

and tin, which they probably discovered quite independently of the Aztecs, whom they rivaled also in the cutting of gems.

Roman Tunnels.

The Romans, however, were undoubtedly the greatest tunnel builders of early history. They drove tunnels for passage, drainage, water supply and mining, not only in Italy, but wherever their conquests led them, as is evidenced both by records and by old workings left behind in the countries they dominated. One hardly needs to mention the numerous aqueduct tunnels and sewers of the ancient city of Rome, some of which are in use to-day, attesting the ability of the Romans in this branch of engineering. Remains of their work, many of them remarkably well preserved, have been found in France, Switzerland, Portugal, Spain, Algiers and even Constantinople.

Their tunnels were of no mean size. A road tunnel near Naples, constructed, according to Strabo, about 36 B. C., was approximately 4,000 ft. long, 30 ft. high and 25 ft. wide. About 359 B. C. Lake Albanus, which lies about 15 miles southeast of Rome, was tapped for its supply of clear water by a tunnel over one mile long 8 ft. high and 5 ft. wide. Possibly the greatest Roman tunnel was driven by the Emperor Claudius to drain the overflow waters from Lake Fucinus, which is situated about 75 miles nearly due east of Rome and has no natural means of outlet. This tunnel, completed in 52 A. D., after 11 years' labor, is over 3 miles long and was designed to be 19 ft. high and 9 ft. wide; but it appeared to have been even larger than this when, in 1862, it was reopened to obtain valuable land beneath the lake.

These works seem all the more marvelous when one considers the primitive methods available at that time. Explosives were unknown and machinery was not then used in mining. Rock openings were usually made by chipping, by channeling and wedging as in Egypt, or by cutting large grooves around the block to be excavated, using hand tools made of iron, copper and bronze, although it is quite possible that for certain classes of stone cutting diamonds or some similarly hard minerals were employed in conjunction with primitive tube drills and saws. These methods were often supplemented by fire setting, a method chiefly employed, however, in the large chambers or stopes and not well adapted for driving small tunnels. It consists simply of heating the rock to a very high temperature and quenching suddenly with water (or sometimes with vinegar in calcareous rocks), producing shattering and disintegration because of sudden contraction. Many writers have described the intense and fearful sufferings of men engaged in this work, usually slaves and prisoners of war, who perished by the thousands—a fact, however, of little concern to the ancient builders.

The value of Spain as a storehouse of precious metals, offsetting somewhat the influence of eastern wealth, was well appreciated by Roman leaders, and an armed force for the protection of the mines was maintained there constantly, in many cases at the cost of serious political and financial embarrassment at home. In southern Spain, where the numerous silver and copper mines contained much water, Roman tunnels are very common. They are remarkable for their small size, being usually about 5 ft. in height and, where timbered, 16½ to 36 in. in width. One adit, as far as explored, has a length of 1,850 ft. and a maximum depth of 183 ft., and another is 2,300 ft. long and has a maximum depth of 215 ft.

As nearly as can be ascertained to-day from discoveries in them of various objects of interest, including coins, it is certain that these adits must have been driven very early in the Christian era. Toward the latter end of the period in which these particular tunnels were used by the Romans attempts were made to work the orebodies below them by raising water from the lower stopes by means of slave-operated water wheels.

As artificial ventilation by means of blowers was at that time unknown, like most of the Roman tunnels these were ventilated by shafts which were spaced in the tunnel mentioned above at about 25 meter intervals; in order also to minimize the depth to which the shafts were sunk, the courses of the tunnels corresponded very nearly to those of the valleys or gulches above them instead of being straight, as is the usual modern practice. Like the adits, the ventilating shafts were remarkably small. Where timbered the adits were usually about 2 ft. 10 in. square in the clear, and where the rock would stand without timbering they were circular and generally did not vary much from 2 ft. 4 in. in diameter.

Tunneling in Europe During the Middle Ages.

With the fall of the Western Empire, tunnel work in Europe practically ceased for many centuries. Some excavations were made, it is true, for tombs and the crypts of monasteries and underground passages to a secluded exit for escape in time of defeat were a necessary part of the equipment of each castle. Crude attempts at mining also were practised in Germany. The Teutonic tribes, whose main occupation was warfare and who were barbarous and essentially nomadic at the time of the conquests of Julius Caesar, probably learned from the Romans the value of gold; later they began to search for precious metals and to pursue other peaceful occupations.

During the Middle Ages tunneling was devoted almost exclusively to the needs of war and was seldom employed in constructing aqueducts or other public works. There is, however, a record of a road tunnel begun in 1450 by Anne of Lusignan. It was intended to pierce the Alps at an elevation of nearly 6,000 ft. and afford better means of communication between Nice and Genoa, but was never completed. Work was subsequently resumed in 1782 by Victor Amadens III., but was finally abandoned 12 years later after a total of nearly 8,000 ft. of tunnel had been constructed.

Development of the Use of Gunpowder in Tunneling.

Although gunpowder in Europe, according to the consensus of opinion, was probably invented early in the fourteenth century, and by the end of the sixteenth century was commonly used in military operations for gunnery and for blowing up fortifications, it was not applied directly to mining or tunnel operations during this period. Agricola's "Bergwerck Buch," the third edition of "De Re Metallica," published by Basel in 1621, a complete English translation of which has been issued, pictures Roman methods and hand work and fire setting as the usual means of mining.

In the year 1613 Martin Weigel is said to have introduced gunpowder in mining. Gatschmann at this time describes the use of wooden plugs for stemming. The plugs were later (about 1685) supplanted by clay. August Bayer ("Das gesegnete Markgrafenthum Meissen," 1732) and Henning Calvor ("Nachrichten uber das Bergund Maschinewesen am Harze, etc.") also confirm the date of 1613 as that of the invention of drilling and blasting, but Honemann and Rossler make it 15 or 20 years later. Whatever may have been the date when