

‘The Minerals of Laurion’

Graham Ogle first played compliments to the late Laurie Lawrence who was quite familiar with the silver mining area of Laurion in Greece having visited several times, written various articles and a book on the area not to mention having given more than one lecture to Society Meetings on the subject. There are several spellings of the name but ‘Laurion’ was the one used by the speaker. The story of the Laurion area is a story of a number of different groups of people - rich Greek shipbuilders, eccentric Englishmen, somewhat obsessional Germans, expansionist Persians, and entrepreneurial French.

With the aid of a number of slides Graham Ogle first indicated the location of the Laurion mines which cover about two hundred square kilometres over an area some 40 kilometres to the south-east of Athens in Attica. The geology is metamorphic with basement rocks of Triassic and Jurassic marbles and mica schists. Laid on top of these has been a nappe of Cretaceous rocks pushed over the earlier rocks from the north at the time when the Alps were being built. The nappe rocks included Cretaceous phyllites, some marble, micaceous quartzites and various metamorphic igneous rocks derived from lava flows and volcanic tuffs, the whole having been later subjected to high-pressure metamorphism. More modern theories suppose that there has been a marine transgression over the area contributing an erosion surface and a karst landscape with deep weathering. Complicating the geology has been later granite intrusions causing contact metamorphism of the schist in places and the production of hornfels.

The metal deposits are mostly tabular or amorphous masses penetrating deep into the marble. They are Mississippi Valley-type deposits of silver-lead-zinc with fluorite and sometimes barite in the carbonate limestone rock. They consist primarily of sulphides with also arsenates, carbonates, fluorides, and phosphates. There are two types of primary ores, the iron and manganese ores which were deposited first containing ankerite, rhodochrosite, fluorite, barite and quartz, some of which have oxidised to limonite and pyrolusite. Later ores were of mixed sulphides, primarily of zinc, iron and lead containing sphalerite, pyrite and galena. These ores are associated with a number of other elements including arsenic, bismuth, nickel and cobalt which led to the development of a large number of other minerals. The sphalerite contained not just zinc and iron but also manganese and cadmium whilst the galena also contained silver and a little gold, about two grams per ton. Weathering and oxidation of these primary minerals has produced a range of secondary minerals, cerussite, anglesite, adamite, smithsonite, malachite and azurite. Slag heaps from ancient ore-processing were often on beaches, and with contact with sea-water have produced a further range of secondary minerals.

The mineralogy of the area is fascinating with at least 432 species known including about 100 found in the ancient slags which have been influenced by contact with or immersion in seawater. Mineralogists owe much of the knowledge about Laurion minerals to the activities of fastidious German collectors who have investigated and collected in the area for many years. The range of silver and lead minerals is similar to that found at Broken Hill with a number of the rarer type species originally found at Broken Hill also identified at Laurion. However unlike at Broken Hill, garnets are very rare and there is no rhodonite or bustamite, but at Laurion significant amounts of elements such as copper, nickel, bismuth and antimony occur which has given rise to a number of minerals containing these elements. Other more unusual elements and minerals containing them found at Laurion in smaller but identifiable amounts include cadmium, strontium, germanium, indium, titanium, tellurium, cobalt and even uranium.

There are a number of type species from Laurion, the first being laurionite which is a lead chloride and which was described in 1887 by Koechlin, (who has had the bismuth molybdate koechlinite named after him). Specimens of other type species from Laurion had been brought to

the Meeting to display by the speaker who also proceeded to work through and describe numerous slides of Laurion minerals, mostly of micro-mount size but many very spectacular in appearance.

Mining at Laurion commenced about 3,000 BC. This date has been ascertained because lead found in Egypt and dated to that time has been found to have the same isotope ratios. Similarly lead from Laurion was used in the Minoan culture in Crete in about 1100 BC. The mines were worked variously by the Greeks, by the Phoenicians, then the Greeks again. The various classical period Greek writers, Pericles, Theophrastos and others have reported on the mines and mining from time to time, the mines being described by one historian as 'the treasure house of the country'. The miners first started working the surface ores and discovered that silver was in the galena by noting that when the lead oxidised the silver precipitated as the pure metal with argentite on top. Accordingly the miners followed first the galena and then the cerussite knowing that where lead was found there would also be silver. Laurion lead ores contained about $\frac{1}{2}$ % silver. By the second millennium BC the mining had reached a depth of 20-30 meters using stone tools. By 483 BC according to Aristotle mining had penetrated down to 100 meters using metal hammers and chisels by that time.

Quoting from Laurie Lawrence's article Graham Ogle noted a description by Laurie of an underground visit he had made at Laurion. Many of the ancient adits were horizontal for substantial distances but only generally about two feet high which indicated the awful working conditions of the ancient Greek slave miners who were probably taken underground wearing leg irons, chained to the work-face, worked and basically stayed underground probably for the rest of their lives. Modern miners and explorers of the mines have sometimes found portions of skeletons of ancient miners with leg irons still attached to their ankle bones. Laurion was however worked over a very long period and conditions for the work-forces may have varied over the years and with the profitability of the mining. Records of deeds of leases dating to the ancient period have been found in Athens which indicated large work-forces at times. Also records show that some slaves were paid and were allowed possessions and graveyards so conditions for the slaves, at some of the mines and working for some of the owners, may have been more comfortable. It has been estimated that over some periods there were over 20,000 slave labourers working at Laurion. There are over a thousand ancient shafts in the Laurion area, some over a hundred meters deep and many leading to underground networks of low narrow tunnels. Over the last century, very much like in ancient times, many have been operated by private entrepreneurs who held lease contracts under government licenses.

Silver was of course used for making currency, ornaments and utensils; the lead was used for reinforcing ships hulls and water pipes etc. Zinc was not used as a metal in ancient times - not until 1520. A number of views were shown of the ancient tools used in the mining and some of the ore processing equipment, washing areas and remains of furnaces etc. Archaeologists have found remains of ore processing plants where ore had been hand-crushed using hard quartzite rocks and grinding stones, sieved and the concentrate then loaded onto washing plants with sloping platforms to separate the lead-containing minerals, mainly galena and cerussite. After stacking to dry the ore concentrate was carried to smelters which were set up nearer to the coast from the mining areas in order to have access to wood. The furnaces were about three meters high and were loaded from the top with charcoal and ore and fired up. The liquid pig-lead flowed out of a hole at the base of the furnaces leaving slag behind which was then dumped by the miners nearby or on to the beaches along the coast of the mining area. The pig lead was then oxidised to litharge (cupellation) in a second type of furnace, also with bellows. The litharge - a thin layer on top of the crucible - was carefully blown off with bellows. The non-oxidisable silver - left in crucible at increasing concentrations. More pig-lead added and the process repeated until purity of 09-99% was obtained.

The Laurion mines were worked up to about the second century BC, by which time the underground deposits were exhausted by the methods then in use. A revival of metal production occurred in the 1800s and 1900s when French and Greek companies started re-working much of the ancient slag material since these still contained up to 15% lead, also cadmium and manganese. The refining techniques by then involved cupellation in bellows-assisted furnaces operating at higher temperatures than the smelting furnaces. Some of the underground workings have been reopened with new tunnels dug and modern companies have been working in the Laurion area up to twenty years ago. Geologists have calculated that the ancient mining and ore processing left about 1.5 million tonnes of slag behind after having extracted about 1.4 million tonnes of lead and 3.5 million kilos of silver.

The speaker next provided an overview of the historical situation over the ancient period that the Laurion mines were being worked and the influence that the metals being produced had on the international situation at that time. In the early part of the first millennium the Greeks lived in a series of large and small independent city states and were mainly under the influence of the Phoenicians but in driving the Phoenicians away they were threatened by the expanding Persian empire which was at that time the largest that the world had yet seen. The Persians initially took over Greek settlements and cities along the coast of Ionia, (modern Turkey), but a series of revolts by these cities which were aided and encouraged by Athens determined the Persian king Darius to assemble and send a large force to punish and subjugate all the Greeks. The Persians were initially successful advancing through the islands off the Greek mainland but their force was defeated by the Greeks at the battle of Marathon in 490 BC. It is from this event that the word marathon came into athletic significance because a runner was sent from the battle-field to relay the news to Athens that 'We are victorious' only for him to drop dead from exhaustion as soon as he had delivered the message!.

The expectation that the Persians would not give up meant that the Greeks had to prepare for another invasion and in so doing were persuaded by Themistocles of Athens, at that time the largest and wealthiest of the Greek city-states, to build a hundred ships to help beat back the Persians. The silver from the Laurion mines which were owned by the Athenians was very significant in paying for the ship-building program and also for fortifying the harbour at Athens. The second Persian invasion in 480 BC under the command of Darius's son Xerxes came by land and by sea and supposedly comprised some 200,000 soldiers and a thousand ships. The land force moved to face the Greeks at Thermopylae in central Greece with the Persians prevailing although the heroic resistance by the Spartan '300' under their king Leonidas, (currently the subject of a film being shown in Australian cinemas), and also of some 7,000 other Greek soldiers, held up the Persian army sufficiently for Athens and Themistocles to be warned and to evacuate the city. The Persians then occupied Athens and burnt the Acropolis but Themistocles had escaped and was busy rallying the Greeks at Salamis, a port near Athens on the coast.

The oracle of Delphi had pronounced that "Salamis would bring death to women's sons but the Greeks would be saved by a wooden wall". This had been interpreted in different ways by Greek factions, the Spartans wanted to build a wooden wall at Corinth, but Themistocles persuaded everyone that the wooden wall would be the ships that had been built. Accordingly about two weeks after Thermopylae the Greek and Persian navies clashed at Salamis with Xerxes himself supposedly watching from a hill-top. The Greeks had about 378 ships, about half provided by Athens due to the program initiated by Themistocles, and the Persians about a thousand but superior Greek tactics with lighter, swifter craft held the day. This was a decisive turning point in the Persian campaign. The Persian navy was not completely wiped out but Xerxes had lost too many ships and was unable to keep his land army supplied. Much of the army returned to Persia

with the remainder wintering in Greece only to be defeated decisively by the Greeks the following year at Plataea.

This ended Persian aspirations towards occupying Greece and ushered in the golden age of Greek civilisation over the next 200-300 years. The names of eminent Greek philosophers, writers, dramatists and sculptors such as Pericles, Socrates, Plato, Aristotle, Eurypides and many others as well as Greek institutions and culture became established over this period. It is surmised that the establishment of Greek culture instead of Persian over the few centuries has profoundly influenced other European cultures to the present day and has been due in effect to the decisive battle at Salamis.

Over this period Athenian coinage bearing an image of the god Athena and an owl on the reverse became very well established with the tetradrachm, four drachmas, made mostly from Laurion silver. It was minted in large numbers from 510 to 38 BC, particularly in the middle of the fourth century BC. In many respects the Athenian tetradrachm was the first 'euro' coin, recognised and accepted everywhere although in later centuries was superseded by the Roman denarius. The tetradrachm would buy a sheep or a bushel of barley whilst a single drachma was equivalent to about a day's wages. The rate of inflation was very low, about 50% over two hundred years. The drachma persisted in use until 2001 (AD) when the Greeks would joke that all it would buy would be a strand of spaghetti and the coin was finally demonetized in favour of the euro. (Athenian tetradrachms can be bought today from coin dealers for about US\$400).

Graham Ogle finally took some time to display and describe a list of the Laurion slag minerals and then ran through a large number of images of the various minerals provided by collectors in Europe. He also showed images of collectors searching and working on the beaches at Laurion and advised that in organising field trips to the slag beaches in Greece the collector in addition to the usual collecting tools would need a swimming costume, snorkel and face-mask etc!. The slags would have initially been composed of silicates with iron and calcium oxides and some residual lead but immersion in and contact with sea-water has added a number of elements, sodium, potassium, chloride, bromide, iodide, sulphur and phosphate. Over the centuries crystallisation of new minerals has occurred in the cracks in pieces of the material.

Some slag material can be found away from the beaches although most of this has been reworked by modern mining companies and material not having been in contact with seawater has not developed new minerals. About 100 slag minerals have been identified in the Laurion material although the I.M.A. in 1995 decided that these should not be considered to be natural species.