This paper discusses evidence related to the genesis and occurrence of mixed lead-tin ore deposit consisting of cassiterite and the secondary minerals formed from galena. These evidences belong to a very long time period ranging from pre-historic to as late as the nineteenth century A.D. This type of mixed ore deposits was smelted to prepare lead-tin alloys. The composition of the alloy depended on the composition of the starting ore mixture. A nineteenth century evidence for the production of directly smelted lead-tin alloys in southern Thailand is discussed. A unique and rather uncommon metallurgical terminology in Sanskrit language—Nāgaja—was introduced in India for the tin recovered from impure lead. This suggests that Indians developed a process for recovering tin from lead-tin alloys, which in all probability was based on the general principle of fire refining. It has been shown that in the context of India the possibility of connection between the word Nāgaja and the directly smelted lead-tin alloys cannot be ruled out.

INTRODUCTION

Lead and tin are amongst the oldest known metals. The most important mineral used for extraction of lead in ancient times was galena (PbS) together with the secondary minerals such as cerussite (PbCO₃) and anglesite (PbSO₄), derived from its chemical weathering. It is reasonable to believe that the use of secondary lead minerals for extracting lead preceded that of the primary min-
zone of the deposit consists of cassiterite, in the form of quartz-cassiterite aggregates, cemented with a limonite-hematite-cerussite aggregate. The composition (wt.%) of the deposit has been reported as follows: Sn = 0.01–6.61%, Pb = 0.06–15%, Cu = 0.001–0.5%, Zn = 0.004–0.1%. The content of the sulfide tin does not exceed 0.01%. Thus, most of the tin was in the form of cassiterite, and lead in the form of cerussite.

The most important fact in the present context is that the deposits show signs of ancient working; however, details of the ancient working have not been reported. Cassiterite (density = 6.99 g/cc) and cerussite (density = 6.5 g/cc) have similar densities. It would not have been difficult to obtain a cassiterite-cerussite concentrate from the crushed and ground deposit by the panning process.

In another tin deposit at Syaghar, Ghazni Province, Afghanistan (32°56′20″N, 67°40′20″S), the presence of both cassiterite and cerussite minerals has been reported. In Seh-Kuta, Farah Province, Afghanistan (33°05′N, 61°42′E), the main minerals present have been reported as cassiterite and galena. The oxidized zone would contain cassiterite, cerussite and, or anglesite. Similarly, cassiterite together with secondary minerals of lead has been reported at Khinjak, Ghazni Province, Afghanistan (32°51′45″N, 67°37′05″E).

Thus it is clear that a mixed lead-tin ore deposit has been located in western and eastern parts of Afghanistan.

**Southeast Asia**

In 1894 A.D., Louis described a very interesting mixed lead and tin mineral deposit, near the river Patani passing Biserat in Benag Sta area in the then Siamese Malay states, situated in the Malay Peninsula. The map given in Figure 1 shows the area (dotted portion), where the mixed lead-tin ore deposit was noticed by Louis. Presently this area is a part of the Yala province of southern Thailand bordering Malaysia, as shown in Figure 1. A detailed map of this area (after Reference 5), showing the locations of tin and lead ore mines, is shown separately in Figure 2. This deposit was near the Kedah Province of the present day Malaysia. As discussed later, Kedah was an important trade center in ancient and medieval times. The place formed the port of the cassiterite and galena mines, as shown in Figure 2. The deposit was produced by the gradual degradation of cassiterite-bearing granite and of limestone containing pockets of galena. The gravels in the deposit were cemented by iron oxide formed by the decomposition of iron and arsenical pyrites. The lead mineral present in the deposit were the secondary lead minerals obtained from the oxidation of the original galena.

It was reported that local workers were mining this deposit by breaking it with crowbars followed by stamping under tilt hammers. The crushed gravel was washed, and a mixture of cassiterite and oxidized lead ores like anglesite (PbSO₄), cerussite (PbCO₃), pyromorphite (Pb₃[Cl(PPO₄)₂]) and mimetite (Pb₂[Cl(AsO₄)₃]) were obtained. All the above lead minerals were formed by chemical weathering of galena in the oxidized zone. It is possible to construct the sequence of processes which led to the formation of such a lead-tin composite deposit.

The products of weathering of rocks are subject, from the moment they are formed, to dispersal by various agents, such as moving water, air, or ice. Running water is the most common agent for the transport of the weathered product. Depending on the topography, the transported weathered products may be collected near the base of the mountain. Such deposits are called colluvial placers. It is possible that the colluvial placers may get relocalized in a low-level area. In the presence of air and water, the surface of galena oxidizes leading to the formation of a range of oxidation products, such as lead sulfates (anglesite), lead hydroxides, and lead oxides. The exact nature of the oxidation product is greatly dependent on the pH value of the oxidizing fluid. In the presence of CO₃⁻ anion, lead forms a lead carbonate mineral such as cerussite. Similarly the iron pyrite present in the rock will also oxidize and form the oxides of iron. Thus in the oxidized zones of lead veins, secondary minerals such as anglesite (PbSO₄) and cerussite (PbCO₃) would be present.

If the galena deposit is situated adjacent to the cassiterite deposit, as is the case in the deposit found in Siamese Malay states, it is possible that the respective colluvial placers may get redeposited in a low-level land area. The iron oxide, derived from iron pyrite, present in such clastic sediments will act as a cementing agent. Such a deposit will contain minerals such as cassiterite, anglesite, and cerussite together with the ingredients of the host rock in a mechanically mixed condition.

According to a report submitted to the Federated Malay States in 1907, tin deposits were also worked at Blanda Mabok in Taiping, Malay Peninsula.