PRACTICAL TUNNELLING.

CHAPTER I.

GEOLOGICAL FEATURES OF THE SOUTH-EASTERN RAILWAY. — GENERAL ACCOUNT OF BLECHINGLEY AND SALTWOOD TUNNELS, THEIR COST, ETC.

The Blechingley and Saltwood Tunnels are situated upon the line of the South-Eastern Railway between London and Dover, which passes through a district of country, not only celebrated for the beauty of its landscape, but highly interesting to the Geological enquirer; the Railway being formed through the Tertiary strata, and the cretaceous group of the secondary formation. Commencing at the Metropolis, it is constructed upon the London Clay till it reaches New Cross; where, at about one hundred yards to the south of the public road bridge, the Plastic Clay formation appears on the slopes near the bottom of the excavation, in situ beneath the London Clay.

The junction of the two formations at this place is described in an interesting paper read before the Geological Society, April 17, 1844, by H. Warburton, esquire, the President, containing some results of an examination of that locality, in which I had the pleasure of assisting him; and is represented in the following section.

London Clay:

1.	Yellow clay,	thickness not determined.
	Blue or slate-coloured clay,	thickness 10 to 15 feet.

Plastic Clay formation:

		ft.	in.
2.	Rolled flint pebbles or shingle, thickness	1	10
3.	Fine fawn-coloured sand,	0	3
4.	Lignite,	0	0½
5.	Fine fawn-coloured sand,	2	0
6.	Ferruginous sand, with marine fossils, oyster shells, and cerithia	0	4
7.	Loose grey sand, with fragments of cerithia,	0	8
8.	Strong black clay,	0	10
9.	Black clay and sand, with fragments of oysters and cerithia,	0	9
10.	Black dirty sand,	0	4
11.	Dark sand, containing fossils, oyster shells, &c.	0	6
12.	Calcareous stone, containing paludina, unio, &c. (freshwater fossils)	0	6
13.	Decomposed stone and sand, with oysters, &c.	0	3

The shells belonging to the upper part of the Plastic Clay series in this neighbourhood have been well described by Dr. Buckland in the fourth volume of the first series of the Geological Society's Transactions, but the occurrence of the paludina and unio in the stratum No. 12 of the above section, which are freshwater shells, thus included between marine fossils, appears to have escaped observation, till now discovered by Mr. Warburton; who describes the stone in which they are embedded, as septaria of a texture considerably more earthy than the septaria of the London Clay usually are.

The line of Railway continues upon the Plastic Clay as far as Combe Lane, Croydon; where the Chalk crops out from beneath the sands of the last named formation, and is distinctly to be seen on the north-east slope of the cutting. The Railway then crosses the great Chalk range that extends from Dover to

Hampshire, and rises towards the Chalk escarpment at Merstham in Surrey, where its greatest summit level between London and Dover is attained in the tunnel near that place.

In the deep cutting at the south of the tunnel, a good section of the Upper Green Sand stratum appears, cropping out from beneath the Chalk; this is succeeded at the village of Merstham by the Gault, through which the road to Blechingley has been lowered that it might be passed under the Railway.

At a short distance further southward, the Lower Green Sand formation rises to the surface, in beds of fawn-coloured sand, very silicious, and good for Engineering purposes. The middle beds of the Lower Green Sand, as indicated by the presence of rushes and wet land, next appear; and these are followed by the lower beds of the same formation, which contain the Kentish ragstone, fuller's earth, &c.—the fuller's earth pits of Nutfield being near this locality. The lower beds of this formation rise to a considerable height, and form the range of sand hills that passes through the country, parallel to the great chalk range before named.

The place where the railway crosses the sand range is called Redstone Hill, and is the point where the Brighton railway diverges to the south, while the Dover railway passes round the hill with a curve of half-a-mile radius to the eastward; and towards the further end of this curve, near to a bridge at Robert's Hole farm, the next inferior stratum, the Weald Clay, emerges from beneath the sand. This spot may be further identified by the greater width of the excavation, or flatness of the slopes, occasioned by the slipping of the earth at the junction of the two formations, where much water was present. In making this excavation, some stone was found, that was much jointed, and contained innumerable fossils, which, upon examination in April 1843, by Mr. Warburton, Dr. Fitton, Mr. Austen, and myself, was found to include some of the most characteristic of M. Leymerie's Neocomien species, with a few belonging also to the quarrystone of Hythe; as, arca raulini, panopœa depressa, pholadomya acutisulcata (Leymerie), pecten obliquus (interstriatus), pinna sulcifera, gervillia aviculoides, perna mulleti, p. alæformis, trigonia dœdalea, t. Fittoni, gryphæa sinuata, nautilus radiatus, &c. This stone appears to correspond with the Atherfield rocks in the Isle of Wight; which it resembles in its mineralogical and geological character. [See paper, by Dr. Fitton, read before the Geological Society, May 24, 1843, entitled "Observations on the Section of the Lower Green Sand at Atherfield, on the coast of the Isle of Wight."]

From Redstone Hill the line passes eastward, along the Weald Clay, in successive cuttings and embankments for many miles, except that near Blechingley there is a tunnel, bearing that name, formed through a spur of Tilburstow Hill: the Weald Clay at this place is indurated into a shale, or blue bind, and being full of joints and faults, caused much difficulty in the work, as will be described in the following pages. The fossils found during the construction of the tunnel, were, portions of the iguanodon, hylœosaurus, cypris, paludina, clathraria (Lyelli), &c. &c. and a fine specimen of the lepidotus (Mantelli), presented by me to the Geological Society, accompanied by a short paper upon the subject of the strata at this place, which was read at the Society's meeting on February 21st, 1844.

Near the town of Ashford the line leaves the Weald Clay, and again enters upon the Lower Green Sand formation, which continues to be its base as far as Folkestone, a distance of about fifteen miles: the summit is passed by means of a Tunnel, at Saltwood, not far from the out-crop of the Sand from beneath the Gault; consequently the shafts were sunk through the upper beds, and the tunnel is formed at the junction between that and the middle bed; where a large quantity of water was encountered, which greatly retarded the progress of the works. Among numerous fossil remains found at Saltwood, chiefly in ferruginous concretions, the following may be particularly enumerated: nautilus radiatus, gervilia aviculoides, terebratula, tethys major, panopœa, trigonia alœformis, venus, cardium, tornatella, pecten quinquecostatus, p. orbicularis, &c. &c. with fossil coniferous wood pierced by gastrochæna; together with a remarkable product, a new and beautiful resin, which partakes of the properties of amber and of retin-asphalt, and is principally marked by its clear red colour, its infusibility, and the difficulty with which it is acted upon by many chemical solvents. I was indebted to Mr. Edward Solly, through the kindness of Dr. Fitton, for a chemical examination of this substance, the results of which are inserted at length in a paper read before the Geological Society, June 7th, 1843, giving an account of an investigation of the strata from the summit of the Chalk escarpment above Saltwood tunnel to the sea at Hythe; or, at right angles both to the range of hills and the direction of the line of Railway in that locality. It may not be uninteresting to insert the result of such examination.

The Upper Green Sand stratum, which at the back of the Isle of Wight is one hundred and four feet thick, is here altogether wanting, it having thinned out at this place.

Strata from beneath the Chalk to the Wealden, through Saltwood.

					ft.	in.
Upper Green Sand, . (wanting,—but) at Folkestone, five miles distant, it is in thickness					15	0
Gault					126	0
Lower Green Sand.			ft.	in.		
Upper division, . . .			70	0		
Middle ditto . . .			158	0		
	ft.	in.				
Sand above the quarries, .	67	0			406	6
Quarry Rock, . .	48	0	.	178 6		
Sand and Stone, previously concealed	14	0				
Clay beneath the sand and stone .	49	6				
Total thickness from the Chalk to the Wealden . .					547	6

Near Folkestone station the line leaves the Sand, and crosses the Gault formation; where, at the junction of that stratum with the Upper Green Sand, and then of the Chalk above, a tunnel is made through the hill to the undercliff called the Warren, and from thence to Dover, entirely in the Chalk, through and along the face of the cliffs;—altogether one of the grandest Engineering Works in the kingdom;—and where Mr. Cubitt, the Engineer-in-Chief to the Railway Company, so successfully introduced the use of gunpowder in blasting rock upon a great scale, especially in removing that large mass of chalk, "The Round Down," on January 26th, 1843: the particulars of which are given by Lieutenant Hutchinson, R. E., in the sixth volume of the Professional Papers of the Corps of Royal Engineers.

Such are the Geological Features of this line of Railway.

The Engineer-in-Chief charged with the construction of the line was William Cubitt, esquire, F. R. S. &c. &c. That gentleman divided the whole line into three districts; over each of which he appointed a resident Engineer. To that nearest London he appointed the author; the district through the Weald of Kent was assigned to Mr. Barlow; and the third, or Dover district, was given to Mr. Wright. In the district first named the Blechingley Tunnel is situated: and, upon its completion, the author was further appointed to superintend the construction of the Tunnel at Saltwood:—the particulars of which two works form the subject of the following pages. And to my col-

leagues, and myself, it is gratifying to know that our Engineer-in-Chief has expressed himself, both in public and private, satisfied with the manner in which we, severally, have carried his views and intentions into execution.

A general description of the Blechingley and Saltwood Tunnels, explaining their cost, and the circumstances under which they were constructed, is annexed, previously to entering upon the details of the same.

BLECHINGLEY TUNNEL.

So named from the Parish where it is situated, is in the county of Surrey, and about twenty-five miles from London. The Tunnel is twenty-four feet wide in the clear, and twenty-one feet from the upper surface of the rails to the crown of the arch; its figure is elliptical above the skewback, or springing of the invert: the versed sine of the invert is three feet, and the level of the rails is one foot above the skewback. The Tunnel is inclined from west to east, at the rate of three feet per mile. The dimensions of the brickwork varied, and were regulated according to the appearances of the ground, from time to time, as the lengths, which were twelve feet long, were excavated: these particulars are given in figure 3, plate I. the left half of which shews half the cross-section of the Tunnel at Blechingley; and the right half, that at Saltwood. Figure 1, plate I., is a longitudinal section of Blechingley tunnel, and figure 2 that of Saltwood; shewing the positions of the working shafts, and of the Observatory, &c.—all of which subjects will be described in further details in the course of the work in each tunnel.

The ridge through which the Tunnel passes is the main axis of elevation of this part of the country; and, from the dip of the strata in both directions from its summit, forms a north and south anticlinal axis; its direction being that of the meridian, nearly; which, so far as I can judge, extends from the chalk range between Godstone and Merstham in Surrey, to about Ditchling in Sussex: the waters which fall on the surface along the said line of direction, form sources or feeders to the rivers Medway and Ouse, on the east, and to the Mole and Adur on the west. Besides the inclination of the beds both ways from the axis, they dip to the north at an angle of about thirteen degrees; but westward, from the summit of the ridge, there is no regularity in this respect. the strata lying as it were in heaps, at almost every angle, from five

to sixty degrees, and dipping in all directions, from west-by-north to east; besides which a detached mass of sand-rock lay across my path, near the top of the Tunnel, and from whence a great body of water was discharged into the workings, causing no small trouble and difficulty.

The Blue Clay of the Weald in which I was working was at first greasy to the touch; and when dry, and in situ, formed a hard shale, requiring an extensive use of gunpowder in its excavation, but upon exposure to damp and atmospheric action, it swelled considerably and then slaked: this obliged me to close-pole the face of the work in all directions as far down as the lower sill, and frequently to the bottom. The expansion, or swelling, was occasionally so great as to threaten the hurling in of the lengths after they were completely timbered, and would probably have done so but for constant watchfulness, and strong timbers properly applied. The pressure upon the work was sometimes so great that sound oak bars, fourteen or fifteen inches in diameter, were cracked and broken as if they had been mere sticks.

The pressure we had to contend with was variable, and uncertain in the highest degree; sometimes a length could be got out, and the arch turned, without any apparent movement of the earth around and above us; at other times, the ground when partly excavated would begin to move, and press upon the bars on one side of the arch; at others, it would act upon the crown bars; the former action was principally confined to those parts of the Tunnel that were deepest below the surface, whilst the greatest pressure (which mostly acted upon the crown) took place towards the ends of the Tunnel, where the surface was so much nearer to the arch. It sometimes occurred that after a length had been excavated satisfactorily, and by the time the bricklayers had built up the side walls, the weight on the top was so great as to press the bars down to an extent nearly equal to their own thickness, which was seldom less than fifteen inches; consequently, when the centres were set, there was not sufficient space between them and the bars to insert the brickwork of the arch: the remedy for this was, to remove the poling, and excavate more earth from above the bars, and to prop them again at a higher level; which occasioned considerable loss of time, and consequently increased the expense.

In one of the pits,—No. 11, at the east end,—this weighting of the crown occurred constantly after getting in three lengths west of the shaft, and therefore we elevated the extremity of the bars sufficiently high, upon their first insertion, to allow for the expected subsidence: in the other pits its occurrence was

uncertain; consequently it was impossible to provide for it, without running the risk of having a great opening above the arch, to be filled solid with brick work, or with earth, which is often imperfectly done, and would be liable to bring a greater weight upon the work when the earth again takes its bearing, after the mass has been in motion. It is the general movement of the mass in adjusting itself to equilibrium, after the disturbance occasioned by the excavation, that causes the weight, and whose searching influence finds out the weak points in the work.

The greater pressure upon the work in shallow ground over that where the tunnel is very deep below the surface, I can explain only upon the supposition that, in the former case, the whole superincumbent mass is acting perpendicularly downwards; whilst, in the latter case, a small portion only gets into motion, the upper part acting as a key, (if I may so express myself,) by which the mass supports itself. This action was clearly shewn in pit No. 11, above referred to; where the working below could be distinctly traced upon the surface of the ground, by its sinking in the form of a basin as our work proceeded, and at the same time cracking into large fissures.

The sinking of the shafts was commenced in the beginning of August, 1840. These were down to the depth necessary for the shaft-sills by the middle of September; which, together with the further sinking, including the square timbering to the bottom of the Tunnel, was completed by the end of October. The driving of the heading at the level of the top of the invert was then commenced, and was finished by Christmas. From this time till February 12th, 1841, preparations were made for commencing the excavation of the Tunnel: these consisted in making a gin for each shaft, and the ground-moulds, leading-frames, and centres. On the above date the miners broke ground in No. 3 pit, being the first commencement of the tunnelling; but it was not until early in April that the whole of the shafts were got to work; and as soon as each was started, the work was pushed on with the utmost vigour, night and day.

On September 3d, the first junction was effected; and on November 1st, the last junction was keyed in; the Tunnel, as originally intended, was therefore complete; but it was resolved to extend it at each end in consequence of the backwardness of the open cuttings that were let to two different contractors. My instructions were, to extend the tunnel until I should meet the open cuttings, and thus enable the Directors to open the Railway to the public at the time proposed, which otherwise could not have been done. The exten-

sion of the Tunnel, and the erection of the entrances, were not completed until early in the following May; and the Railway was opened to the public on May 26th. The Tunnel, as completed, is 1324 yards in length.

Although it would appear, from what has above been stated, that the sinking of the shafts did not commence until the month of August,—yet this must be understood as in reference to the working-shafts only; because, in the preceding February, two trial-shafts were sunk, to ascertain the character of the ground in which the Tunnel was ultimately to be constructed. The particulars of this work will be given in chapter IV. After two trial shafts had been sunk, it still appeared desirable to examine the ground at two intermediate points; accordingly two other shafts were commenced early in the spring, and, to save expense, they were made the full size of working-shafts in the first instance, with the intention of employing them as such in the course of the work. The working-shafts were nine feet diameter in the clear, while the trial-shafts were but six feet. These large shafts had, however, not been far proceeded with, when an unpleasant difference arose between the Company and the Occupiers of the land, who demanded an exorbitant amount of compensation, forbidding the proceedings until such was paid. Under these circumstances the work was suspended until the following August; when the said differences having been adjusted, possession of the land was obtained, and the works were prosecuted with vigour.

Previously to laying the permanent way, a culvert was constructed upon the invert, throughout the Tunnel, as shewn in section, figure 3, plate 1. The Tunnel was also lime-whited twice, with a view of increasing the light; but this did not answer as was expected.

The monthly rate of progress, during the time the work was in full activity, was as follows. During May, 1841, 104 yards were completed;—June, 185 yards;—July, 264 yards;—and August, 228 yards. The bricks were all made on the ground, and wheeled or carted to the various shafts; their cost when thus delivered at the pit's mouth, including waste and all other expenses incurred, was £2 : 1s : 6d. per thousand. A portion of the bricks was made during the winter of 1840, and dried in flues, by coal fires; which increased the cost considerably. [See paper by the author, on this subject, read before the Institution of Civil Engineers, April 25th, 1843.]

The following abstract will shew the whole cost of this important work.

ABSTRACT OF THE COST OF BLECHINGLEY TUNNEL.

	£ s. d.	£ s. d.	£ s. d.
Materials:			
Bricks,	30,499 12 10		
Cement,	11,016 0 11		
Timber,	11,341 19 2		
Wrought and cast ironwork, and ironmongery	2,499 3 1		
Miscellaneous: including pumps, weighing machine, broken stone for roads, lime, ropes, stationery, and all materials not included under any of the above heads,	6,555 2 8		
		. . .	61,911 18 8
Labour:			
Mining, Shafts, heading, and preliminary works,	3,273 2 8		
Mining, Driving the tunnel—including the hire of gin-horses, and the open excavation, for lengthing the tunnel,	15,727 7 0		
		19,000 9 8	
Brickwork, Shafts, and preliminary works,	378 8 0		
Brickwork, Constructing the tunnel, and lengthening the tunnel in open excavation,	11,265 4 11		
		11,643 12 11	
Miscellaneous: Including the erection of the tunnel entrances, culvert through the tunnel, part ballasting the tunnel, construction of machinery, erection of buildings, carpentry, sawing, clerks' and inspectors' wages, &c. &c.		6,980 16 6	
			37,624 19 1
			99,536 17 9
Deduct estimated value of plant, removed to Saltwood, upon the completion of Blechingley tunnel			4,300 0 0
Total Cost of Blechingley Tunnel,			£ 95,236 17 9

Being at the rate of £71 : 18s : 7d. per lineal yard, for the whole tunnel; 1324 yards in length, or three quarters of a mile and four yards.