CHAPTER VI

CONCLUSION

The preceding discussion of geologic factors in relation to the origin of the Song Toh mineralization summarizes the doubts which exist on theories of origin put forwards to date. It must be admitted that the origin so far remains unsolved.

In view of the combined amount of time spent by the author on the Song Toh mineralization it is considered worthwhile to summarize his present opinions relating to ore origin, in the hope that these will stilmulate constructive discussion and further investigation.

The author at present favour a syn-diagenetic origin. The term is used in the sense that the sulfide minerals were present prior to deformation, having been penecontemporaneously formed by chemical precipitation or clastic concentration at the interface in lime mud or ooze, and during early stage of compaction, cementation, and water-expulsion, but before deep burial. The syn-diagenetic origin for the orebodies has been influenced by a number of pertinent points resulted from previous descriptions and his own limited observations. For examples :

1. The sulfide lenses tend to favour particular facies and horizons and to be absent from other masses of associated limestone.

2. Large-scale fault structures are apparently not regional associates of ore occurrence.
3. The lack of an obvious genetic association between mineralization and an igneous source rock
4. In a broad sense, the lode horizons are concordant with the sediments .
5. In zones of folding the orebodies exhibit the same contortions of form characteristic of the structurally deformed host rocks .
6. The sulfide grain boundaries are, by and large, of impingement and accretionary type. Particular noteworthy is the occurrence of colloform and framboidal pyrite which are progressively overgrown by coarser zoned pyrite. This evidence, experimentally, appear to be indicative of diagenetic or later-stage hydrothermal recrystallization of early-formed syn-sedimentary iron-sulfides .
7. The ubiquitous of a profuse sub-grain structure in galena overgrown with fragmented sphalerite lead to a suggestion that the galena had been plastically deformed between more resistant minerals.

Assuming that sedimentary processes were responsible for the origin of the Song Toh mineralization, it is of interest to investigate the possible processes further in an attempt to arrive at a model for the formation of the lode. The model must provide satisfactory explanations of the following : (1) sources of the constituents;

(2) collection and transportations via a suitable medium and ;
(3) deposition of the constituents. Each of these aspects is, in inturn, considered as follows :

Source : Possible sources of metals for the formation of a sedimentary sulfide ore deposit are, as concluded by White (1968) and Anderson (1969), metals dispersed in rocks undergoing weathering, metals dispersed in a pyroclastic or volcanic pile, or a deep crustal or mantle source. It should be noted that the probability of any one, or combination of more than one, of these mentioned sources depends partially on the nature of the transport mechanism.

Transport : Two mechanisms for transporting metal have been recently proposed in recent years,i.e., the first one is chloride complexes (Helgeson, 1964, 1967) and the other one is bisulfide complexes (Barnes and Czamanske, 1967). Though sulfide complexes of metals are highly soluble, but high pH's and high total sulfide concentrations are required. According to his study on the natural waters rich in heavy metals, White (1968) indicated that the metals may likely be transported in Na-Ca-Cl brines with high metal to sulfide ratios. Likewise, Skinner, et al., (1967) ; and Degens and Ross (1969) had respectively studied the brines of the Salton Sea and Red Sea geothermal system and demonstrated that the brines are predominantly consisted of Cl, Na, Ca, and K with usually high contents of several metals, but considerably low sulfur content. Furthermore, White (1968) had also investigated evidence for the

origin of the water of the Salton Sea brine, and concluded that water of the brine concerned was dominantly meteoric origin. He also postulated other processes where Na-Ca-Cl brines may evolve, and hence become potential ore-forming solutions. The processes include vapour phase separating from magma, connate water evolving to saline brines during diagenesis, membrane filtration of dilute meteoric waters, extention boiling of initially dilute waters, and formation of brines in the pore spaces of metamorphic rocks.

Deposition : It is of importance to point out that the occurrence of metal-rich sediments in the Red Sea and Salton Sea brine pools demonstrates a relationship between metal-rich brines and the formation of sulfide deposits. The geothermal systems concerned also provide the first contemporary example of syngenetic concentrations of ore metals. There are a variety of mechanisms theoretically capable of precipitating sulfide minerals from sulfur-poor brines. For instance, Kaplan, et al. (1969) suggested that mixing of the metal-rich brine with sulfide-rich brine derived from reduction of sulfate with organic-rich shale during hydrothermal activity have caused precipitation of the metal sulfides in the Atlantis II Deep. In contrast, Bischoff (1969) argued that the metals are transported in the brine as chloride complexes and become unstable on cooling as the brine discharged into the ocean, and the metals would be precipitated as sulfides. Another mechanism proposed by Lovering (1961) is that precipitating sulfides from sulfur-deficient solutions react with earlier-formed pyrite leading to deposition of other sulfides.

Finally, it is of interest to note that anaerobic sulfate-reducing bacteria may be important in the formation of sedimentary sulfide deposits in reducing marine environment (Kaplan, et al., 1963).

The above discussion enables certain proposals to be made concerning deposition of the Song Toh mineralization. These are made on the assumption considered earlier, that the constituents of the orebodies were deposited penecontemporaneously with the enclosing sediments.

The sequence of events is summarized as follows :-

1. Formation of a saline brine from connate, meteoric or ocean water.
2. Migration of the brine through a sedimentary and/or volcanic pile, leading to enrichment of heavy metals ratios in the brine.
3. Intermittent discharge of the brine into a basin environment and subsequent deposition of the sulfides and other materials on the floor of the basin.
4. Folding of the host rocks took place during a period of late Carboniferous to Permo-Triassic deformation resulting in an approximately northwest-southeast trending sequences, weakened by fractures.
5. Subsequent uplift and erosion exposed the sulfide orebodies.