, the workings had been carried on with a remarkable degree of security and freedom from influx of water, in consequence, as he believed, of the argillaceous character of most of the measures above the seams that were worked. The shafts had an average depth of about 120 to 150 fathoms. In consequence of the numerous up-throw faults or dykes passing out to the westward, the average workings were from about 70 fathoms to 120 or 140 fathoms under the bottom of the water. It had been already recognised that where the depth was less than 70 fathoms, it would be probably insecure to remove large portions of coal, and pillars were accordingly left about 20 yards square. These might, elsewhere, be split or divided down the middle, with perfect freedom from accident, and without the slightest influx of water. Further than this, the pillars had been removed from continuous areas, extending over many acres, without any evil effect; no doubt in consequence of the argillaceous materials above the coal tending to fill up a larger space than they originally occupied, so that there was no movement in the bed of the sea above. Parts of some of these areas were beneath the piers of Whitehaven Harbour, and it did not appear that a crack had been seen in them, or a stone observed out of place. This was a remarkable instance of large excavations being possible under the sea in strata of which a sufficient portion consisted of thoroughly argillaceous material. A little further north a sad example was presented by the colliery at Workington, which, in 1837, in consequence of the pillars having been worked too thin, and at too small a depth below the sea, was inundated, and almost every soul in the workings perished. A sufficient thickness must be left over such excavations – a thickness sufficient to dam out, not only all the springs occurring in the measures, but also the entire body of sea water. In these Palæozoic rocks it was important to be prepared for the contingency of jointy ground, which might accompany some of the dykes or dislocations. In certain instances, where several of these had ramified from one point, or others had met in one point, it had been found desirable to trust no longer to the usually retentive character of the measures, but to fill up closely excavations of that kind with packing, and to excavate no further in the vicinity. The workings to which he alluded had been carried 2 miles along the shore, and to a distance varying from 2 miles to 3 miles from the shore, and there had been no mishap from breakages of the surface or the influx of water. Passing to the coast of Cornwall, one or two instances might be taken as a warning. There were no measures of an argillaceous kind overlying the mineral ground. The mining was carried on in rocks of a more ancient and a harder character, and the mineral veins were unfortunately in a vertical position, striking upwards towards the bed of the sea. In some of these cases, as at Botallack, the workings had been carried on for many years, sometimes to within a small distance from the sea; yet owing, as it would appear, to a considerable amount of water-tight silt occupying the bed of the sea, the water had no tendency to make its entrance where it might be expected, along the line of the back or the outcrop of the vein. And singular to relate, four or five mines along that coast were remarkable for their exceeding dryness, as compared with average mines of the same depth in the same county. There was, however, an instance in the mine of Levant of the danger which might accrue from excavating ground of that sort to within too small a distance of the sea bottom. Some years ago the miners had passed along the 40-fathom level (*i.e.*, 40 fathoms deep from an adit a little above the level of the sea), and penetrated to a distance of 150 fathoms seaward from a shaft close to the cliff. They there met with favourable ground for tin, and commenced workings, which were ultimately carried to a height of 15 or 20 fathoms. This, coupled with the excessive rise of the level or gallery that had been driven out from the shore, brought the workings to within less than 20 fathoms of the sea bed. At that point an abundant stream of salt water was cut; but the men, seduced by the favourable appearance of the veins, were constantly advancing and taking away more of the ground. In 1866 great uneasiness was felt. In consequence, he examined the workings from end to end to determine what should be done, and he came to the conclusion that it would be unsafe to advance them a single foot further. The men owed their security to the fact that, instead of a mere chalk or limestone, much fissured, the veins consisted chiefly of a strong quartzose material, which was also fissured, and the salt water poured down in streams. The workings below attained a depth of nearly 300 fathoms from the surface, and men were still working in the deeper parts of the mine. From the dense, hard nature of the vein stuff, the water was unable to do more than find its way through: it dissolved nothing, and washed nothing tangible away. Some of the older miners stated that, between thirty and forty years ago, the stream from the level was as abundant as at the present moment. That was a remarkable fact, as showing the small amount of wear and tear produced by a considerable stream of water, although under great pressure, upon a rock of suitable hardness, and not likely to be decomposed or dissolved. Before an attempt was made to construct a tunnel under the Channel, it was important to ascertain all the facts that could be arrived at by preliminary investigations. It was better to trust to argillaceous material, even of comparatively small thickness, than to a greater thickness of material of another character.

Mr. BAZALGETTE, C.B., said a few years ago he had to sink a well at Crossness, and expected to get a quantity of pure water from the Chalk; but it turned out brackish, and unfit for the purposes required. The boring was continued with the hope of penetrating the Gault clay to the Lower Greensand, in order to obtain a better supply of water. The Gault clay was reached at a depth of about 800 feet before Ordnance datum, and the stratum proved about 150 feet thick; but the boring having been commenced with the intention of continuing it to the Chalk only, the pipes were so reduced in size, that the boring tools were not sufficient to get through to what was believed to be the required depth, 1,000 feet below the surface. The work had since been in abeyance. Two facts had been ascertained—that, at Crossness, at the depth of nearly 1,000 feet, Gault clay existed, and that the Lower Greensand was not to be found at that depth. It became a question of the greatest interest to determine whether, if there should be a fault in the Lower Greensand at that point the Old Red Sandstone might not be found in its stead, and the existence of Coal under London be thereby solved.

Mr. W. Topley, of the Geological Survey of England, remarked, through the Secretary, that the Paper might be divided into two parts:—1st, that treating of matters connected with the Channel Tunnel, which had been more or less discussed before; 2ndly, that which was entirely new.

With respect to the first division, it might only be necessary to consider the Chalk in any detail; for although, as the Author had shown, the London clay was well adapted for tunnelling, any tunnel to pass wholly through this formation must be of enormous length. Below the London clay there was no formation worth considering for this purpose till the Chalk Marl was reached. It was not disputed that the Chalk Marl afforded a thick and readily accessible stratum through which a tunnel could be driven; and it was known that this, and the Chalk without flints immediately above it, formed the bed of the Straits of Dover. There was no evidence, either positive or presumptive, of any fault or other disturbance of the strata between the English and the French coasts. The only question of real importance, then, was the amount of water likely to be met with. On this point the Author expressed an unfavourable opinion. The Chalk Marl was known to be a practically impervious stratum; but it, like the higher beds of Chalk, was often traversed by fissures, which gave a ready passage to large quantities of water. It should be remembered, however, that this was chiefly the case where the Chalk lay above the sea level, where water was constantly passing through the rock and enlarging such fissures as already existed. Fissures were sometimes met with in deep wells, or in headings driven from wells far below the line of saturation; but such fissures would certainly be rarer and less important than where the Chalk was above the sea or the line of saturation, and consequently where water passed steadily and constantly through the rocks. The Chalk now beneath the Channel had been there for many ages, and, although it might, in past geological periods, have sometimes been above the sea, and even above the line of saturation, yet the fissures would probably have been but slightly worn and enlarged; and consequently there was the less likelihood of meeting with large bodies of water pouring through them. But even if fissures occurred, the modern methods of pumping would be adequate to overcome any amount of water which they would be likely to yield. He had elsewhere the discussed feasibility of constructing a tunnel through any of the Secondary formations underlying the Chalk;[1] and he had shown that, in passing from the French to the English side of the Channel, a series both of porous and of impervious beds would be traversed, the former possibly fully charged with water. Tunnelling through them would be almost impossible. The Author suggested that perhaps the Weald clay might abut against the Kimmeridge clay in the bed of the Channel, so that it might be possible to drive a tunnel direct from one to the other, both being mainly (although not entirely) impervious formations. Recent discoveries in the Sub-Wealden boring rendered it unlikely that this was the case. Even if it were so, there were no means of ascertaining where the overlap of the beds took place, or where a tunnel should be driven so as to offer the least chance of meeting with the Portland or Hastings sands. Tapping either of these beds would probably be fatal to the undertaking.

The Author broke new ground when he introduced the Palæozoic rocks into the question. No geologist now doubted that beneath the south-east of England and the north-west of France there was a floor of Palæozoic rocks, the depth and range of which were wholly independent of the range of the Secondary and Tertiary rocks above. Where these rocks had been reached, in wells or in borings, or explored by actual workings, they were generally free from water, the exceptions being some cases where Carboniferous Limestone occurred. If a tunnel could be driven through these rocks (other than limestones), it was almost certain that no trouble would be felt from the presence of water. The chief difficulty in the matter was the depth, and consequently the long approaches which must be made at either end, thus enormously lengthening the tunnel and increasing the expense. The maps and sections submitted to the Institution by the Author, embodied all the known facts as to the depth, &c., of these rocks. The only hope of taking a tunnel through them lay in the chance, that they might somewhere be at a less depth near the shores of the Channel than borings had hitherto proved them to be. The Author supposed that the strike of the Palæozoic rocks, which could be observed near Marquise, would continue across the Channel, and that on the English side, along the same line which would come near Folkestone, there would be a ridge of old rocks at no great depth from the surface. The old rocks attained a height of 370 feet above the sea

[1] *Vide* "Quarterly Journal of Science" for April, 1872.

near Ferques, but along the presumed line of the ridge they sloped down so rapidly as to be beneath the sea level at Wissant; how far beneath was not known. If this slope continued, their depth beneath the sea at Folkestone would be considerable. Many considerations led to the inference, that the Palæozoic floor in the south-east of England would generally be found at a depth not much exceeding 1,000 feet below the sea; sometimes at a less depth than this. It was probable that it would be somewhat nearer the surface along the strike of the ridge which traversed the north-eastern corner of the Bas Boulonnais; but the exact direction on the English side could only be known by experimental borings. The Sub-Wealden boring could not fail to yield important information upon this point. If further explorations were determined upon, it was desirable that the boring in St. Margaret's Bay should be continued; probably an additional depth of 150 feet there would reach the Palæozoic rocks. It should be borne in mind that such explorations would also throw important light upon the question of the occurrence of the Coal Measures beneath the south-east of England. In connection with the possible depth of the Palæozoic rocks at Folkestone, Mr. Prestwich had referred to the supposed thickness of the Weald clay at Hythe. Mr. Topley stated that near Leith Hill this clay was about 1,000 feet thick; at Maidstone it was 600 feet. If it thinned regularly to the east, it might be expected to be about 350 feet thick at Hythe; and he thought its thickness there would not greatly exceed that amount.

Captain Tyler said he had for many years taken great interest in this question, and had referred to it at some length in an official report in 1869, in which he had enumerated the different schemes that had been brought forward. Since then the project had been in abeyance; but he hailed with pleasure the reading of this Paper, as a new starting-point for the undertaking. The Author had ably and concisely stated all that was known as to the geological conditions of the Channel, upon which must be founded any decision as to further explorations with a view to solve the question under consideration. The Paper consisted partly of a statement of facts and partly of deductions from those facts, and it was the latter which the Meeting had principally to discuss. It was stated that a tunnel through the London clay would require to be 80 or 90 or 100 miles in length, which was quite enough to put that formation out of court. It was considered that it would be inexpedient, or it might be impossible, to work through even the lower part of the Chalk formation in consequence of (1) difficulties connected with land springs; (2) the probable occurrence of faults or fissures; and (3) the dangers of leakage through the exposed Chalk at the bottom of the Channel. Preference was given to the Palæozoic rocks. No alarm was experienced at the idea of tunnelling through Silurian slates, or Devonian or other limestones; and there was evidently a lingering notion that coal might be extracted during the progress of the tunnel. That was, no doubt, a tempting prospect,—the idea of realising 40*s.* a ton for the excavated materials. But the practical question was, what further explorations should be made? Considering the length of a tunnel through the clay, and the evidently great but uncertain depth of a tunnel through the Palæozoic rocks, the safe and middle course seemed to be a further exploration, as had been proposed, through the Lower or Grey Chalk. Land springs might prove an obstacle; but these would be found at the commencement of the work, and before any serious expense had been incurred. With regard to leakage, any one who knew much of the Lower Chalk would be pretty well convinced that the impermeability of the argillaceous Chalk Marl at a considerable depth was so great as to afford every probability of success, if only drift ways were successfully pushed in the first instance to a distance of $\frac{1}{2}$ a mile from the land on each side. There was, of course, a possibility of meeting with faults or fissures; but there was also a probability that they would be completely choked up by material as impermeable, at the depth of the tunnel, as the Grey Chalk itself. It appeared to him that the prospect of success was sufficient to justify an attempt at boring through the Chalk from each side of the Channel. It was hardly possible, indeed, to test the problem in any other way. The difficulty and expense of boring vertically through the water in the Channel would be considerable; a number of such bore holes would be necessary in order to afford any degree of certain information; and they might, even if they were carried out, cause mischief by creating, so to speak, the very fissures which it was so desirable to avoid. All must admit the necessity for an improvement of the present means of communication across the Channel; and those who were in favour of a tunnel should not consider as rivals any other schemes having that object in view. There were three or four hundred thousand persons crossing every year, in spite of the inadequate facilities afforded for the passage, and in spite of the disturbed weather that prevailed for three quarters of the year. These numbers would soon be doubled if the facilities for crossing were increased; and it was to be hoped some of the vessels now in course of construction would tend to that result. The greater the number of persons crossing the greater would be the necessity for the future construction of a tunnel. If it should be found that the Gault below the Chalk Marl was a sufficient protection against water from below, that the vast mass of the Chalk Marl was itself a sufficient protection against water from above, and that the land springs were not too great an obstacle to the progress of the work for the first $\frac{1}{2}$ mile from each shore, then hope might be entertained of the ultimate success of the project. A tunnel 20 miles long under the sea, with 5 miles of approaches at either end, would be in any case a gigantic operation; but provided only that the work was not stopped by water, it was not in reality so formidable as might appear at first sight. In the Mont Cenis tunnel, $7\frac{3}{4}$ miles long, every yard of rock had to be drilled and blown away by gunpowder; and he had seen the steel jumpers, worked by machinery, losing their edges and exchanged for others, whilst apparently making little impression for half an hour at a time upon the opaque quartz rock, which extended through a distance of 300 metres in that tunnel. The cutting away of the Chalk Marl under the Channel would be comparatively an easy operation. Not only would much less labour be necessary, but the work would progress with far greater rapidity, only to be measured by the arrangements for the removal of the material as fast as it could be cut away from the faces of the headings. And it was easy to conceive that the real difficulties to be encountered might not be in the excavation of the 20 miles under the sea, but in the sinking of the shafts, and in the construction of the land approaches. Some persons feared that a tunnel might facilitate an invasion of the country by foreign powers. There need, however, be no apprehension on that score; for though it might be difficult to get through the tunnel without too much water, it would be easy to contrive means of letting in water if desired. It would also be easy to deposit adequate quantities of gunpowder at given points to be exploded by means of electric wires from any desired positions. If a hostile army were to enter the tunnel, the old drama of a certain host being drowned in the Red Sea might be repeated on a larger scale and with equally satisfactory results.

Professor Ramsay thought it might be possible to make a tunnel through the London clay, but its length would, in his opinion, be an insuperable barrier. The project of a tunnel through the Palæozoic rocks was so problematical that it could hardly be entertained as feasible. No one knew at what depth the

Palæozoic rocks lay on this side of the Channel. In the Wealden exploration, now going on, they were not expected to be found at a less depth than about 800 feet, and the depth was not likely to be more accessible between that boring and the coast. To go westward, to a point where they cropped up to the surface, would add more than 130 miles to the length of the tunnel, and no man knew at what depth they might lie between that point and the Wealden boring. If it happened that the Kimmeridge and the Wealden clays came together, it might be possible to make a tunnel through them without serious difficulty; but the general feeling seemed to be in favour of the Cretaceous strata. It was said that the Gault was much thicker than was usually supposed. It was known to be much thicker in some other areas than it was in the Wealden area—the district near which it was considered the tunnel could be best constructed. From personal knowledge he could state that it was there so thin that it could not be relied on for the passing of a tunnel through it from one side of the Channel to the other. The dip of the strata all across the Channel was not known with anything like precision, and no one could say that it might not vary considerably. The line of outcrop of the Gault and the Upper Greensand (which was also exceedingly thin), and of the base of the Chalk, would not be straight, but somewhat sinuous, depending on the angle of inclination of the strata, and the denudation they had undergone, either beneath the sea or before they were depressed beneath the sea level. To execute a tunnel, therefore, with anything like certainty, it would be necessary to begin in a set of strata of considerable thickness, and not immediately near the outcrop. The partially argillaceous beds lying at the base of the Chalk were not of great thickness, but were thick enough to render it certain that they might be bored through all the way, making allowance for unknown accidental circumstances; but if the dip varied, the boring would have to follow the sinuous line described by the strata under the level of the sea. No doubt fissures might occur; but there was no reason to suppose that there was any great line of fault passing through the Channel: there was no proof of it, and no absolute proof against it. But considering how little the Chalk was fractured by important faults on the English side of the Channel, and how regularly it lay on the opposite side, he did not think it likely that there would be a disturbance by any serious faults. There were often fissures at the surface, but such fissures were apt to be closed at great depths, and were not likely to be of any importance in passing through one stratum of chalk into another. There was a difficulty, however, which he thought of some importance, namely, the existence throughout the Chalk districts of pot-holes. Water from the surrounding area ran into these holes, disappeared in the Chalk, and went down to unknown depths. Any one who had examined deep railway cuttings must have been struck with the frequency of these pot-holes, which were filled not only with clay, but often with sand, to a considerable depth. There was no reason why these sinuous veins of sand might not go down to almost an unknown depth in the Chalk. It would have to be considered whether or not they might not pass through the marly Cretaceous strata lying towards the base of the Chalk. There was so much calcareous matter in the greater part of these subformations of chalk, that it might be a question whether much of it might not in the course of time be dissolved by the carbonic acid absorbed by the rain water falling through the Cretaceous strata, and whether these pot-holes might not be produced even towards the base of the Chalk formation itself. He did not suppose that the permeability of the Chalk to water, in a general way, was so extreme that it could not be overcome by ingenuity and mechanical appliances; but the obstacle to which he had referred was one that it might be more difficult to encounter. There was another point to which attention should also be drawn. In passing in a straight, or approximately straight, line through these strata, it would be necessary to take into account the possible sinuosity of the line that would mark the junction of the true Chalk with the Chalk Marl.

Sir John Hawkshaw said there were several points connected with the project (for at present it was only a project), with regard to which geologists appeared to require some information. In the first place the project, so far as he was concerned, was not put forward without consideration. It was long since he first thought of the practicability of a tunnel across the Channel; and in 1864–5, feeling dissatisfied with the geological information then obtainable, he employed Mr. H. Day, a practical geologist, who could also use the spirit level, to investigate the matter. He spent some months in ascertaining the outcrop and depth of the strata on both sides of the Channel; and when he had completed his labours, he made an accurate chart of the region in which it appeared that the tunnel would have to pass. He still felt that was not sufficient, and that a more extensive inquiry would be required. Accordingly his friend, the late Mr. Brassey, Mr. George Wythes, and himself, were at the expense of further investigations, which consisted of borings through the Chalk on the English coast, and

and he expected that in three or four months it would be completed. In like manner water in the Chalk would not prevent the construction of a tunnel across the Channel. The only thing that would prevent it would be some direct and open fissure, of considerable magnitude, communicating with the sea, and leading to an irruption of water too large to be dealt with; and the question for geologists to consider was whether it was possible, or likely, that such a fissure could exist, and extend to the depth of 200 feet below the bottom of the sea. His own impression was that no such fissure would be found. It was not unlikely that there might be fissures, but he believed that in the countless ages which applied to geological formations they would have become filled up. A large provision, however, had been made for meeting any contingency of that kind, so much so that some persons thought it too large. In the construction of the tunnel at Brighton, twelve pumps were employed. The engines were, in the aggregate, of 150 horse-power, but provision had been made, in estimating the possible cost of the Channel tunnel, for engines of about 2,000 horse-power. The construction of a tunnel like that at Brighton was absolutely exposed to more annoyance from water than the Channel tunnel would be, because it was shallower, and in order to get the work done rapidly it was opened out at a great variety of places into which the water came at the same time; but that could not well be done with the Channel tunnel. The driftways and the tunnel itself could be lined with brickwork as soon as the excavation was made, so that he did not believe, as regarded the ordinary percolation of water, or water from land springs, there would be more trouble with it than at Brighton. The chief difficulty would be, he believed, on the sea-coast. The Grey Chalk could not be reached on either shore without going through the White Chalk; but the Chalk appeared to him to be, on the whole, the best formation for the tunnel. Of course the work was not to be undertaken lightly. The conclusion he had arrived at long since was, that it was a work of which there was a reasonable prospect of success, the only risk being the possibility of a fissure between the sea bottom and the tunnel; but this could be ascertained, in the first instance, by driving driftways from each side. If the tunnel were made through clay and soft material it would be necessary to timber the whole distance. One of the most troublesome operations would be to get the materials in and out; and if timber as well as bricks should be required, the operation would be greatly delayed. It had occurred to him that this might be done by means of two pneumatic tubes like those used by the Post Office, which borings of great depth on the French coast. Then arose the question whether the Chalk was continuous. There were suggestions as to the existence of a great fault. It was thought by some persons that the Channel might have been formed by the strata being riven asunder, and that the Chalk might not be continuous. In order to obtain information on the subject they had a steamer in the Channel for several months under the charge of Mr. Henry Brunel, who, with an apparatus contrived for the purpose, examined the bottom of the Channel for a considerable breadth all across and in the line that the tunnel would probably take. These investigations showed, as far as such investigations could show, that the Chalk was continuous; and they afforded remarkable proofs of the accuracy of Mr. Day's observations, for the outcrop at the bottom of the Channel was found very nearly to coincide with that which he had predicted from his geological inquiries. Having ascertained the outcrop of the strata and the dip, his endeavour was to place the tunnel so that it would run, except at the sides, uniformly through the Grey Chalk, and the question now was whether that was the proper place to put it. There was an observation which he had made over and over again, viz.: that at a sufficient depth it was of no more consequence having the sea above the tunnel than having a mountain above it. But then there were other considerations involved in the question. In going down a thousand feet deep it would be necessary to begin a long way off to get to such a depth, and the tunnel would be very long. Unless the tunnel could be so laid out as to pass at a moderate depth under the bed of the Channel, it would be no use proposing it at all. The tunnel proposed by himself and Mr. Brunlees would be about 23 miles in length, and would be nowhere less than 200 feet below the bottom of the Channel. It could be approached from Dover by a gradient of 1 in 80, and it would emerge on the French coast by a similar gradient, so that it could be connected with the railways going to Calais, Boulogne, and Paris. So far, therefore, it was in an engineering point of view in the right situation. With regard to the question of water, he might be permitted to say that land springs, which seemed so serious to the geologists, would not deter an engineer from making a tunnel through chalk. He was now completing, at Brighton, a tunnel $5\frac{1}{4}$ miles in length, wholly through the Upper Chalk, and below the level, and within a short distance of the sea. There was a large amount of water from land springs. The quantity of water pumped in constructing this tunnel varied from 8,600 to 10,000 gallons a minute. This was a large quantity, but it did not prevent the tunnel from proceeding, conveyed easily a ton or a ton and a half in a wagon. One tube could bring out the Chalk, and the other take in the bricks; and they would at the same time serve for ventilation. He believed that some day this important work would be carried into execution.

Mr. RAWLINSON, C.B., said it did not follow that springs, such as those referred to by Sir John Hawkshaw, passed to any great distance under the sea, or that there was much interchange between the ocean water and the strata below. He had sunk wells in places near the sea, and much below the low-water level, but sea water did not penetrate the strata. At Worthing, in the Chalk, a well and bore-hole had been sunk about 400 feet. There were, however, all round the coasts of Great Britain mines and wells existing near the sea, and under it, to which salt water did not penetrate, the strata having been solidified so as to bear without leaking the vast pressure of the ocean above. Many persons imagined that it was only required to go deep enough into the earth to get water in abundance. Those who had sometimes to seek for it knew the contrary. In the North of England, where mining operations were carried on, floods of water were met with at a depth of 500 or 600 feet, but on reaching a depth of 1,000 feet the water disappeared. He did not believe that below the bed of the sea there could exist any such open fissure, as had been surmised, that would seriously interfere with the operations of tunnelling. On the contrary, he thought the whole stratification, of whatever character it might be, in the enormous period that had elapsed, would have been grouted and compressed by the superincumbent mass of water, so as to be solid, cohesive, and impervious. It had been suggested that there might be pot-holes which had existed in past ages before the submergence of the land. No doubt in railway cuttings such pot-holes were found; but he was not aware that they extended to anything like 200 feet in depth. The pot-holes alluded to had an origin easy of explanation. The water falling upon the surface was rain water, which dissolved chalk. Where there was a depression of a basin-shape the water flowed in, dissolved the Chalk, and if there was an escape below, carried it away, and the gravel from the surface sunk in and filled the cone-shaped space; hence the formation of pot-holes. But how could such formations occur at the bottom of the ocean? If they had ever existed, they must long since have been silted up and have disappeared. He believed that when the Engineers who had to carry out the work had got a short distance from the shores on both sides, they would no longer be troubled with water, at any rate not in the overwhelming quantities some persons anticipated.

Professor Ramsay said the Chalk had not always been in its present position relatively to the sea. England and France were once joined. The bridge across was a bridge of chalk, and England had been separated from the Continent by denudation. The Chalk was formerly high above the level of the water; and it was under these circumstances that pot-holes at a great depth might have been formed; and the relics of such pot-holes might now exist below the water, though the immediate surface of the Chalk that once united the two countries had been destroyed by denuding agents.

Mr. Bateman, V.P., said every one must sympathise with those who desired to improve the communication between England and the Continent, for nothing could be more wretched than the existing means. It was refreshing to hear Sir John Hawkshaw and Mr. Rawlinson express so confident an opinion as to the possibility of making a tunnel under the bed of the Channel; but he could not help thinking the difficulties that would have to be encountered were much underrated. Mr. Prestwich's Paper was exceedingly appropriate, considering how much the engineering operations depended upon proper geological knowledge; and the members must feel indebted to him for having so clearly stated the probabilities of position and superposition of the strata intervening between this country and the Continent. There was probably no gentleman who, from extensive knowledge and cautious observation, was better qualified to determine, within such bounds as the question permitted, the character of the material to be dealt with. But, after all, what was the whole question but one of speculation? Certain observations had been made on each side of the Channel, and Sir John Hawkshaw stated that experiments were undertaken with a view of ascertaining whether the Chalk found on both sides was continuous. Every geologist, and every one who had tunnelled, knew that a rock might be continuous, and yet highly fractured. Every gentleman who had spoken or written on the subject, had mentioned the possibility and probability of faults existing. The distance was at least 20 miles; and it was impossible to determine beforehand what were the probabilities of faults or dislocations occurring between one side and the other. Almost every valley was merely denuded ground, following the line of the greatest dislocation of several which were parallel. He had had, in many cases, to dig deep trenches across beds of rivers for the purpose of making reservoir-embankments; and he had rarely, if ever, crossed a valley at any great depth without encountering a dislocation. All the great rivers in the country owed their primary origin to dislocation; and the question had been pertinently asked, What was the original cause of the disruption between England and the Continent? If the denudation which had taken place, and had separated one country from another, had followed a line of fault or dislocation, and if the fault should be a water-bearing fault, no human agency could overcome the difficulty of the irruption of water. Faults varied according to the nature of the rocks which they traversed. Those passing through argillaceous measures no doubt occasionally puddled themselves —made themselves water-tight by the infiltration of the softened material of the rocks; but this was not the case with harder rocks. In arenaceous rocks the faults were generally dry; and the infiltration of argillaceous matter from above did not, he believed, extend to any great depth. Taking the case of a fracture in the Coal Measures, or in the Millstone Grit, with alternating beds of shale and stone one after the other; the fissure below the bed of shale might, for a short distance, be filled with argillaceous matter, but it did not extend to any great distance, nor was it of any great consistency; and far down below the shale would be found an open, cavernous crack, that would pass water in abundance. The source of the water, if a fracture were met with, would be the sea, and no human agency could exhaust the water supplied by so copious a reservoir. He did not desire to throw any doubt upon the tunnel beyond that which was reasonably required before so gigantic an undertaking was attempted; but he would be a bold man to commence a tunnel without considering, at all events, the possibility of the existence of fractures of such a nature as to overcome all efforts to drive a tunnel through them. The Paper was entirely geological, and it ought to be studied and discussed in a geological spirit. Mr. Prestwich discarded the London clay, because, he said, a tunnel through that formation would be 100 miles in length. He also discarded in succession every formation until he reached the Kimmeridge clay. He thought it possible that half-way across the Channel, beginning on the French side, that clay would be deep enough and in sufficient mass to enable a tunnel to be driven through it, and that it might there meet with another impervious formation, the Wealden, and pass into it. If he understood the Paper aright, the Author stated that it would be necessary to follow the dip; but for engineers to follow up and down the sinuosity of a bed of clay, without any means of ascertaining the thickness, or the position, or the depth, would, he thought, be an impossibility. The Palæozoic rocks, as far as his experience went, were more highly fissured, and more permeable to water than any others. They contained the Coal Measures, the Millstone Grit, the Carboniferous Limestone, and the Old Red Sandstone. Below these were the Primary rocks, which he believed were almost absolutely free from water. All the rocks from the Old Red Sandstone to the New Red Sandstone were arenaceous or limestone; the one breaking with a dry fracture like an old drain, and the other breaking with a fracture that allowed the water to melt and dissolve it, as it were, and enlarge any cavern that might exist. Professor Ramsay, speaking as a geologist, said that there was a time when these pot-holes of gravel or other matters on the surface of the Chalk were deposited, and when the whole bed below the Channel was above the surface of the water; that fissures enlarged then by the penetration of water would still exist; that when they were dropped below the surface they would still be there; and if there were an outcrop of the various measures notoriously permeable to water, such as the Upper and Lower Greensand, or the Hastings sands, and other sand beds occurring in the various measures lying immediately below and above the Chalk—if any such measures were met with, he believed the water would pass freely through them, and that no mechanical means at the command of man would enable engineers to overcome the difficulty. On the whole, he thought that the Paper was not encouraging to the advocates of a Channel tunnel. A tunnel through the London clay would, as he had said, be an impossibility; and most of those who had paid attention to the thicknesses, and position, and circumstances of the various measures which would have to be considered, would probably agree with him in rejecting all the rocks down to the Palæozoic, except the London clay, and possibly the Kimmeridge clay. With regard to the Palæozoic rocks, there was no certainty whatever. These were said to be at a depth of 1,000 or 1,100 feet, and then it would be necessary to go to a greater depth to be clear of water. This depth, with an inclination of 1 in 50, would greatly increase the length of the tunnel; and if the tunnel were 1,000 feet only below the level of the sea, there would be an approach of 10 miles at each end, not including the elevation of the ground above the surface of the water, so that there would be a tunnel between 40 and 50 miles long. With regard to the Gault, he agreed with the Author that it was generally of small dimensions. Mr. Bazalgette and Mr. Homersham had spoken of piercing

330 and 500 feet of Gault, and it was therefore thought that Mr. Prestwich might be wrong in the dimensions stated; but the whole was involved in uncertainty. He inferred, from the Paper, that the opinion of the Author, like that of geologists generally, was against the feasibility of the project. If Sir John Hawkshaw and his adherents could satisfy the public and themselves that the Chalk through which they desired to take the tunnel was continuous, and offered no objections that could not be overcome, he wished them all possible success, and should be delighted to be amongst the first to travel through the tunnel when it was completed. The ardent geologist broke out at the end of the Paper. Like Mr. Godwin Austen, the Author appeared to be impressed with a belief that Coal Measures rose to within a comparatively short distance of the Weald clay in Sussex, and he was engaged in a boring operation to ascertain what rocks were below the Weald clay in that part of the country, "and," added Mr. Prestwich, "the tunnel underneath the Channel would assist in determining that important question." No doubt it would.

Mr. Russell Aitken could not agree with geologists in the lengths to which they pushed the deductions obtained from their science. Some years ago he was engaged in the construction of a tunnel in the Coal Measures, and when the Bill was before Parliament, it was stated by geologists that there was every reason to expect a length of $\frac{3}{4}$ or $\frac{1}{2}$ mile of the tunnel would have to be driven through a peculiarly hard trap rock, and that it would be therefore enormously expensive. In making the tunnel, however, there was only found a wall of about 12 feet of this kind of trap. There was nothing certain in geology as a science but its uncertainty. He thought that if the Channel tunnel were made, it would have to be driven within a reasonable depth from the surface. If it were at a great depth, it would involve long entrance tunnels at both ends, and these tunnels would require to traverse for considerable distances the water-bearing strata underneath the Chalk. When engaged on the Admiralty Pier works at Dover, he had observed, in laying the foundation courses of the piers, that the surface of the Chalk, except near the shore, was to a depth of several feet in a pasty condition, not at all dissimilar to good puddle. Under these circumstances he thought it not unlikely that but little water would be found in a tunnel driven in the Lower Chalk.

Mr. F. W. Shields said about four years ago the promoters of the undertaking applied to Government for a grant in aid, and he was instructed to report upon the subject. First he considered the probability of the sea water permeating through a fissure, or otherwise, into the Lower Chalk stratum selected for the tunnel. In making inquiries as to what depth wells had been sunk in the immediate vicinity of the coast, he ascertained that one had been sunk to a considerable depth below the sea, to supply Dover Castle, together with galleries or drift-ways from it, in different directions, in order to collect a larger supply of water; and the contractor who executed the work informed him that the water from the well was perfectly sweet, without the slightest taint of salt. If this was so in the fissured beds of the Upper Chalk, it followed of course that the comparatively solid state of the Lower Chalk would be still more likely to be free from the irruption of sea water. It appeared also, from Sir John Hawkshaw's investigations, that chalk existed along the entire surface of the bed of the Channel, except about 3 miles from Calais, which might be accounted for by the great mass of sand drift in the neighbourhood of Calais which was washed over the Chalk. He had no doubt that the bed of the sea had been puddled, by the action of the tides washing the softened chalk backwards and forwards, and had become impermeable. He believed no one experienced in well-sinking would say that he had got water out of the Grey Chalk, for as soon as that formation was reached the fissures ceased, and the water-bearing strata ceased along with them. Under these circumstances he was favourably impressed with the probability of constructing a tunnel in the Grey Chalk from Dover to Calais as compared with any other direction. By going further west, so as to intersect the Palæozoic strata, instead of getting a bed of tolerable continuity, there would be found a vast variety of strata made up of clay, sand, stone, etc., which would involve the greatest uncertainty. With regard to the possible irruption of water, he did not think that difficulty insuperable, even if it occurred. It appeared to him that in making the drift-way recommended by Sir John Hawkshaw, it would be possible to run a small boring, say from 20 to 25 feet, in advance of the main boring, so as to ascertain beforehand whether any such pervious fissure existed. The main boring would be provided, as a matter of precaution, with an iron shield, which in such a case would be pushed forward so as to pass through the porous stratum into the solid one beyond it. He was encouraged in this view by the fact, that Mr. Bateman had proposed a scheme for laying an iron tube, large enough to hold a railway train, along the bed of the Channel from one side to the other, with an arrangement for such a shield at the head. On the whole, his opinion was favourable to the construction of a tunnel such as Sir John Hawkshaw had proposed, believing that the stratum he had selected offered far greater chances of success than any other. He had examined the question of the comparative cost of working the tunnel by pneumatic pressure and by locomotive power. The difficulty with locomotive power, which he thought was in every way preferable, was that of ventilation. The subject had not been referred to by the promoters in the documents placed before him, but he thought the best way of working the line by locomotives would be by two small tunnels, one for a train in each direction, sending a current of air for the purpose of ventilation in the direction in which each train ran, there being an engine at one end forcing air into the tunnel, and an engine at the other sucking it out. By this means the whole body of the air in the tunnel would be kept constantly in motion, and the deleterious vapour emitted by the locomotive would be discharged at the end before the succeeding train could overtake it. His calculation was that the cost of ventilation alone in that way, for trains going through every hour, would be about £30,000 a year, and for trains every half hour, about £70,000 a year, these amounts being considerably augmented by the rise of prices at the present day. The work would not, he thought, be remunerative enough to induce its construction by private capital; but the national advantages which would accrue to England, France, Belgium, and Germany rendered its construction by the Governments of those countries a matter worthy of consideration.

Sir John Hawkshaw said he had not purposely avoided the subject of the permanent ventilation, which he thought might be provided by a simple process. The process would require an engine of about 100 H.P., and would not, therefore, be very expensive.

Mr. Bruce said he understood the cost of the tunnel to be estimated at £10,000,000. Making allowances for contingencies, he would suppose it to be £12,000,000. In order to make it pay 5 per cent., allowing 50 per cent. for working expenses, £1,200,000 a year of gross receipts would be required; so that, assuming the line to be 28 miles long, it would require to earn £824 per mile per week. The Metropolitan, running through the heart of the population of London, with stations every mile, earned about £1,099 per mile per week; the Lancashire and Yorkshire, £147; the Great Western, £65; and the London and North Western, £105: so that the tunnel—having only stations at the two ends —would have to earn, in order to pay 5 per cent. interest on the cost, nearly as much as the Metropolitan, five and a half times as much per mile as the Lancashire and Yorkshire, going through populous districts with frequent stations, eight times as much as the London and North Western, and thirteen times as much as the Great Western. He had no doubt as to the possibility of making a tunnel, but the idea of its being an undertaking that would pay was, he feared, quite chimerical.

Mr. Prestwich, in reply, said he had but little to add to the opinions expressed in the Paper. With regard to faults in the Chalk, no one could walk along the chalk cliffs without seeing one every few hundred feet. Mr. Morris had counted as many as ten small faults, of different sizes, in three hundred and forty paces of the chalk cliffs near Ramsgate. These, however, were unimportant; and it would only be from larger ones that any danger need be apprehended, and then not always. The water was now fresh in deep wells in the Chalk near the sea, such as at Dover Castle and at Margate; but if instead of the line of water level being so high inland as to force the land springs seaward, it were lowered or interfered with from any cause, the same fissures which now allowed of the escape of those springs below the sea bottom would serve as channels for the influx of sea water. As for any efficient puddling of the present sea bed, none such was apparent on the top of the adjacent Chalk where overlaid by Tertiary strata, which were deposited in the old seas formerly spread over that formation. Mr. Evans had remarked upon the uncertainty of the depth of the Palæozoic rocks, in consequence of their being contorted and disturbed; but these rocks, after their disturbance, had been so planed down as sometimes to present a perfectly even surface. Notwithstanding their disturbance, they were found within 100 feet of the same level under Calais, Ostend, and Harwich. Further, if there were any irregularity of surface, it was always greatest in a line at right angles to the strike, and was much less in the line of the strike. In the Boulonnais, for example, the Palæozoic rock-surface dipped southward much more rapidly than along the line of strike to the eastward. With regard to the Gault, no doubt if it were as thick as it was in Cambridgeshire, it would offer favourable conditions for the execution of the tunnel; but he was not aware that it was anywhere more than 200 feet thick along its southern outcrop at the foot of the North Downs. At Folkestone it was 130 feet thick. He had estimated it to be 40 feet to 50 feet thick on the opposite coast, and Mr. Topley had arrived at the same figures. Mr. Homersham stated that in order to be sure of its thickness, the Gault must not be taken where it outcropped from under the Chalk; he was not, however, aware of any place in Kent where the Gault had traversed under

Chalk; but on the French coast, at a distance of about 6 miles from the outcrop of Gault, and 9 miles from Calais, it was found to be 32 feet thick, while at Calais it was 26 feet thick. As to the possibility of the Kimmeridge clay in the neighbourhood of Boulogne passing under the Weald clay, near Hythe, without the intervention of Portland sand and stone, so that a tunnel might possibly pass from one clay formation to the other, he had been led to make that observation because in the Boulogne area the Portland beds were so frequently denuded. The suggestion had, however, since this Paper was written, been confirmed by the circumstance that in the deep Sub-Wealden boring at Battle, after passing through the Wealden series, the Kimmeridge clay was at once reached. The boring had passed from one deposit to the other without meeting with Portland beds, or their equivalent. With regard to the depth of the Palæozoic rocks, he had estimated that near Battle they would be found not less than 1,000, nor more than 1,700 feet deep. But Battle was out of the line of strike of the rocks of the Boulonnais. Rising in that district considerably above the sea level they dipped southward rapidly, and by the time they reached Boulogne they were about 1,000 feet beneath the surface of the Kimmeridge clay; whereas on the eastward line of strike, it was doubtful if in that distance the level of those rocks was 100 feet less. The question, however, was, presuming the ridge to be prolonged across the Channel in a N.W. direction, at what depth would it probably be found on this other side? It might be at a depth not exceeding 500 or 600 feet. Near Marquise the old rocks disappeared beneath the surface at about 100 feet above the sea level. Of course it was a matter of uncertainty, and could only be determined by experiment. All that was known was that these rocks did not exceed, at Kentish Town, a depth of 1,000 feet below the sea; that they were at nearly the same depth at Harwich, Calais, and Ostend,[1] and that they came to the surface between Calais and Boulogne. Between this point and Mons they passed beneath Tertiary strata and Chalk all the way; and in no case were they more than 1,200 feet below the surface, and were generally at depths of from 400 feet to 600 feet. With regard to the comparative scarcity of water at great depths, this would occur where the beds were divided vertically into isolated compartments by faults, or where they were protected by overlying impermeable strata, but not otherwise.

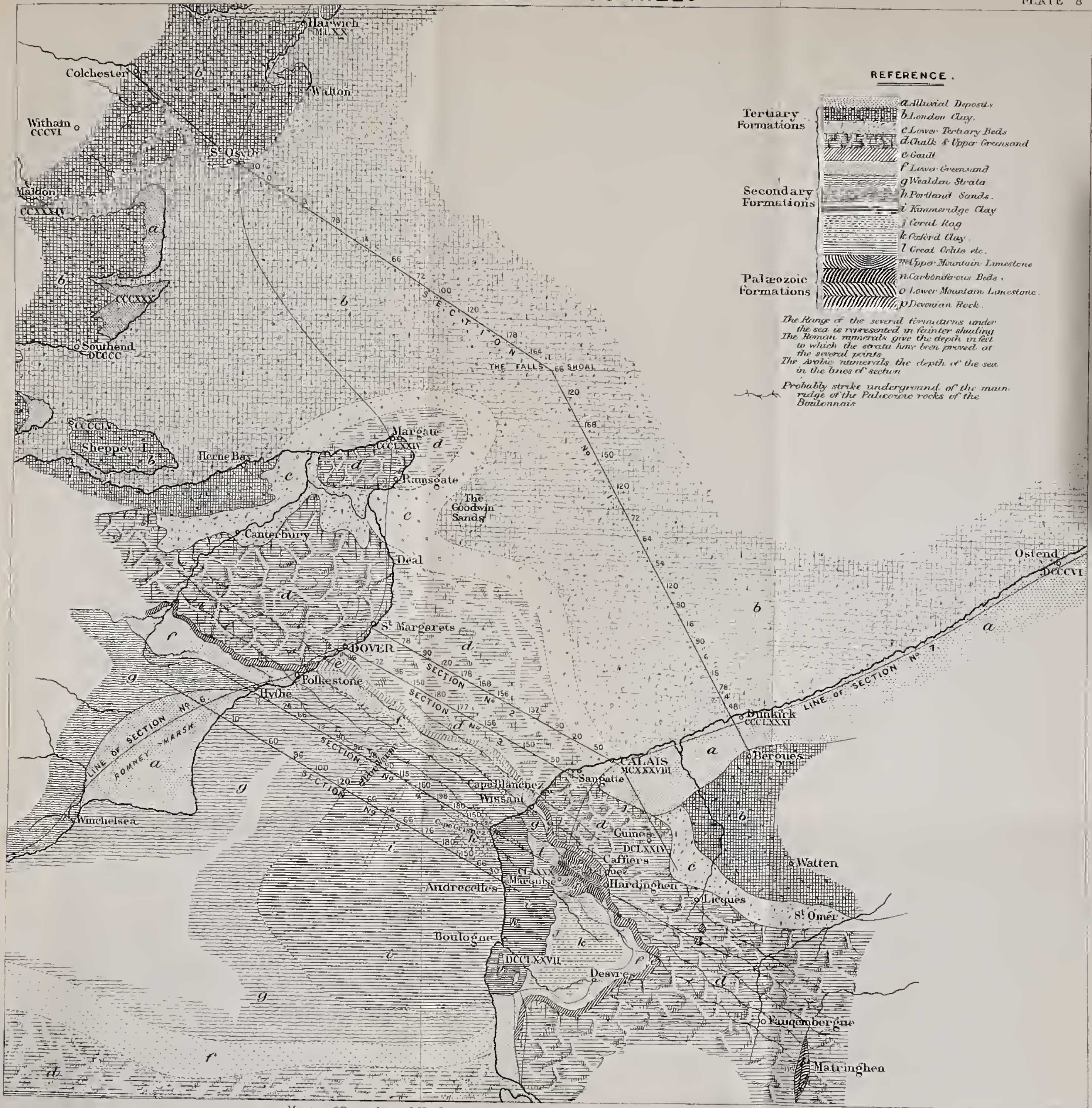
[1] "Popular Science Review" for July 1872.

December 16, 1873.

T. HAWKSLEY, President,
in the Chair.

The discussion upon the Paper, No. 1,358, "On the Geological Conditions affecting the Construction of a Tunnel between England and France," by Mr. Joseph Prestwich, was continued throughout the Meeting.

# CHANNEL TUNNEL.

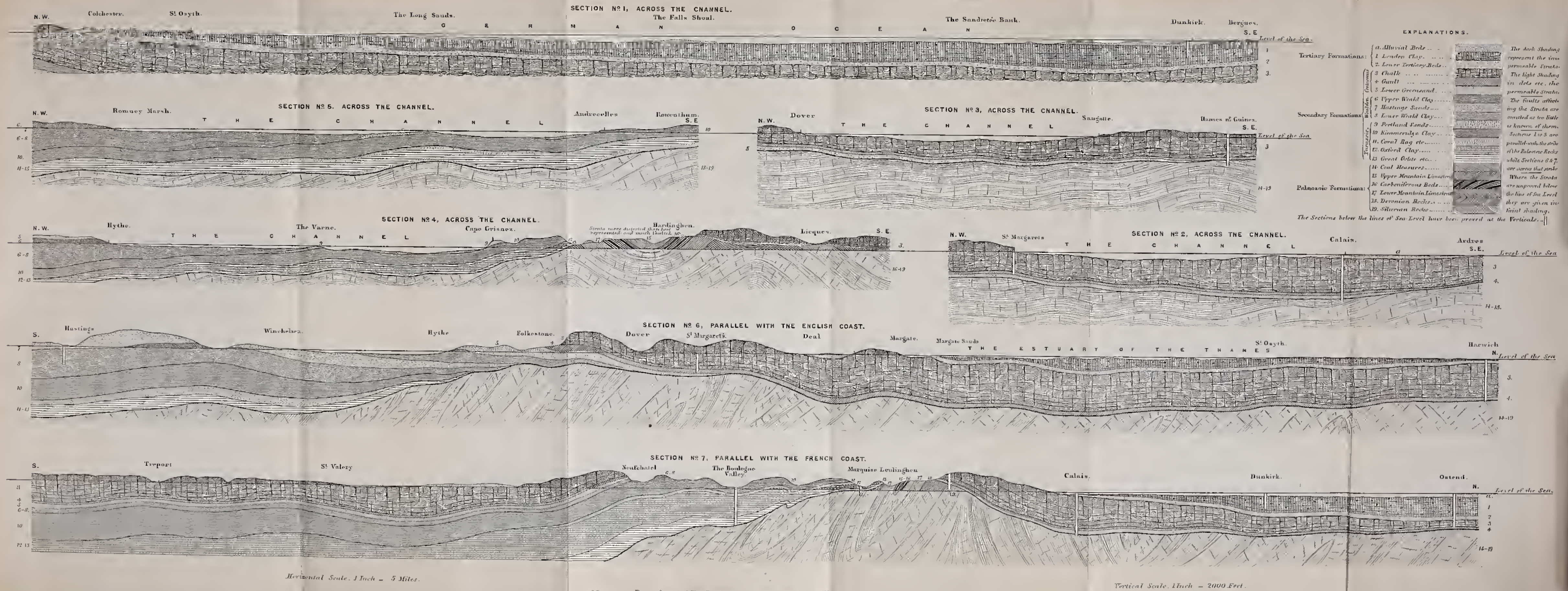





THOS KELL LITH 40 KING ST COVENT GARDEN

# CHANNEL TUNNEL.

DIAGRAM SECTIONS TO ILLUSTRATE THE PROBABLE GEOLOGICAL STRUCTURE UNDER THE CHANNEL, BETWEEN THE SOUTH-EAST OF ENGLAND AND NORTH-WEST OF FRANCE.






THOS KELL, LITH 40, KING ST COVENT GARDEN.