CHAPTER V

THE CARBONATE-HOSTED LEAD-ZINC SULPHIDE

In this chapter, an attention has been focussing upon the ore deposits which are associated with the Ordovician carbonate sediments. However, it is considered that the most update theoretical background knowledge on the carbonate-hosted lead-zinc sulphide deposits should be reviewed to serve as a conceptual framework. They are outlined in Appendix F.

5.1 Petrographic and geochemical characteristics of the ore-bearing carbonate sediments.

5.1.1 Petrographic characteristics.

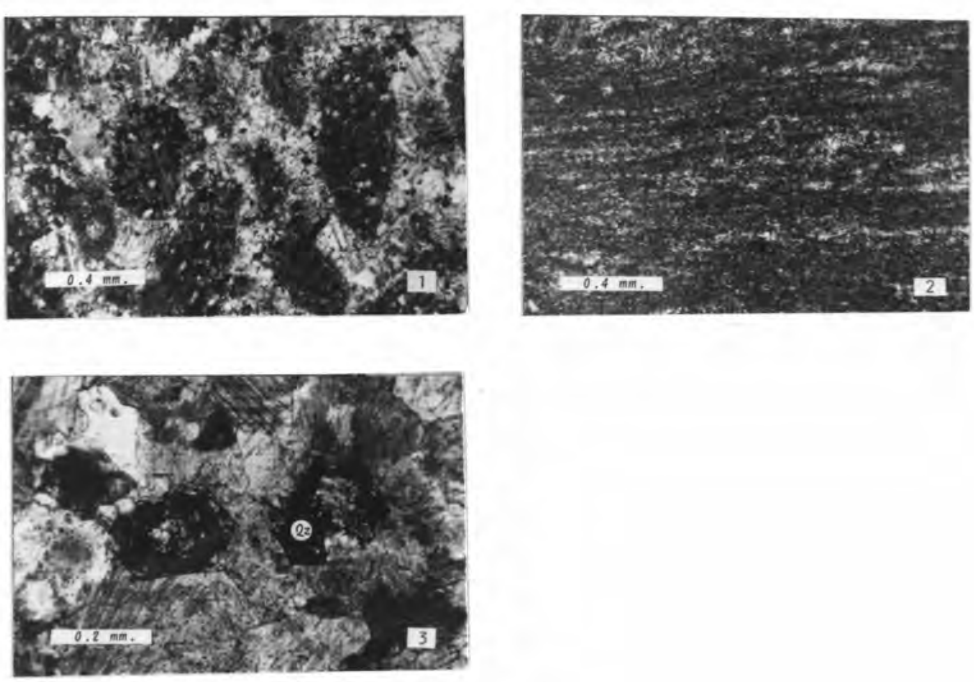
Generally, the petrographic characteristics of the Ordovician carbonate sediments in the lead-zinc mineralized zone is slightly different from those in the non-mineralized zone. However, the most distinctive carbonate rock type which is only present in the mineralized zone is dolomitic intraclastic pelsparite (Plate 5-1: 1). Besides, the finely crystalline rocks in the mineralized zone usually exhibit the flaser structure of micrite or microsparite which show micro-layer alternation with medium-grained dolomite lenses (Plate 5-1: 2).

Plate 5-1 Photomicrographs of the ore-bearing Ordovician carbonate sediments from the Song Toh Mine area.

1 Dolomitic intraclastic pelsparite showing intraclasts with disseminated sulphide ores, and detrital quartz (under transmitted light; crossed nicols)

2 Dolomitic fossiliferous micrite showing micro-layers alternating with medium-grained dolomite lenses (under transmitted light; crossed nicols).

3 Isolated authigenic quartz (Qz) showing heavily embayed in carbonate matrix (under transmitted light; crossed nicols).



It is noted that, the veinlets of coarsely secondary calcite with associated dolomite rhombs and medium to coarsely crystalline authigenic quartz mosaic are quite common in the carbonate rocks of the mineralized zone. Almost all of the isolated detrital and/or authigenic quartz commonly show heavily embayed by carbonate matrix (Plate 5-1: 3).

5.1.2 Geochemical characteristics.

Under the present investigation, the determination of geochemical parameters of the Ordovician carbonate sediments in the lead-zinc mineralized zone has been carried out altogether 25 samples. These parameters include calcium, magnesium, iron, strontium, lead, zinc, barium, manganese, cobalt, and acid insoluble residue. The analytical results are summarized and presented in Table 5.1.2a.

An attempt has been made to determine the geochemical correlation among these geochemical parameters using the correlation matrices (Table 5.1.2b). The degree of significant correlation among geochemical parameters has also statistically evaluated (Table 5.1.2c).

It is apparent that the very strong positive geochemical correlation exists between the lead and barium ($r=+0.8193$), zinc and acid insoluble residue ($r=+0.8101$). Besides, there is the strong positive geochemical correlation between lead and zinc ($r=+0.7775$), iron and manganese ($r=+0.7576$), lead and acid insoluble residue ($r=+0.7315$), and barium and strontium ($r=+0.6423$). For calcium and acid insoluble residue, there is a strong negative

Table 5.1.2a The analytical results of the geochemical parameters.

Parameters	Range	Mean	SD
Calcium (wt.%)	6.25-38.75	31.11	10.98
Magnesium (wt.%)	0.30-19.22	7.40	7.18
Iron (ppm.)	22-203	64.48	39.85
Strontium (ppm.)	1.14-9.26	4.60	2.14
Lead (ppm.)	0.10-171.5	25.16	15.42
Zinc (ppm.)	0.18-209.5	29.83	18.50
Barium (ppm.)	6.11-32.44	12.81	7.04
Manganese (ppm.)	2.15-17.75	4.81	3.13
RS (wt.%)	1.59-75.69	13.70	6.60

RS = Acid insoluble residue.

Number of sample = 25.

Table 5.1.2b The correlation matrices of the geochemical paramenters.

	Sr	Pb	Zn	Ba	Mn	Mg	Ca	Fe	Ca/Mg
Pb	0.4333								
Zn	0.2481	0.7775							
Ba	0.6423	0.8193	0.4271						
Mn	0.0357	-0.1391	-0.2364	0.0299					
Mg	-0.2286	0.2642	0.0011	0.2923	0.0736				
Ca	0.2662	-0.4706	-0.6029	-0.2344	-0.05515	-0.4003			
Fe	-0.0295	-0.0482	-0.1243	-0.0190	0.7576	0.0433	0.0382		
Ca/Mg	0.2147	-0.2145	0.0668	-0.1843	0.0849	-0.5595	0.4101	-0.0304	
RS	0.0964	0.7315	0.8101	0.4056	-0.2193	0.0678	-0.6906	-0.0527	-0.2744

RS = Acid insoluble residue.

Number of sample = 25.

Table 5.1.2c The correlation coefficients and significance of the geochemical parameters.

Correlation coefficients		t	Significant			Not significant
			95%	99%	99.9%	
Pb-Ba	r = +0.8193	+6.8535			x	
Zn-RS	r = +0.8101	+6.6254			x	
Pb-Zn	r = +0.7775	+5.9286			x	
Fe-Mn	r = +0.7576	+5.5667			x	
Pb-RS	r = +0.7315	+5.1454			x	
Ba-Sr	r = +0.6423	+4.0188			x	
Pb-Sr	r = +0.4332	+2.3056	x			
Zn-Ba	r = +0.4271	+2.2653	x			
RS-Ba	r = +0.4056	+2.1283	x			
Ca-Sr	r = +0.2662	+1.3245				x
Ca/Mg-Sr	r = +0.2147	+1.0543				x
RS-Sr	r = +0.0964	+0.4646				x
Mg-Mn	r = +0.0736	+0.3538				x
Ca-Mn	r = +0.0736	+0.3256				x
RS-Mg	r = +0.0678	+0.2649				x
Ca-Fe	r = +0.0382	+0.1832				x
Fe-Sr	r = -0.0295	-0.1416				x
RS-Fe	r = -0.0527	-0.2351				x
Fe-Zn	r = -0.1243	-0.6008				x
Mg-Sr	r = -0.2286	-1.1261				x
Ca-Ba	r = -0.2344	-1.1563				x
Ca-Pb	r = -0.4706	-2.5579	x			
Ca-Zn	r = -0.6029	-3.6241		x		
Ca-RS	r = -0.6906	-4.5797			x	

r = correlation coefficient between parameters.

t = T-test values.

RS = Acid insoluble residue.

Number of sample = 25.

geochemical correlation (r=-0.6906).

In the ore layers, there are associations of galena, sphalerite and barite in different proportion. However, the galena appears to be the most dominant. This explains the very strong and strong positive geochemical correlations among lead, zinc, barium, acid insoluble residue. In addition, it is noted that the quartz content both of authigenic and terrigenous origins, and the clay content of terrigenous origin in the ore layers are exceptionally higher than the adjacent non-mineralized zone. Therefore, this explains the strong positive geochemical correlations among lead, zinc, and acid insoluble residue. The strong positive geochemical correlation between barium and strontium indicates that they can be both present as trace element in the carbonate rocks. The strong negative geochemical correlation between calcium and acid insoluble residue indicates that the contents of acid insoluble residue (quartz both of authigenic and terrigenous origins, and clay) in ore layers are significantly increased.

An additional attempt has been made to compare the geochemical characteristics of the Ordovician carbonate sediments in the non-mineralized zone with mineralized zone. This comparison is summarized in Table 5.1.2d, and graphically represented in Figure 5.1.2. The result reveals that barium, and acid insoluble residue of the mineralized zone are higher than those of the non-mineralized zone, whereas the iron is lower than the non-mineralization zone. The manganese and strontium contents of both non-mineralized and mineralized zone show only slight different.

Table 5.1.2d The analytical results of the geochemical parameters in the mineralized, and non-mineralized zones.

Parameters	$\overline{X} \pm SD$	
	Mineralized zone	Non-mineralized zone
Calcium (wt.%)	31.11±10.98	30.24±5.38
Magnesium (wt.%)	7.40±7.18	8.24±7.06
Iron (ppm.)	64.48±39.85	85.99±44.51
Strontium (ppm.)	4.60±2.14	4.39±2.30
Lead (ppm.)	25.16±15.42	0.22±0.20
Zinc (ppm.)	29.83±18.50	0.31±0.23
Barium (ppm.)	12.81±7.40	10.57±3.46
Manganese (ppm.)	4.18±3.13	4.40±1.65
Cobalt (ppm.)	-	0.95±0.06
RS (wt.%)	13.70±6.60	11.96±9.05

\- = Less than detection limit.

RS = acid insoluble residue.

Number of sample in mineralized zone = 97.

Number of sample in non-mineralized zone = 25.

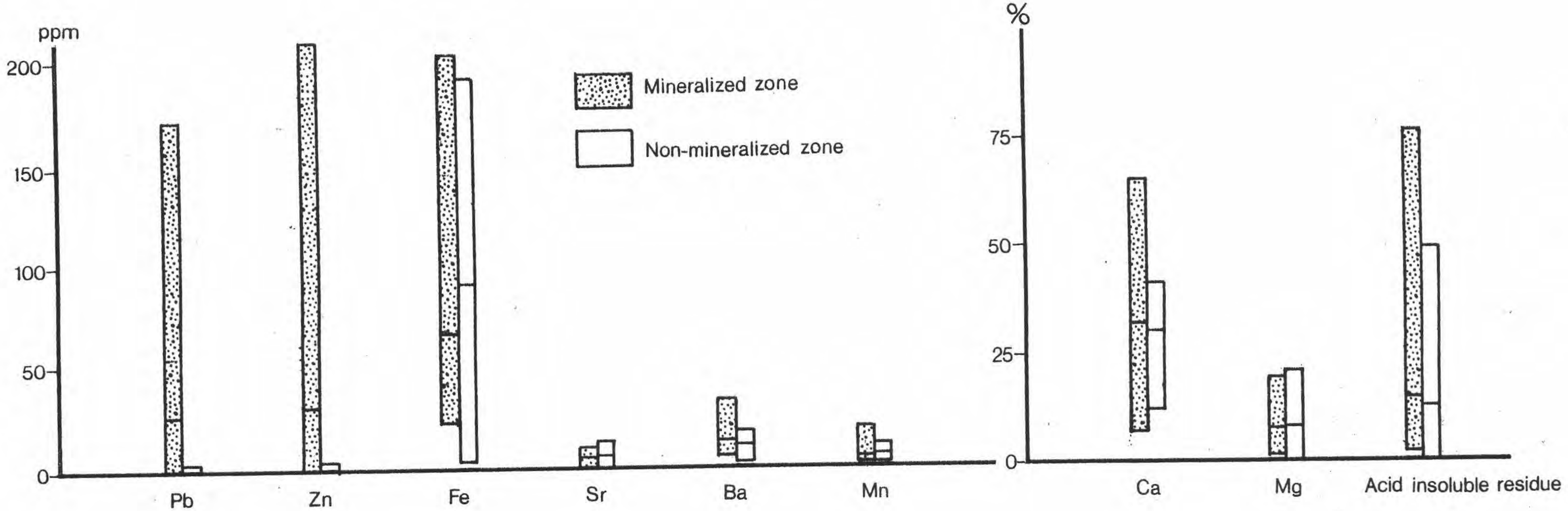


Figure 5.1.2 The graphic presentation of the analytical results of the geochemical parameters in Table 5.1.2d (The length of the column represents the geochemical parameters ranges and the line dividing the column represent the arithmatic means).

5.2 Lead-zinc ores.

5.2.1 Megascopic characteristics.

The major sulphide ores of the Song Toh Mine area are galena [PbS] and subordinate sphalerite [ZnS], whereas pyrite [FeS_2], barite [$BaSO_4$], quartz [SiO_2], dolomite [$CaMg(CO_3)_2$], calcite [$CaCO_3$], and clay are associated gangue minerals. Besides, secondary ores which are associated with the exposed primary ore zone or as oxidized minerals are cerussite [$PbCO_3$], smithsonite [$ZnCO_3$], hemimorphite [$Zn_4(OH)_2(Si_2O_7).H_2O$], and hydrozincite [$Zn_5(CO_3)_2(OH)_6$] (Suksa-nguan, et al., 1986).

The mineralization of galena and sphalerite is entirely confined within the Ordovician carbonate sequence. With respect to the type of mineralization, at least three different main types have been recognized in the mine. They are:

(a) Layered or banded galena/sphalerite ores: The thickness of a single layer varies from one to several inches. Generally, the ores appear to be concordant with stratification of the carbonate-host rock but pinched out over short distance along the strike. The ores are very fine-grained, and the galena is the predominant sulphide showing the sharp contact with the carbonate-host rock. The layers or bands of sulphide ores are closely related to the bedding plane of the carbonate-host rock which are mostly tectonically deformed (Plate 5-2: 1). Occasionally, the galena and sphalerite are closely intercalated each other. (Plate 5-2: 2). In addition, the jasperoid associated with this ore type appears as small lenses or bands concordant with the bedding plane and showing sharp contact with the carbonate-host rock (Plate 5-2: 3, and 4).

(b) Massive sulphides ores: This ore type appears as compact ore body of 10 to 20 metres long, and up to 15 metres thick (Suksa-nguan, et al., 1986). Most of primary sedimentary structures, and primary ore structures have been tectonically destroyed by the processes of remobilization and/or recrystallization. The mineral association in this ore type is galena, sphalerite, pyrite, and barite (Plate 5-2: 5).

(c) Disseminated sulphides ores: It occurs mostly in the neighbourhood of the orebodies without the alteration of original bedding of the carbonate-host rock. It has been recognized as lateral limitations of layered or banded galena/sphalerite ores and between single ore bands or layers. In addition, it commonly occurs along small fissure faults, bedding fissilities, and stylolitic surfaces. The most dominant sulphide mineral is galena, and the ore is generally fine-grained.

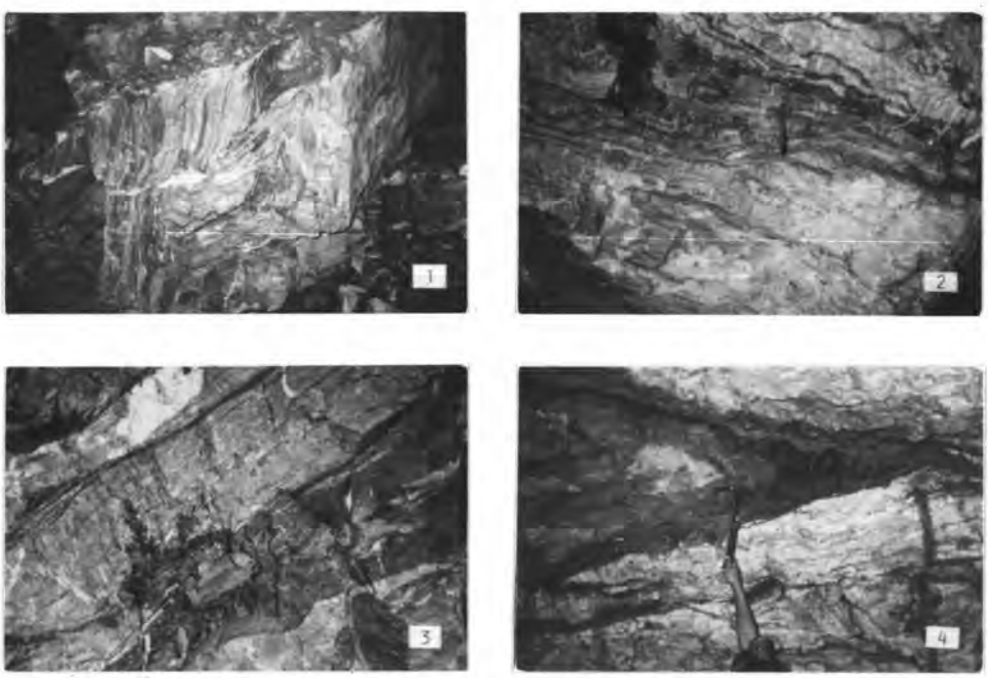
Plate 5-2 Photographs of the ore-bearing Ordovician carbonate sediments from the Song Toh Mine area.

1 Layered or banded galena/sphalerite ores showing the sulphide ores stratified with the carbonate-host rock and highly tectonically deformed.

2 Layered or banded galena/sphalerite ores showing interbedding between galena (black colour) and sphalerite (gold colour).

3 Jasperoid lens in the layered or banded galena/sphalerite ores showing sharp contact and stratified with the carbonate-host rock.

4 Massive sulphide ores lenses showing sharp contact with the carbonate-host rock.



5.2.2 Microscopic characteristics.

The microscopic examination of about 50 doubly polished thin-sections of the ore-bearing Ordovician carbonate sediments from the Song Toh Mine area has been undertaken. The main emphasis will be focussed upon the layered or banded and disseminated sulphide ores because of the primary ore textures, and sedimentary textures and structures are best observed in these ore types. In contrast, most of the massive sulphide ores, as suggested and demonstrated by Permthong (1982), has suffered the remobilization and recrystallization. Furthermore, the doubly polished thin-sections would allow the determination in details not only on the relationships between ore and gangue minerals but also the textures of sphalerite both in transmitted and reflected light which have never been carried out in this area before.

Only the textures of the major of ores and gangue minerals, namely, galena, sphalerite, pyrite, barite, calcite, dolomite, quartz, and clay are considered in this study. The textures and the distributions of more exotic minerals are reported elsewhere (Permthong, 1982).

The microscopic characteristics of the ores are described in descending order of their abundances as follows:

GALENA [PbS]

Between the two major sulphide minerals, galena and sphalerite, the galena is by far the most abundant in the Song Toh orebodies. Microscopically, at least two types of galena are recognized in the layered or banded galena/sphalerite ores. The type I galena occurs as fine-grained or irregular inclusions in detached dolomite rhombs and/or mosaic calcite (Plate 5-3: 1a, 1b, 3a, and 3b), and framboidal to pyritohedral pyrite. These calcite crystals were late overgrowth into the clear mosaic sparry calcite cement. These sparry calcite cement was later replaced by detached dolomite rhombs occasionally trapped the inclusions of galena type I. Frequently, framboidal pyrite, fine-grained sphalerite type I (see later section), and clay are closely associated with this type (Plate 5-3: 4a, 4b, 5, and 6; Plate 5-4: 1a, and 1b; Plate 5-5: 6a, 6b, and 7). The type I galena is probably represents the early-formed galena that has been preserved by trapping as inclusions in the detached dolomite rhombs and/or mosaic calcite. The type I galena is also found as small irregular or fine-grained bodies closely associated with the type I sphalerite (Plate 5-3: 4a, and 4b). The type II galena represents by the majority of galena in the layered or banded galena/sphalerite ores and/or disseminated sulphides ores especially in the massive sulphides ores. This type appears as fine to coarsely patches to massive aggregate or irregular mass wrapping around detached dolomite rhombs and/or framboidal to pyritohedral pyrite (Plate 5-4: 2, and 3). The secondary foam texture (Permthong, 1982), and curved cleavage pits as a result of post-depositional deformation and recrystallization texture of the type II galena is frequently observed especially in the massive sulphide ores (Plate 5-4: 3). Evidences of late infiltration of the type II galena along fracture and cleavage planes and replacement along outer crystal boundary of the detached dolomite rhombs are also not uncommon (Plate 5-4: 2, and 3). It also occurs as intergrowth with quartz, and

Plate 5-3 Photomicrographs of the ore-bearing Ordovician carbonate sediments from the Song Toh Mine area.

1 Fine-grained galena type I (Ga) embedded in detached dolomite rhombs (Do) and/or sparry calcite cement, and the late stage pyrite type II (Py) under reflected light (1a) and under transmitted light (1b; uncrossed nicols).

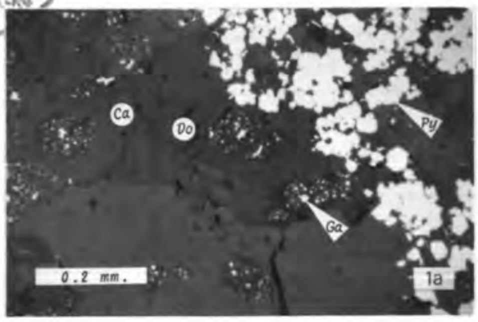
2 Fine-grained galena type I (Ga), and sphalerite type I occurs as inclusions in intraclast of dolomitic intraclastic pelsparite under reflected light (2a), and under transmitted light (2b; crossed nicols).

3 Showing fine-grained galena type I (Ga) occurs as inclusions in sparry calcite cement (Ca), and late stage detached dolomite rhomb (Do) under reflected light (3a) and under transmitted light (3b; uncrossed nicols).

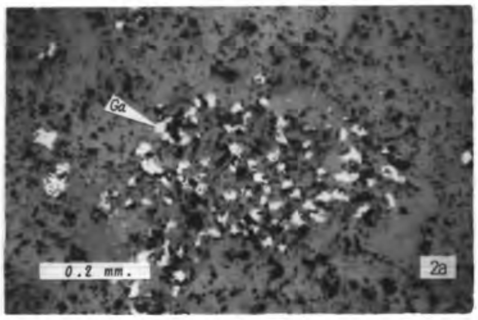
4 Fine-grained galena type I (Ga) and sphalerite type I (Sp) are associated with clay and quartz (Qz) under reflected light (4a) and under transmitted light (4b; crossed nicols).

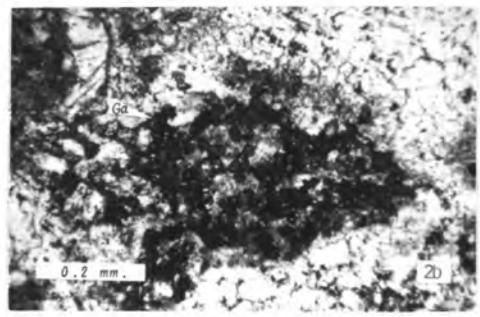
5 Galena type I (Ga), framboidal pyrite (Py), and sphalerite type II (Sp) embedded in clay under reflected light.

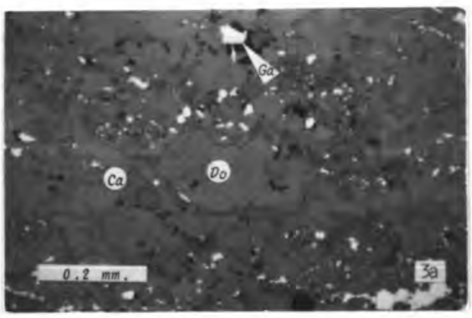
6 Framboidal pyrite (Py) trapping as inclusions in galena type II (Ga) and associated with sphalerite type II (Sp) under reflected light.

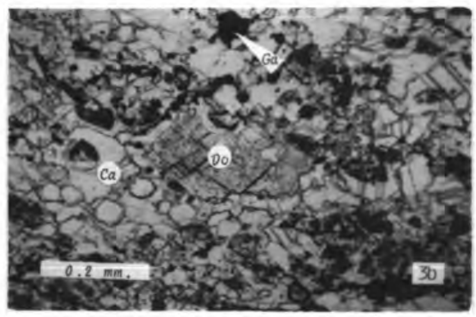

Ca
Do
Py
Ga
0.2 mm.
1a

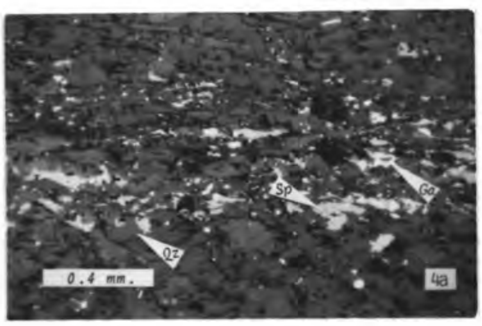

Ca
Do
Py
Ga
0.2 mm.
1b

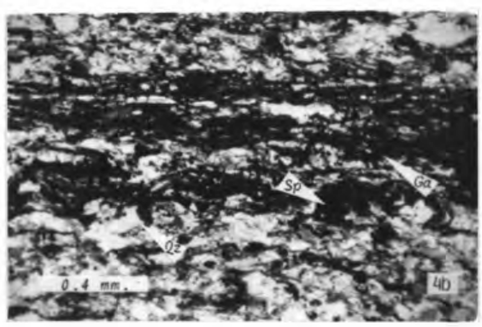

Ga
0.2 mm.
2a

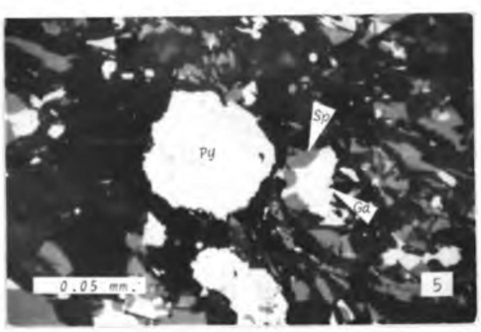

Ga
0.2 mm.
2b

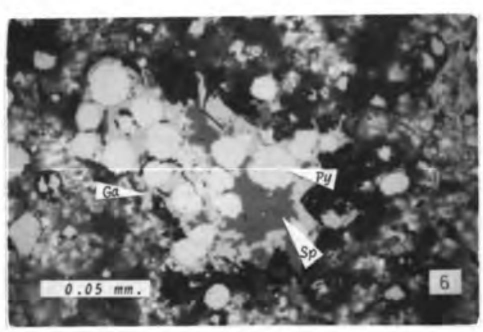

Ga
Ca
Do
0.2 mm.
3a


Ga
Ca
Do
0.2 mm.
3b


Sp
Ga
Qz
0.4 mm.
4a


Sp
Ga
Qz
0.4 mm.
4b


Py
Sp
Ga
0.05 mm.
5


Ga
Py
Sp
0.05 mm.
6

sphalerite type I and II, and barite (see later section) (Plate 5-4: 4a, 4b, 5a, 5b, 5c, and 6). The type II galena probably represent subsequent recrystallization and/or remobilization of the "primary" or "early-formed" type I galena that were deposited penecontemporaneously with the surrounding carbonate sediments.

SPHALERITE [ZnS]

In layered or banded galena/sphalerite ores, and disseminated sulphide ores, sphalerite shows a diversity in grain size and morphology. However, at least two genetic types of sphalerite are clearly recognized under the doubly polished thin-section. The most common and widely distributed sphalerite in the layered or banded galena/sphalerite ores is the fine-grained (approximately 10 micrometres in size) type I sphalerite. It ranges from irregularly polycrystalline or clusters to semi-linear bands to finely laminated bands, anhedral crystals in barite and dolomite matrix (Plate 5-4: 1a, 1b, 5a, 5b, and 5c) or alternating with barite-rich bands. Occasionally, when viewed in transmitted light, sphalerite demonstrates the systematic growth zoning. The fine-grained laminated sphalerite commonly mixed with oriented clay laminae, type I galena, and framboidal to pyritohedral pyrite (Plate 5-3: 4a, 4b, and 5). Somewhat less common is the type II sphalerite. It is characterized by a clear, medium- to coarse-crystals or aggregates and commonly associated with remobilized galena (type II), and detached dolomite rhombs (Plate 5-4: 6; Plate 5-5: 1). Type I sphalerite transitionally recrystallized to form type II sphalerite is not uncommon especially in the highly deformed ores. The type II sphalerite is also formed subhedral crystals in late secondary calcite vein cross-cutting

Plate 5-4 Photomicrographs of the ore-bearing Ordovician carbonate sediments from the Song Toh Mine area.

1 Semi-linear band of very fine-grained type I galena and sphalerite associated with clay laminae under reflected light (1a), and under transmitted light (1b; crossed nicols).

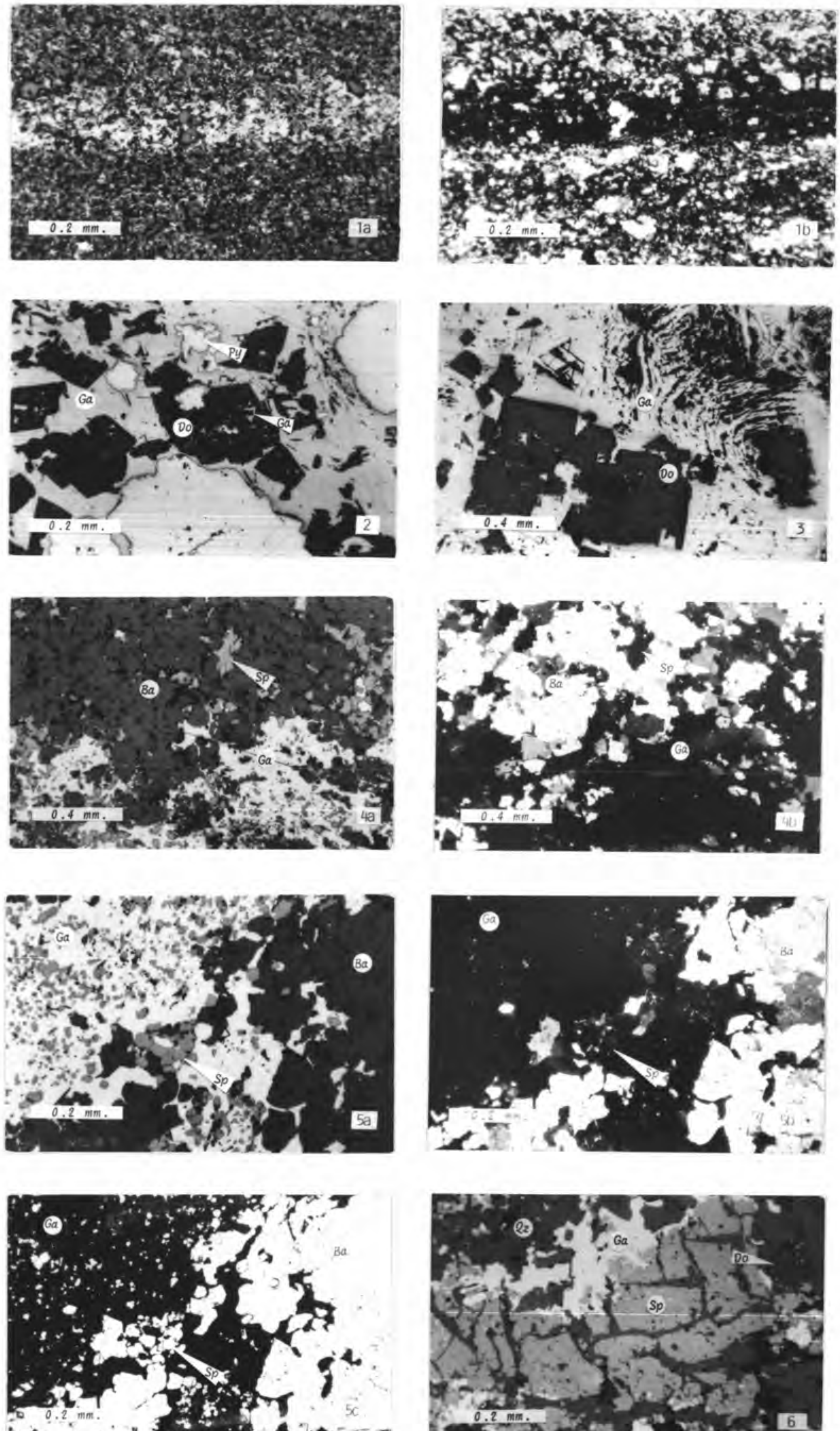
2 Galena type II (Ga) wrapping around detached dolomite rhombs (Do) and/or framboidal to pyritohedral pyrite (Py), and galena type I (Ga) occurs as inclusions in detached dolomite rhombs (Do) under reflected light.

3 Showing curved cleavage pits as a result of post depositional deformation, and late infiltration of galena type II (Ga) along fracture of detached dolomite rhombs (Do) under reflected light.

4 Galena type II (Ga) associated with barite (Ba) and Sphalerite type I (Sp) under reflected light (4a), and transmitted light (4b; crossed nicols).

5 Fine-grained sphalerite type I (Sp) are closely associated with galena type I (Ga) and barite (Ba) under reflected light (5a), under transmitted light (5b; crossed nicols and 5c; uncrossed nicols).

6 Medium- to coarse-grained or aggregates sphalerite type II (Sp) occasionally with remobilized galena (type II) (Ga), detached dolomite rhombs with galena type I, and Quartz (Qz) under reflected light.


0.2 mm.
1a
0.2 mm.
1b
Py
Ga
Do
Ga
0.2 mm.
2
Ga
Do
0.4 mm.
3
Sp
Ba
Ga
0.4 mm.
4a
Sp
Ba
Ga
0.4 mm.
4b
Ga
Ba
Sp
0.2 mm.
5a
Ga
Ba
Sp
5b
Ga
Ba
Sp
0.2 mm.
5c
Qz
Ga
Do
Sp
0.2 mm.
6

across the bedding plane of dolomitic intraclastic pelsparite (Plate 5-5: 2). Those textural evidences seem to suggest that the sphalerite type II probably has its genetic relation to post-depositional deformation and recrystallization similar to that of galena type II.

Among the common gangue minerals associated with the lead-zinc mineralized zone are barite, pyrite, quartz, calcite, dolomite, and clay. Each of these minerals will be discussed as follows:

BARITE [$BaSO_4$]

Barite is one of the most common gangue mineral in the layered or banded galena/sphalerite ores. It is recognized as bands that are composed of fine to coarsely crystalline aggregate of barite with frequently intergrowth detached dolomite rhombs, quartz, and galena (Plate 5-4: 4a, 4b, 5a, 5b, and 5c; Plate 5-5: 3, and 4). These barite bands are commonly alternating with galena-rich band, sphalerite-rich bands, clay-rich bands, pyrite-rich bands (i.e., compositional layering). These bands probably represent original sedimentary textures. Inclusions of type I galena in detached dolomite rhombs is occasionally observed and suggested that dolomite (as well as barite) is penecontemporaneously or slightly post-dated galena.

PYRITE [FeS_2]

At least two distinctive textures have been recognized, namely, framboid, and euhedral crystals. Besides, intermediate textural characteristics between framboid and euhedral-formed are also presented. Sometimes it forms aggregate and semi-linear bands associated with clay (i.e., sericite) and parallel to the bedding plane (Plate 5-5: 5, 6a, and 6b). Framboidal pyrite, type I, commonly shows an aggregate form in carbonate matrix, associated with galena type I and II, sphalerite type I, and clay (Plate 5-3: 1a, and 1b; Plate 5-5: 5, 6a, 6b, and 7). The late stage or euhedral-formed pyrite, type II, usually occurs as cubes and/or pyritohedrons (Plate 5-5: 7; Plate 5-3: 1a, and 1b) that seems to be recrystallized from of the original pyrite type I. These crystals frequently contain inclusions of sulphide ores (Plate 5-4: 2).

QUARTZ [SiO_2]

Quartz found in the mineralized zone can be classified into three different textural characteristics, notably, silt-sized detrital quartz (Plate 5-1: 1, and 2), detached fine euhedral authigenic quartz crystals (Plate 5-1: 3), and fine-grained mosaic authigenic quartz (Plate 5-6: 1). It is important to note that the most common diagenetic features of silica in the mineralized zone are hematite-bearing quartz and chert, commonly known as jasperoid (Plate 5-6: 2). These features megascopically appear as small lenses in the ore layers concordant with the bedding showing sharp contact with the host rock (Plate 5-2: 3), whereas microscopically they are present as a tight-fitting mosaic embedded with fine-grained hematite

Plate 5-5 Photomicrographs of the ore-bearing Ordovician carbonate sediments from the Song Toh Mine area.

1 Medium- to coarse-grained sphalerite type II (Sp) occurs as irregular mass wrapping around detached dolomite rhombs (Do) under reflected light.

2 Isolated euhedral crystal sphalerite type I embedded in carbonate matrix under transmitted light (crossed nicols).

3 Closely intergrown among barite (Ba), Quartz (Qz), and dolomite (Do) under transmitted light (crossed nicols).

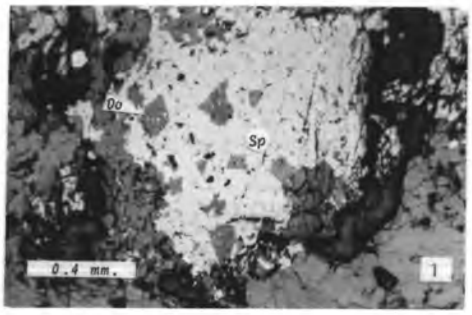
4 Detached dolomite rhombs in barite under transmitted light (crossed nicols).

5 Semi-linear of very fine-grained pyrite type I associated with clay laminae under reflected light.

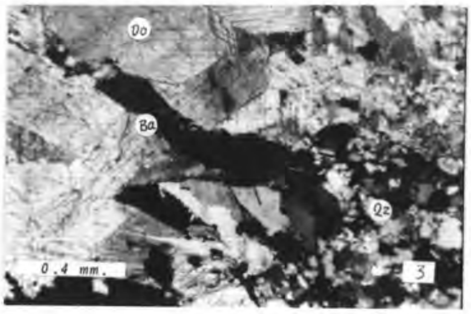
6 Framboidal pyrite (Py), quartz (Qz) and galena type I (Ga) in clay laminae under reflected light (6a) and transmitted light (6b; crossed nicols).

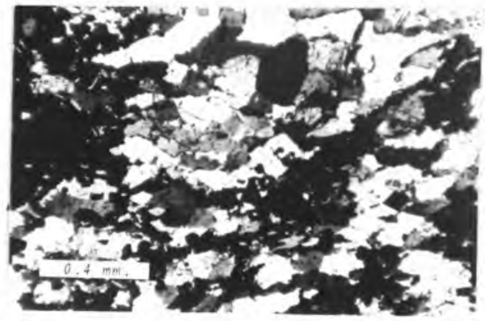
7 Closely intergrown among framboidal pyrite type I, galena type I (Ga), and sphalerite type I (Sp) under reflected light.

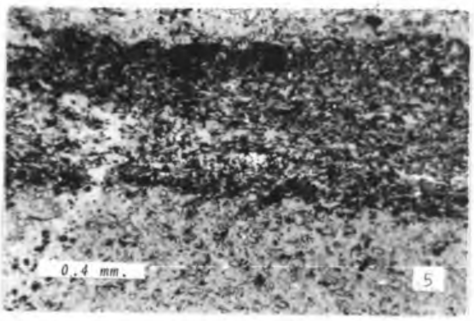
8 The late stage or euhedral-formed pyrite type II occurs as cubes and/or pyritohedrons under reflected light.

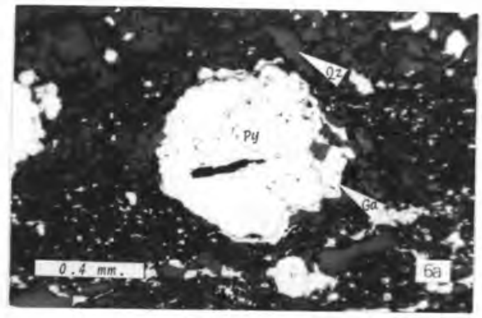

Do
Sp
0.4 mm.
1

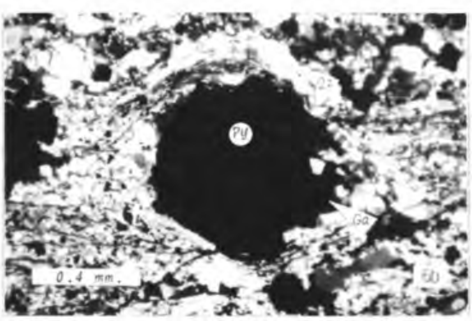

0.4 mm.
2

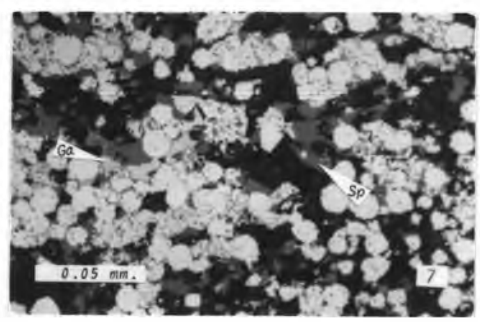

Do
Ba
Qz
0.4 mm.
3

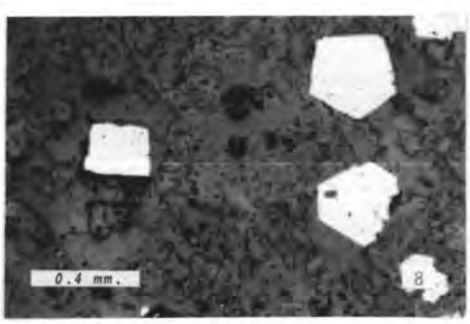

0.4 mm.


0.4 mm.
5


Qz
Py
Ga
0.4 mm.
6a


Py
Ga
0.4 mm.
6b


Ga
Sp
0.05 mm.
7


0.4 mm.
8

disseminated along the growth zone. Association of jasperoid and framboidal pyrite is also frequent. Texturally, jasperoid occasionally is enclosed in detached dolomite rhombs (Plate 5-6: 3). This evidence seems to suggest that dolomitization and formation of well-crystalline pyrite slightly post-dated jasperoids.

DOLOMITE [$CaMg(CO_3)_2$]

Dolomite is another common gangue occurring in layered or banded galena/sphalerite ores as well as massive sulphide ores. In contrast to the dolomite in the carbonate-host rock, dolomite in the ore layers only formed as a detached dolomite rhombs (Plate 5-6: 4). No dolomite mosaic has been observed in the ore bands. Most of dolomite rhombs are mainly fine-grained, and detached. Textural relationships between detached dolomite rhombs and most of the sulphide minerals (i.e., sphalerite type I, galena type I, and framboidal pyrite), jasperoid and barite indicate that the formation of detached dolomite rhombs is penecontemporaneously and/or slightly post-dated those minerals.

CALCITE [$CaCO_3$]

Calcite is a very common and widely distributed gangue mineral, occurs both as well-formed crystals in fracture and/or allochemical grains, and as matrix and/or cement of various sizes up to sparite-sized with galena type I inclusion (Plate 5-3: 1a, 1b, 3a, and 3b). It may also occurs as an interstitial matrix in the porous jasperoid, having crystal continuity in sizes ranging from micrite- to sparite-sized under the reflected light. Hematite disseminated in calcite bands or laminations are occasionally observed. The amount of

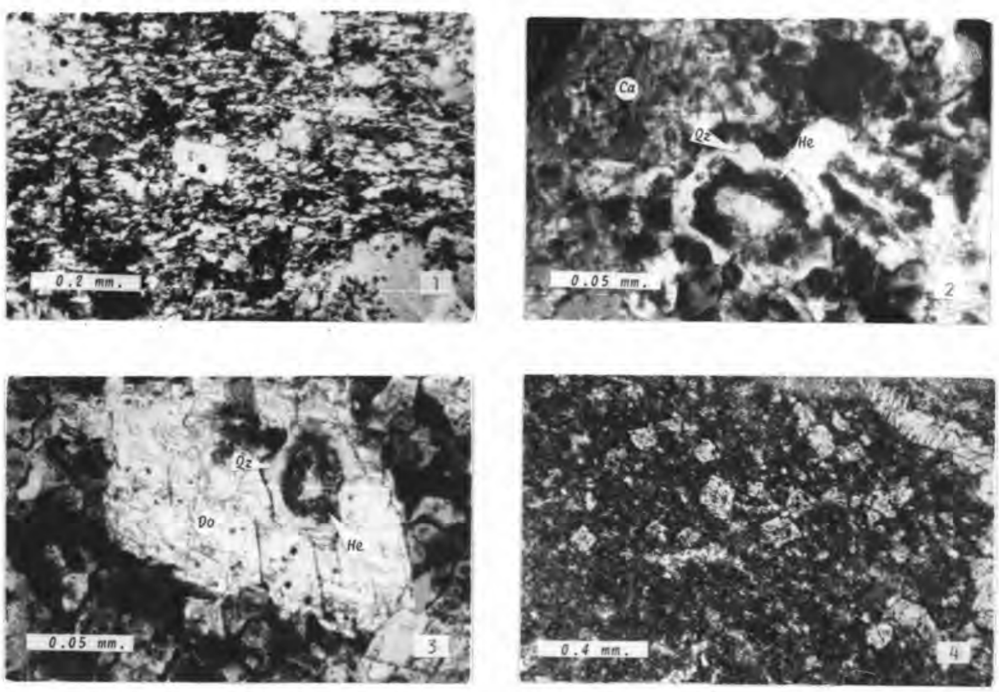
Plate 5-6 Photomicrographs of the ore-bearing Ordovician carbonate sediments from the Song Toh Mine area.

1 Fine-grained mosaic authigenic quartz associated with detached dolomite rhombs and/or sulphide ores (black colour) under transmitted light (crossed nicols).

2 Jasperoid showing quartz (Qz) and hematite (He) enclosed in carbonate matrix (Ca) under transmitted light (crossed nicols).

3 Jasperoid showing quartz (Qz) and hematite (He) enclosed in detached dolomite rhomb (Do) under transmitted light (crossed nicols).

4 Detached dolomite rhombs embedded in carbonate matrix under transmitted light (crossed nicols).



calcite is very irregular, from abundant outside the mineralized zone to even absent or almost absent in the ore layers.

CLAY

The most common clay in the ore zone is muscovite natural 3T. They commonly show a preferred orientation and intimately mixed with the fine-grained type I sphalerite, galena (both type I and II) and occasionally with detached dolomite rhombs and detrital quartz grains. In an interbedded shaly layer underlying the mineralized zone in the Song Toh South, it is composed essentially of intimate mixture of oriented sericite, detrital quartz, fine-grained type I sphalerite, type I galena, framboidal pyrite and small detached dolomite rhombs (Plate 5-3: 4a, 4b, and 5; Plate 5-4: 1a, and 1b; Plate 5-5: 5, 5, 6a, 6b, and 7). The presences of detrital quartz and clay suggest that both of ore and gangue minerals were formed syngenetically by sedimentary processes.

5.2.3 Proposed paragenesis of the Song Toh lead-zinc sulphide deposit.

From the mineralogical and textural relationships outlined in section 5.2.2, a general mineral paragenesis of the Song Toh lead-zinc sulphide deposits particularly for the layered or banded galena/sphalerite and disseminated sulphide ores can be illustrated as a diagramme in Figure 5.2.3. From the fact that most layered or banded galena/sphalerite ores and disseminated sulphide ores are conformable to the bedding plane, and that in the ore layers themselve, the early-formed ores (i.e.,sphalerite type I, and galena type I) are very fine-grained and frequently mixed intimately

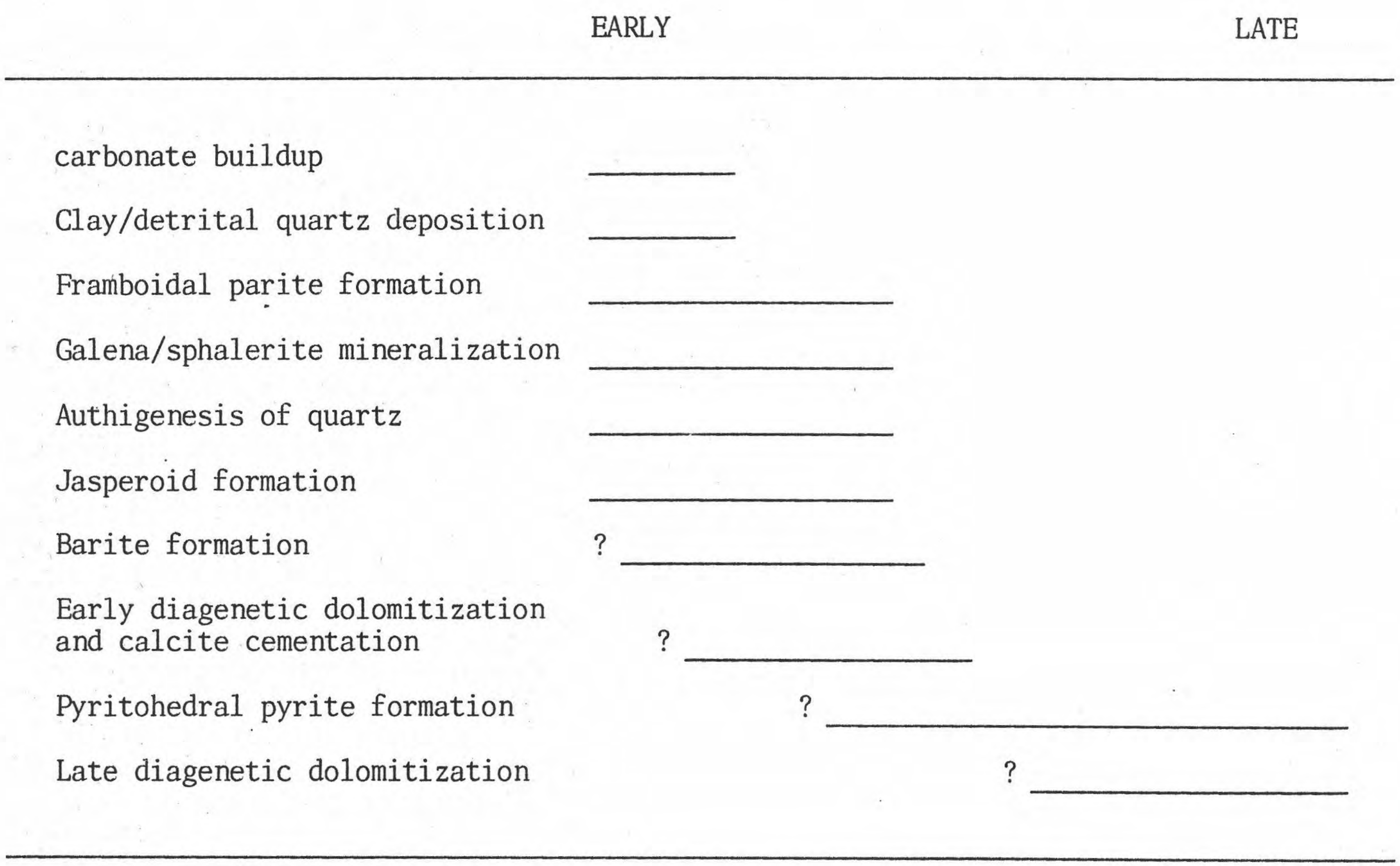


Figure 5.2.3 Proposed paragenetic diagramme of the Song Toh lead-zinc sulphide deposits, (excluding subsequent tectonic deformation, and recrystallization).

with somewhat oriented clay flakes and detrital quartz grains clastically derived, it is therefore likely that most of the layered or banded galena/sphalerite ores as well as disseminated sulphide ores including barite layers and jasperoid were deposited syngenetically during the carbonate-host rock builtup with occasionally terrigenous clastic influx. This condition probably took place above the seawater/sediments interface. However, some portions of the sulphide ores might be introduced during the early diagenetic cementation as evidenced from the co-precipitation of some sulphide ores with detached dolomite rhombs and/or sparry calcite cement. Subsequently, majority of the galena and some of the sphalerite were recrystallized and remobilized by post-depositional deformation and probably responsible for the formation of massive sulphide ores especially at the crest of the folds.

5.2.4 <u>Proposed model of the Song Toh lead-zinc sulphide deposit.</u>

Although there is a great variety of stratiform, strata-bound lead-zinc deposits in sediments, new discoveries and new ideas seem to be leading to an understanding that the deposits are all part of a continuum that is related essentially to the migration of metal-charged connate waters (and often hydrocarbons) out of basinal sedimentary prisms during their compaction. The migration may be early or late, fast or slow, voluminous or insignificant. As a consequence mineralizing fluids may accumulate in sedimentary, diagenetic or lithified environments and deposition may take place wherever the fluids encounter suitable physicochemical conditions. The sulphides may therefore occur in sedimentary, diagenetic or epigenetic environments : hence the great variety of deposits. The essential aspect of them all is that they contain predominantly lead and zinc sulphides, usually with barite and are usually deficient in copper (Badham, 1981).

For the geological environment of the Song Toh Mine area, the carbonate-hosted deposits of galena, sphalerite, barite, and pyrite in rock having primary and secondary porosity are commonly related to near-shore carbonate shelf facies. The lithological characteristics of the carbonate-host rock is characterized by the association of dolomitic intraclastic pelsparite, dolomitic fossiliferous micrite, dolomitic dismicrite, and medium crystalline dolomite. With respect to the textures and structures of the host rock, calcilutites are most abundant and calcarenite are not uncommon, and almost all of them are very thin layered. Regarding the alteration, regional dolomitization of early and late diagenetic origins are common. The geological age indication of carbonate sequence is probably of Lower Ordovician to Middle Ordovician Epoch (Diehl and Kern, 1981). The carbonate-host rock are shallow marine carbonates facies with prominent subtidal and some intertidal facies. The deposits show a certain degree of terrigenous clastic influx.

Generally, the origin of ore deposits in sedimentary rocks can be classified into two main categories, namely, primary and secondary (Badham, 1981). However, there are of course no clear divisions between primary and secondary processes but the following broad definitions may be adopted:

- Primary: the products of sedimentary processes as or above the water/sediments interface. They may be clastic, chemical or both, for example, placer deposit, and chemical sediment-iron formation.

- Secondary diagenetic: the products of interactions between primary sediments and pore waters derived essentially from their dewatering.

- Secondary epigenetic: the products of interactions between sedimentary rocks and pore waters which attained their physical and chemical conditions elsewhere.

Finally, the data and information on microfacies and geochemical facies of the Ordovician carbonate sediments, paragenesis, regional geological setting of the area concerned will be considered in the light of theoretical framework of the carbonate-hosted lead-zinc deposits for the formulation of the genetic model of the Song Toh deposit.

The lead-zinc mineralization in the Ordovician carbonate sediments of the Song Toh Mine area usually shows sharp contact, without any evidence of hydrothermal wall-rock alteration (Permthong, 1982) between the ore zone and the host rock. Besides, the geochemical profiles of the lead and zinc across the mineralized zone are sharp and abrupt without any transitional zone. Petrographic characteristics of the carbonate sediments within and outside the ore zone show a similar diagenetic fabrics.

So far, the indications of igneous activity in the vicinity of the Song Toh Mine area are tuffaceous layers and volcanic breccia which can be related to the mineralization (Diehl and Kern, 1981). However, it is interesting to note that there is a thick Cambro-Ordovician fine-grained clastic rocks underlying the ore-bearing Ordovician carbonate sediments (Koch, 1973; Hagen and Kemper, 1976; Diehl and Kern, 1981).

Based on the previously stated evidences on the Ordovician carbonate sediments and the characteristics of the lead-zinc mineralized zone, it is proposed that the ore-bearing fluid is believed to be either squeezed out of the thick fine-grained clastic sediments of Upper Cambrian to Lower Ordovician Epoch during compactional and/or tectonic dewatering or metal-rich brine which might be derived from exhalative processes to be generated and migrated to the edge of epicontinental basin floor. This ore-bearing fluid will eventually be precipitated penecontemporaneously with the Ordovician carbonate sediments at the seawater/carbonate sediments

Ordovician carbonate sediments at the seawater/carbonate sediments interface which was the active site of the Ordovician carbonate sedimentation in the shallow marine environment under low temperature of syn- and early diagenetic conditions. Besides, the reducing conditions probably caused by the discharges of H_2S in high concentration produced by organic-rich sediments and/or sulphide-reducing bacterial action of connate water can react with the lead/zinc-bearing fluid to precipitate galena and sphalerite.

A proposed model for the Song Toh lead-zinc deposit is illustrated in Figure 5.2.4 (page 149).

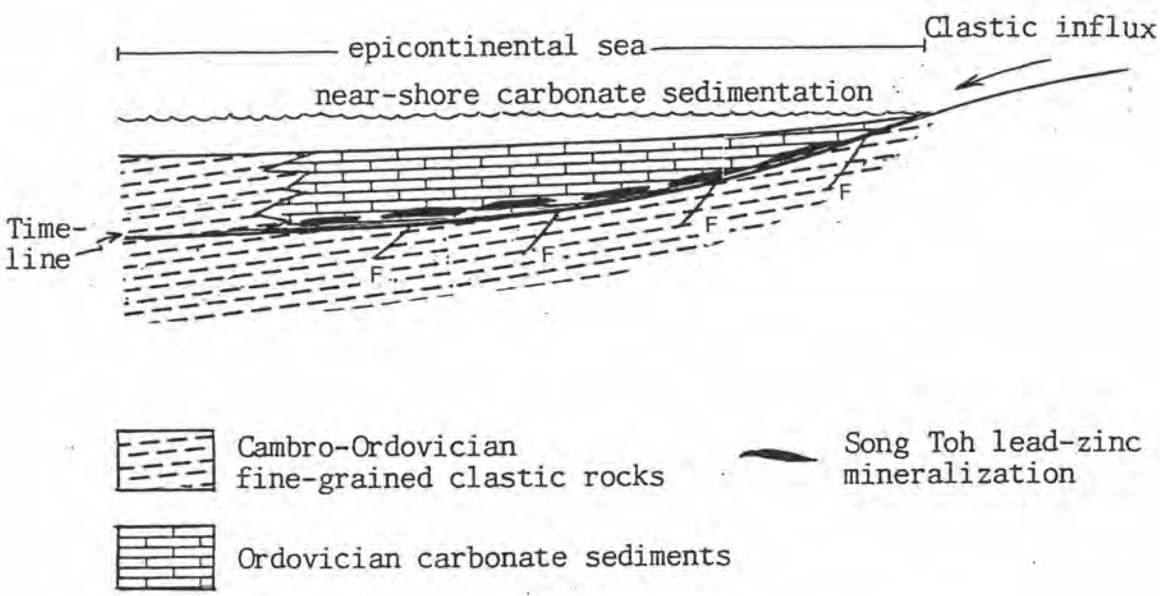


Figure 5.2.4 Proposed model of the Song Toh lead-zinc sulphide deposit.