Where granite, diorite, and other hard stone had to be cut, the work was done by tube drills and by saws supplied with corundum, or other hard gritty material, and water, —the drills leaving a core of rock exactly like that of the modern diamond drill. As instances of ancient tunnels through soft ground and requiring masonry arching, re­ference may be made to the vaulted drain under the south­east palace of Nimrúd and to the brick arched tunnel, 12 feet high and 15 feet wide, under the Euphrates. In Algeria, Switzerland, and wherever the Romans went, re­mains of tunnels for roads, drains, and water-supply are found. Pliny refers to the tunnel constructed for the drainage of Lake Fucino as the greatest public work of the time. It was by far the longest tunnel in the world, being more than 3½ miles in length, and was driven under Monte Salviano, which necessitated shafts no less than 400 feet in depth. Forty shafts and a number of “cuniculi” or inclined galleries were sunk, and the excavated material was drawn up in copper pails, of about ten gallons capacity, by windlasses. The tunnel was designed to be 10 feet high by 6 feet wide, but its actual cross section varied. It is stated that 30,000 labourers were occupied eleven years in its construction. With modern appliances such a tunnel could be driven from the two ends without intermediate shafts in eleven months.

No practical advance was made on the tunnelling methods of the Romans until gunpowder came into use. Old en­gravings of mining operations early in the 17th century show that excavation was still accomplished by pickaxes or hammer and chisel, and that wood fires were lighted at the ends of the headings to split and soften the rock in advance (see fig. 1). Crude methods of ventilation by

*Subaqueous Tunnelling.—*In 1825 Brunei commenced and in 1843 completed the Thames tunnel, which was driven at points through liquid mud by the aid of a “shield” at a cost of about £1300 per lineal yard. It is now used by the East London Railway. In 1872 Chesborough began tunnelling under the Detroit river, between Canada and Michigan, U.S., but the work was abandoned owing to continued irruptions of water after some 600 yards of headings had been driven.

The most important subaqueous work yet accomplished—the Severn tunnel, 4⅓ miles in length—was commenced in 1873 and finished in 1886, Messrs Hawkshaw, Son, Hayter, and Richardson being the engineers and Mr T. A. Walker the contractor. The bed of the Severn is formed principally of marls, sandstones, and con­glomerates in nearly horizontal strata, overlying highly inclined coal measures, shales, and sandstones, which are also exposed in the bed of the river. The tunnel is made almost wholly in the Trias and Coal Measure formations, but for a short distance at its eastern end it passes through gravel. The lowest part of the line is below the “Shoots,” where the depth is 60 feet at low water and 100 feet at high water, and the thickness of Pennant sandstone over the brickwork of the tunnel is 45 feet. Under the Salmon Pool, a de­pression in the bed of the river on the English side, there is a cover of only 30 feet of Trias marl. Much water was met with through­out. In 1879 the works were flooded for some months by a large land spring on the Welsh side of the river. The water which sup­plied the spring came from fissures in the carboniferous limestone, which was met with only at this place, and it is now conveyed by a side heading parallel to the tunnel to a shaft 29 feet in diameter, in which are fixed pumps of adequate power. On another occasion the works were flooded by water which burst through a hole in the river bed at the Salmon Pool. This hole, which was in the Trias marl and had an area of 16 feet by 10 feet, was subsequently filled with clay and the works were completed beneath it. The tunnel is for a double line of railway and is lined throughout with vitrified bricks set in Portland cement mortar. A heading was first driven entirely across the river to test the ground and sub­sequently another heading at a lower level. "Breakups ” were made at intervals of two to five chains and the arching was carried on at each of these points. All parts of the excavation were timbered, and the greatest amount excavated in any one week was 6000 cubic yards. Owing to the inrush of water it was frequently necessary to completely roof the timbering with felt or corrugated iron before the bricklayers could commence the arching. The total amount of water raised at all the pumping stations is about 27,000,000 gallons in twenty-four hours; but the total pumping power provided is equal to 66,000,000 gallons in twenty-four hours. The ventilation is effected by a fan of the Guibal pattern, 40 feet in diameter and 12 feet wide, making forty-three revolutions and drawing 447,000 cubic feet of air per minute from the tunnel through an 18-feet shaft at Sudbrooke (Monmouth).

Another example of subaqueous tunnelling, second only in im­portance to the foregoing, is the Mersey tunnel, the length of which between the pumping shafts on each side of the river is 1 mile. From each shaft a drainage heading was driven through the red sandstone with a rising gradient towards the centre of the river. This heading was partly bored out by a Beaumont machine to a diameter of 7 feet 4 inches, and at a rate attaining occasionally 65 lineal yards per week. All of the tunnel excavation, amounting to 320,000 cubic yards, was got out by hand labour, since heavy blast­ing would have shaken the rock. The minimum cover between the top of the arch and the bed of the river is 30 feet. Pumping machinery is provided for 27,000,000 gallons per day, which is more than double the usual quantity of water ; and ample ventila­tion is secured by two 30-feet diameter and two 40-feet diameter Guibal fans. Messrs Brunlees and Fox were the engineers, and Messrs Waddell the contractors for the works, which were opened in 1886, about 6 years after the commencement of operations.

Proposals for the construction of a tunnel about 30 miles in length to connect England and France have been brought forward periodically from the commencement of the 19th century, but nothing was done until 1881, when preliminary works of some im­portance were commenced by Sir Edward Watkin and the South- Eastern Railway Company. At the proposed point of crossing the deepest part of the channel is 210 feet, and, as the beds on the English side and those on the French side, so far as relates to the grey chalk and chalk marl, are each 225 feet thick, it is assumed that those strata are continuous and that the tunnel would be driven through a water-tight material. Shafts have been sunk near Folkestone, and experimental headings have been driven 2000 yards under the sea, on the line of the tunnel. The heading, 7 feet in diameter, was cut by a Beaumont boring machine, having two arms with steel teeth, and driven by compressed air ; the usual rate of progress was 15 lineal yards per day.

A partially constructed subaqueous tunnel now lies drowned under the Hudson river at New York. An attempt was made to drive a double tunnel through the mud and silt forming the river bed. In 1880, when about a hundred yards had been completed, the water burst in, and twenty men were drowned. Work was sub­sequently resumed on the following plan (see fig. 2). A pilot tunnel, consisting of an iron tube of 6 feet 6 inches in diameter, was advanced from 30 to 40 feet ahead of the main tunnel, to form a firm support for the iron plates of the latter by means of radial screws. Compressed air, pumped into the tunnel at a pressure of about 20 lb per square inch, prevented the weight of silt and water from crushing the plating and flowing into the tunnel. The excavated