5-3-5 Conclusion and suggestions

Although the discriminant functions developed based on analytical values of drill cores in Mina Esperanza has many problems, as mentioned above, the results are not remarkably inconsistent with existing information and results of field surveys.

Because the number of samples for analysis is too small for the scope of examination, it would be premature to judge the propriety of application of the discriminant now.

It is desired to employ discriminant analysis after executing systematic trial exploitation in and analysis of the whole north part including the area around the Rio Grande prospect near target drill holes, and based on the results of this analysis, to carry out surveys while expanding the target step by step to Zone 18 including La Colorada and Limeca in the southwest part and further to the Santa Victoria mountain range (Zone 3) in the northeast part and the area to the east of this range.

In the above work, it is desired to carry out not only geochemical examinations but also petrographic and paleontologic studies necessary for presumption of deposits horizon.

For the development of discriminants, discussion should be made on inclusion in targets of not only drill cores in Mina Esperanza running through the SEDEX mineralized zone but also similar drill cores (excavated by Pacific Rim and in the custody of the Mining Bureau of Salta) in La Colorada whose type is a topic of discussions, i.e., whether it is VMS or SEDEX.

5-4 Lito geochemical characteristics of siltsones and volcanic rocks

Fig.II-5-4-1-1and Fig.Ii-5-4-1-2 show the compariosn between chemical composition of Ordovician sedimentary rocks in the survey area(Appendix Table A-4), and average composition of contineral crust(PAAS; Post Archean Austrarian Shale), sediments of ocean trough, hydrothermal sediments(red shale) and amber(Fujinaga and Kato, 1999). According to the comparison, siltsones that are not close to SEDEX/Zinc deposits indicate similar compositin of average composition of contineral crust and have no clear indications for hydrothermal activities.

5-5 Sulfur isotopic ratios of SEDEX-type lead and zinc deposits and vein-type polymetallic deposits.

In the Ordovician system in the north part of this area, there are many lead and zinc vein deposits, and lead and zinc and barite vein deposits, represented by Pumahuasi Deposits. There is a hypothesis that the origin of lead and zinc of these vein deposits is sought in SEDEX-type lead and zinc deposits (Martin, 1989). In order to verify this hypothesis, we measured sulfur isotopic ratios of deposits of the above-mentioned two types and Neogene vein-type lead and zinc deposits. The results are shown in Fig. II-5-5-1 and an Appendix.

Sulfur takes the following chemical species in nature: H_2S (-2), Hs^- (O) , S^{2-} and HSO_4 (4). Large isotopic fractionation is generated by oxidation or deoxidation reactions. Fluctuation of the isotopic ratio is also bought about by biochemical reaction of sulfate-reducers bacteria. H_2S (-2) works as a carrier of heavy metal ions and as a sedimenting agent, and transfers and thickens metals.

Goodfellow et al. (1993) mentions that formation of SEDEX-type lead and zinc deposits resulted from mixture of metallic chloride originating in crust and sea water rich in H_2S deoxidized in an anaerobic environment (Fig. II-6-1-1). The sulfur isotopic ratio of sulfide in El Aguilar Deposits ranges from +10.3 to + 26.8%. There is no data of anglesite. The sulfur isotopic ratio of Lower Ordovician marine evapotite is +25 to +30%, which suggests, as Goodfellow et al. (1993) mention, that the origin of sulfur is magma.

As to black ore deposits, the sulfur isotopic ratio of sulfide mineral is +5 to +8%, and that of anglesite is +22 to +24%. It is considered that the origin of sulfide sulfur is magma, and almost all of the sulfate is sedimentation from sea water (Sasaki and Ishihara, 1979).

On the other hand, the sulfur isotopic ratios of lead/zinc and barite in vein-type polymetallic deposits of the Ordovician system are 2.5 to +12.8% and +10.5 to +25.6%, respectively. These minerals show clearly lower isotopic ratios than those in Aguilar Deposits, which are similar to those of sulfide sulfur in the adjacent Neogene hydrothermal deposits or the above-mentioned black ore deposits instead. From this, it is difficult to consider that SEDEX-type lead and zinc deposits formed in the Lower Ordovician were re-moved merely by the tectogenesis that occurred later and formed vein deposits (Fig. II-5-5-2)

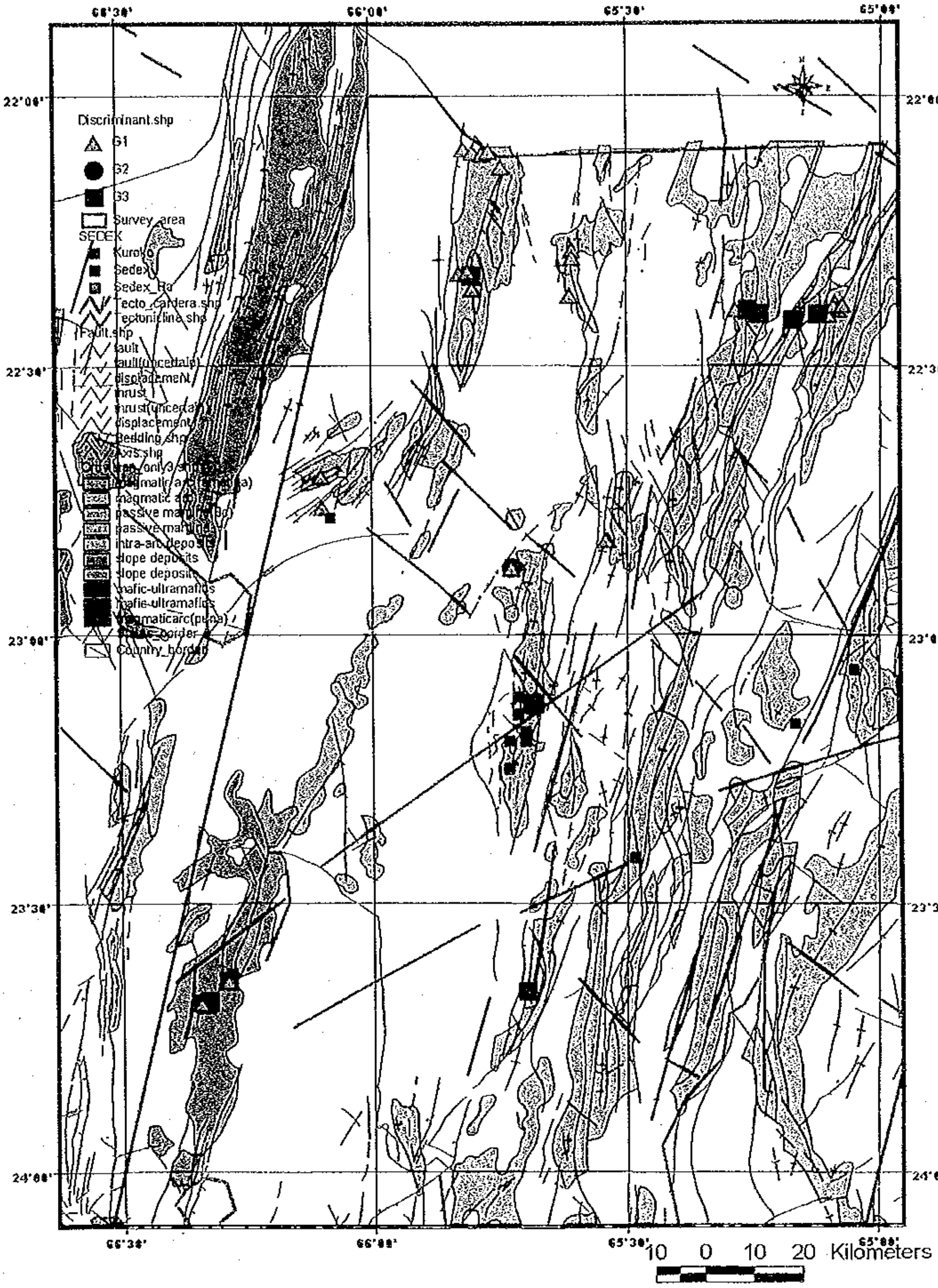


Fig. II-5-3-1. Distribution of the Ordovician rock samples discriminated to 3 groups

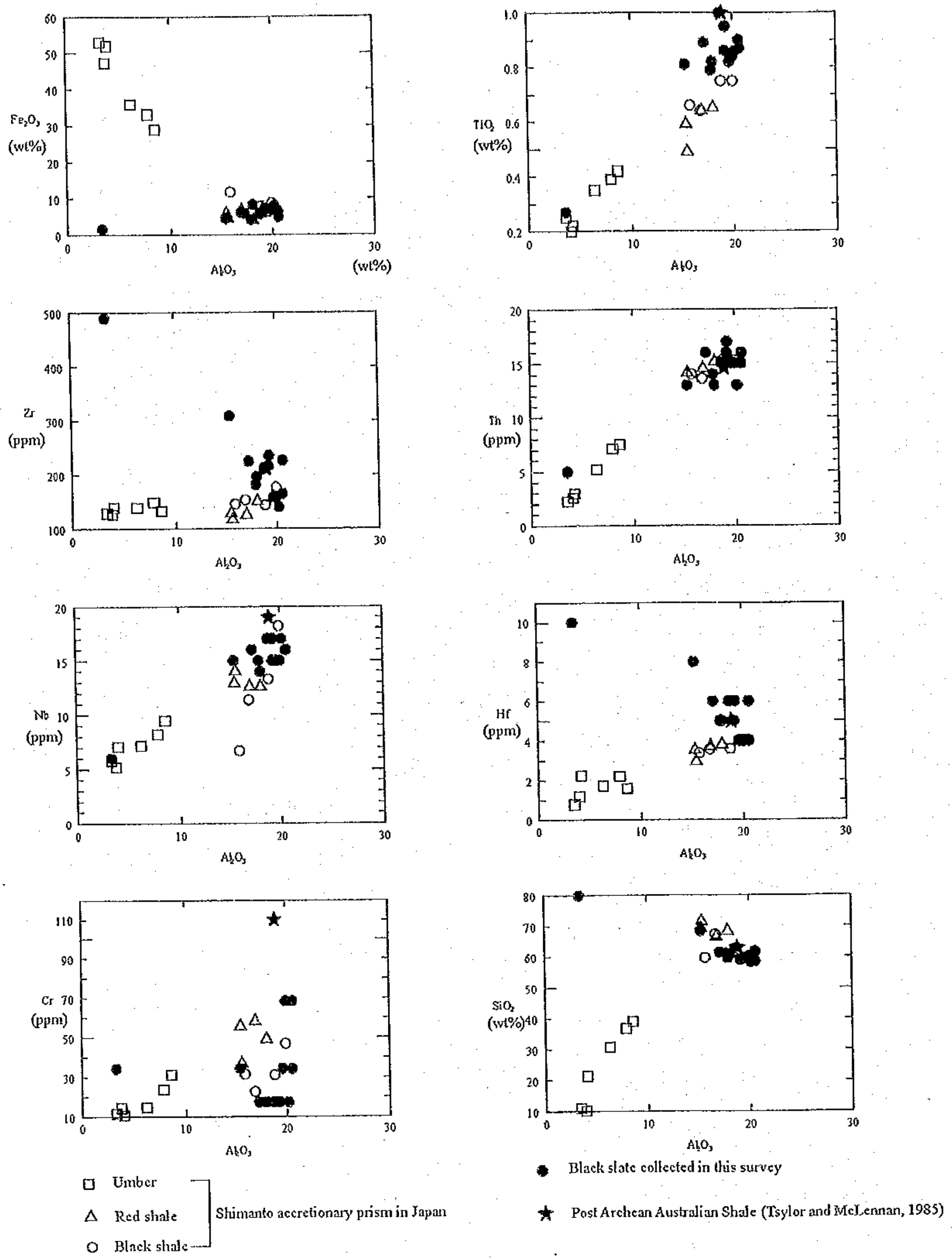


Fig. II-5-4-1-1 Chemical comparison slate in the survey area with the Shimanto accretionary prism (Fujinaga and Kato,2001)

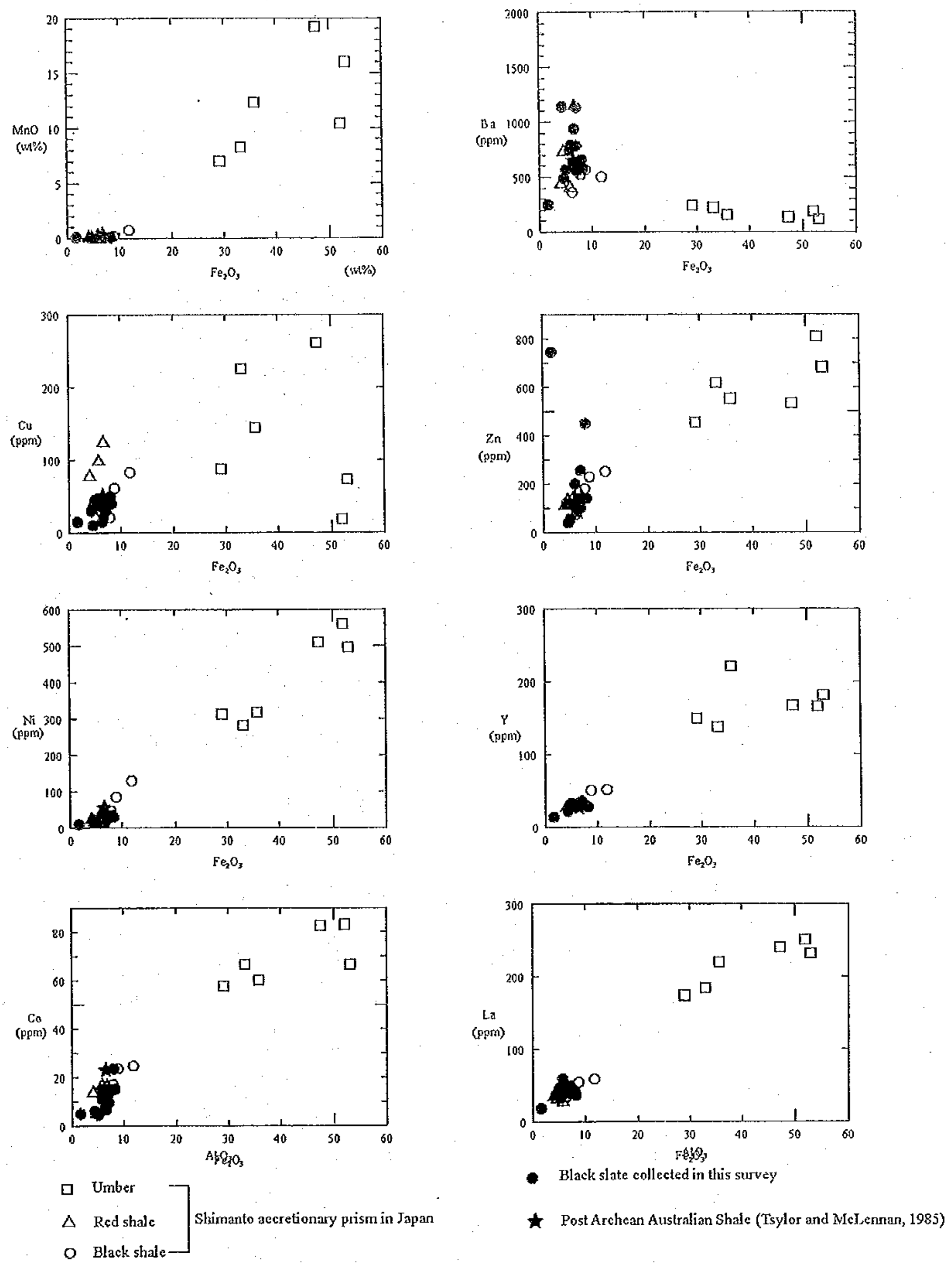
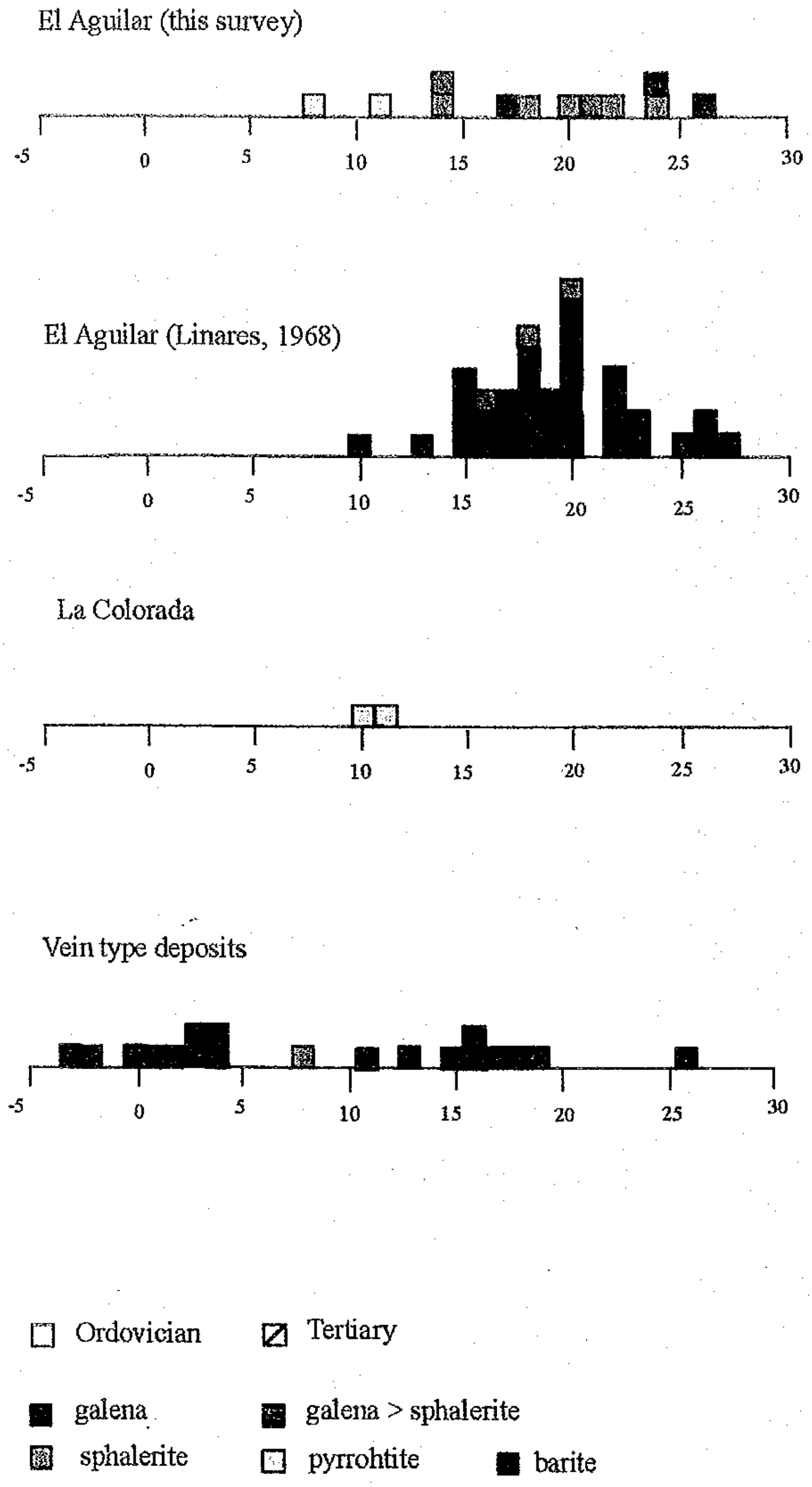


Fig. II-5-4-1-2 Chemical comparison slate in the survey area with the Shimanto accretionary prism (Fujinaga and Kato,2001)


El Aguilar (this survey)
-5
0
5
10
15
20
25
30
El Aguilar (Linares, 1968)
-5
0
5
10
15
20
25
30
La Colorada
-5
0
5
10
15
20
25
30
Vein type deposits
-5
0
5
10
15
20
25
30
Ordovician
Tertiary
galena
galena > sphalerite
sphalerite
pyrrohtite
barite

Chapter 6 Discussion

6-1 Geology, mineralization and structural control of mineralization

Tectonics in the northwestern part of Argentina was, as mentioned in Chapter 3, Part I, formed by collision and accretion of micro continents on the southwest margin of Gondowana continent of the upper Precambrian to the lower Paleozoic, and by cordillera type orogeny due to subduction of the ocean plate from the west side, which has continued since the upper Paleozoic.

In the geological body of the Precambrian to the Quaternary developing in this area, there are deposits each of which is closely related to the history of tectonics development and has characteristics of its own age. Deposits of the Ordovician system, whose potential of existence is considered to be high are SEDEX-type lead and zinc deposits and volcanogenic massive sulfide deposits, while those of the Neogene system are porphyry type copper and copper/gold deposits and epithermal gold deposits. Deposits of these types have economic effectiveness. The following descriptions are the time-space relation between the history of tectonics development and deposits of the above mentioned types, and subjects related to exploration that are drawn from this relation.

1) SEDEX type lead/zinc deposits and volcanogenic massive sulfide deposits

[Corresponding to Classification Codes 8.b.Tipo Kuroko, 8.c. SEDEX (Pb-Ag-Zn-Cu) and 8.d. SEDEX Ba of Zappettini (1999)]

From Venezuela in the north part of the South American continent to the north part of Argentina, there is wide development of non-active platform sediments of the lower Paleozoic in the passive margin of continent, surrounding Amazon and Amazonia Craton (Ramos and Aleman, 2000). Among them, El Aguilar Deposits exist as only one SEDEX type lead/zinc deposits.

The Ordovician system developing in Puna from the northwest part of Argentina to the west part of Chile has many known vein type lead/zinc/barite deposits. There is an idea that these were originated from the SEDEX type lead/zinc deposits (for example, Martin, 1989).

SEDEX type lead/zinc deposits are considered to be formed in small-scale sedimentary basins of the secondary to tertiary order such as passive margin, intracontinental rift and continental margin (Fig. II-6-1-1). Especially, an anoxic environment is deemed as important for generation and preservation of deposits. Volcanic activity is considered to be the heat source partly because volcanic rocks exist near deposits in some cases, although direct participation of volcanic activity is not clear (Goodfellow et al., 1993).

The geological environment where this area was on the margin of the non-active continent (or was a sedimentary basin that existed between Arequipa - Antofalla Massif and Gondowana continent) meets the necessary condition of formation of SEDEX type lead/zinc deposits. The Ordovician systems in this area are widely distributed from Cordillera Oriental to Puna, surrounding the

Precambrian basement (Pampian Craton) from the central part to the southeast part of this area (Fig. II-6-1-2). These are divided into sedimentary bodies without volcanic activity on the east side and sedimentary bodies with volcanic activity. These sedimentary bodies have been suffered strong deformation by Famatinian Event (of the middle Paleozoic) and Andean Event (of the Cenozoic). Although detailed analysis of the sedimentary phase and restoration of sedimentary basins have not been carried out so far, Zappettini (1999) classified the sedimentary body without volcanic activity located on the east side as the passive margin and the sedimentary body with volcanic activity located on the west side as intra-arc deposits and slope deposits, while Bahiburg (1999) classified the former as pelites, sandstone and rare conglomerates and the latter as turbidites and rare volcanoclastic mass flow with granitiods of the "Faja Eruptiva de la Puna Oriental." El Aguilar Deposits belong to the former and La Colorada Deposits belong to the latter geological body.

According to Sureda and Martin (1990) and Sureda (1999), it is considered that El Aguilar Deposits were formed by hydrothermal activity in the ocean bottom in the Tremadoc of the Ordovician inside Padrioc Basin of the tertiary order placed between two rises in Santa Victoria Basin of the primary order. Formation of sedimentary basins of the tertiary order and hydrothermal activity are presumed to have been related to tensile tectonics of "Iruyic diastrophic phase" when the Ordovician Santa Victoria group deposited.

Volcanic activity of the sedimentary body on the west side is that of "Faja Eruptiva de la Puna Oriental" belonging to the calc-alkali series comprising bimodal volcanic rocks, quartz andesitic and andesitic porphyry. It is considered to be products in a volcanic-arc environment formed by plate subduction from the west side accompanying eastward movement of Arequipa-Antofalla Massif (Bahlburg, 1990). In this sedimentary body, La Colorada deposits exist. There are two ideas of the genesis of La Colorada deposits: one is volcanic massive sulfide deposits (accoeding to internal report of Pacific Rim Co., Ltd.) and the other is SEDEX type lead/zinc deposits (e.g., Mayon et al., 1999). Generally, submarine volcano-hydrothermal system plays an important role for generation of deposits formed on island arcs or back arcs with active bimodal submarine volcanic activity and deposits of the Cyprus type formed by an expansion axis with active MORB type volcanic activity without sediments. Massive sulfide deposits in Juan de Fuca Ridge Middle Valley, which is an sedimeted ridge (Goodfellow and Frasklin, 1999), exist in the thick sedimentary body but have an ocean crust in the deep part, and originate in volcanic hydrothermal activity on a spreading axis. However, when only the vicinity of the deposits is observed, it is considered there is no volcanic activity. It cannot be judged, only from the phenomenon that distribution of volcanic rocks is small around it, that La Colorada deposits are SEDEX type lead/zinc deposits. This survey was carried out assuming that this deposit was a volcanogenic massive sulfide deposit, because the grade of copper was higher than those of typical SEDEX type lead/zinc deposits and sulfides filling spaces between brecciated volcanic rocks. Further examination is required for determination of the genesis of the deposit. From the fact that massive sulfide deposits exist in the zone with volcanic, it is expected that there are similar deposits in this zone. At present, however, restraining conditions have not been clarified except that there are Limeca mineral showings in the horizon almost the same as that of La Corolada and these are deposits of the strata bound type.

2) Vein-type polymetallic deposits

[Corresponding to Classification Codes of Zappetini (1999) 14. a.Polimetalicos ricos en As-Ni-Co (Ag-Ni-Co-Bi-U-As) and 14 c. Polimetalicos simples (Pb-Ag-Zn-Ba-Cu)]

There are many vein type deposits in the north part of the survey area. These are divided into those that contains lead, zinc and barite (14.a.) and those that contain lead, zinc, copper, nickel and uranium (14.c.). Both of them occurred Precambrian Puncovicana formation to Ordovician Mecoyta formation as wall rock and do not occurred in the Cretaceous sedimentary rocks. As long as we observed in the ground truth, the form of veins ranges from those cutting bedding plane of slate clearly (Rumicruz) to those parallel to the bedding cleavage plane of slate (Santa Rosa) and those that fill fractures of the folding axis (La Cienaga). Although the age of the formation of veins has not been determined precisely, it is after the Famatinian Event and before the Cretaceous. It is considered that these vein type deposits are small and do not have economic value. As mentioned above, there is a hypothesis that lead and zinc comprising these vein type deposits removed from SEDEX type lead/zinc deposits. However, the origin of sulfide of SEDEX type lead/zinc deposits seems different from that of vein type deposits because 15 to 25‰ is shown as the isotopic ratio of sulfide sulfur of the former, while -3 to 4‰ is shown as that of vein-type deposits. As interpretation of Goodfellow et al. (1993), it seems more reasonable to consider that the isotopic ratio of sulfide sulfur in El Aguilar Deposits originates in sea water. The isotopic ratio of sulfide sulfur in vein type deposits is quite similar to that of Neogene epithermal deposits, but there are a few traces of igneous activities after the Ordovician. The origin and the time of generation of vein type polymetallic deposits have not been clarified so far.

3) Porphyry type copper and copper/gold deposits and epithermal gold deposits

[Corresponding to Classification Codes of Zappetini (1999) 4.b.Porfiros de Cu (± Mo ± Au), 4.c.Porfiros de Cu (-Au), 7.b. Depositos auriferous de baja sulfuracion, 7.c. Depositos auriferous de alta sulfuracion, and 7.f. Depositos diseminados distales y hot spring de Ag (-Au-Cu)]

Porphyry type deposits south of Peru are divided into three groups: those of the lower Cretaceous, those of the Palaeocene to the upper Eocene and those of the middle Neogene to the Pliocene. Distribution of these moves toward the continent (the back arc side) gradually together with eastward movement of magmatic activity. It is considered that this eastward movement of both magmatic activity and porphyry type deposits is caused by the fact that the angle of slab became lower due to subduction of buoyant aseismic ridges (Nasca and Juan Fernandez Ridges) (Woriel, 1986). A magmatic arc of the Miocene to the Pliocene accompanied by porphyry type copper deposits, such as Los Pelambres and El Teniente, is widely distributed all over the Andes near the border between Chile and Argentina.

The survey area is located on the east extremity of this magmatic arc. There is distribution of four zones of volcanic rocks that branch away from the magmatic arc extending north and south, and which extend in the arm like form in the SE direction. These four zones are tentatively called No. 1, No. 2., No. 3 and No. 4 respectively from the north. These arms correspond to NW-SE tending transcurrent fault themselves and their extension.

Arms No. 1, No. 2., No. 3 and No. 4 almost correspond to Lipez Fault Zone, Clama-Olacapato and El Toro Fault, the extension of Archibarca Fault, and Culmoaia Fault, respectively (Fig. II-6-1-3). Distribution of volcanic rocks shows good consistency, with the area with abnormal short wavelength magnetism found from the results of air-borne magnetic exploration (Fig. II-6-1-4). Volcanic activity of each arm is accompanied by eruptions as characterized by formation of a resurgent caldera. Of course, the caldera is arranged in the NW-SE direction same as the direction to which the arms extend. It is presumed that this NW-SE tending fault shows fracture in the deep part which controlled ascending of magma.

Large-scale deposits of the Palaeocene to the upper Eocene, such as Quebrada Blanca, El Abra, Chuquicamata, Zadivar, Chimborazo, Spence, La Escondida, El Sadovador and Poirerillos deposits, are distributed along Domeico fault parallel to the subduction zone of Nazca Plate. These deposits tend to concentrate in the part with conjunction with the NW-SE tending fault mentioned above (Richards, 2000). It can be read that deposits tend to exist in the extension of this major porphyry type deposits (Fig. II-6-1-5).

As porphyry type copper and copper/gold deposits, there exist Cerro Redondo Deposits (porphyry type gold deposits) in Arm No. 1, Pancho Arias Deposits (porphyry type copper/molybdenum deposits) and Organullo Deposits (porphyry type gold deposits) in Arm No. 2, Taca Taca (porphyry type copper deposits), Cerro Sementa (porphyry type copper deposits) and Inca Viejo (porphyry type copper/gold deposits) between Arms 2 and 3, El Arisar (porphyry type copper deposits) in Arm 3, and Bajo de Agua Tapada (porphyry type copper/gold deposits), Bajo de la Alumbrera (porphyry type copper/gold deposits), Bajo El Durazno (porphyry type copper/gold deposits), Bajo de San Lucas (porphyry type copper/gold deposits), Bajo las Juntas (porphyry type copper/gold deposits), Agua Rica (porphyry type copper deposits) and Filo Colorado (porphyry type copper/gold deposits) in Arm 4 (Fig. II-6-1-3).

On the other hand, as epithermal gold deposits, there exist Chocaya deposits in Arm No. 1, Esperanza, Bsiher, Concoedia, Bajos de Incachule, Organullo, Saturno deposits in Arm No. 2, Centenario deposits between Arms No. 2 and 3, and Farallon Negro, Alo de la Blenda and Carmen deposits in Arm No. 4 (Fig. II-6-1-3).

Regarding the space-time relation between magmatic activity and mineralization, mineralization of the porphyry type is collectively distributed around Farallon Negro in Arm No. 4. Besides this, there is mineralization accompanied by smalldscale stocks in basement rock, which are not expressed on a small scale geological map (e.g., Agua Rica, Pancho Arias and El Pago). The latter is observed at the east end of the Tertiary volcanic rock distribution area, erosion is considered to advance and stocks appear on the surface.

Although distribution of volcanic rocks around Inca Viejo is small, this place is adjacent to the area with abnormality of relatively long wavelength found from the air-borne magnetic exploration, and the potentiality for the intrusive rock body is indicated in the surrounding deeper part. Deposits including Centenario, Inca Vielo, Diablilllos and Condor Yacu are arranged around the place where N-S tending Diablillos-Cerro Galan Fault and NW-SE tending faults cross each other. Centenario and Diablillos deposits are high sulfidation type gold deposits, and we may see the relatively shallow part of the porphyry system (Fig. II-6-1-4).

By contrast, the volcanic rock distribution area forming a caldera accompanied by ignimbrite may be a target of epithermal deposits because the level of erosion is naturally shallow. However, mineralization of the porphyry type cannot be expected in such a shallow part.

Both Incachule and Rachaite mineral showings where the ground truth was carried out this time are located inside a caldera wall (Fig. II-5-2-9-2, II-5-2-18-2), which means that the caldera wall was a discharge zone of hydrothermal solution (Fig. II-6-1-5). The same phenomenon was seen in Galan Caldera. It is inferred that the alteration zone (No.015-1) extracted by the analysis of the ASTER image corresponds to alteration of this type. Alteration zones of this type are characterized by neutral pH type hydrothermal alteration and are accompanied by lead, zinc and antimony mineralization. Although gold and silver deposits themselves have not been found, it is expected that low sulfidation type gold and silver deposits exist in the surrounding deeper part.

6-2 Potential of the existence of deposits and selection of promising area

1) SEDEX type lead/zinc deposits and volcanogenic massive sulfide deposits

The Ordovician system developing from the north central part to the northeast side of the survey area is composed with sediment of the passive margin or sediments in the sedimentary basin between Arequipa-Antofalla Massif and Gondowana continent. The whole area where these sediments develop has high potential for the existence of deposits of the same type as represented by El Aguilar. Particularly, it is considered that the highest potential exist in Zones 2, 11 and 15, spreading from El Aguilar, which is the area with distribution of lower Ordovician Acoite formation hosting El Aguilar deposits, through Pumahuasi to the border with Bolivia. It is considered that the strata above Acoite formation are dominants in the area (Zones 3, 5, 12, 14 and 17) with distribution of Santa Victoria formation, which is on the east side. It is expected that SEDEX type lead/zinc deposits exist in the lower part of these formation.

On the northwest side of the survey area, the Ordovician system accompanied by volcanic rocks develops and is considered to have magmatic arcs. La Colorada deposits considered to be volcanogenic massive sulfide deposits exist in this zone. The factor restraining genesis of this deposit has not been clarified from surveys carried out so far. Therefore, there is a possibility that deposits of the same type exist over the area with distribution of the Ordovician system accompanied by volcanic rocks. However, as the horizon hosting deposits already exists around La Colorada deposits, it is considered that Zone 18 containing La Colorada deposits is a zone to be surveyed with priority (Fig. II-6-2-1).

2) Porphyry type copper and copper/gold deposits and epithermal gold deposits

Porphyry type copper and copper/gold deposits and epithermal gold deposits were formed accompanying volcanic activity of the Miocene to the Pliocene. Volcanic rock arms extending NW and SE and their extension part is fundamentally extracted as a zone where deposits of this type exist and as a zone with high potential for the existence.

Porphyry type copper and copper/gold deposits are collectively distributed in Farallon Negro area (Zone 43) where erosion advances among volcanic rock arms and around Inca Viejo (Zone 31) where the potentiality for intrusive rocks among arms is estimated. These have already been investigated in detailed. Another zone with high potential is the vicinity of small sale stock (El Pago) in the Precambrian basement in the southwest part of Zones 28, 46 and 46, which are in the extension of the arms (Fig. II-6-2-2).

Except for the places around Farallon Negro deposits and Diablillos deposits, epithermal gold deposits are expected around and in the lower part of the alteration zone developing around the Caldera (Zones 7, 9, 16, 27, 39 and 42 and around Garan caldera) accompanied by ignimbrite with exfoliation of the low level among volcanic rock arms (Fig. II-6-2-2-2).

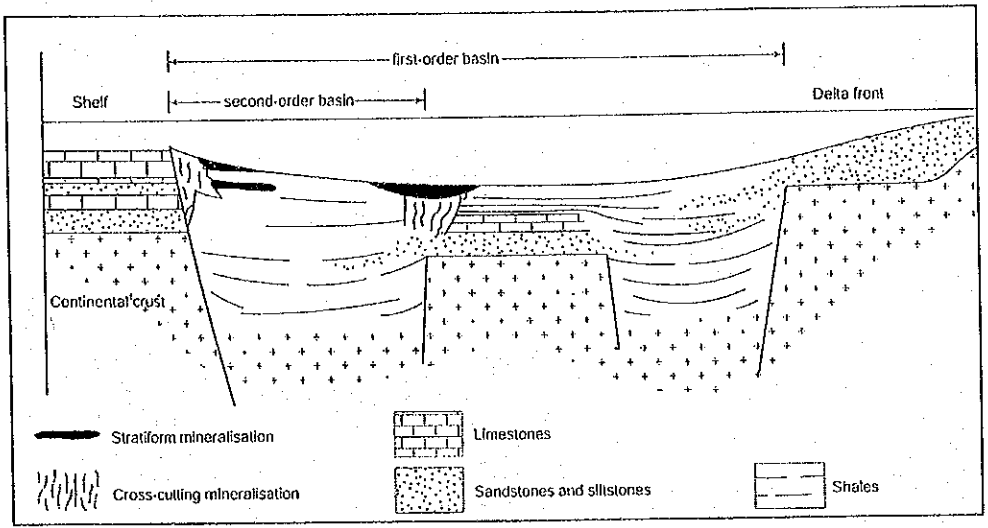


Fig.II-6-1-1 Environment of formation of SEDEX deposits (take from Sangster and MacIntyre,1983).

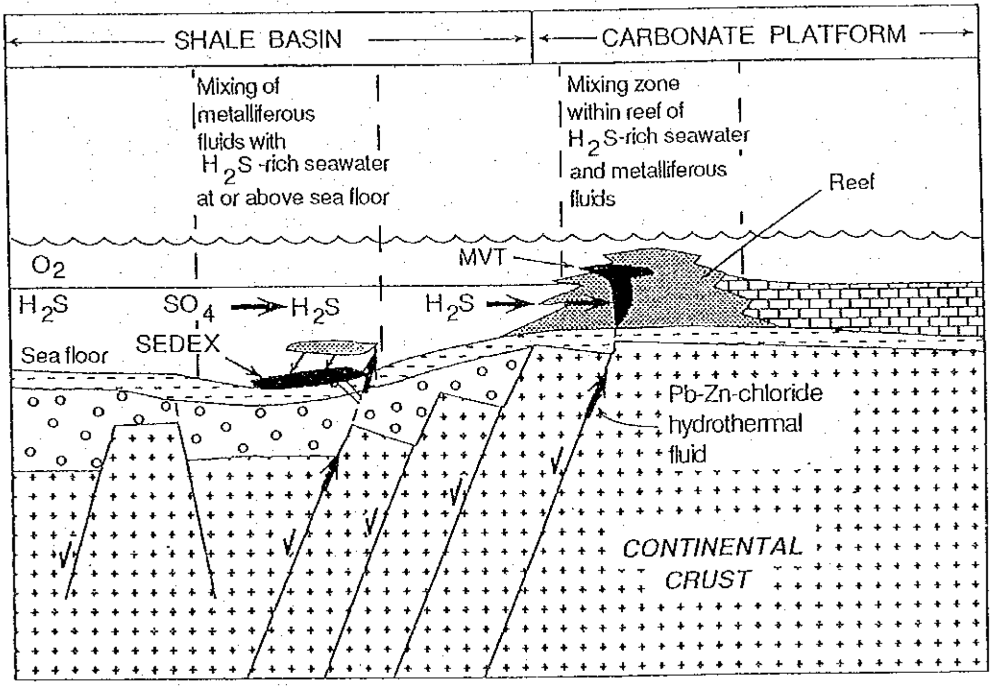


Fig. II-6-1-6 Genetic models of SEDEX and MVT representing the mixing of basal metalliferous fluids with ambient anoxic waters at the sea floor (taken from Goodfellow et al, 1993).

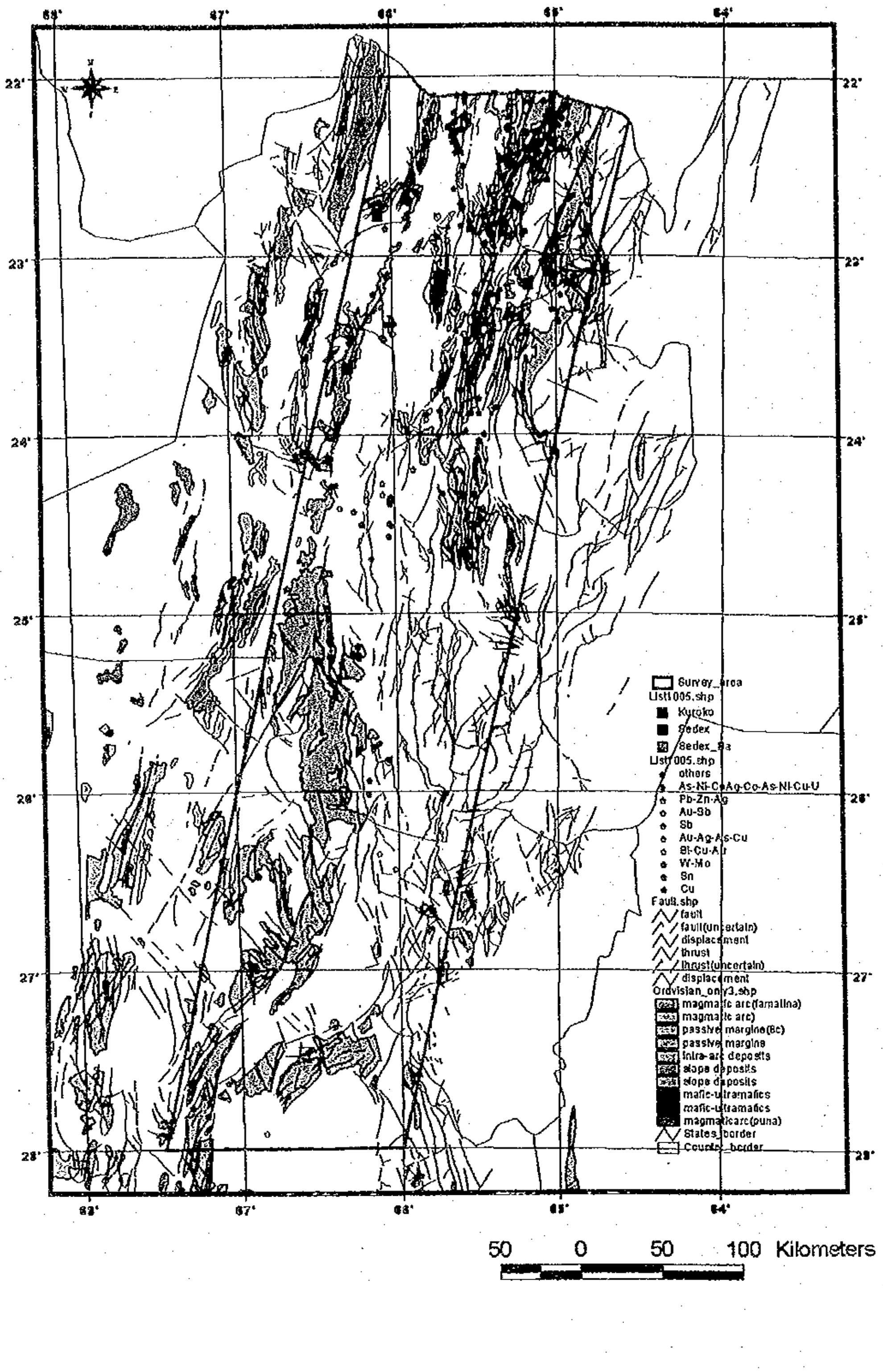


Fig.II-6-1-2 Distribution of the Ordovician systems, Precambrian Puncoviscana Formation, SEDEX type deposits and volcanogenic massive sulfide deposits.

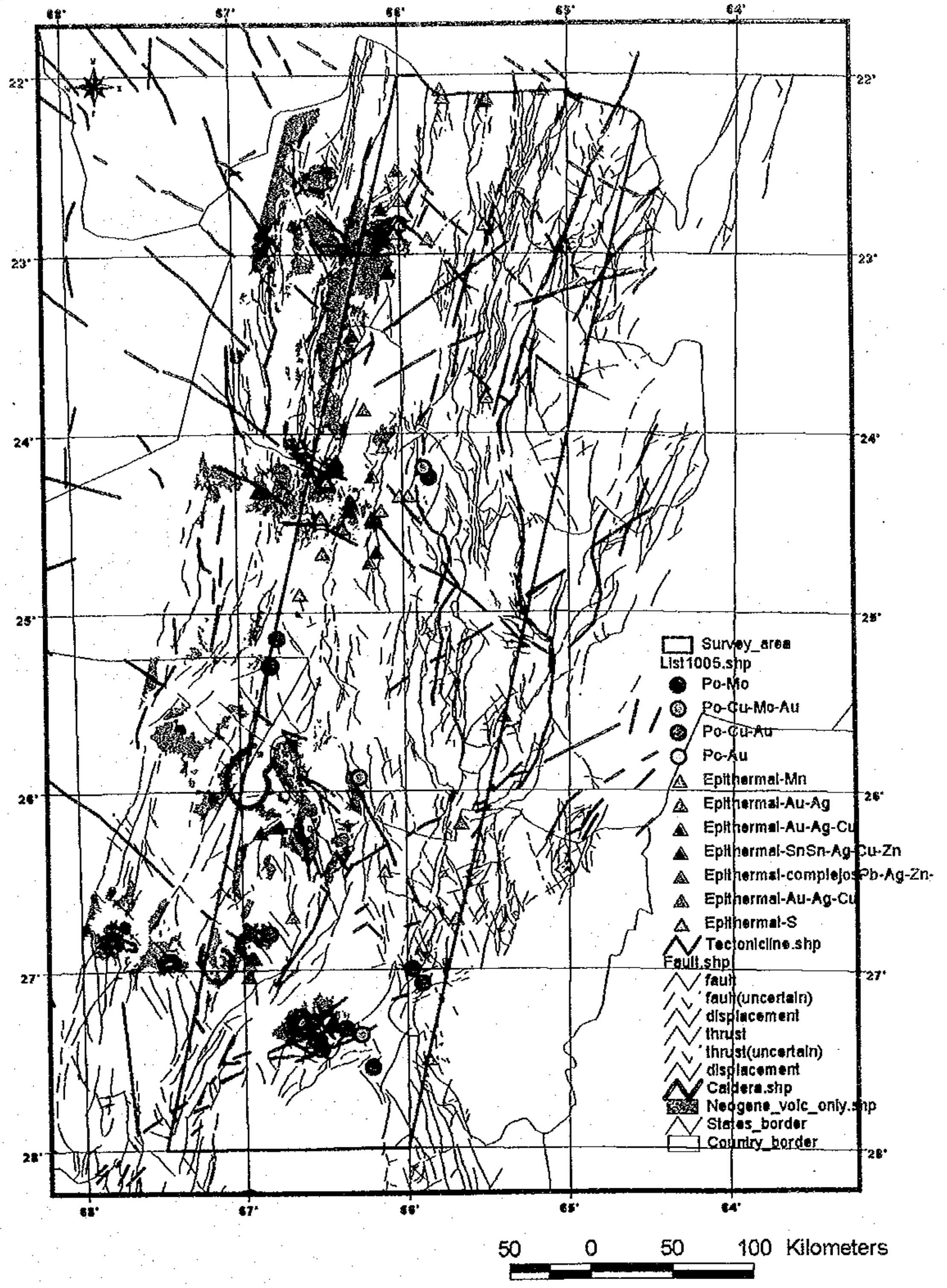


Fig. II-6-1-3 Distribution of Neogene volcanics, porphyry and epithermal type deposits and major faults.

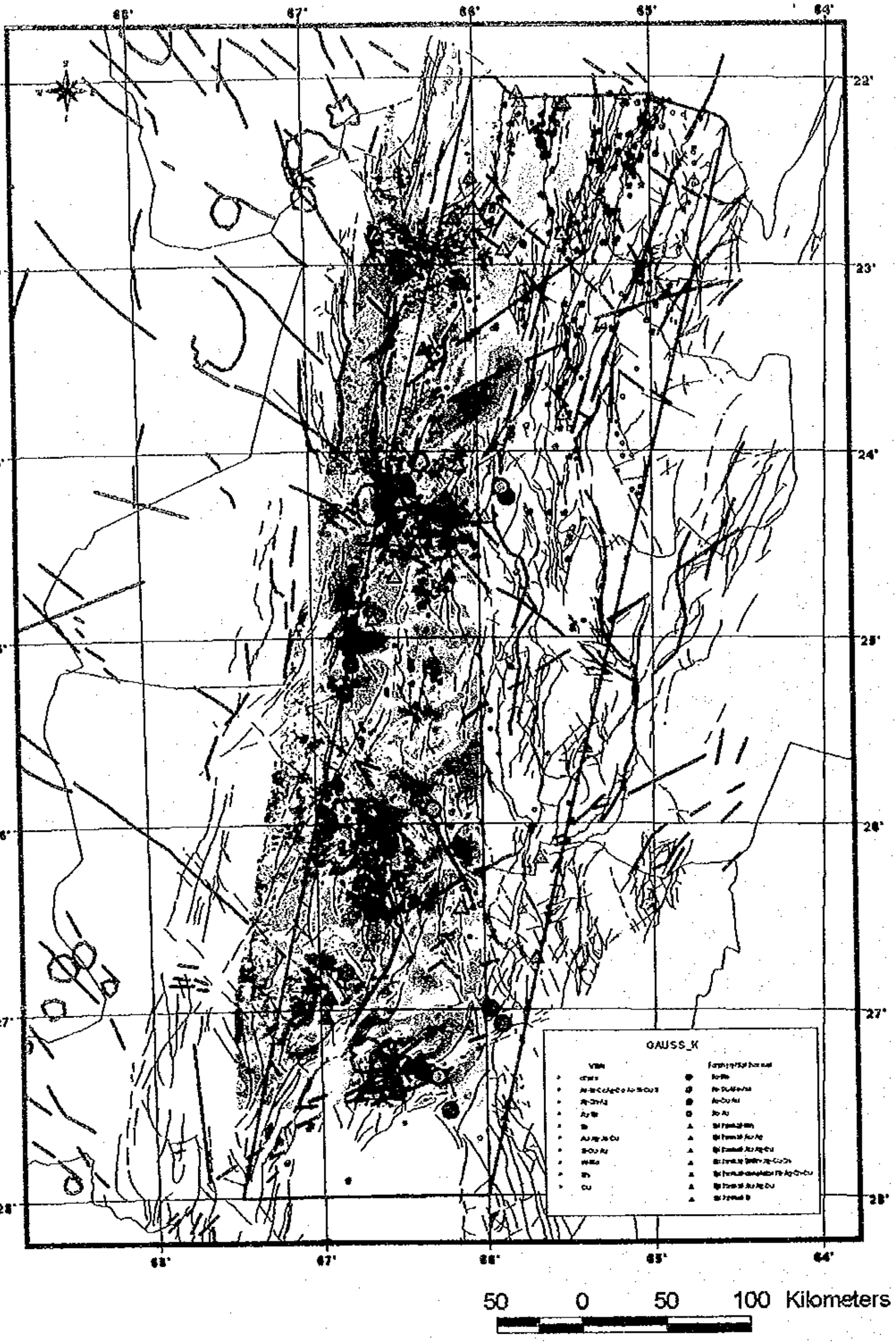


Fig.II-6-1-4 Total magnetic intensity (reduced to the pole) and distribution of porphyry and epithermal type deposits.

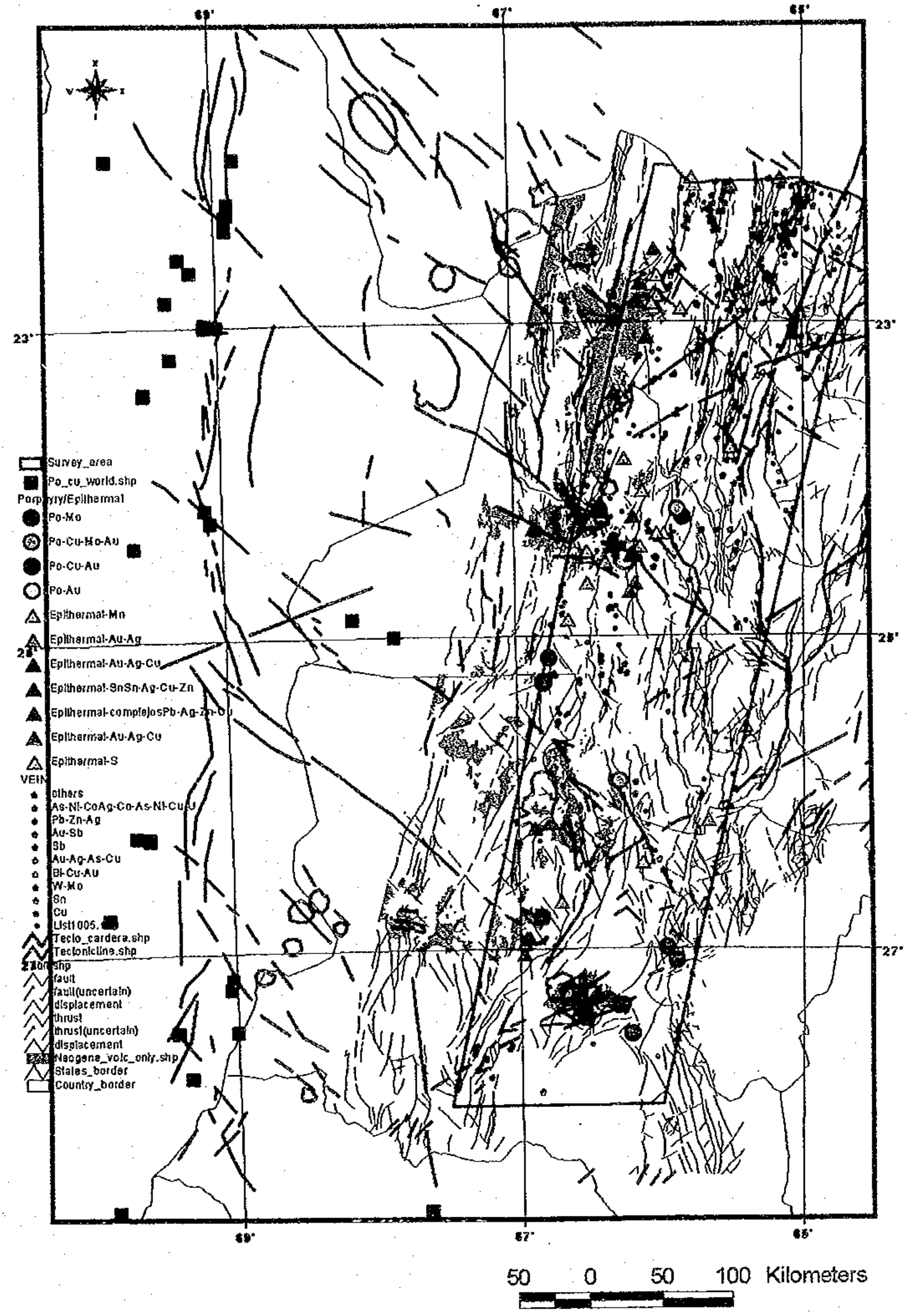


Fig.II-6-1-5 Spatial relationship of major lineaments, and porphyry type deposits and

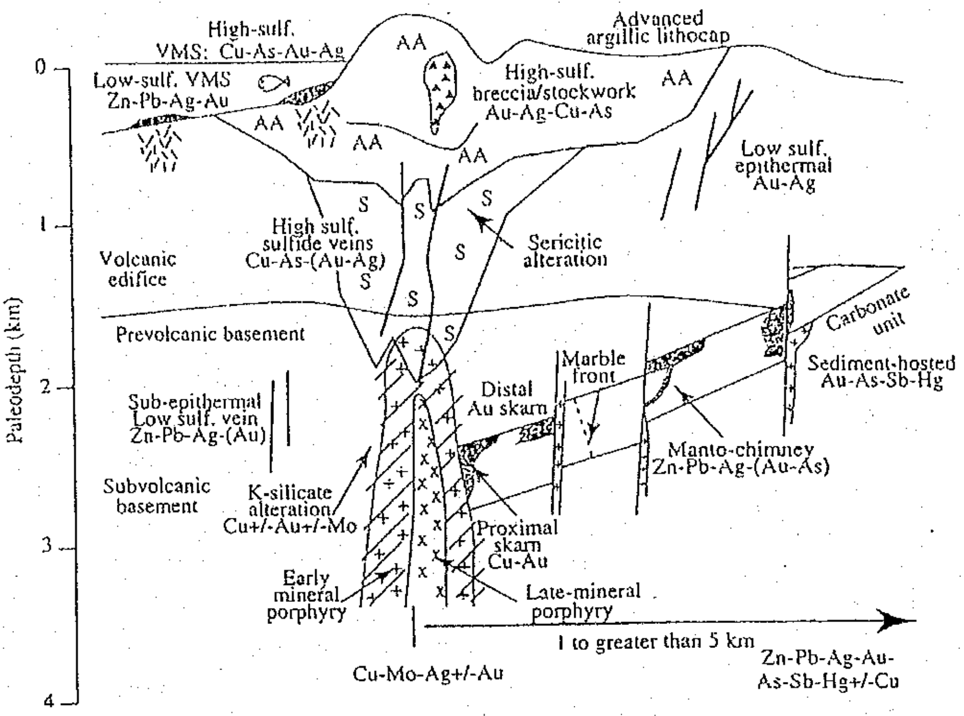


Fig.II-6-1-7 General model of a zoned magmatic hydrothermal system and spatial relationship of porphyry and epithermal system (taken from Richard, 2001).

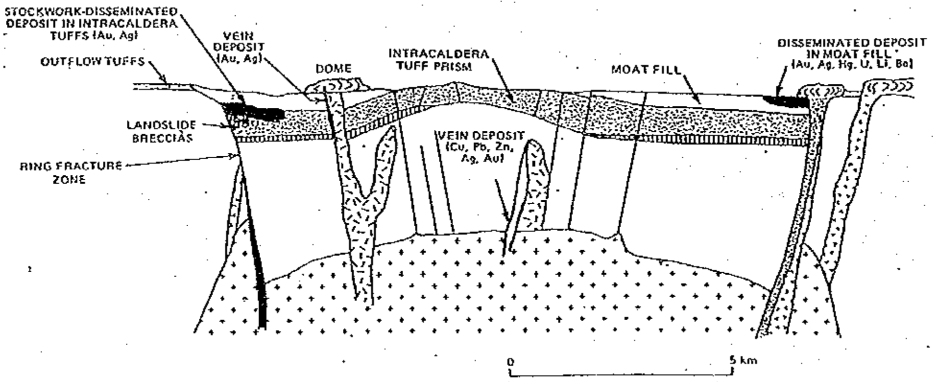


Fig.II-6-1-8 Idealized model of caldera structure and mineralization (taken from Sillitoe, 1984)

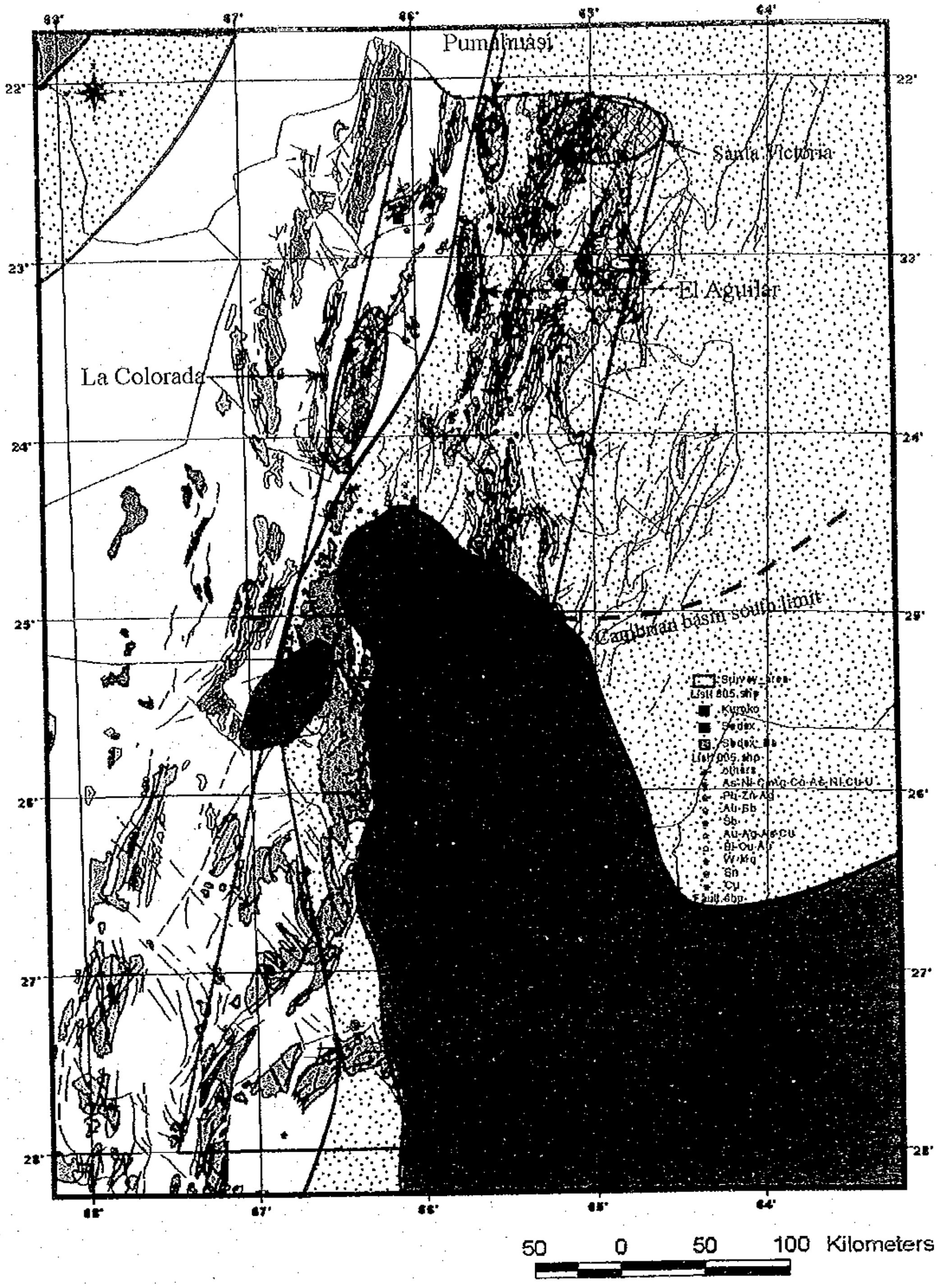


Fig.II-6-2-1 Selected promising area and recommended area for the survey of next year (SEDEX and VMS type deposits).

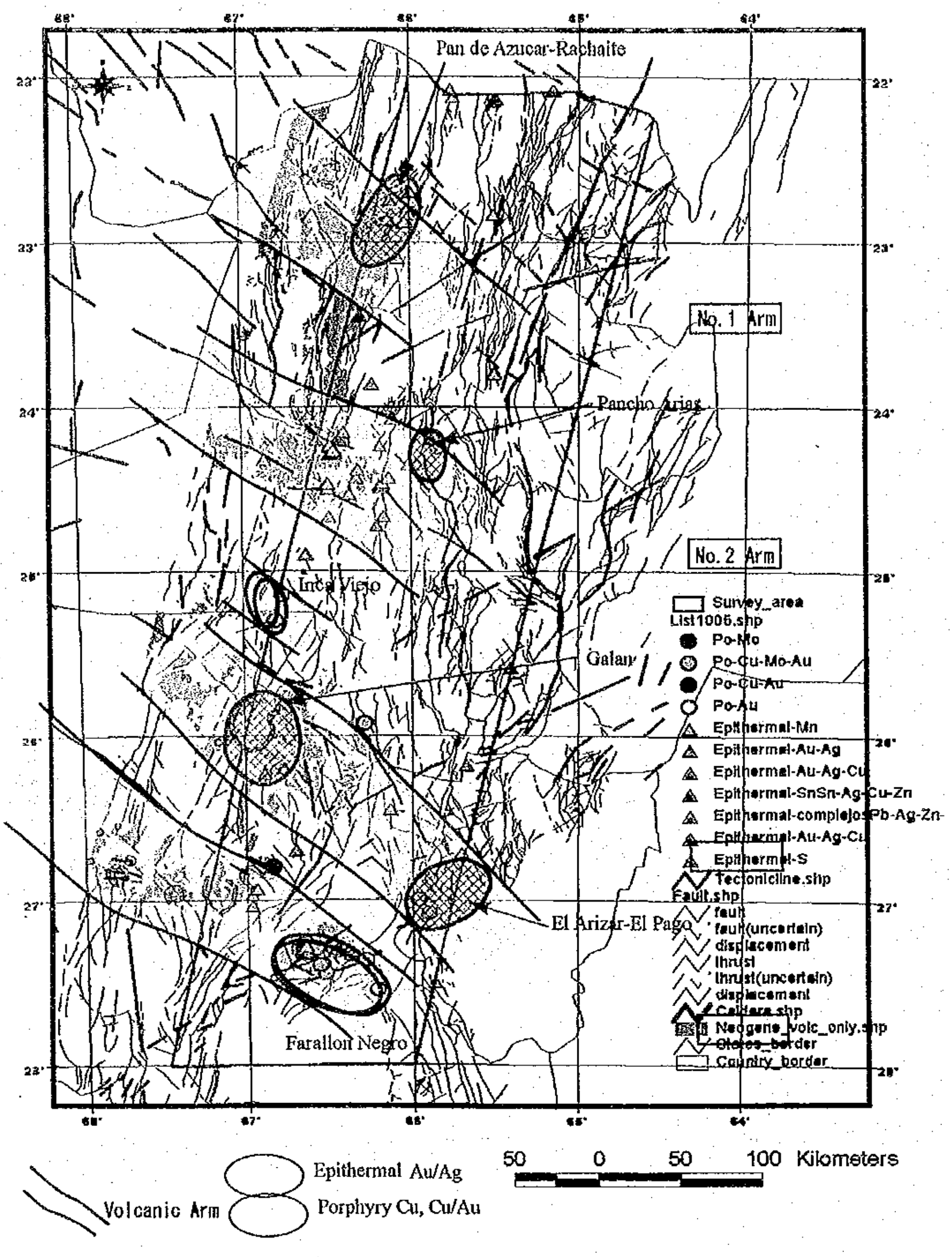


Fig.II-6-2-2 Selected promising area and recommended area for the survey of next year (porphyry and epithermal type deposits).