REPORT ON GEOLOGICAL SURVEY

OF

ANTA GORDA

BRAZIL

PHASE Ⅲ

MARCH 1983

JAPAN INTERNATIONAL COOPERATION AGENCY
METAL MINING AGENCY OF JAPAN

PREFACE

The government of Japan, in response to the request of the Government of the Federative Republic of Brazil, decided to conduct collaborative mineral exploration in Anta Gorda areas in southern Brazil and entrusted its execution to Japan International Cooperation Agency (JICA) and Metal Mining Agency of Japan (MMAJ).

Between 2 July and 21 October, 1982, Metal Mining Agency of Japan dispatched a survey team headed by Mr. Tsuyoshi SUZUKI to conduct geological survey and geophysical survey of the Phase III of the project.

The survey had been accomplished under close cooperation with the Government of the Federative Republic of Brazil and its various authorities.

This report is a compilation of the survey of the Phase III, and after the completion of the project the consolidated report will be submitted to the Government of the Federative Republic of Brazil.

We wish to express our appreciation to all of the organizations and members who bore the responsibility for the project; the Government of the Federative Republic of Brazil Departmento Nacional da Produção Mineral, and other authorities and the Embassy of Japan in Brazil.

February 1983

Keisuke Arita
President
Japan International Cooperation Agency

Masayuki Nishiie
President
Metal Mining Agency of Japan

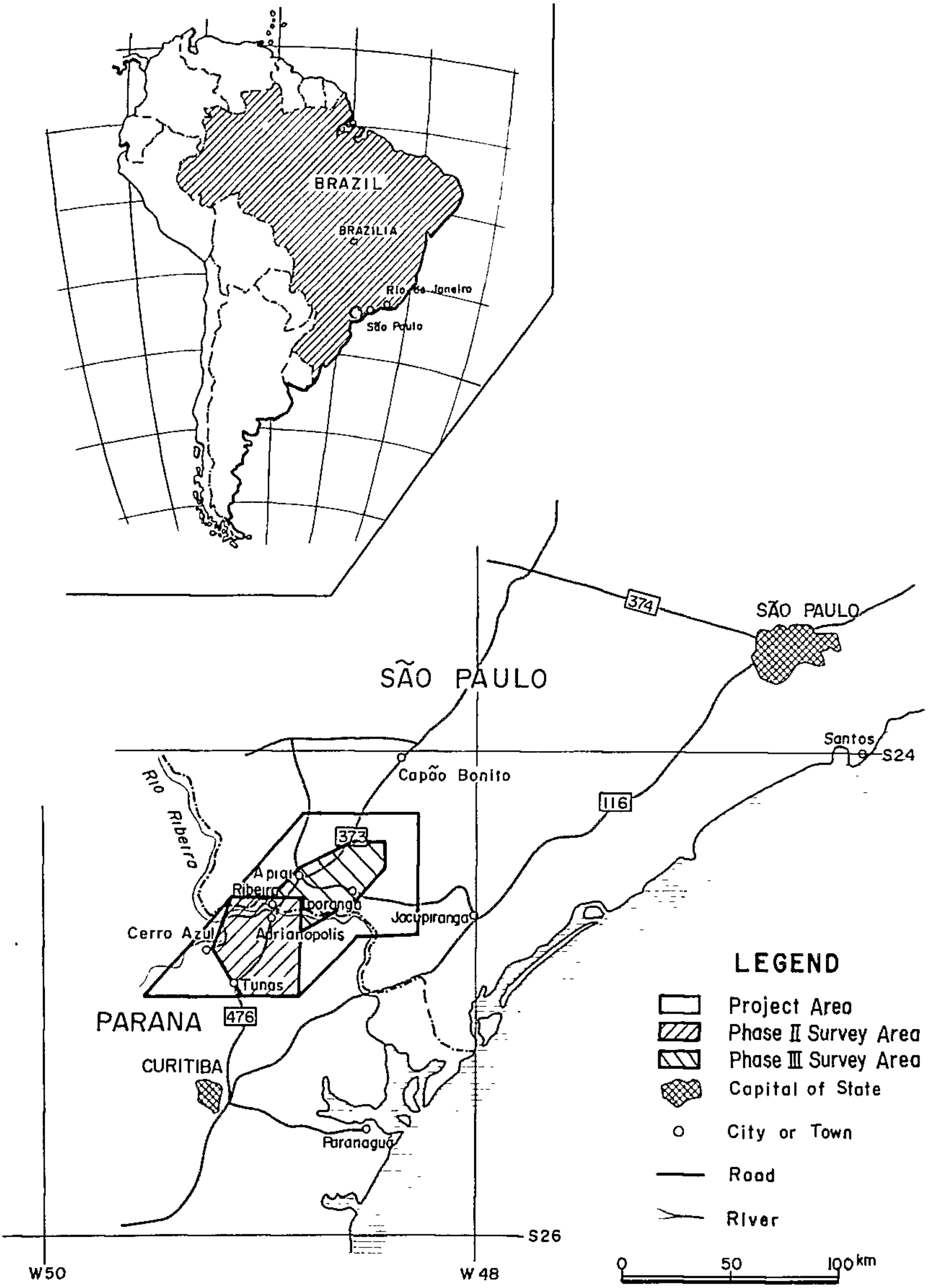

Fig. 1. Location Map of Survey Area

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ABSTRACT

In the survey of the third year in the Anta Gorda area of the Federative Republic of Brazil, geological survey, geophysical survey and drilling survey were carried out to establish the useful guide for future exploration by detailed studies of the stratigraphy, geological structure, igneous activity and mineralization of the area as well as the mutual relation between them.

In the semi-detail survey area, regional geological survey was conducted, and also in the detail survey area, Perau area and Barrinha area, geophysical survey as IP and SIP method and detailed geological survey were conducted.

Furthermore, the drilling survey was carried out in the Peran area.

The measurements of lead isotopes of the ore deposits distributed in the whole the Anta Gorda area were also carried out in order to determine the age of these ore deposits.

1. Semi-detail survey area

As the result of geological survey, the Precambrian Açungui group was subdivided and the stratigraphy was established.

The Açungui III formation was further subdivided, and it is confirmed that the Lageado ore deposit is embedded in $AIIIL_2$ limestone member and the Furnas and Espirito Santo ore deposits are embedded in $AIIIL_3$ limestone member.

As the result of chemical analysis of these limestones, the geochemical characteristics of each limestone member were clarified, especially, the Pb-Ag-Zn components related closely to the mineralization distribute predominantly in the Furnas, the Lageado and the Espirito Santo area.

2. Detail survey area

1) Perau area

As the result of the detailed geological survey and geophysical survey of IP, no mineralization of the Peran ore horizon in the southern area was clarified.

As the result of the drilling survey in the western part of the Perau mine, a promising stratiform lead, zinc and barite ore deposit was recognized in the Perau ore horizon. This new ore deposit has possibility to expand the size of the deposit towards the western and northern areas.

2) Barrinha area

The ore deposits, vein type or irregular massive type, embedding in the $AIIIL_2$ limestone of the Açungui formation are situated mainly in the axis and the limb parts of complicated fold structure.

As the result of the geophysical survey, IP and SIP, some anomalies were detected, especially anomaly on the anticline in the eastern part and anomaly of the southeast of the Quatro deposit have been remarked.

3. Measurements of lead isotopes

The lead ore deposits of the Anta Gorda are divided roughly into the Perau type stratiform ore deposit and the Rocha type vein or irregular massive ore deposit.

As the result of the measurement of lead isotope, age of the Perau type ore deposits, Perau and Canoas etc., show about 1,400 m.y. and age of the ore deposits embedded in the Açungui III limestone show 1,000 ∿ 1,200 m.y.

It is interpreted that the Perau type ore deposit was sedimented syngenetically in the Açungui I formation and the Rocha type ore deposit was formed such as the basemetals concentrated to the fracture in the host rock limestone after precipitated syngenetically in the limestone of the Açungui III formation.

GENERAL REMARKS

CHAPTER 1 INTRODUCTION

1－1 Purpose and Scope of the survey

The natural resources development collaborative mineral exploration in the Federative Republic of Brazil was started in 1980 by the Metal Mining Agency of Japan (MMAJ) as the request of the Japan International Cooperation Agency (JICA).

In October, 1980, the MMAJ agreed a Scope of Work in relation to the project with Departamento National da Produção Mineral (DNPM).

Many small lead ore deposits have been found in two states of São Paulo and Parana in the southeastern part of Brazil and various studies have been conducted in the past, but as yet there is still no widespread acceptance about the relationship between mineralization and geologic structure or igneous activity as well as the ore genesis.

In the survey of JICA and MMAJ, the basic survey was started in the first year, and the survey have been gradually raised the accuracy year by year to clarify the geologic structure and the genesis of ore deposits, and in the third year, a new ore deposit was discovered in the west of the Perau deposit.

Based on the Scope of Work, preliminary geological survey was conducted in the first year in the area of 5,800 km^2 to establish the stratigraphy and to clarify the relation of the geologic structure and mineralization.

In the survey of the second year, semidetailed geological survey was carried out over the extent of 1,200 km^2 in the southern part of the area, southern side of Rio Ribeira, located in Parana State.

The detailed survey of the Perau mine and the Rocha mine conducted to clarify the situation of emplacement of the ore deposits as well as their characters.

In the survey of the third phase, geological survey was conducted over the extent of 1,000 km^2 in the northern part, northern side of Rio Ribeira, located in São Paulo State to clarify the situation of the ore deposits of the area. In addition, detailed geological survey geophysical survey and drilling survey were carried out in the Perau area which had been selected on the basis of the result of survey of the second year to clear the possibility of blind ore deposits.

Similarly in the Barrinha area, detailed geological survey and geophysical survey (IP, SIP) were conducted to make clear the possibility of the promising target.

1–2 Substance of the Survey

In the semidetailed geological survey, the field data were compiled on the topographical map of 1 : 25,000 scale and the geological map was produced with reference to the interpretation of the aerial photograph.

In the Perau area and the Barrinha area, detailed geological survey was conducted along the geophysical survey lines using the topographical map of 1 : 10,000 scale.

In the geophysical survey in the Perau area, the IP method was applied on the south of the area of the second year for the total length of survey lines of 10 km.

In the Barrinha area, the IP method of 14 km and SIP of 6 km were carried out.

In the drilling survey, three holes were drilled in the Perau area with the total length of 912.20 meters (331.15 m. in Hole AG–01, 350.55 m. in Hole AG–02 and 250.50 m. in Hole AG–03).

The present investigation i.e. the survey mentioned above was conducted by eight Japanese technical engineers and six Brazilan technical engineers.

The authors wish to express the appreciation for guidance which were given for contribution to preparation of this report from Dr. Akira Sasaki of Geological Survey of Japan for lead radiometric dating, Prof. Sukune Takenouchi of Tokyo University for microscopic observation of the polished ore section, and Assis. Prof. Takahiko Maruyama of Akita University for identification of the metamorphic rocks.

1–3 Organization of the Survey Team

The members engaged for the planning and the field survey were as mentioned below. As the Brazilian counterparts from the Federative Republic of Brazil, geologists and geophysical engineers of CPRM participated in the survey entrusted by DNPM.

1–3–1 Planning and Negotiation

(1) Japanese Counterparts

Nobuhisa Nakajima	MMAJ
Yoshitaka Hosoi	MMAJ
Takashi Tsujimoto	MMAJ

(2) Brazilian Counterparts

Carlos Oiti Berbert	DNPM
Luis Eraldo Matoz	DNPM
Fernando Batolla Junior	DNPM

1–3–2　Field Survey Team

(1) Japanese Counterparts

Team leader

Tsuyoshi Suzuki　　Bishimetal Exploration Co., Ltd. (BEC)

Geology

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Hiroshi Takahashi　　BEC

Geophysical survey

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(2) Brazilian Counterparts

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Geology

Armando Teruo Takahashi　　CPRM

Cassio Roberto da Silva　　CPRM

José Carlos Garsia Ferreira　　CPRM

Osamu Maeyama　　CPRM

Geophysical survey

Frederico Augusto Varjão Marinho　　CPRM

1–4　Previous Surveys

The geology of the area under study has been investigated by many people, and it is apparent that Pre-Cambrian age rocks, a principle part of the area, are well distributed throughout the area.

Cordani et.al. (1967) have obtained calibrated results of radiometric age as 3,000 – 450 m.y., and described that orogenic movements took place several times in the period.

For the petrological and stratigraphical studies, Bigarella et.al. (1956), Marini et al. (1967), Fuck et al. (1971), Ebert (1971), Continho (1971), and Kaefen (1972), have all attempted to define the geological stratigraphy.

For the studies of mineral deposits, Melcher (1968), has reported on the ore deposits

in the limestone of the Açungui group.

Leonardos et at. (1956), thought that the origins of the ore deposits of the area have to do with hypogene deposits, which are related to granite. However, Melcher (1968) and others have proposed differing viewpoints from their studies on the Pb radiometric age and the grades of Pb.

For the regional geological map of the survey area and its surrounds, the DNPM's compiled map in scale (1/1,000,000) Curitiba (1974), the CPRM Produced 1/100,000 geological map for Projeto Leste do Parana and the CPRM produced 1/50,000 geological map for Projeto Sudelpa in the province of São Paulo in 1974 were widely used. As for surveys done in recent years, Projeto Chumbão, which was carried out between 1978– 1979 by the CPRM on a request by the DNPM, studied the geology and ore deposits of the Perau and Rocha areas. In 1980, their report, including a 1/25,000 geologic map, was published (this was not for general publication). Also, the MMAJ carried out the first year survey of the collaborative mineral exploration of the Anta Gorda area from January to April 1980, on a request by the JICA. In their report, the classification of the geologic stratigraphy followed basically the 1/1,000,000 Curitiba maps (1974), dividing the Açunqui Formation I, IIand III. According to the same report, the lead ore deposits of the area are classified to the bedded ore deposits of Perau type and in the fissure filling deposits of Rocha type. It also describes that the Perau type is distributed in Açungui Formation I, while Rocha type is distributed in the limestone of Açungui Formation III.

1 – 5 Reference

(1) ALMEIDA, F.F.M. de (1967) – Origem e Evolução da Plataforma Brasileira. Bol. 241, DGM/DNPM, Rio de Janeiro, GB.

(2) ALMEDA F.F.M. et al. (1976) – The upper Pre-Cambrian of South America, – Bull. I.G. U.S.P. v.7 : 45–80, 1976.

(3) BARBOSA A.F. (1955) – Estrutura e Génese da Jazida de Chumbo de Furnas, Estado de São Paulo.

(4) CORDANI, U.G.; BITTENCOURT, I.(1967) – Determinação de Idade Potássio-Argónio em Rochas do Grupo Açungui. – Anais XXI.º Congr. Bras. Geol., SBG, Curitiba, PR.

(5) COUTINHO, J.M V. (1971) – Estado Atual de Conhecimentos do Pré-Cambriano Superior Sul-Brasileiro; Uma Sintese. – Anais XXV.º Congr.Bras.Geol., vol. 1, SBG São Paulo. Sp.

(6) CRPM (1981) – Projeto Integração e Detalhe Geológico no Vale do Ribera, Area Ribeirão do Rocha, vol. VII (Texto).

(7) CRPM (1981) – Projeto Integração e Detalhe Geológico no Vale do Ribera, Area Ribeirão do Perau, vol. VI (Texto).

(8) Damasceno, E.C. (1966) – Nota Sôbre a Composição Isotópica de Chumbo em Galenas de Jazidas do Vale do Rio Ribeira – XX. Congr. S.B.C., n. 1.

(9) D.N.P.M. (1972) – Projeto Sudeste do Estado de São Paulo, Mapa Geológico Itararé 1:25,000.

(10) D.N.P.M. (1974) – Carta Geologica do Brazil ao Milionésimo Folha Curitiba – SG22.

(11) D.N.P.M. (1977) – Projeto Leste do Paraná (Anexo, Folha Apriai, Ribeira 1:1,000,000).

(12) EBERT, H. (1971) – Observações sobre a Litologia e Subdivisão do "Grupo Setuva" no Estado do Paraná ; com Sugestões à Tectônica Geral do "Geossinclínio Açungui". – Anais XXV.º Congr. Bras. Geol., vol. 1, SBG, São Paulo, SP.

(13) FUCK, R.A.; MARINI, O.J.; TREIN, E.; MURATORI, A. (1971) – Geologia do Leste Paranaense. – Anais XXV.º Congr. Bras. Geol. SBG, São Paulo, SP.

(14) HASUI Y. et al (1975) – The Ribeira Folded Belt – Revista Brasileira de Geociéncias vol. 5, 1975.

(15) JICA (1981) – On Geological Survey of Anta Gorda Brazil, Phase I.

(16) JICA (1982) – On Geological Survey of Anta Gorda Brazil, Phase II

(17) KAEFER, L.Q. & ALGARTE, J.P. (1972) – Folha Itararé SG. 22-X-B. Geologia Preliminar. vol. 1, Proj. Sudeste de São Paulo, DNPM/CPRM, São Paulo, SP. inédito.

(18) LEONARDOS, O.H. (1956) – Carbonatitos com Apatita e Pirocloro. – Av. n°. 80, DEPM/DNPM, Rio de Janeiro, GB.

(19) MAACK, R. (1947) – Breves Notícias sobre a Geologia dos Estados do Paraná e Santa Catarina. – Arq. Biol. Tecnol., vol. II, Curitiba, PR.

(20) MARINI, O.J.; FUCK, R.A.; TREIN, E. (1967) – Intrusivas Básicas Jurássico-Cretáceas do Primeiro Planalto do Paraná. Bol. Par. Geoc , N°. s. 23 a 25 Curitiba, PR.

(21) MELCHER, G.C. (1968) – Contribuiçao ao Conhecimento do Distrito Mineral do Ribeira de Iguape, Estados de São Paulo e Paraná.

(22) MELCHER, G.C.; GOMES, C.B.; CORDANI, U.G.; BETTENCOURT, J.S.; DAMASCENO, E.C.; GIRARDI, V.A.V.; MELFI, A.J. (1973) – Geologia e Petrologia das Rochas Metamórficas e Graníticas Associadas do Vale do Rio Ribeira de Iguape, SP e PR. – Rev. Bras. Geoc , vol. 3 n°. 2, SBG, São Paulo, SP.

(23) MIYASHIRO A (1979) – The Earth Science 16, Iwanami Shoten, Tokyo (In Japanese).

(24) Odan Y. (1978) – Geologia da Mina de Chumbo de Panelas – Adrianópolis – PR Anais do XXX Congresso B.G. Recife, 1978 v.4.

(25) Oliveira, G.M. de A. (1937) – A gazida de Galena Argentifera de Panelas de Brejaúvas – Min. e Met., v. 1. n. 5.

(26) PEDERSEN, F D. (1980) – Remobilization of the Massive Sulfide Ore of the Black Angel Mine, Central West Greenland.

(27) CPRM (1978) – Relatorio Calculo.

(28) D.N.P.M. (1981) – Relatorio de Processamento, Projeto Aerogeofisico Sao Paulo-Rio de Janeiro, Sub-Area IV.

(29) Hallof P.G., (1974) – The IP phase measurement and inductive coupling, GEOPHYSICS' Vol. 35, No. 5, pp.650–665.

(30) Nettleton L.L., (1971) – Elementary Gravity And Magnetics For Geologists and Seismologists, Society of Exploration Geophysicists.

(31) Pelton W.H., etc. (1978) – Mineral Discrimination and Removal of Inductive Coupling with Multifrequency IP, GEOPHYSICS, Vol. 43, No.3, pp.588–609.

(32) Petric W.R., Pelton W.H., and Ward S.H., (1977) – Ridge Regression Inversion Applied to Crustal Resistivity Sounding Data from South Africa, GEOPHYSICS, Vol. 42, No.5, pp.995–1005.

(33) Summer J.S., (1976) – Principles of Induced Polarization for Geophysical Exploration, Elsevier.

CHAPTER 2 SUMMARY OF THE SURVEY AREA

2–1 Location and Transportation

The area of the present survey is located to the southwest of São Paulo the largest city in Brazil, and is located to the north of the Rio Riberira in the state of São Paulo (Fig. 1). The state road route 373 runs through the western part of the survey area, with Apiai base camp of the present survey, about 320 km away from São Paulo, a five hour drive by automobile. The survey area is also about 170 km away from Curitiba, the provincial capital of Parana, which can be reached in about three hours by car. Closer towns, such as Adrianopolis, which was the base for the survey of the second year, is about 40 km. away. On the eastern side of the survey area, a main state highway, route 116, runs from São Paulo to Curitiba. Buses run regularly several times a day to the cities of São Paulo and Curitiba from Ribeira. Also, there are several domestic flights a day between São Paulo and Curitiba.

2–2 Topography and Drainage System

The topography of the area of the present study is mainly controlled by geological structures of the Pre-Cambrian system, with mountain systems mostly running NE-SW. Limestone is found in many places of the survey area. In this area, very steep topography and karst topography are characteristically developed, and doline is frequently seen. In the eastern part and southeastern part of the area, low grade metamorphosed phyllite are developed. These areas have a relatively gentle sloping topography, however, deep valleys are developed well.

The NE-SW mountain systems, which are largely dominated by these folded structures and very steep topography is often seen. In the northern area, western area and southern area, large intrusive rocks of granite are distributed, and in these areas relatively gently sloping topography is seen. There are also places which show very steep topography at the boundaries of granites.

For the drainage system, the Rio Ribeira is a quite large river running from the western side of the area towards the north, then flowing towards the northeast. The drainage system of the neighboring areas are all branches of Rio Ribeira which is about 100 meters above sea level. Neighboring mountain tops are over 1,000 meters above sea level.

In the limestone zone, a karst topographical plateau with V-shaped valley are formed and a dendritic drainage pattern forms. At places where doline develops, the water system is halted locally.

In areas where metamorphic rocks have been formed, the system is controlled by structural lines, and lattice-like and parallel-like water systems have developed. Gently sloping topography and deep dendritic drainage patterns are characteristic of these granite areas.

2–3 Weather and Vegetation

The weather in the survey is characteristic of the region, with much sub-tropical rains, the differences in the four seasons are relatively well-defined. The average annual rainfall is between 1,200 – 1,300 mm, the bulk of which falls between the months of October – February. The average annual temperature is between 16–19 degrees C., but it is nor rare for the daily highs in the summer (January–March) to exceed 35 degrees C. Sometimes the temperature falls nearly to 0 degrees C. in the winter (July–September).

The vegetation in the area is thickly wooded, with pines, oaks and miscellaneous trees, although large parts of the area have been cleared to the neighboring mountaintops and are used as fields and pastureland. Other than the previously mentioned trees, small shrubs and ferns grow densely. Some ferns, (Samambaias), grow especially thickly in areas where granite and metamorphic rock are distributed. However, they usually do not grow where limestone is distributed.

CHAPTER 3 COMPREHENSIVE INVESTIGATION

3–1 Geological Survey

3–1–1 Semidetailed Survey Area

(1) Stratigraphy

Geology of the semidetailed area consists of the Precambrian Açungui group, meta basic rocks and granitic rocks of Brazilian Orogeny (750 ∿ 500 m.y.) intruded into the above, the diabasic of Cretaceous.

The Açungui group is mainly composed of mica schist, phyllite, meta sandstone and carbonate rocks and it is classified into three formations of AI, AII and AIII.

The AIII formation is further subdivided, from the base upward, into L_1, S_1, L_2, S_2, L_3, S_3, L_4, and S_4 according to the combination of meta sedimentary rocks (S) and carbonate rocks (L).

The Açungui group and meta basic rocks have been subjected to regional metamorphism of Brazilian Orogeny, showing metamorphic phacies of green schist to epidote amphibolite.

Contact metamorphism is also observed in the surrounding area of the granite masses as represented by biotite hornfels.

(2) Geologic Structure

The main geologic structure in the semidetailed survey area consists of fold and fault structure of NE-SW to NEE-SWW system and is considered to have been formed during the stage of Brazilian Orogeny. It is assumed that the lateral compression of approximate direction of NW-SE from the result of analysis of geologic structure. Within those fold structure which NNW-SSE system fold have been formed by the more old tectonic movement, is partly observed.

In addition, the fault structures of N-S system of the post Brazilian Orogeny and NW-SW direction as the trend of Jurassic to Cretaceous diabasic dykes, are predominantly observed.

(3) Measurement of Lead Isotopes

The lead ore deposits in the project area are roughly divided into two types such as the stratiform deposit of Perau type and vein type deposit of Rocha type.

The Pb isotope values are plotted on the growth curve of lead ore of Cumming and Richard (1976), the result of the second year showed that the isotopic ages of the Perau deposit were concentrated to 1,400 m.y. and those of the Rocha mine to 1,100 m.y.

In this time, 20 samples of lead ore were taken from the various deposits in the Anta Gorda project area to measure the lead isotopes, and which resulted in that the same ages as

to correspond to the result of the second year: those of the Perau type deposit showed 1,400 m.y. and those of the Rocha type deposit showed a concentration to 1,000 to 1,200 m.y., though some range was observed.

These isotopic ages are older than the time of intrusion of the granitic rocks (550 m.y.) in the project area, and it is negative to the opinion that the mineralization was related to the intrusion of the granitic rocks. Therefore it is considered that the Perau type deposit formed syngenetically with the host rock and the Rocha type deposit was formed by the concentration of base metals in the fractures of the host rock, which once had deposited in the host rock (AIII Formation).

(4) Microanalysis of Carbonate Rocks

Analysis of minor elements of the carbonate rocks was carried out to study the indicator element for mineralization and the sedimentary environment of the host rock of the ore deposits.

One hundred and twenty samples were analyzed by atomic obsorption analytical method and wet method for 15 components such as Cu, Pb, Zn, Ag, Co, Ni, Mn, Ba, Sr, F, CaO, Mgo, Na, K, I, R. (Insoluble residues). The multi-variate analysis for these data was carried out and its result feeded back to single component analysis.

As the result of the multi-variate analysis factor-1 (I.R.-K-Ba-Na-Cu-Zn-Ni-F-Mn), factor-2 (Pb-Ag-Zn), factor-3 (Sr-Ca) and factor-4 (Mg-F) were extracted.

The factor-1 shows the reduced sedimentary environment with abundant impurities, and the factor-2 is assumed to be factor of the mineralization. Both factors show an overlapped distribution and include the known deposits.

The anomalous zone of single component analysis of each Pb and Zn show a distribution which is consistent with the known deposits.

The factor-3 is interpreted to have corresponded the rock characteristics, showing a distinct difference between the horizons.

(5) Ore Deposits

In the area, vein type lead ore deposits of so-called Roch type such as the Furnas deposit the Lageado-Serra deposits and the Espirito Santo deposits are distributed. Although the country rock of these ore deposits had been considered to be only one limestone member of the Açungui III formation in the past, it was clarified that the Furnas deposit and the Espirito Santo deposit are embedded in the $AIIIL_3$ member in this time.

The ore minerals of these ore deposits are mainly composed of galena, accompanied by pyrite, sphalerite, chalcopyrite and cerussite, filling the high angle fractures and bedding

fissilities.

Based on the synthetic result of geological surveys and ore deposit and that of the analysis of the carbonate rocks, the mechanism of formation of the above Rocha type lead ore deposits is considered to be as in the following.

Sedimination of Pb-Ag-Zn took place under the reduced environment contemporaneously with deposition of the carbonate rocks. And it is assumed that these base metals moved to and concentrated in fractures which seems to have been formed by the later lateral compression of approximate direction of NW-SE caused by Brazilian Orogeny.

3–1–2 Detailed Survey Area

(1) Perau Area

Geology of the Perau area consists of gneissose rocks of the Setuva formation, and quartzite, carbonate rocks to carbonate schist, mica schist and amphibolitic rocks of the Açungui I formation.

The Perau deposit is a stratiform lead deposit emplaced in limestone to carbonate schist in the lower part of the Açungui I formation.

Limestone to carbonate schist of the Perau Horizon overlies quartzite of the base of the Açungui I formation, and is distributed in a form of lense, swelling in the surrounding area of the Perau mine, pinching out on the north and the south.

The main ore body of the Perau mine has a strike length of about 350 meters and that of shoot of 120 meters. It is composed of several ore beds, forming several ore shoots. The lower limit of the ore shoot is about 120 meters below the surface and a half of the main ore body seems to have been eroded out.

Graphite schist underlies immediately below the ore horizon, and a barite zone accompanied by lead mineralization is locally concentrated in lenticular to stratiform in the hangingwall immediately above or several meters upward from the ore horizon. Further upward in the hangingwall five to 20 meters from the barite zone, "Magnetite zone" is widely distributed.

These graphite schist and the magnetite zone are very important key beds for survey and exploration of the ore deposit in the Perau horizon.

As the result of geophysical survey IP and SIP conducted in the second year, the Perau ore horizon have been detected clearly, and continuity of the ore horizon. As result of the drilling tested at the most promising part, a mineralized zone showing the occurrence of a new ore deposit was discovered in the same horizon on the west of the Perau deposit.

The mineralized zone is a strata-bound ore deposit characterized by the mineral assemblage of barite-sulphide, galena, sphalerite, pyrite etc. Although any conspicuous variation is not shown in this mineral assemblage basically compared with the Perau deposit a little different characteristics, such as association of barite and occurrence of abundant sphalerite are recognized, which lead to the assumption that the time of mineralization was a little later than that of the Perau deposit and that mineralized zone is positioned in a slightly upper part stratigraphically.

Geophysical survey of the Perau area was carried out in the southern part of the Perau mine where the Perau horizon has pinched out. The result showed a good consistency with that of the geological survey, and the ore horizon was not detected in the depth of the area.

Taking the result mentioned above into account, the future exploration in the Perau area is recommended to conduct a drill survey to confirm the extension of the mineralized zone toward the west and the north.

(2) Barrinha Area

Geology of the Barrinha area consists of mica schist, limestone to carbonate schist and phyllite to mica schist of the Açungui III formation

The ore deposits of the Barrinha mine are the vein-type or irregular to massive lead deposits emplaced in limestone and carbonate schist with dominant fold structures. Ore minerals are composed mainly of galena and pyrite, accompanied by subordinate amount of sphalerite and chalcopyrite.

Although many ore deposits and showings have been found in the Barrinha mine area, only the Quatro deposit is currently being operated.

The Quatro deposit has been emplaced in the upper part of the limestone member stratigraphically, and is positioned in the axial part of the anticline from the standpoint of geologic structure.

Other deposits show a similar form of distribution, especially these show a tandency that the mineralization is concentrated near the boundary with the upper mica schist member, and this is an effective guide for the future exploration.

The result of geophysical survey IP and SIP of the Barrinha area showed that apparent resistivity of IP well reflected the geologic structure.

As the anomalous zones which seems to be related to the mineralization, the southern anomalous zone which is a group of small-scale anomalies likely to have reflected the vein-type mineralization and the northern anomalous zone distributed continuously and in harmony with the anticlinal structure of the limestone member, were detected.

It is expected that a strata-bound or irregular massive mineralized zone would occur below the northern anomalous zone.

It is recommended, from the result of the above, for future exploration that the drill survey is conducted to investigate into the relationship between the mineralization and the northern anomalous zone on the east of São Joaquim and the SIP anomaly to the south-east of Quatro.

3–2 Geophysical Survey

(1) Results of IP Electrical Survey

a. Perau Area

Judging from the results of the IP method, as the mineralizations of the Perau ore horizon are weak, the possibility of the existence of the ore deposits in this area is thought to be very little.

The southern limit of the C anomalous zone, detected in the Phase II survey, seems to be located in the vicinity of the Perau anticlinal axis, which may be due to graphite schist and/or pyrite in the Perau ore horizon.

b. Barrinha Area

Strong IP anomalies are found in the northern and southern parts of the survey area.

The former are found at north dipping from the surface to the depths in the northern sides of lines BA to BD, and seem to be caused by the eastern extensions of the Oito ore deposits, São Joaquim mineral showings etc.

On the other hand, the latter is detected as local or independent anomaly in the shallow depth, and in the depths, this anomaly is found as a bload anomaly although it is impossible to locate its center. In the vicinity of this anomaly, there are mineral showings like as Cecrisa etc., therefore this anomaly is thought to be due to these mineral showings.

(2) Results of Spectral IP Survey

Three kinds of typical phase spectrum are classified in the results of the spectral IP conducted over the Oito deposit and the Quatro deposit.

Temporarily they are named as A, B and C, which have the following characteristics.

Type A anomaly ;	A peak of phase in the frequency range of 0.625–0.875 Hz
Type B anomaly ;	Decreasing phase shift with increasing frequency in the frequency range less than 1 Hz
Type C anomaly ;	Almost constant or slightly increasing phase shift with increasing frequency in the frequency range less than 1 Hz

A typical type A anomaly is seen where there is pyrite mineralization, while type B anomaly reflect the very good conductive body as detected around No. 8 on line BH, which is a kind of electromagnetic phenomenon called as "pipeline effect".

Type C anomaly is the most interesting spectrum detected over the both deposits of the Oito and the Quatro. Type C anomalies are widely distributed around the Oito deposit surrounding the deposit itself, but type B anomalies were found in the southern part of the Oito deposit and type A anomalies were detected as the local ones.

These three types of anomaly seem to extend to the northeastern anomalies confirmed by the conventional IP survey via São Joaquim, with some of them seen in the western part of the Oito deposit.

On the other hand, type C anomaly detected near the Quatro deposit tend to continue to the southern anomaly of conventional IP survey through the depths of No. 11 on line BM.

3–3 Drilling Survey

The drilling survey in the Perau area was carried out on the selected point based on the data of geology and geophysics of second year, and as the result of the drilling survey, a promising barite-sulphide ore deposit were intersected.

The drilling work was conducted by CPRM stuffs using two drill machines, Boyles-56 wire-line method and final diameter is BQ and two shifts per day (ten hours each shift) were carried out for drilling work.

The drill survey was carried out for three holes with total hole length of 912.20 meters. The amount of works of each hole are shown in the following.

Holes	Drill length (m)	Core length (m)	Core recovery (%)
AG–01	331.15	326.20	98.50
AG–02	330.55	299.90	96.26
AG–03	250.50	238.35	98.69

The assay results of ore intersections of each hole is as follows:

Holes	Depth of ore intersection (m)	Length of intersection (m)	Pb %	Zn %	Cu ppm	Ag ppm	CaO %	MgO %	SiO_2 %	BaO
AG–01	255.95∿263.45	7.5	4.36	2.96	214	95	11.36	8.91	5.62	15.20
	263.45∿265.90	2.45	2.56	0.56	236	56	12.5	8.85	33.06	4.44
AG–02	242.85∿247.85	5.0	4.7	0.48	162	86	12.6	6.2	9.0	20.5
	251.40∿252.50	1.1	4.5	4.5	60	68	12.2	7.5	4.3	17.9
	253.35∿253.60	0.25	5.7	5.6	40	110	13.2	6.9	7.6	12.3
AG–03	194.30∿196.20	1.9	2.5	0.9	293	35	8.3	3.1	40.4	4.7

CHAPTER 4 CONCLUSION AND RECOMMENDATION

In order to obtain a useful guide for the future exploration and to study mutual relationship between the geologic structure and the ore forming portion have been conducted in the semidetailed survey area.

In the Perau area, a detailed geological survey, geophysical survey (IP) and drill survey were carried out.

In the Barrinha area, a detailed geological survey and geophysical sruveys (IP and SIP) were carried out.

4–1 Conclusion

(1) The survey area is composed of Precambrian metamorphic rocks of the Açungui group which have been intruded by igneous rocks. The Açungui I, II and III formations according to the stratigraphical classification established on the result of surveys in the first year and the second year, and the Açungui III formation was further subdivided.
The Açungui I formation, so named in the past survey, was divided into the Açungui I and the Açungui II formations on the result of survey of this time.

(2) The metamorphic rocks in the area were produced by regional metamorphism. Arenaceous to pelitic schist belong to muscovite zone to biotite zone and meta basic rocks belong to green schist to epidote amphibolite facies.
On the west of the Itaoca granite mass, garnet hornfels and biotite hornfels can be observed as the contact metamorphism have been overlapped above metamorphism.

(3) All the ore deposite distributed in the semidetailed survey area are vein type or irregular massive deposits embedded in limestone of the Açungui III formation. The limestone, the host rock of the ore deposits, is subdivided into $AIIIL_2$ and $AIIIL_3$. The Lageado deposit and the lead deposit in the eastern part of Itaoca have been emplaced in $AIIIL_2$ and the Furnas deposit and the Espirito Santo deposit have been emplaced in $AIIIL_3$. Among these, the Furnas deposit is a vein-type to irregular massive silver-lead deposit, and there is a possibility of the same kind deposit in the surround, and it is considered that the Furnas area is a promising area in future.

(4) As the result of analysis of limestone of each member distributed in the Açungui III formation, geochemical characteristics of each limestone were obtained.
The Pb-Ag-Zn factor though to be related to mineralization predominates in the area of known deposits.

(5) As the result of the detailed geological survey, geophysical survey (IP) and the drilling survey, it was found that the Perau ore horizon pinched out in the southern part of the Perau mine.

A stratiform deposit of barite-sulphide (galena, sphalerite and pyrite) was discovered by the drilling survey conducted on the west of the Perau deposit. There is a great possibility that the size of the deposit expand toward the west and the north.

(6) As the result of detailed geological survey and geophysical survey (IP and SIP) in the Barrinha area, it was clarified that the deposits of the area was vein-type or irregular massive lead deposit emplaced in the upper part of the $AIIIL_2$ limestone member of the Açungui III formation, and especially that the mineralized zone was distributed from the axial part to the part of the limb of the fold structure.

Blinde ore deposits are expected underneath the IP anomaly in the eastern part of São Joaquim and SIP anomaly on the southeast of the Quatro deposit.

(7) The result of measurement of lead isotope age determination of galena taken from the whole project area, Perau-type deposit show 1,350 ∿ 1,400 m.y. and the other vein-type to irregular massive lead deposit show 1,000 ∿ 1,200 m.y.

The Perau deposit was formed syngenetically with the host rock of ore deposit and other deposits were formed by concentration of base metals in fractures of the host rock produced during the Brazilian Orogeny(750 ∿ 500 m.y.), which had been once precipitated in the host rock.

4–2 Recommendation

As the above conclusion, various basic data have been obtained in the past three years, and it is desirable to be conducted future exploration according to priority as follows (Fig. 2):

(1) The drilling survey is to be conducted on the west and the north of the stratiform ore deposit, intersected by the drill survey of this year in the Perau area, in order to grasp the scale of the ore deposit.

(2) Because of the IP and SIP anomalies in the Barrinha area have possibility to be related with mineralization, the drilling survey is recommended in order to clarify the situation of the mineralization.

(3) In the Furnas area, geological survey, geophysical survey (IP or SIP) and drilling survey should be carried out in order to clarify the existence of the concealed ore deposit because the area has more possibility of the mineralization such as vein type or irregular massive lead ore deposit.

(4) In the Canoas area to the northeast of the Perau area, an occurrence of mineralization similar to the Perau ore deposit has been known, therefore geological survey and geophysical survey (SIP) is expected to confirm the possibility of the mineralization.

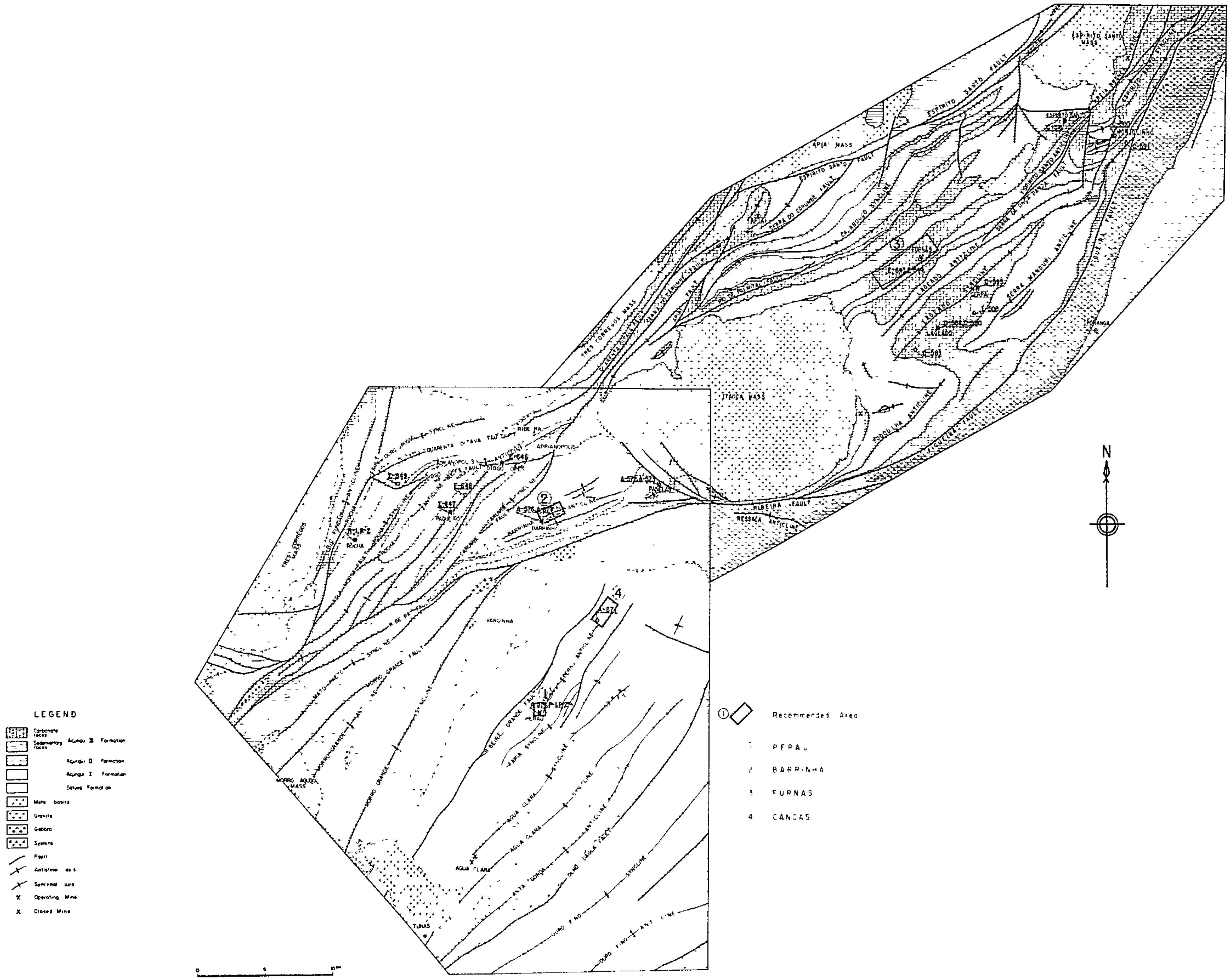

Fig. 2 Recommended Area for Next Phase

PARTI PARTICULARS

PART Ⅰ GEOLOGLCAL SURVEY

CHAPTER 1 SEMIDETAILED SURVEY AREA

1–1 Geology

1–1–1 Summary of Geology

The geology of semidetailed survey area consists of the formations such as the Açungui I, Açungui II and Açungui III from the base upward,and which have been intruded by the meta-basic rock and granitic rocks of Brazilian orogenic cycle and the Cretaceous meta diabasic rocks.

The Açungui I, II and III formations and the meta basic rocks subjected to metamorphism of the Brazilian orogenic cycle showing the metamorphic phases of green schist to epidote amphibolite.

The geologic structure is dominated by fold and fault structure of approximately NE–SW system, and in addition, the faults of N–S system and the NW–SE system are shown. Intrusion of diabasic dyke rocks are also found within NW–SE faults.

As for the ore deposits and mineral showings, numerous vein-type lead deposits are found to have been embedded in the carbonate rocks of the Açungui III formation.

Plate I–1 and Fig. I–1 show the geology of the area. Fig. I–2 shows the generalized stratigraphic columnar section and Plate I–3 the correlation of the columnar section of each area.

I–1–2 Stratigraphy

The geology of the area consists of the Açungui group* comprised mainly of mica schist, phyllite, meta sedimentary rock of psammytic origin and carbonate rock.

As the result of survey of this year, the Açungui I formation of the past survey was subdivided into the Açungui I and Açungui II formations.

(1) Açungui I Formation

The Açungui I formation constitutes the lowermost part of the area.

It mainly consists of phyllites interbedded with amphibolite and very small amount of meta sandstone and meta conglomerate. Among the Açungui I formation of the past survey, the amphibolite dominated part on the east of Iporanga is called the Açungui I formation in this report.

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* The Açungui group is divided into Açungui I, II and III formations from the base upward on the basis of previous surveys.

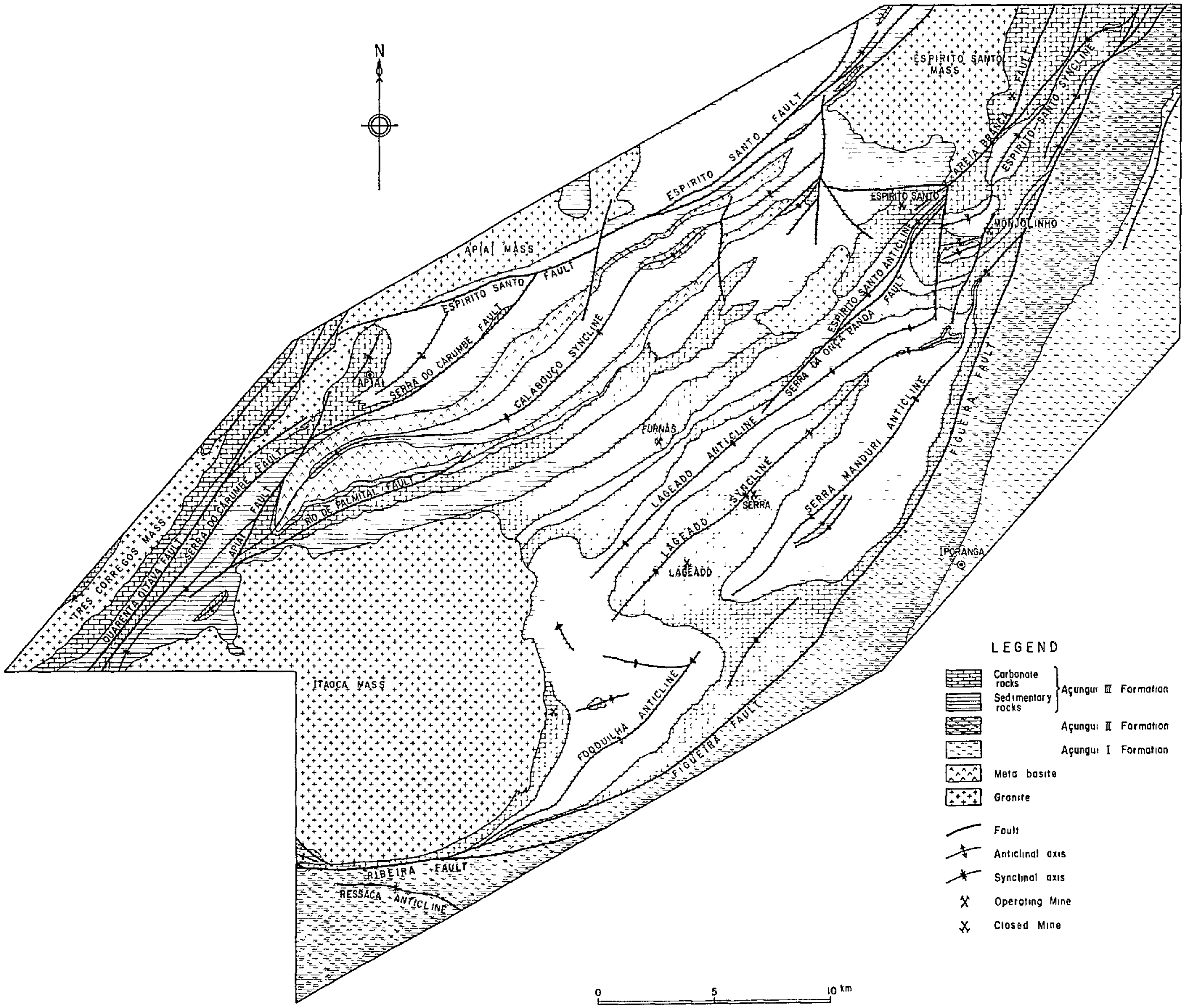


Fig. I—1 Geological Map of Survey Area

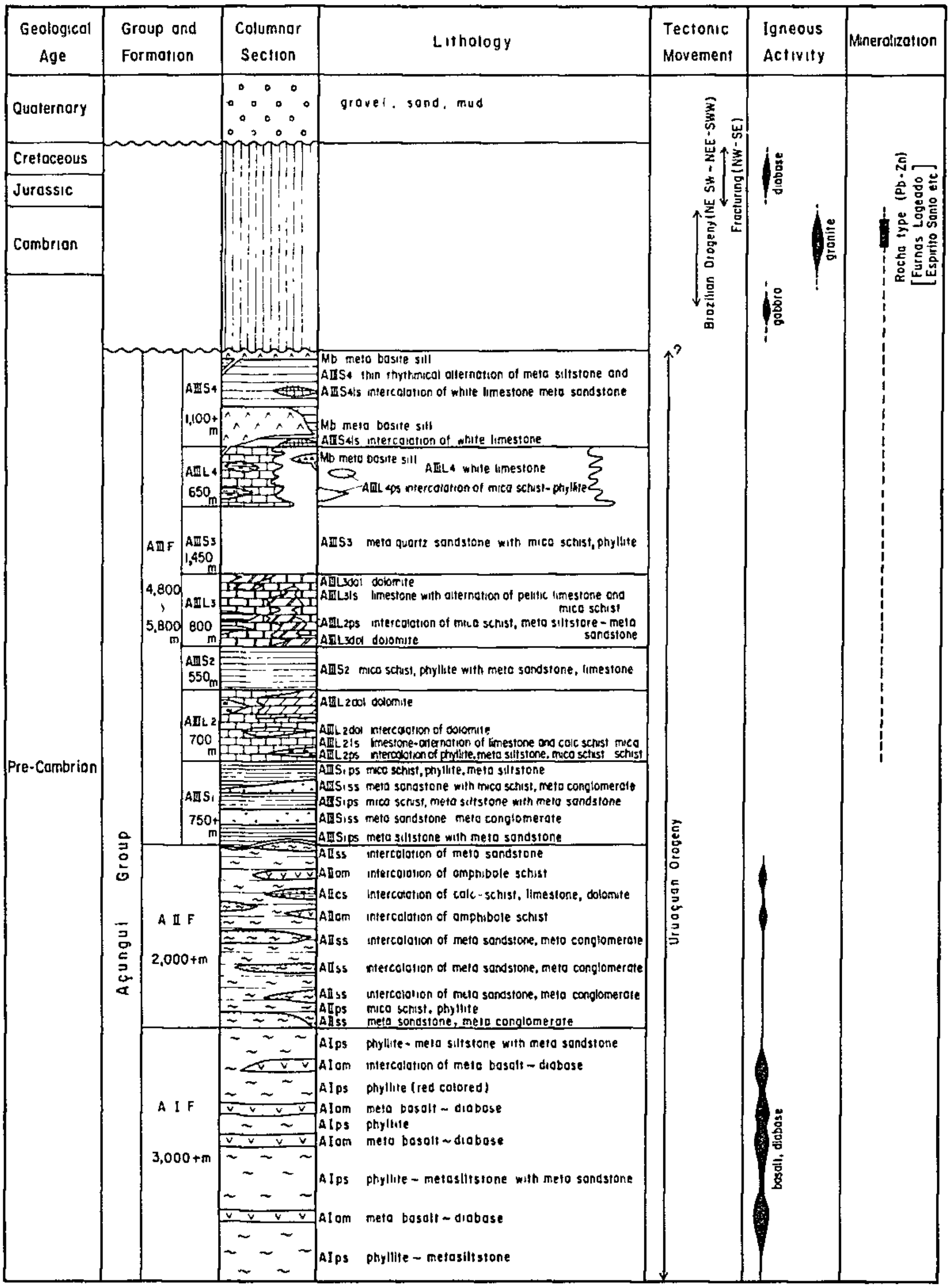


Fig. I—2 Generalized Stratigraphic Columnar Section in Survey Area

Distribution

The formation is distributed in the eastern peripheral area of the survey area. It occupies the eastern side of Iporange – Serra do Monte Negro line showing the NNE–SSW trend.

Thickness

Although the true thickness of the formation is unknown because no basement rock has been found in the survey area, the maximum thickness is assumed to be more than 3,000 meters on the east of Serra do Monte Negro.

Rock Facies

The formation mainly consists of phyllite to meta siltstone (AIps) interbedded with amphibolite (AIam) and thin beds of meta sandstone to meta conglomerate.

(a) Phyllite and Meta silt

The rock with distinct schistosity is called phyllite, which without it is called meta silt.

The most parts consist of phyllite, and interbedded with meta sandstone to meta conglomerate. The phyllite shows fine grained rock facies and light brown, purplish to grayish green tints color. Main constituent minerals are sericite and quartz, and as others, graphite, hematite and chlorite are observed.

A red phyllite bed, bearing hematite, between the two thin layers of meta basic rock in the upper part of the formation in the eastern part of Serra do Monte Negro forms an effective key bed in the area.

In the nothern part of Iporanga, phyllite shows pale brown to bluish purple color forming an alternating bed of fine-grained and coarse grained parts with the thickness of five to ten centimeters.

Thin layers of meta sandstone and meta conglomerate in phyllite are fine grained, white and massive quartzose sandstone, and conglomerate mainly composed of the pebbles of phyllite, quartzite and quartz.

To the west of the Feital settlement, the rock shows a weak schistose texture with sericite contained.

The characteristics under the microscopic observation of representative rocks are as follows:

Phyllite (E–578)

Location : Morro do Mouro

Texture : lepidoblatic texture

Constituent minerals :

quartz > muscovite, hematite > chlorite > actinolite

Quartz shows anhedral microcrystals with the size of 0.01 milimeters across.

Muscovite is microcrystalline and anhedral to subhedral crystal forms showing an equidimentional arrangement, closely accompanied by actinolite and chlorite.

Actinolite forms subhedral crystals 0.02 milimeters in size scattered in the microcrystalline aggregate of muscovite, chlorite and quartz.

Hematite is 0.01 milimeter across and occurs in the interstices between the grains of muscovite, chlorite, actinolite and quartz.

(b) Metabasalt (AIam)

The rock is dark green, fine grained to medium grained and massive, in general, and shows schistose rock facies in the marginal part. It forms saddle shape topography, showing good continuation along the trend of strike up to 17 kilometers. The thickness is several tens meters up to 100 meters, and seven layers are found in the area. Subophitic textures of lower metamorphism are observed.

The main constituent minerals are plagioclase, and as metamorphosed minerals, pyroxene and actinolite are found.

Metabasalt is considered basaltic lava flow origin because it is accompanied by green phyllite which seems to be tuffaceous origin, although it is difficult to determine the origin of the rock whether it has been metamorphosed from lava or sheet.

Stratigraphical relation

In the southern part of the survey area, the area of the second year, the Setuva formation underlies and the Açungui II formation overlies the Açungui I conformably. The rock of the Açungui I formation in the area is correlated to the upper part of the Açungui I formation based on the rock facies and the stratigraphical relation. It is conformably overlain by the Açungui II formation.

(2) Açungui II Formation

In generally the Açungui II formation mainly consists of mica schist to phyllite interbedded with metasandstone and metaconglomerate, in addition, interbedded with amphibolite in the upper part of the formation in the southern part of the Itaoca area and accompanied by carbonate rocks in the adjacent area of amphibolite facies.

The formation distributed between the west of Iporanga and the Figueira fault and interbedded with a number of sandstone and conglomerate lenses is treated as the Açungui II formation.

Distribution

The formation is distributed on the eastern side of the Figueira fault in a zone 2.5 to 4.0 kilometers wide and also widely distributed through the south of the Ribeira fault to the southeast beyond the boundary of the survey area.

Thickness

Although the formation making difficult the estimation of the accurate thickness of it because of minor folds deminant and difficulty of grasping the structure, it is assumed more than 2,000 meters in the northeastern and southern parts of the area.

Rock facies

The formation consists mainly of mica schist ~ phyllite (AIIps) intercalated with a small amount of meta sandstone, meta conglomerate (AIIss), amphibolite (AIIam) and carbonate rocks (AIIcs).

(a) Mica schist ~ phyllite (AIIps)

Mica schist occurs dominantly on the southern side of the Ribeira fault in the southeastern part of Itaoca. The rocks show fine grained to medium grained with colors of gray to dark gray partly pale green to yellowish brown.

In the lower to middle parts, the rock mainly consists of muscovite-biotite schist which contains quartz and sericite, in which porphyroblasts of garnet, 3 to 4 milimeters across, cutting the schistose structure obliquely.

The middle and upper part are composed of sericite-chlorite schist, included porphyroblasts of magnetite, partly intercalated with graphitic part.

Phyllite is distributed in a zone on the eastern side of the Figueira fault. It is pale brown, red and pale green, and no difference can be observed by the naked eyes with phyllite of the Açungui I formation. The schistosity is not distinct in general, although it shows wavy appearance in some part.

In the northeastern part of the area, red phyllite predominates in the zone, 700 to 800 meters, to the west of the boundary with the Açungui I formation.

The characteristics under the microscopical observation of representative rocks are as follows:

Chlorite biotite schist (B–602)

Location : 2 kirometers western part to Ressaca

Texture : Lepidoblastic texture

Constituent minerals :

quartz > muscovite > biotite > plagioclase > chlorite, epidote, cordierite

Quartz is 0.005 to 0.1 milimeters in size forming an anhedral granulose aggregate, and wave extinction is observed.

Muscovite forms subhedral crystals 0.05 to 0.2 milimeters in size showing an equidimentional arrangement.

Biotite forms euhedral porphyroblast one milimeter across in general, and encloses quartz poikilitically producing muscovite on the periphery.

Plagioclase is observed in small amount showing scarce twinning, though Carlsbad twin is partly found.

Epidote shows granular form 0.04 milimeter across and anhedral crystals are rarely observed.

Chlorite forms mainly in the intergranular interstices partly on the periphery of biotite rarely replacing cordierite.

Cordierite is granular anhedral crystal 0.1 milimeters in size having generally altered to chlorite.

(b) Meta sandstone ~ Meta conglomerate (AIIss)

The rocks are gray to brown and medium to coarse grained partly including thin layers of phyllite.

A bed dominant in meta conglomerate constitutes the lowermost part of the AIIss formation, and distributed discontinuously in a narrow band from the surrounding area of Rio Ribeira in the southeastern part of the area toward Serra do Monte Negro in the northeast with maximum thickness of 150 meters. The formation above this bed is named the Açungui II formation.

The meta conglomerate is distributed along the mountain pass to the television tower, and immediately above the Açungui I formation along the Rio Ribeira in the southern part of the survey area. Pebbles consist mainly of phyllite, quartzite and meta sandstone, and the pebbles considered to be granite and gneiss are partly contained at Iporanga.

Diameter of the pebbles is 5 milimeter to 5 centimeter in general, sometimes reaches up to 20 centimeters, showing lenticular form. Sorting and grading are poor in general.

The Matrix consists of lithic sandstone, showing a weak schistosity.

The meta sandstone found in the southwestern part of Iporanga partly contains biotite.

Massive and lithic part is also observed.

The characteristics under the microscopic observation of representative rock are as follows:

Meta conglomerate (D–528)

Location : 3.5 kirometers southwest to Iporanga

Texture : Lepidoblastic texture

Constituent minerals :

Muscovite > quartz > plagioclase > actinolite, chlorite, graphite

Muscovite is found as small subhedral crystals of about 0.01 milimeters across partly found as microgranular aggregate (sericite).

Quartz forms fine-grained anhedral crystals 0.01 to 0.04 milimeter across.

Plagioclase forms layers of mozaic aggregate with quartz. Twinning is generally rare, though some Carlsbad twins are observed. Relatively coarse crystals 0.2 milimeter across in average are found in lithic pebble about 1.7 milimeters in size.

Graphite forms thin layers of microgranular aggregate with muscovite and is also found sometimes along the boundary of muscovite aggregate.

Actinolite shows subhedral form and constitutes microgranular aggregate with muscovite, graphite and chlorite.

(c) Amphibolite (AIIam)

Amphibolite is distributed in the southern part of the survey area as three to four thin layers in the upper part of the formation. It is medium to coarse grained and pale green to dark green in color, showing massive and schistose rock facies. Schistosity is notable in general.

A tendency of gradual transition from amphibolite through chlorite-sericite schist to mica schist is observed in the vicinity of amphibolite occurrence.

(d) Carbonate rocks (AIIcs)

Carbonate rocks consist of limestone, dolomite, calcareous phyllite and calcareous schist, and are distributed north of Ribeirão da Pescaria in the northeastern part of the survey area and on the west of Ressace in the southern part of the area close to the amphibolite bed (AIIam).

Rocks show white to dark grey color, and show bright tint compared with that of carbonate rocks of the Açungui III formation.

Although Projeto Leste do Panamá Report (1977, CPRM) describes the copper, lead and zinc showings in small scale calcareous limestone in the western and southern part of Ressaca, mineral showing could not be confirmed during this year survey.

Stratigraphical Relation

As the result of survey in the first year, the rocks in the area on the east side of the

the Figueira fault had been lumped together as the Açungui I formation.

It was, however, further divided into the Açungui I and II formation during this survey, of which the former is the lower portion below the bottom of meta sandstone and meta conglomerate dominant bed (AIIcs) distributed from Rio Ribeira to Serra do Monte Negro in the southeastern part of the area, while the latter is the upper portion above that boundary. The Açungui II formation conformably overlies the Açungui I formation, while it is contacted with the Açungui III formation by the Figuira fault.

In the southern part of the area, it overlies the Açungui I formation with the bottom of meta sandstone, and which has been cut by the Ribeira fault on the south of the Mendez settlement.

(3) Açungui III Formation

The formation consists mainly of mica schist, phyllite, meta sandstone and carbonate rocks. It is widely distributed in the northeastern, the western parts and the central part of the area.

As the result of survey of the second year, Açungui III formation was subdivided into three members such as the lower member ($AIIIL_1$, $AIIIS_1$), the middle member ($AIIIL_2$, $AIIIS_2$) and the upper member ($AIIIL_3$, $AIIIS_3$) depending on the combination of carbonate rocks and meta sedimentary rocks.

In the survey of this year, the extention of each member have followed up in details, and the existence of carbonate rocks ($AIIIL_4$) and meta sedimentary rocks ($AIIIS_4$) were discovered further in the upper horizon, as the result of the survey, it have been clarified that the formation can be divided into four members in all. Classification of the formation into four members, however, was averted this time, because the occurrence of $AIIIL_4$ is limited in the locally and because it is in the relation of interfinger with the upper part of $AIIIS_3$ stratigraphically.

The members were further subdivided by the rock facies.

(a) $AIIIS_1$ Member

The member consists of mica schist to phyllite, meta siltstone, and meta sandstone ~ meta conglomerate, etc.

Distribution

It is distributed in the mountainous region. Morro do Manduri to Serra Sem Fim and Morro Grande to Foçouilha, forming the core of anticlinal structures such as Lageado anticline and Serra Manduri anticline in the central and southeastern parts of the area, and also distribute surrounding $AIIIL_2$ member.

Thickness

The maximum thickness of 750 meters is shown in the upstream of Rio Betari at about four kilometers from the Betari settlement.

Rock facies

The main rocks are mica schist to phyllite and meta siltstone (AIIS$_1$ ps) interbedded with meta sandstone to meta conglomerate (AIIS$_1$ ss)

(a) Mica schist, phyllite and meta siltstone (AIIS$_1$ ps)

Mica schist and phyllite are dominantly exposed in the surrounding area from Porto Velho through Foqouilho to Serra Sem Fim in the southern part of the area, showing a tendency of decreasing the intensity of metamorphic grade from the southern part toward the northeastern part of the area.

The mica schist ~ phyllite consist of fine to medium-grained sericite-chlorite. The rocks include chloritoid (6 mm x 4 mm in size) in some part, and oblique intersection of bedding plane and schistosity plane is observed in many places.

Meta siltstone is gray to purplish gray, showing massive rock facies, partly interbedded with dark brown graphitic schist and gray quartz-sericite schist.

Meta conglomerate ~ meta sandstone (AIIS$_1$ ss) is reddish gray. The pebbles of meta conglomerate consists of quartzite alone showing subangular to subround shapes with diameter of four to 15 milimeters, having been poorly sorted.

Meta sandstone is grayish white, fine to medium-grained quartz sandstone, and contains chloritoid. Meta siltstone and sericite schist are partly intercalated.

The characteristics under the microscopic observation of representative rocks are as follows:

Meta conglomerate (I–546)

Location : 3 kirometers west to Betari

Texture : Granoblastic texture

Constituent minerals :

quartz > potash feldspar > muscovite > chlorite ≫ hematite, opaque minerals, zircon

Quartz displays granular and anhedral crystal form and occurs as single crystal about one milimeter across or mozaic aggregate of 0.05 to 0.2 milimeters in size, having a notable wavy extinction.

Muscovite is 0.02 to 0.12 milimeters in size with euhedral to subhedral crystal forms, being scattered through the rock as the aggregates filling the interstices of quartz and potash feldspar or as independent crystals.

Hematite is observed between the grains such as quartz and potash feldspar as micro-granular aggregate.

Chlorite forms at the periphery of muscovite, or occurs as pools of fine-grained aggregate. Iron rich chlorite is partly found.

Zircon forms granular, anhedral crystals 0.05 milimeters across.

(b) $AIIIL_2$ Member

The main rocks of the member are limestone and dolomite locally intercalated with thin beds of phyllitic rocks.

Distribution

The member is distributed from the central part of the survey area to the Figueira fault and in the adjacent area of the southeast of Apiai in the western part of the area.

In the central part of the area, it is distributed NE–SW trend showing zone and basin shapes, repeatedly exposed by folding structures such as the Lageado anticline, the Lageado syncline and the Serra Mandurı anticline.

In the western part, it is exposed in a narrow zone on the western side of the Quarenta Oitava fault which runs parallel to the road from Apiai to Ribeira.

The lead ore deposits such as Lageado, Agua da Limeira and Santo Antonio do Parão, fluorite deposit such as are embedded in limestone of the member, which forms an important host rock together with the $AIIIL_3$ member overlying the above.

Thickness

Thickness of the member is estimated to be 650 meters at Rio Iporanga, 500 to 700 meters at Lambari to Lageado, about 800 meters in the vicinity of the road from Apiai to Ribeira.

Rock facies

The main rocks of the $AIIIL_2$ member are limestone ($AIIIL_2$ ls) and dolomite ($AIIIL_2$ dol). The former is dominant in the lower part, while the latter in the middle and upper parts.

Limestone ($AIIIL_2$ ls) is gray to dark gray and fine to medium grained, showing an appearance of muddy to massive and compact rock in the northeastern part. The rock is interstratified with well bedded meta sandstone ~ meta siltstone ($AIIIL_2$ ps) with thickness tens meters to 100 meters.

Dark gray, fine-grained pelitic limestone occurs in the lower part in the surrounding area of Lageado to Lambari having been interbedded with calcareous to arenaceous rocks, phyllitic rocks ($AIIIL_2$ ps) and dolomite. Diagonal foliation is often observed in limestone having been disseminated by fine-grained pyrite.

The upper part of the member is composed of massive and compact, fine to medium-grained limestone dark gray to gray in color, intercalated with pelitic limestone of distinct bedding. In the adjacent area of Serra, it is interbedded with dark gray, fine-grained pelitic dolomite to fine-grained gray dolomitic limestone, with dominant diagonal foliation in both rock facies. In the upstream area of Corrego de Coita, breccia zone of siliceous rocks is observed in the fault zone.

The Lageado ore deposit is a vein-type lead deposit emplaced in the lower part of the limestone member.

Some calc silicate rock is exposed along the road from Apiai to Ribeira.

Limestone is subjected to thermal metamorphism by the intrusion of the Tres Corregos granite mass, and characterized hornfels by calcsilicate minerals. It has an appearance of compact rock pale green to gray in color, alternating with biotite hornfels having the width of two to five centimeters of each unit. The rock contains biotite, quartz, tremolite and epidote. Porphyroblasts of biotite, three to four milimeters across, are also observed.

Dolomite ($AIIIL_2$dol) is distributed in the middle to upper part, Lambari to Lageado, and in the upper part of the $AIIIL_2$ member. It is fine grained and dark gray, having an appearance of massive and compact rock. It is difficult to discriminate it from limestone megascopically. It shows a distinct bedding in general with layers of five to 30 centimeters in width.

Irregular veins of calcite and dolomite less than five centimeters wide are often observed in limestone and dolomite.

(c) $AIIIS_2$ Member

The member consists mainly of mica schist to phyllite, interbedded with meta sandstone.

Distribution

The member is distributed in the central part of the survey area from the north of Morro Grande through Santana to Espirito Santo forming a narrow zone of NE–SW trend. In the northern part, the member occurs on the northern side of the Espirito Santo fault and the Serra do Carumbe fault, and shows a narrow distribution on the west side of the Quarenta Oitava fault.

Thickness

The thickness of the member is 350 meters at Rio Betari, which reaches, on the northeast, up to 700 meters. It is, however, more than 700 meters at Serra Agua Limpa to the east of Apiai, and 300 meters at Pouso Triste in the western part of the area.

Rock facies

The member is composed of dominant mica schist ~ phyllite and meta siltstone ($AIIIS_2$),

interbedded with meta sandstone and siliceous sandstone.

Thin layers of limestone and dolomite are only partly intercalated.

Mica schist ~ phyllite show fine grained and predominant schistosity gray to reddish brown in color, and often showing the rock facies of biotite-sericite schist and graphite-sericite schist.

To comparing with $AIIIs_1$ member the rocks are more arenaceous and rich in manganese in chemical composition, showing manganese dioxide stain everywhere on the surface.

The member consists of mica schist and graphite schist with distinct schistosity at the left bank of Rio Iporanga, and includes the porphyroblasts seem to be dolomite.

In the surrounding area of Rio Betari, sericite schist predominates and reddish meta sandstone ~ psammytic schist are interbedded Chloritoid is partly contained, and black graphitic part is also observed.

The main rock facies on the east of Apial are gray to red mica schist ~ phyllite interbedded with yellow quartz schist to meta sandstone, while the rocks distributed along the Espirito Santo fault change into siliceous rocks toward the fault.

Dark gray quartz-sericite schist occurs in a narrow zone along the Quarenta Oitava fault and contains abundant coarse garnet in the surrounding area of Tres Corregos granite mass.

Meta siltstone shows red to purplish gray, fine-grained rock facies and is exposed at Serra de Parana-piacaba and on the left bank of Rio Iporanga.

It alternates with fine to coarse grained, white to red meta sandstone partly with arkosic quartz schist, having intercalated with thin layers of limestone and dolomite at the left bank of Rio Iporanga.

(d) $AIIIL_3$ Member

The member consists mainly of limestone ($AIIIL_3$ ls) often accompanied by dolomite ($AIIIL_3$ dol). It is intercalated with meta sandstone and mica schist ($AIIIL_3$ ps).

Distribution

The member is distributed in a narrow zone with general strike of NE–SW trend in the area from Boa Vista through Furnas to Espirito Santo, and in addition, it is exposed in zones in the area from Apiai to Pouso Triste on the western side of the Carumbe fault.

The lead ore deposits and mineral showings such as Furnas, Espirito Santo, Monjolinho de Sebastião and Braça da Pescaria are embedded approximately in one horizon, and the member constitute an important host rock of the lead ore deposits.

Thickness

The thickness of the member is 840 to 1,030 meters in the adjacent area of Furnas. It is

about 1,000 meters in the vicinity of Espirito Santo, which is located on the northeastern extention of the above. The thickness is unknown at Caracol in the western part of the area because the upper part of the member has been faulted, though it is assumed to be more than 800 meters.

Rock facies

Limestone ($AIIIL_3$ls) shows fine to medium grained and gray to dark gray, with variation of rock facies from massive and compact to coarse grained. It is similar to the $AIIIL_2$ member in rock facies, and cross-lamination is often observed.

In the surrounding area of Furnas, the limestone ($AIIIL_3$ls) is interbedded with two layers of meta sedimentary rocks ($AIIIL_3$ps) with relatively good continuation, and it is sub divided into three parts of upper, middle and lower.

Limestone of the lower part consists mainly of fine to medium-grained, gray to dark gray massive limestone, partly interbedded with pelitic limestone, calcareous schist, and meta siltstone to meta sandstone. It forms the host rock of the Furnas deposit.

Limestone of the middle part is predominant with gray, fine to medium-grained rock facies and disseminated by fine-grained pyrite. Thin alternating beds of limestone, dolomite and sericite schist are observed in a small creek to the west of Furnas.

Limestone of the upper part shows gray to dark gray, medium to coarse-grained rock facies, with partly dominant cross lamina. Calcite veins are often contained.

Dolomite predominates in the surrounding area of Espirito Santo and on the southwest of it. Limestone occurs dominantly in the northeastern area. Difference of rock facies between limestone and dolomite can not be recognized, and lithological difference from the $AIIIL_2$ member can not be observed. The distinct bedded structure of five to 30 centimeters width is common, and often, pyrite dissemination is observed.

In the vicinity of Apiai, the member consists mainly of dark gray, medium to coarse-grained pelitic limestone finely interbedded with thin layers, 20 to 50 centimeters, of meta sandstone and meta siltstone. Limestone on the peripheral part of the Apial granitic mass has been subjected to contact metamorphism to have become massive siliceous limestone accompanied by epidote, tremolite and garnet.

It shows, at the limestone quarry of Camargo Correia, medium to coarse-grained rock facies gray to dark gray in color.

At the contact with the Itaoca granite mass, it has been metamorphosed to marble showing coarse-granined rock facies with abundant concentration of coarse biotite flakes.

Dolomite ($AIIIL_3$dol) is gray, pale green and purplish gray, fine to coarse-grained massive

dolomite accompanied by calcite and dolomite veins.

Three parts of the $AIIIL_3$ member is recognized in the vicinity of the Furnas. The rock of lower part is gray and fine grained. The of middle part is pale green to purplish gray and accompanied by small veins of quartz, sphalerite, pyrite and calcite veinlets. The upper part is gray and coarse grained, partly accompanied by stockwork of calcite and dolomite in dark gray brecciated dolomite.

Along the São Paulo State road 373, a notable Zebra structure with a pattern of banding consisting of fine-grained dark gray part and pale gray part is observed.

In the vicinity and on the southwest of Espirito, gray, fine-grained, massive and compact rock facies is shown, and cross laminae are often observed.

Meta sedimentary rocks ($AIIIL_3ps$) consists of mica schist, meta sandstone and meta siltstone. It occurs as the intertrappean beds in limestone and dolomite.

Mica schist is mainly composed of dark gray to brown sericite schist associated with graphitic part. Meta sandstone is fine to medium-grained meta quartz sandstone gray to brown in color.

Porphyroblasts of garnet, two to three milimeters across, are observed in the surrounding area of Apiai, obliquely cutting the bedding plane of meta sandstone.

(e) $AIIIS_3$ Member

The member mainly consists of meta quartz sandstone interbedded with thin layers of mica schist to phyllite.

Distribution

The $AIIIS_3$ member is distributed in narrow zones in the southern limb and the northern limb of the Calabouço syncline, and in addition, in a small scale along the axis of the Espirito Santo syncline.

In the southern limb of the Calabouço syncline, it occurs from the vicinity of the Camargo Correia limestone quarry through Serra Boa Vista and Serra da Vargem Grande to the north of Espirito Santo, while in the northern limb of the syncline, it occurs along the São Paulo State road 373.

Thickness

Although the thickness of the member is 900 meters in the mountainous area of Boa Vista, it reaches up to 1,500 meters in the surrounding area of Serra da Vargem Grande to the north of the above.

Rock facies

The main rock facies of the member consists of meta quartz sandstone ($AIIIS_3$) inter-

bedded with thin layers of mica schist ~ phyllite and partly with meta siltstone.

Meta quartz sandstone mainly consists of fine to medium-grained siliceous sandstone grayish white, reddish brown and purplish gray in color, intercalated with thin layers of mica schist and phyllite every where in the rock.

Bedding is generally distinct, although massive and non-bedded rock facies, and alternating beds with mica schist and phyllite, are observed. Pyrite dissemination is locally found.

Sericite and chiastolite are observed at the contact with the Espirito Santo granite mass. Porphyroblast of garnet is also found in the surrounding area of the Itaoca granite mass.

The characteristics under microscopic observation of representative rocks, are as follows.

Meta quartz sandstone (A–525)

Location : 2 kirometers north to Furnas

Texture : Granoblastic texture

Constituent minerals :

quartz > potash feldspar > muscovite > chlorite, hematite, opaque minerals

Quartz is 0.1 to 0.6 milimeters in size and displays subround to subangular crystal form. Parting and wavy extinction is observed.

Potash feldspar shows subround to anhedral crystal forms about 0.5 milimeters across. Twinning of a fine lattice structure is observed.

Muscovite displays subheral to euhedral crystal form 0.02 to 0.06 milimeters in average size (about 0.1 mm in maximum and fills together with hematite the interstices of quartz and potash feldspar. It has been altered to chlorite along the rim and the cleavage.

Chlorite is found along the cleavage of muscovite and replacing the hornblende crystals.

Ziron is rarely observed as clastic crystals about 0.6 milimeters in size.

(f) $AIIIL_4$ Member

The member mainly consists of limestone interbedded with mica schist and phyllite.

Distribution

It is distributed in the southern limb of the Calabouço syncline and is not found in the northern limb. It occurs in a narrow zone from Gurutuva through Corrego Passa Vinte and the upstream of Rio Betari to the southeast of Bairro da Cachimba.

Thickness

The thickness of the member is 530 to 750 meters in the area between Rio de Pamital and Rio Betari, gradually reducing toward northeast. It is about 70 meters on the southeast

of Bairro da Cachimba.

Rock facies

The limestone is characterized by the rock facies of white to pale gray color and fine to coarse grain sizes, with relatively distinct bedding, which makes easy to discriminate it megascopically from dark gray $AIIIL_2$ and $AIIIL_3$ members.

Two thin layers of brown sericite schist to phyllite are intercalated in the rock at Rio de Parmital. The upper part of the limestone is impure in the vicinity of Rio Betari having been interbedded with thin layers of dolomite and calcareous schist.

In the upstream of Rio Betari, the intertrappean layers of meta quartz sandstone gradually increase in number toward northeast grading into meta quartz sandstone ($AIIIS_3$). On the other hand, this limestone can not be found in the northern limb of the Calabouco syncline being distributed by meta quartz sandstone ($AIIIS_3$) in the horizon to correspond to the limestone member, which leads to the assumption that both members might grade into each other in the relation of interfinger.

(g) $AIIIS_4$ Member

The $AIIIS_4$ member constitutes the uppermost part of the geology in the survey area.

Alternating beds of meta siltstone, meta sandstone and carbonate rocks, among which meta siltstone is most dominant, are the main rocks, and these are interbedded with thin layers of limestone.

Distribution

The member is distributed in zones along the axis of the Calabaço syncline from the west of Gulutuva through Palmital to the east of Cachimba.

Thickness

The member is divided into two zones by meta basic rock intruded into the $AIIIS_4$ member in the shape of the sheet. The thickness of the underlying part below the meta basic rock is 50 to 320 meters while that of the overlying part is 80 to 780 meters.

Rock facies

It is composed of very regularly alternating thin beds, 5–10 cm thick, consisting mainly of meta siltstone which displays various tints of gray, pale green and brown, associated with meta sandstone and carbonate rocks. It is locally intercalated with silicious rock facies.

The characteristics under microscopic observation of representatives rocks, are as follows.

Meta siltstone (B–544)

Location : 2 kirometers west to Gurutuva

Texture : Lepidoblastic texture

Constituent minerals :

Muscovite > quartz > chlorite > opaque minerals > sphene, andalusite, chloritoid

Muscovite is 0.05 milimeter across in average and dispalyas tabular to prismatic euhedral crystal form, showing mainly preferred orientation, partly unoriented structure.

Quartz is about 0.01 to 0.05 milimeters in size showing anhedral crystal form. Some are scattered through the rock and others form fine-grained thin layers.

Chlorite and sphene occur as anhedral microgranular aggregates.

Opaque minerals are scattered as granular crystals about 0.05 milimetered in size.

Andalusite occurs as subhedral long prismatic porphyroblasts reaching up to two milimeters in length and includes poikiloblastically abundant quartz and opaque minerals, rarely muscovite. Cleavage is poor and pleochroism is hardly observed.

Chloritoid is about 0.03 milimeters across. Prismatic to staut prismatic crystals are seldom observed.

1–1–3 Intrusive Rocks

The intrusive rocks in the survey area are distributed into meta-diabasic rocks, granitic rocks and diabasic rocks. Meta basic rocks and granitic rocks are considered to be products of the Brazilian Orogeny took place from the end of Precambrian to Cambrian. Diabasic rocks are considered to have formed as a part of basic volcanic activity associated with the reactivated movement of the South American plateau.

(1) Meta Basic Rocks (Mb)

The rock have intruded into the Açungui III formation showing a sheet form, having been subjected to folding and metamorphism together with the Açungui group.

The main body intruded into the $AIIIS_4$ member, which is distributed in a narrow zone NEE–SWW trend with of 28 kilometers extention. The thickness is 300 to 400 meters in average, and maximum 780 meters.

In addition, the small scale intrusions in the upper part of the $AIIIS_4$ member and a small body in meta sandstone of the $AIIIS_3$ member to the northeast of Faz Bachada Grande are recognized.

Rock facies

The rocks show various rock facies such as dark gray to dark green, fine to coarse grained massive gabbro, meta diabase and meta basalt. It has a tendency that the metamorphic grade of the rocks increases toward the periphery of rock mass, although it is low in the inner part.

The main constituent minerals are plagioclase, pyroxene and magnetite, with accompanying metamorphic minerals such as chlorite, actinolite and epidote. Chlorite veins and leucocratic mineral veins are partly found.

The characteristics under microscopic observation of representative rock are as follows.

Meta gabbro (H–516)

Location : One kilometer to the south of Parmital

Texture : Ophitic texture

Constituent minerals :

plagioclase > augite > hypersthene ≫ actinolite, biotite, magnetite

Plagioclase displays a long prismatic crystal form 1.5 x 0.4 milimeters in size in average showing albite twin and Carlsbad twin. It has a composition of andesine.

Augite is less than one milimeter across in average with maximum size of two milimeters, and weak pleochroism is observed. Exsolution texture of pigeonite in often observed.

Hypersthene shows an anhedral crystal form about 0.4 milimeters across and a weak pleochroism. Vermicular exsolution texture of augite is often observed.

Actinolite is 0.01 to 0.03 milimeters in size and occurs surrounding the augite crystals.

Biotite forms anhedral to subhedral crystals about 0.1 milimeter across, but is small in amount.

Meta gabbro (E–538)

Location : Right bank of Rio Betarizinho

Texture . Ophitic texture

Constituent minerals :

actinolite, hornblende > plagioclase > quartz ≫ sphene, epidote

Actinolite is found along the rim of hornblende forming fibrous or long prismatic crystals, showing synneusis texture in many cases.

Hornblende is surrounded by actinolite, forming subhedral to anhedral crystals of 0.6 x 0.2 milimeters in size in average.

Plagioclase forms anhedral to subhedral crystals with the size of 0.3 to 0.5 milimeters across in average. Twinning is not common. The composition is andesine.

Quartz is less than 0.1 milimeter in size and found on the periphery of plagioclase and epidote. Wavy extinction is common.

Sphene shows anhedral crystal form and is arranged in parallel with the schistosity

in actinolite and hornblende associated with epidote.

Epidote is granular and anhedral, and found in plagioclase and hornblende. Cleavage is poor.

Time of intrusion

The time of intrusion is after the sedimentation of the Açungui group and before folding and metamorphism of it. The intrusion may have been caused by the activity at the beginning of the Brazilian Orogeny or before it.

(2) Granite (Gr)

Distribution

The granite is distributed from the northeastern part to the southwestern part of the survey area forming batholiths or stocks such as a part of the Espirito Santo mass, a mass on the north of Serra da Onça Panda, a part of the Apiai mass, a part of the Três Corrêgos mass and a part of the Itaoca mass.

The Itaoca mass shows the widest distribution in the area, and elliptical shape batholithic intrusion having the extention of 18 kilometers from east to west and 12 kilometers from north to south. Various sizes of xenolithic blocks consisting of meta sedimentary rocks of the Açungui III formation have been caught in it at the peripheral part. Small granitic dyke rocks are found in the surrounding area of the Itaoca mass, on the southeast of Lageado in the upstream of Rio Betari.

Rock facies

The rocks consist of pale gray to gray, fine to coarse-grained biotite granite to granodiorite to granodiorite. Although phenocrysts of potash feldspar 0.5 milimeters to two centimeters across are included in general, those of five centimeters across are found in the Itaoca mass.

Matrix consists of potash feldspar, quartz, biotite, hornblende and magnetite one to three milimeters in size.

Hornblende is less abundant in amount in the Espirito Santo mass compare with other masses.

Although the flow structure and the megascopical metamorphic texture have not been observed, a mylonite texture can be observed in a part of the Apiaí mass. Quartz veins of NW–SE system are found in some places of the peripheral part of the Itaoca mass.

The characteristics under microscopic observation of representative rocks are as follows.

Biotite granodiorite (C–685 : Espirito mass)

Location : 4.5 kilometers to the north of Espirito Santo

Texture : Granular (to porphyritic) texture

Constituent minerals :

potash feldspar, plagioclase > quartz > biotite > hornblende ≫ zircon, sericite, chlorite, sphene, apatite, epidote

Plagioclase displays subhedral crystal form about three milimeters across. Various twinnings are observed, but zonal structure is not conspicuous. It is partly sericitized and the composition shows oligoclase.

Quartz is anhedral and fills the interstices of other crystals. Wavy extinction is observed.

Maximum size of potash feldspar is 6 x 4 milimeters, showing porphyritic structure. It includes biotite, plagioclase and quartz.

Perthetic texture is commonly observed, but lattice twinning is rarely found. Myrmekite forms at the boundary between quartz or plagioclase.

Biotite forms anhedral to subhedral crystals 0.5 to 0.7 milimeters across, altered sometimes to chlorite, sphene and epidote which shows zonal structure.

Hornblende displays subhedral crystal form about 1.2 x 0.5 milimeters in size. Pleochroism is remarkable.

Time of intrusion

The intrusion took place as one of the activity at the time before and after the fault movement after the metamorphism during the Brazilian orogenic cycle.

K/Ar of biotite by Cordani et al. (1967) showed 510 ± 15 m.y. of the Corregos mass and 500 ± 15 m.y. of the Itaoca mass, both of which correspond to the beginning of Cambrian.

Cordani et al. classified the time of intrusion at the time of Brazilian orogenic cycle into three stages as shown in the following.

(1) 650 – 600 m.y. intrusion during the orogenic movement

(2) 600 – 590 m.y. intrusion in the later stage of orogenic movement

(3) 590 – 500 m.y. intrusion in the final stage of orogenic movement

The time of intrusion of the granitic rocks of the area is, therefore, has been considered to be (3), the final stage of the orogenic movement.

(3) Diabase (Db)

Distribution and occurrence

Diabasic rocks have intruded the Açungui formation and the Itaoca granite mass as dykes of NW–SE system. The width of dykes is several meters to tens meters in general reaching up to 75 meters. Although the strike length is various, the longest one measures up to 15 kilometers. The interval between the dykes is about 12 kilometers, and four zones of dyke swarm

are regularly arranged with spacing of the above.

Rock facies

The rocks consists of medium to fine-grained diabase or basalt dark gray to dark green in color.

The constituent minerals consist mainly of plagioclase, pyroxene and magnetite, being sometimes accompanied by olivine and biotite.

In a part of the rock masses, a weak autometamorphism took place to have produced chlorite and pyrite. In very limited occurrence, andesitic and porphyritic rock facies are observed.

The microscopic characteristics of representative rocks, are as follows.

Gabbro (C–501)

Location : About three kilometers to the northeast of Bairro da Cachimba

Texture : Ophitic texture

Constituent minerals :

Augite, plagioclase ≫ actinolite > biotite

Augite generally forms granular anhedral crystals 0.3 to 0.4 milimeter across. Chlorite is observed in the rim.

Plagioclase displays long prismatic subhedral crystal form with maximum size of 2 x 0.06 milimeters. The composition is labradorite.

Time of Intrusion

The time of intrusion of the rocks belongs to the activity after the Brazilian orogenic cycle. The intrusion is assumed to be a part of the basic igneous activity associated with the reactivated movement of the South American plateau commenced in Jurassic.

1–1–4 Metamorphism

In the second year's survey, metamorphic mineral assemblage of the Setuva formation, Açungui I, II and III formation have been classified on the basis of field survey, rock analysis and microscopic observation, and a metamorphic map was produced.

The present survey area is located in the north to the second year's area. The metamorphic facies is classified as second year's classification on the basis of data of field survey and microscopic observation.

A table of synthetic classification of metamorphic facies is shown in Table I–1, and metamorphic distribution map is shown in Fig. I–3.

The metamorphism in the area is classified into reagional metamorphism and contact

Table Ⅰ—1 Classification of Metamorphic Facies of Survey Area

<table>
<tr><td>type of metamorphism</td><td>origin rock</td><td colspan="6">low ← metamorphic grade → height</td></tr>
<tr><td rowspan="4">regional metamorphism</td><td rowspan="2">pelitic rock</td><td colspan="2">muscovite (sericite) zone</td><td colspan="3">biotite zone</td><td>garnet zone</td></tr>
<tr><td colspan="2">graphite-sericite -muscovite-Assem.</td><td colspan="3">muscovite-biotite -Assem.</td><td>garnet-muscovite-biotite-Assem.</td></tr>
<tr><td rowspan="2">Basic rock</td><td colspan="4">green rock facies</td><td colspan="2">epidote-amphibolite facies</td></tr>
<tr><td>chlorite-epidote -Assem.</td><td colspan="3">actinolite-epidote -Assem.</td><td colspan="2">(garnet)-epidote-amphibole-Assem.</td></tr>
<tr><td rowspan="2">contact metamorphism</td><td>pelitic rock</td><td colspan="3">biotite hornfels</td><td colspan="3">biotite-garnet hornfels</td></tr>
<tr><td>carbonate rock</td><td colspan="6">marble</td></tr>
</table>

Assem. : Assemblage

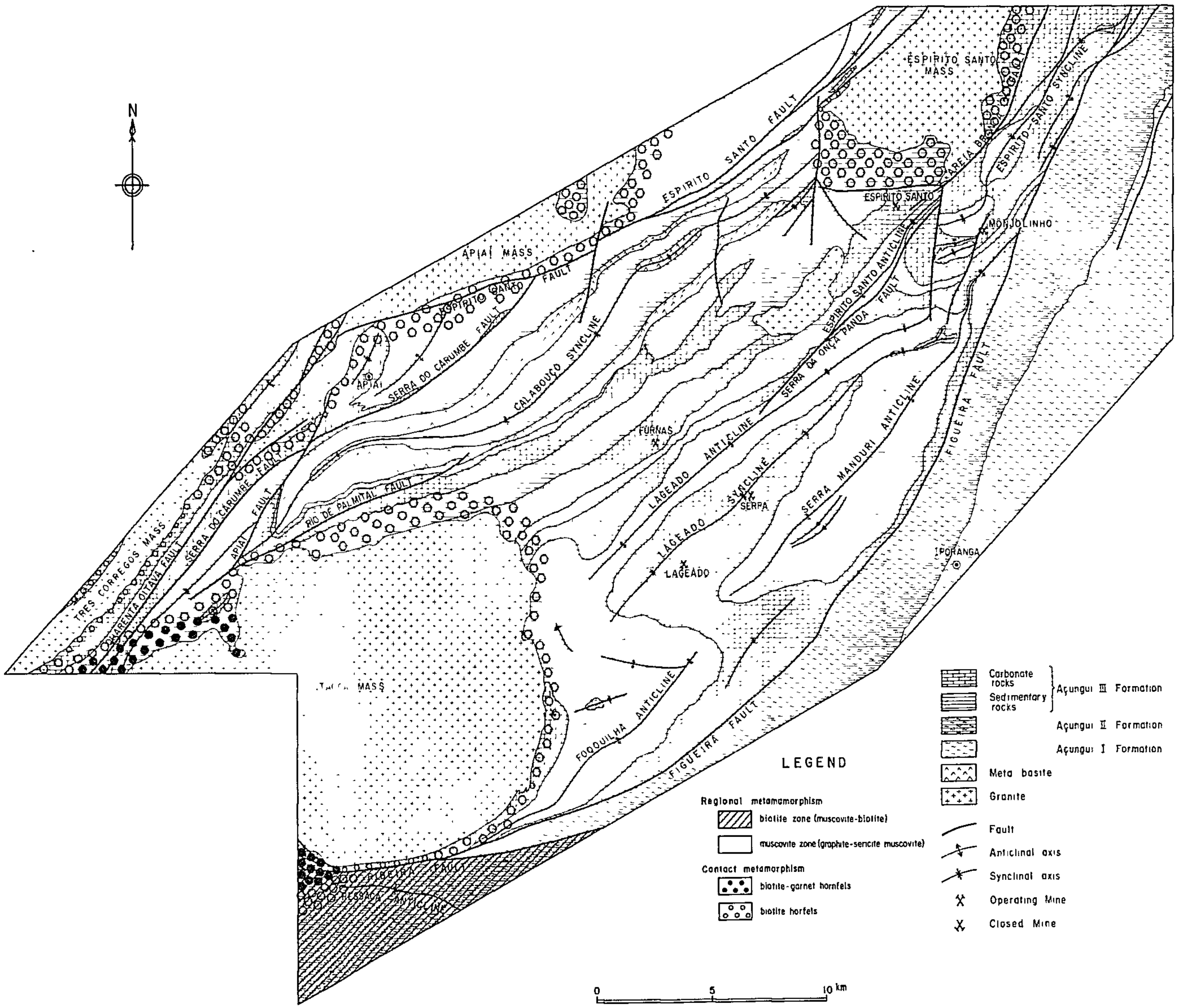


Fig. I −3 Metamorphic Facies Map in Survey Area

metamorphism.

(a) Reagional metamorphism

The giologic structure of the metamorphic rocks, NW–SE system in the area, have been formed in the stage of Brazilian orogeny (JICA and MMAJ, 1982).

The mineral assemblage of the psamitic and peritic origin metamorphic rocks have been classified as follows.

(1) garnet zone .... biotite-garnet

(2) biotite zone .... musecovite-biotite

(3) muscovite zone .... graphite-sericite-muscovite

(1) garnet zone is distribute in the second year's area, though it could not be found in the present area.

(2) biotite zone is continued from the second year's area to the southern area of the Ribeira fault.

(3) muscovite zone distribute in the whole area of the north of the Ribeira fault.

Meta basic rocks in the area belong to green schist to epidote-amphibole facies, and it corresponde with metamorphic facies of peritic rocks as follows;

The mineral assemblage of the Açungui II amphibolite (AIIam) distribute in the southern area of the Ribeira fault is actinolite-epidote or epidote-amphibole, and this mineral assemblage is correspond to (2) biotite zone of the peritic rocks.

The mineral assemblage of the meta basic rock sheeted in the Açungui III formation are shown as chlorite-epidote of the green schist facies in the southern area, and actinolite-epidote of the green schist facies in the northen area, therefore metamorphic grade is slightly higher northern area than southern area, and the mineral assemblage correspond to the (3) muscovite zone of the peritic rocks.

(b) Contact metamorphism

The biotite hornfels bearing biotite porphyroblast have been recognized near the granite mass such as Tres Corregos, Apiai, Itaoca and Espirito Santo, intruded in the late stage of the Brazilian orogeny.

A garnet hornfels zone is situated biside the western margin of the Itaoca granite mass and biotite hornfels is observed in the outer zone of the garnet hornfels zone.

In part of the limestone contacted with the granite, it's clearly recognized marble or skarn.

1–1–5 Geologic Structure

The area is situated in the Apiai fold zone of the Mantigueira tectonic province on the basis of classification of the geologic structure of Brazil (Almeida, F.E.M. 1981). There is a coast range called Paraiba do Sal on the east of the area which consists of composite crystalline rocks, gneissose rocks to migmatite, considered to have formed during the Transamazonian orogenic cycle, 2,200 – 1,800 Ma.

The trend of geologic structure of the area is NEE–SWW system. This trend is considered to have formed during the time of the Brazilian Orogeny (750–500 Ma). In addition, a geologic structure of NWW–SEE system which is likely to have formed as the result of the tectonic movement older than the above, can be observed within those structures mentioned above.

Cutting the directions of all the above systems, the trends such as NW–SE and N–S are found. These are considered to be the newest geological structure in the area.

While a structure of NE–SW system is dominant in the geological structure of the Açungui I and II formations distributed on the eastern side of the Figueira fault, it is difficult to grasp the detailed fold and fault structures because of its indistinct bedding plane and apparently steep dipping.

It is assumed, however, that the rocks become younger toward northwest with the repetition of the folds with various sizes.

The Açungui III formation distributed on the northeastern side of the Figueira and Ribeira faults is characterized by the thick alternating beds of carbonate rocks and meta sedimentary rocks, which makes comparatively easy to grasp the geologic structure both in the field and on the aerial photo. The geologic structure of the systems such as NE–SW and NEE–SWW is predominant in this formation.

The fault and fold structures characteristically found in the area are described in the following.

(1) Fold Structure

A classifications of the folds have been attempted in the past: the categories of classification are, the form of deformation, the shape of fold, the order based on the length of fold axis and the wave length or the ratio of amplitude of vibration.

Classification of the fold structures of the area, however, was made on the basis of geological formation, the length of the folding axis, form of deformation and trend of fold.

(a) Fold structure in the Açungui II formation

Ressaca Syncline

It is located in the southwestern peripheral part of the area. Although the length of fold

axis is seven kilometers in the area, it has been confirmed for about 60 kilometers extending eastward along the Ribeira fault. The fold axis plunges toward east-southeast with the inclination of five degrees to 10 degrees showing waved in NWW–SEE system.

The cross-section shows that the northern wing dips southward by 60° to 70° and the southern wing northward by 30° to 40°, showing an asymmetric fold that the axial plane is almost perpendicular to slightly inclined to the north.

(b) Fold structures in the Açungui III formation

The fold structure such as order NNW–SSE system and new NE–SW to NEE–SWW systems are observed.

Fold structure of NNW–SSE system:

The fold structure of this system can be observed in the $AIIIL_2$ member in the vicinity of Lageado.

The length of fold axis is from 0.5 to 1.5 kilometers with the wave length of 1.5 kilometers. The form of distribution of the fold axis in a plane is linear, and the axial plane is vertical in a cross section. The shape of apex is characteristically gentle and the wings are curved gently. Other characters are that the fold structure of NNW–SSE systems is existent in the NE–SW system and change the direction of the plunge of NE–SW system, at the vicinity of Parmital and in the surrounding area of Morro do Manduri.

Fold structure of NE–SW and NEE–SWW systems:

The fold structures of these systems are notable in the Açungui III formation. These are classified into the following four categories of the order depending on the length of fold axis.

The first order fold is the length of fold axis of more than 35 kilometers. The Calabouço syncline (D.N.P.M., 1977) and the Serra Manduri to Foqouilha syncline (tentative name) fall in this category.

The second order structure is the length of fold axis of about 20 kilometers, to which belong the Lageado syncline (tentative name) and the Lageado anticline (tentative name).

The third order structures is the length of fold axis of about 10 kilometers, to which belong the Espirito Santo syncline (tentative name) and the Espirito Santo anticline (tentative name).

The fourth order structure is the length of fold axis of less than five kilometers, which occur on the northeast of the Monjolinho ore deposit located on the northwest of Betari, and in the adjacent area of Apiai.

Thable I–2 shows the characteristics of geometrical aspects of folds of the first to the third order.

Table I–2 Characteristics of Geometrical Aspects of Folds by Order

Standard of classification \ Order		Fold of the First order	
		Calabouço Syncline	Serra Mandurí ~ Foqouilha Anticline
Wave length of fold		A half of the wave length is 1[illegible] km (*) which is however [illegible] 9 km toward the Lageado anticline	A half of the wave length is 12 km (*) which is however [illegible] 3.5 km toward the Lageado syncline
Length of fold axis		40 km (*)	35 km (*)
Form of distribution in a horizontal plane		The northeastern part is cut by the fault of N-S system on the northwest of Espirito Santo but the southwestern part continues to the area of survey of the Phase II. The axis curves gently from the trend of NE-SW to NEE-SWW at Pamital and Faz da Cachimba. It plunges toward Faz da Cachimba with the inclination of 5° to 10°.	The northeastern part is cut by the Figueira fault on the east of Monjolinho de Sebastião. The southwestern part is cut by the Figueira fault in the vicinity of Porto Velho. It waves gently with the interval of 2-4 km. The direction of plunge changes at the transformational point of waving. The structure is diversified on the south of Lageado.
Shape of fold in cross section	Axial plane of fold	90°	90°
	Characteristics of the apex of fold	The apex closes toward the northeast and southwest with a gentle form having its center in the upstream area of Rio Betari.	Gentle
	Characteristics of the fold wings and wave shape of fold	The southeastern limb continues to the Lageado anticline while the northwestern limb is cut by the Espirito Santo fault and the Serra do Carumbe fault.	The limbs are curved in a gentle form. The northwestern limb extends to the Lageado syncline while the southeastern limb is but by the Figueira fault being curved by several gentle folds (partly asymmetric). It is more open toward the southwest.

Standard of classification \ Order		Fold of the second order	
		Lageado Syncline	Lageado Anticline
Wave length of fold		4.5 ~ 6 km	1/2 wave length is 1 ~ 2 km
Length of fold axis		20 km (*)	20 km (*)
Form of distribution in a horizontal plane		The northeastern part diverges and disappears in the midstream of Rio Iporanga. It diverges in the vicinity of Lageado to about 3 km with the maximum width of interval of 0.5 km and is again put together. On the southwest of Lageado it forms a semi basin structure. The direction of plunge is indefinite because of gentle waving of the fold.	The northeastern part plunges toward the midstream of Rio Iporanga and disappears. The southwestern part forms a dome at Morro Grande. It extends linearly but the direction of plunge is indefinite.
Shape of fold in cross section	Axial plane of fold	90°	90°
	Characteristics of the apex of fold	Gentle	The apex closes toward the northeast and the southeastern part is more gentle.
	Characteristics of the fold wings and wave shape of fold	The limbs waves gently. The ratio of the length of limbs northwestern limb : southwestern limb 1 : 1.5 ~ 1 : 2	The northwestern limb is generally steep. Several gentle folding is observed in the northwestern limb in the vicinity of Morro Grande.

Standard of classification \ Order		Fold of the third order	
		Espirito Santo Syncline	Espirito Santo Anticline
Wave length of fold		[illegible] km (*)	1/2 wave length is [illegible] km (*)
Length of fold axis		[illegible] km	8 km (*)
Form of distribution in a horizontal plane		The northeastern part is cut by the Figueira fault. The southwestern part forms synclinorium and semi basin structure with presence of faults within them. The direction of plunge is indefinite because of gentle waving.	The northeastern part is cut by a branch fault of the Areia Branca fault. The southwestern part is cut by the Serra da Onça Panda fault. It plunges toward the northeast with gentle waving.
Shape of fold in cross section	Axial plane of fold	90°	90°
	Characteristics of the apex of fold	Gentle	The northeastern part is sharply closed. The southwestern part is gentle.
	Characteristics of the fold wings and wave shape of fold	The northwestern limb is cut by the Areia Branca fault. The southeastern limb is cut by the Figueira fault in the northeastern part. It continues to the Serra Mandurí anticline in the southwestern part although it is partly cut by the Monjolinho fault.	The northwestern limb continues to the Calabouço syncline being curved by the effect of the intrusion of granite and faulting. The southeastern limb is cut by the Serra da Onça Panda fault.

(2) Fault Structure

NE–SW fault system is predominant and strongly controls the geological structure of the area. Small NW–SE and N–S fault system are also observed having cut the above faults.

(a) Faults of NE–SW system

Figueira Fault (D.N.P.M., 1972)

It continues from the midstream of Ribeirão Grande in the northeastern part of the area to Ressaca in the southern part, and this fault constitutes the boundary between the Açungui II formation and the Açungui III formation. The northern side has been depressed, and displacement is 1,500 meters at Ressaca in the southern part, which increases toward the northeast reaching to 3,000 meters. Several branch faults are observed in the northeastern peripheral part.

Siliceous breccia-like rock facies and an overturned structure of the strata are observed in limestone along the fault. Small faults with the dips of 70° to 80° to the northwest striking parallel with the Figueira fault occur in the limestone.

Ribeira Fault (D.N.P.M., 1972)

This fault is extending from the area surveyed in the second year, and runs through Ressaca in the southern part of the area to the southeast beyond the boundary of the area.

On the western side of the confluence with the Figueira fault, the sense northern block shows depression of 1,600 to 2,000 meters. On the east of this fault, the block between this fault and the Figueira fault seems to have relatively been raised.

Espirito Santo Fault (D.N.P.M., 1972)

This fault runs along São Paulo State road 373, and it is considered that the fault has been absorbed by the Quarenta Oitava fault on the north of Apiai. It shows depression of the southeastern block, and the displacement increases toward northeast reaching up to 2,500 meters. Plural branch faults are observed in the vicinity of Bairro da Cachimba in the northeastern part, and in addition, black fault clay zones more than 15 meters wide are observed in several places.

Serra do Carumbe Fault (JICA, 1982)

This fault branches off from the Espirito Santo fault and continues to the area of the second year through Pouso Triste in the southwestern part. The fault shows the depression of the southeastern block and the displacement increases toward the northeast, while it almost diappears in the southwestern part. The depression of the northwestern block is shown, however, within the area of the second year, which leads to the assumption that it might be a rotational fault having its axis in the adjacent area of Manto Dentro.

Areia Branca Fault (tentative name) and Serra da Onça Panda Fault (tentative name)

The former shows depression of about 300 meters of the southern block and the latter 250 to 500 meters of the northern block. In the vicinity of Bairro Serra da Duvila, the branch faults of E–W system having northern depression of 500 to 900 meters and N–S system having eastern depression of 300 meters, are present.

Rio de Palmital Fault (tentative name)

This fault is a rotational fault having the axis in the vicinity of Gurutuva and shows the southeastern depression and right hand side dislocation in the northeastern part, which inturn, shows the reverse sense in the southwestern part. The strike slip is 100 to 400 meters and the dip slip is 100 to 200 meters in the northeastern part, while the latter is more than 200 meters in the southwestern part.

Quarenta Oitava Fault (JICA, 1982)

This fault continues from the area of the second year to the northwest of Apiai forming the boundary between the $AIIIS_2$ and $AIIIL_3$ members It seems to have the southeastern depression and dispalcement up to 800 meters.

The distribution of lead ore deposits and showings is confined to within the block relatively depressed by the four faults, Figueira Fault to Serra da Carumbe Fault, among those mentioned above. Beside these, small faults are observed including the Monjolinho fault.

(b) Faults of NW–SE system

A distinct lineament of NW–SE system is observed in the vicinity of Expirito Santo, which is considered to be related to diabasic dykes from their direction and location.

(c) Faults of N–S system

Three faults of N–S system occur at Paranapiacaba in the northern part with each spacing of four to five meters cutting the structure of NE–SW system. The lateral component of displacement of left hand side dislocation seems to be the main.

In the western part, there found a fault which shows a left hand side dislocation, tentatively called the Apiái fault, extending from Apiai to the Camargo Correia limestone quarry, which cuts the Serra do Calumbe fault and the Rio de Palmital fault.

(3) Minor Structures

The schistosity plane which obliquely intersects the bedding plane at a low angle is observed in the $AIIIS_1$ and the $AIIIS_2$ members. Since the schistosity plane has steeper inclination than the bedding plane, in most of these cases, it can be judged that the strata are normal in general.

The schistosity of NW–SE system which have been cut by NE–SW system is observed in

a few points.

In the AIIIL$_2$ member along the Figueira fault, a drag fold is shown by the thin layers of calc-schist which are relatively in-competent and intercalated in limestone. Based on the shapes of drag fold and the positional relation with the fold axis, the strata of normal or reversed was judged without great difficulties.

The dip of strata along the Figueira fault is, however, generally steep, which seems to have been caused by wave surface of the small fold, and more gentle dip is considered caused by wave surface of the fold of the greater order. Numerous vein type deposits and mineral and showings are distributed in the area as small fracture vein fissures. Because of small fracture considered to be the conjugate set was observed in the Furnas deposit and the Lageado deposit, the analysis of principal stress field have been tried (Fig. I–4).

As the result of the conjugate fracture set of vein and bedding plane, it is interpreted that the maximu compression stress is shown NNW–SSE system, and has very gentle inclination rising from SSE toward NNW. The principal stress field is coincide with the result of the Rocha mine in the second year.

It is considered eventually that it might be suggested that the fracture of vein was formed by the Brazilian Orogeny which formed the major fold structures of NE–SW system and NEE–SWW system in the area.

1–1–6 Geotectonic History (Fig. I–5)

It is considered that it is important to describe the geotectonic history for discussion of the ore genesis.

Although the Uruaçuan orogenic cycle (1,400–1,100 Ma) and the Brazilian orogenic cycle (750–500 Ma) are considered to be a single orogenic cycle in a broad sense. The geologic history of the area is classified into four stages and discribed as follows.

Fig. I–5 shows a two dimensional diagram in which the two ore deposits of Furnas and Lageado were projected on the line 5–5 in the geological cross section (Plate I–2).

Stage I (Uruaçuan orogenic cycle)

The original rocks of meta sedimentary facies have deposited in the stage of the Urucuan Orogeny as shown in Rb/Sr dating of 1,400 – 1,100 Ma (Batolla Jr, 1977, C.P.R.M., 1981). Therefore, the stage I is considered to belong to the stage of geosyncline. Also deposition of the lead ore deposits took place during that time based on the data of lead isotopes of the lead deposits (JICA, 1982).

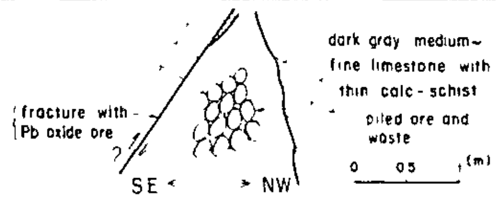
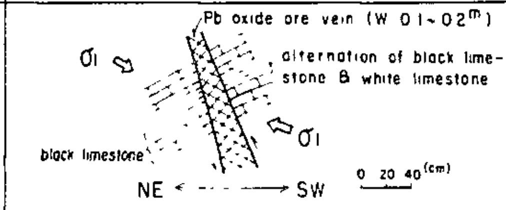
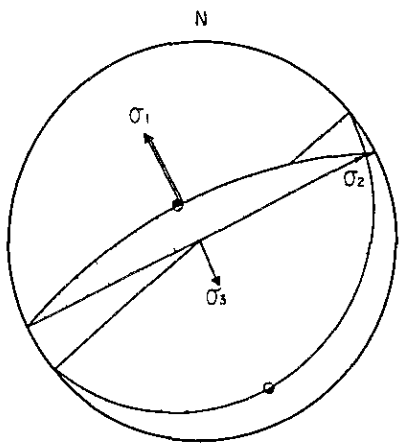
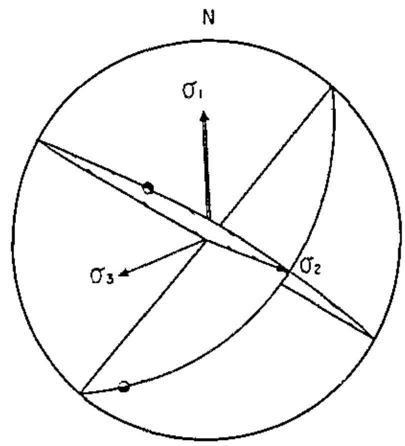
Location	Lageado deposits, Santana Nova G5	Furnas Mine, Santa Barbara
Set of Fractures	f1 N65°E65°S (fracture of vein) f2 N50°E10°N (bedding fissility)	f1 N60°W80°S (fracture of vein) f2. N40°E45°W (bedding fissility)
Sketch		
Stereo net Projection		
PRINCIPAL STRESS AXIS (COMPRESSIONAL)	MAX(σ1) S27°E27°, MED (σ2) S64°W2°, MIN(σ3) N23°W63°, SHEAR PLANE ANGLE 103°	MAX(σ1) S2°E23°, MED (σ2) N69°W42°, MIN(σ3) N68°E39°, SHEAR PLANE ANGLE 91°

Fig. 1-4 Fracture Analysis of Furnes-Lageado Area

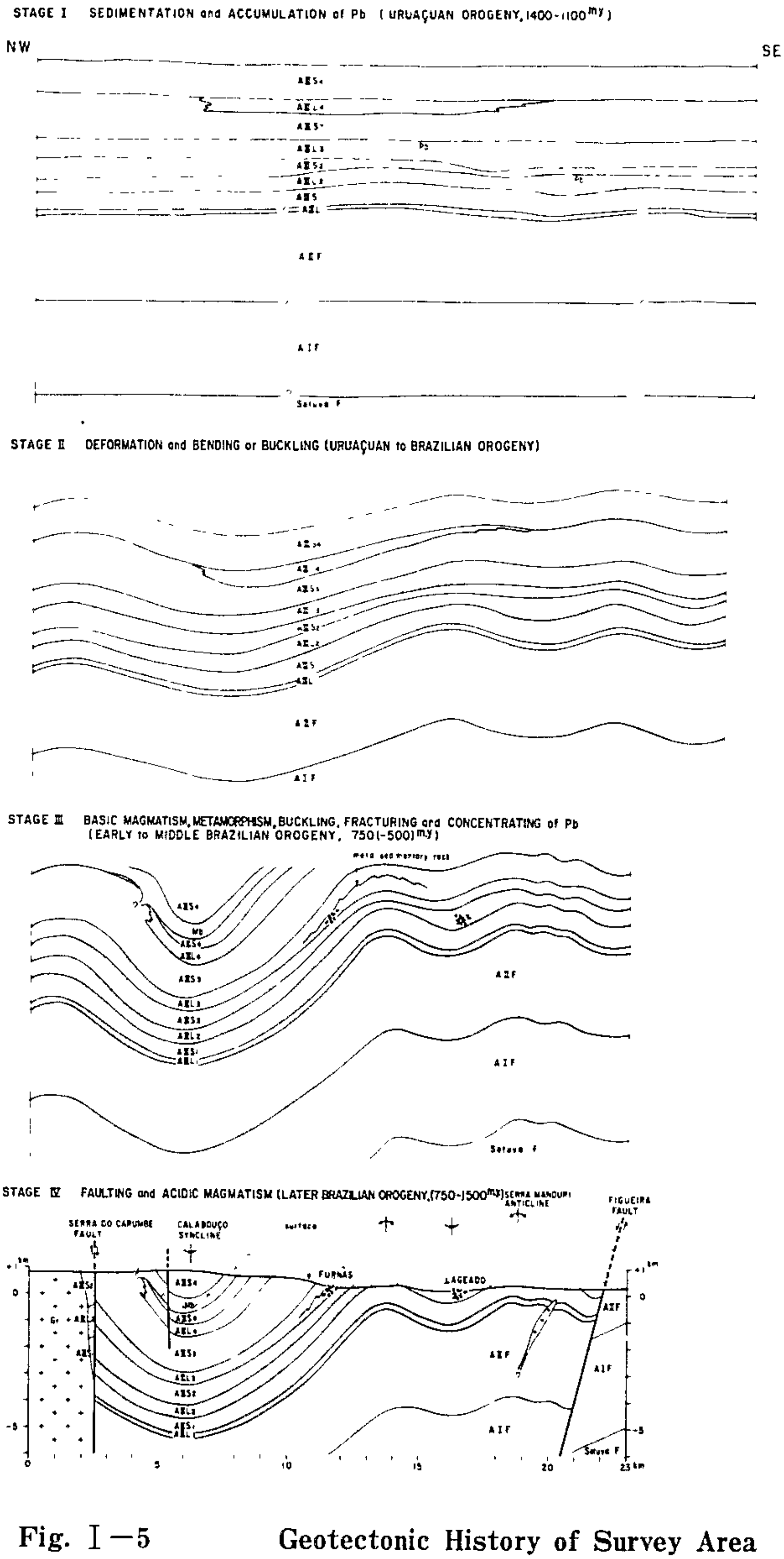


Fig. I —5 Geotectonic History of Survey Area

Stage II (Uruaçuan Orogeny ~ Brazilian Orogeny)

It is assumed that the initial metamorphism took place after the Uruaçuan Orogeny and before the Brazilian Orogeny, because the NW–SE system is cut by NE–SW system.

Heterogeneous load pressure or oscillation of the basement seems to be the origin of metamorphism. Since these movement caused the transverse bending, the fold structure of NNW–SSE system superimposed on the NE–SW system may have formed in this stage. The latter structure, however, is considered to have formed in the stage or before it, and further investigation is still expected.

Stage III (Initial to middle stage of Brazilian Orogeny)

In this stage, basic igneous activity and metamorphism characterizing the schistosity of the apporximate NE–SW system took place, and stratigraphical and regional difference of metamorphic grade was produced depending on temperature-pressure conditions. At the same time, buckling fold was caused by the lateral pressure of the NW–SE system, and the fold structure of the NE–SW system and small fracture structure including vein fracture and fissility on the bedding plane was formed.

Stage IV (Late Brazilian Orogeny)

In this stage, it is considered that the fault structure of NE–SW system represented by the Figueira fault formed, and simultaneously, the acidic igneous activity such as intrusion of the granitic masses of Itaoca, Tres Corregos, Apiai and Espirito Santo took place.

In the more later stage, faulting of left hand-side dislocation of N–S and the activity of Jurassic to Cretaceous diabasic dyke intrusion took place as the movement of the post Brazilian orogenic cycle.

1–2 Ore Deposits

1–2–1 Summary of the Ore Deposits

It has been known that numerous vein-type lead deposits and mineral showings occurred in carbonate rocks of the Açungui III formation distributed in the area (Plate I–4). The carbonate rocks of the Açungui III formation which forms the host rock of ore deposits had been considered to be composed of only one member in the past. As the result of survey of this time, however, it was divided into four members and it was made clear that most of the lead deposits distributed in the areas of Furnas and Espirito Santo have been embedded in $AIIIL_3$, and in the Lageado area and on the east of Itaoca have been embedded in $AIIIL_2$.

The promising areas of ore deposit were selected based on the result of surveys of geology and ore deposit and the result of laboratory analysis of lead isotopes and microanalysis of

carbonate rocks.

1–2–2 Itemized Discussion of Ore Deposit

(1) Furnas Area

The Furnas Mine, the only one mine in operation at present and the showings such as Gruta da Santana, Agua Suja and Cafezal are well known in the area.

(a) Furnas Mine

Summary of the mine

The mine is situated about 17 kilometers to the east of Apiai on the São Paulo State Highway 165. The mine includes the Santa Barabara deposit and the Maxixal deposit, in operation at present, and the São Manoel on the east of which the operation has been suspended.

About 200 tons per month of concentrate was produced from the Santa Barbara deposit until 1955.

As of 1981, 500 tons per month of ore with the grades of 7% Pb and 3,000 g/t Ag was being produced.

Geology

The geology in the surrounding area of the mine consists of alternating beds of limestone ($AIIIL_3$ ls), dolomite ($AIIIL_3$ dol) and meta sedimentary rocks ($AIIIL_3$ ps) of the Açungui III formation.

The Furnas deposit is embedded in limestone in the upper portion about 200 meters from the base of the $AIIIL_3$ member. Meta sedimentary rock, 40 meters thick, occurs 30 meters upward from the ore deposit, which is considered to have contributed to the formation of the ore deposits of the area. (J. Cossedame, 1970).

The area is located on the limb of the Calabouço syncline and the Serra Manduri anticline showing general strike of N60°E and general dip of 45°NW.

Ore deposit

It is composed of lead ore deposits having filled the fractures, vein and iregural shape, formed in limestone of $AIIIL_3$, consisting mainly of abundant galena with subordinate amount of sphalerite, pyrite and lead oxide.

Exploration and mining are being carried out at a part of the Santa Barbara deposit and the Maxixal deposit. The ore body is the lead deposit filling the fissility along the bedding plane and fractures of NWW–SEE system, and it shows a tendency that the ore swells at the intersections of these fractures.

According to the report of Melchel, 1968 and the data owned by the mine, seven pipe-shaped ore bodies have been discovered and exploited, of which those intersections formed by the combination of the above fractures have been the object of mining. A new ore body which is under exploration is of the same type having the dimension of 15 m x 7 m x 100 m in maximum.

As mentioned before, the sense of displacement is reverse, and from the result of analysis of the main stress field of conjugate set as well as NWW–SEE system, lateral compression of approximate NW–SE system can be obtained. Thus it is considered that the fractures have formed by movement of the NE–SW fold structure of the area.

The characteristics under of microscopic observation of representative ore samples are as follows.

E–643

galena > pyrite ≫ sphalerite

Galena fills the interstices between pyrite and gangue minerals. Pyrite is partly corroded by galena. It occurs more densely in gangue minerals than in pyrite.

Relatively large particles of sphalerite containing small amount of fine-grained pyrite and galena are found in galena.

E–645

galena = sphlerite ≫ pyrite = tetrahedrite = cerrusite

Galena contains round particles of sphalerite and pyrite, and irregular patches of tetrahedrite. Corrosion texture is observed between sphalerite and pyrite, while tetrahedrite and galena are in paragenetic relation.

Sphlerite includes abundant fine-grained galena and round pyrite. Veinlets of fine-grained cerrusite are observed in sphlerite and galena.

Assay grades of ore samples are as follows:

	Au g/t	Ag g/t	Cu %	Pb %	Zn %
E–643	0.3	1,540	0.02	12.81	0.13
E–644	0.2	2,586	0.11	12.60	3.82
E–645	0.0	1,891	0.13	11.28	17.75

(b) Cruta de Santana mineral Showing

The mineral showing is located about 2.5 kilometers to the east of the Furnas mine. An unpaved road runs from the São Paulo State road 165 to the Santana limestone cave, and further walking of 500 meters toward northeast along a creek is required.

A production of less than 10 tons of low-grade ore is recorded in the past.

Geology of the surrounding area consists of carbonate rocks ($AIIIL_2$) of the Açungui III formation. The host rock of ore deposit is dark gray, fine-grained limestone ($AIIIL_2$ ls) immediately above the underlying $AIIIS_1$, showing general strike of N60°E and dip of 35°NW.

The position in the geologic structure is on the limb of the Calabouco anticline as in the Furnas deposit.

The ore deposit consists of irregular network veins one to five centimeters wide containing very small amount of galena. Gangue mineral consists of only calcite megascopically.

The result of microscopic observation of the ore sample is as follows.

E–544a:

Galena = sphalerite

Stringers of galena and sphalerite are observed in the gangue mineral. Galena and sphlerite fill interstices of the gangue mineral.

The assay grades of the ore samples are as follows:

	Au g/t	Ag g/t	Cu %	Pb %	Zn %
E–544a	0.0	7.9	0.02	5.92	2.79
E544b	0.0	7.5	0.00	0.17	0.06

(c) Agua Suja ou Abismo do Corrego Seco mineral Showings

According to the literature, CPRM 1975, the mineral showings are described to be located about two kilometers to the northeast of the Furnas mine, but they were not confirmed in the survey of this time, and only some float of oxide ore were observed at the spot further about one kilometers to the east-northeast of the above.

The geology of the area consists of limestone of $AIIIL_3$, and the showings are positioned at the bottom of it.

The result of microscopic observation of the ore sample is as follows.

hematite > goethite

Fine-grained hematite is observed in association with goethite. Hematite shows a fine network texture and occurs as concentric nodules together with quartz, filling the cracks of small veins consisting of pseudomorphs of sulphide minerals. Goethite is found more abundantly on the rough surface. No sulphide minerals were observed.

The assay grades of the ore sample are as follows:

E–548:

Au g/t	Ag g/t	Cu %	Pb %	Zn %
11	2.0	0.01	0.12	0.01

(d) Other mineral showings

A pyrite-zinc oxide-quartz vein is observed about two kilometers west-southwest of the Furnas mine. The showing is located in the horizon 320 meters above the Furnas mine.

The result of microscopic observation of the ore sample (D–542) is as follows:

pyrite > hematite ≫ chalcopyrite = covelline

Pyrite forms massive aggregates in most cases, the interstices of which are filled with chalcopyrite, and partly, especially along the rim of grains, it is replaced by hematite.

Hematite occurs as scaly aggregate surrounding the massive pyrite. Fine-grained covelline is observed in the aggregate of hematite.

The assay result of the ore sample are as follows:

D–542:

Au g/t	Ag g/t	Cu %	Pb %	Zn %
0.1	18	0.02	0.12	31.48

A showing is found further four kilometers west-southwest of the above. However, only collapsed pit entrances and float of quartz were recognized.

(2) Lageado – Serra Area

Twenty three ore deposits and mineral showings are known in the lageado area, and eight in the Serra area (Plate I–5, Fig. I–6–1).

Nine places in the Lageado area and two places in the Serra area out of those mentioned above were investigated in this survey (Fig. I–6–2).

(a) Lageado ore deposits

The ore deposits are situated along about five kilometers to the south-southeast of the Furnas mine, where 23 deposits and showings are concentrated in an area of 1.5 km x 4 km.

These were operated during the period from 1944 to 1968, all of which were small in size and only small amount of ore was produced.

An unpaved road branches off from the São Paulo State road 165, which is about nine kilometers long to reach to the trace of old mine.

The record describes that the Santa Nova deposit, the largest one among the ore deposits occurring in this area (strike length of 600 meters and length of shoot of 200 meters) showed the ore grades of five to 50 percent of lead, having produced several thousands of ore.

Six entrances of tunnels are found including Gl is a tunnel of 30 meters long, G2 is a tunnel of 80 meters long, G3 is a trench of a length of 10 meters and tunnel of 300 meters long, G4 is a trench of a length of 30 meters, G4 is a tunnel of 600 meters long and G6 is a tunnel of 400 meters long.

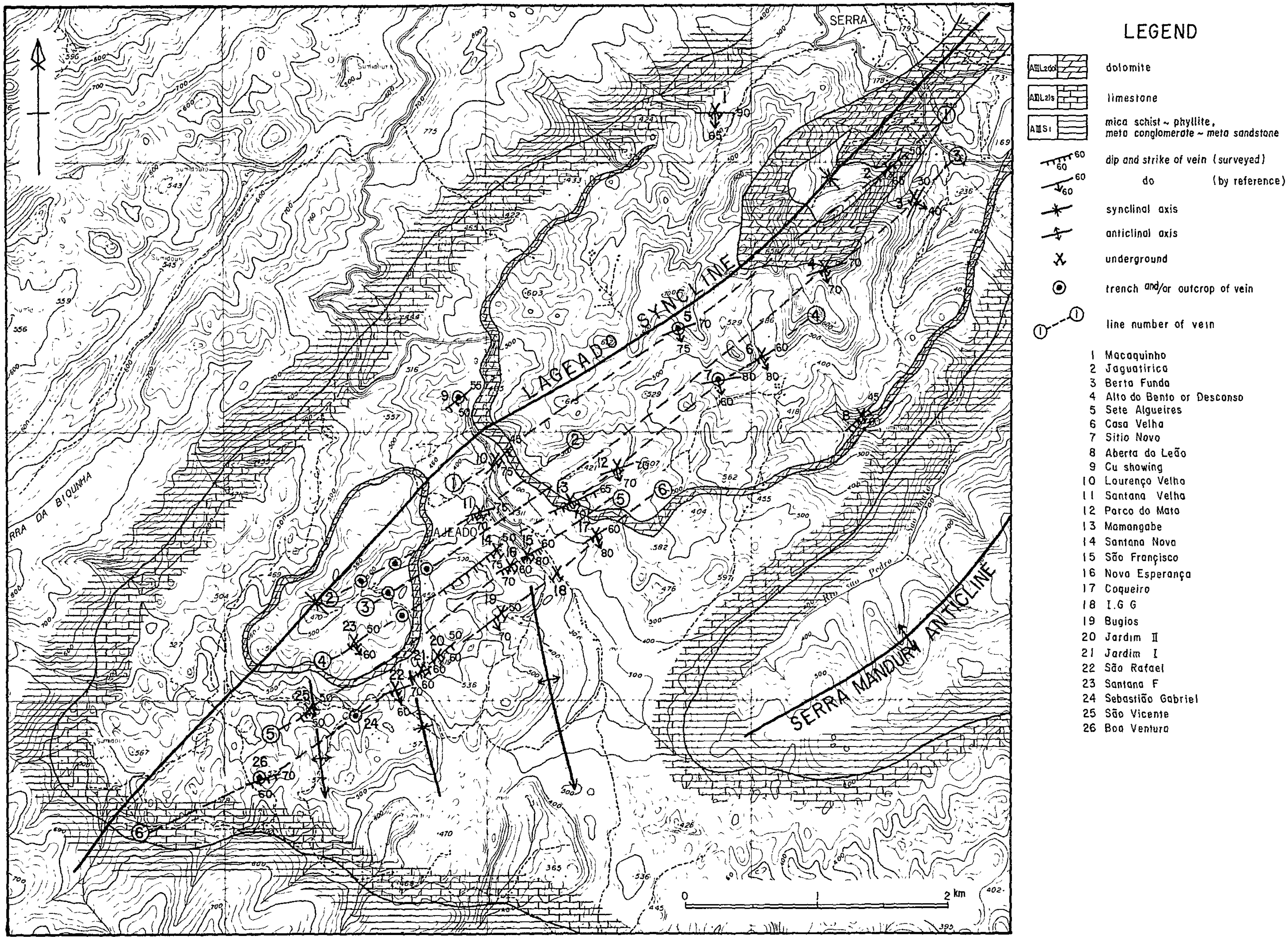


Fig. I−6−1 Geological Map and Vein Map in Lageado-Serra Deposits

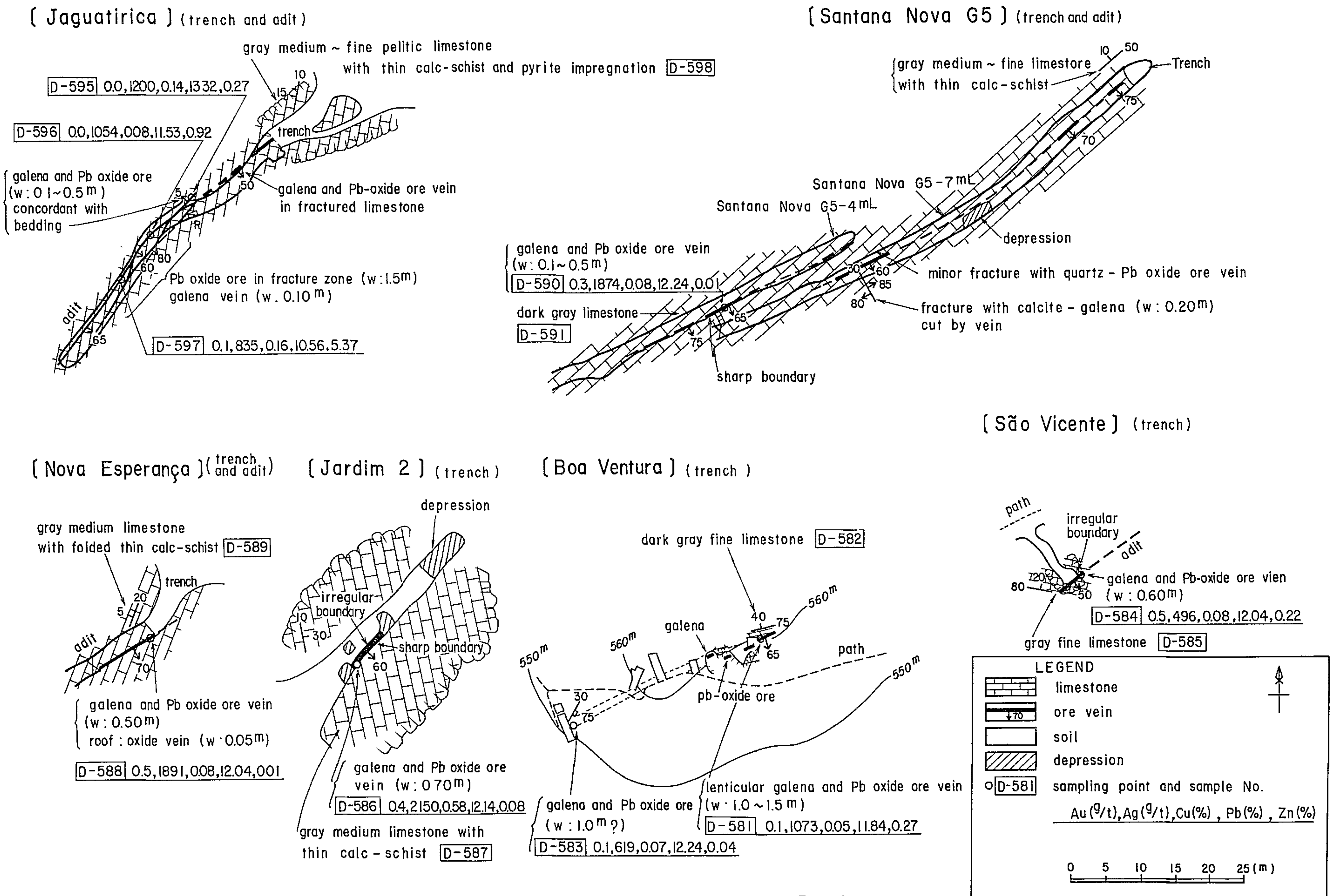


Fig. I—6—2 Geological Sketch of Trench and Underground in Lageado-Serra Deposits

Geology

The geology of the area consists of meta sedimentary rocks ($AIIIS_1$) and carbonate rocks ($AIIIL_2$) of the Açungui III formation.

The $AIIIL_2$ member, the host rock of the ore deposit mainly consists of limestone ($AIIIL_2$ ls) intercalated with dolomite ($AIIIL_2$ dol) and meta sedimentary rocks ($AIIIL_2$ ps).

The country rock of the ore is gray to dark gray pelitic limestone interbedded with very thin layers of calc-schist to calcareous phyllite with micro-fold structure. The ore deposit is positioned in the relatively lower part of the $AIIIL_2$ member.

Although the group of ore deposits is located on the northwestern limb of the Serra Manduri anticline which belong to the first order, it is the characteristics that most of ore deposits and showings are concentrated to the southwestern limb of the Lageado syncline of the second order, and also that are concentrated to the fold structure of NNW–SSE system having intersected NE–SW system. It is considered that overlapping different orders fold and different system would have act on the formation of the ore deposits of the area.

Ore deposit

The group of the ore deposits of the area is composed of vein-type lead deposits, one copper showing is included, in which the vein fractures strike N45°E to N75°E and dip 50° to 80° southeastward. The veins are 0.3 meters wide in average and reaches up to 1.5 meters with repetition of swelling and pinching. Some part of the vein is barren and only shear zone is observed.

According to Melcher (1968), the arrangement of these veins can be divided into parallel six lines when the distribution of outcrops and pit entrances are linked together. These lines can be extended up to the Serra area (Fig. I–6–1) when the survey date of this time are added to them.

As mentioned in the above, the lateral compression of approximate NW–SE system of the main stress field of the conjugate set of the Furnas ore deposit is coincide with the stress which produced the NE–SW system fold structure of the area.

The result of microscopic observation of the ore samples is as follows:

D–581–b (Boa Ventura)

Galena ≫ hematite = Cerussite

Galena forms coarse-grained compact crystals, which is partly replaced by cerussite.

Hematite is found at the center part of cerussite veinlets which occur along the cleavage.

D–588 (Nova Esperança)

Galena ≫ cerussite > pyrite = chalcopyrite = covelline

Although coarse-grained galena is hardly replaced by cerussite, the fine-grained one is often replaced by cerussite.

Pyrite includes very small amount of spotted chalcopyrite and galena.

Small amount of covelline is observed in the cerussite aggregate.

The mixtute of hematite and goethite is found in the aggregate of cerussite, carbonate minerals and quartz as pseudomorph of pyrite.

D–590 (Santana Nova)

Galena > pyrite ≫ cerussite > covelline

Galena is partly replaced by aggregate of cerussite along the boundary and cleavage of the grains. Pyrite is corroded by galena in various forms showing some euhedral crystal form but most are cut by the cracks filled with gangue minerals showing quite irregular shape.

D–593 (Copper showing)

Galena ≫ covelline > pyrite = hematite = cerussite = goethite

Galena mostly fills the interstices of gangue minerals composed of carbonates and quartz. It is found, in some part, as veinlet with quartz cutting the gangue minerals. It is often replaced by cerussite along the cleavage or at the rim.

Fine grained pyrite is found in the interstices filled with the mixture of chalcopyrite and digenite.

The assay result of ore samples is shown in Table A–4–1, Fig. I–6–2 and Plate I–5.

(b) Serra deposits

The group of ore deposits is situated on the northeastern extention of the Lageado ore deposits.

Although the geology, ore deposit and the genesis are the same to the Lageado ore deposits, the ore horizon is positioned in a little upper portion.

The deposits and showings are observed at eight occurrences, which seems to be located on the extention of the Lageado ore deposit as shown in Fig. I–6–1.

The result of microscopic observation of the ore samples is as follows:

D–595–a (Jaquatirica)

Galena > cerussite ≫ sphalerite = magnetite = hematite

Galena is replaced by cerussite along the cleavage and rim.

Cerussitte displays fine colloform or platy texture and contains fine-grained galena.

Pyrite shows euhedral or anhedral crystal forms and found in cerussite aggregate or in galena accompanied by round sphalerite. Covelline is also scattered in the cerussite aggregate.

Magnetite partly replaced by hematite occurs in the cleavage of galena associated with cerussite.

I–508 (Aberta do Leão)

Galena > sphalerite = pyrite

Galena forms coarse-grained mozaic aggregate and is replaced by cerussite and the secondary minerals. Round cubic pyrite is found in galena associated with gangue minerals and sphalerite.

The assay result of ore samples is as follows:

	Au g/t	Ag g/t	Cu %	Pb %	Zn %
D–595	0.0	1,200	0.14	13.32	0.27
D–596	0.0	1,054	0.08	11.53	0.92
D–597	0.1	835	0.16	10.56	5.37
I–508	0.0	1,131	0.01	12.86	0.27

(3) Espiritio Santo Area

The lead deposits and showings known in the area are such as Espirito Santo, Monjolinho de Sebastião, Agua da Limeira, Braço da Pescaria, Paciencia and Figueira.

The former three in which the outcrops of ore or ore float were observed are described in the following.

(a) Espirito Santo deposit

Summary of ore deposit

The ore deposit is located about 24 kilometers to the east of Apiaí. An unpaved truck road runs from the São Paulo State road 373 for about 17 kilometers to the vicinity of ore deposit. The trace of ore sintering facilities and old pits are found on the left bank of Córrego Espirito about 100 meters downstream from the truck road.

The tunnel of old mine is about 85 meters long, in which two limonite veins are found and no lead ore was observed in it.

On the right bank about 250 meters further downstream from the above, a trench and a small adit are found, and these seem to have followed a galena-quartz vein (Fig. I–7–1). The total length of the trench is about 17 meters, in which soil is exposed for about six meters, and the bed rock for about 11 meters. The adit is short with a length of only 1.3 meters. A galena-quartz vein several centimeters wide is found in the trench and adit. It does not

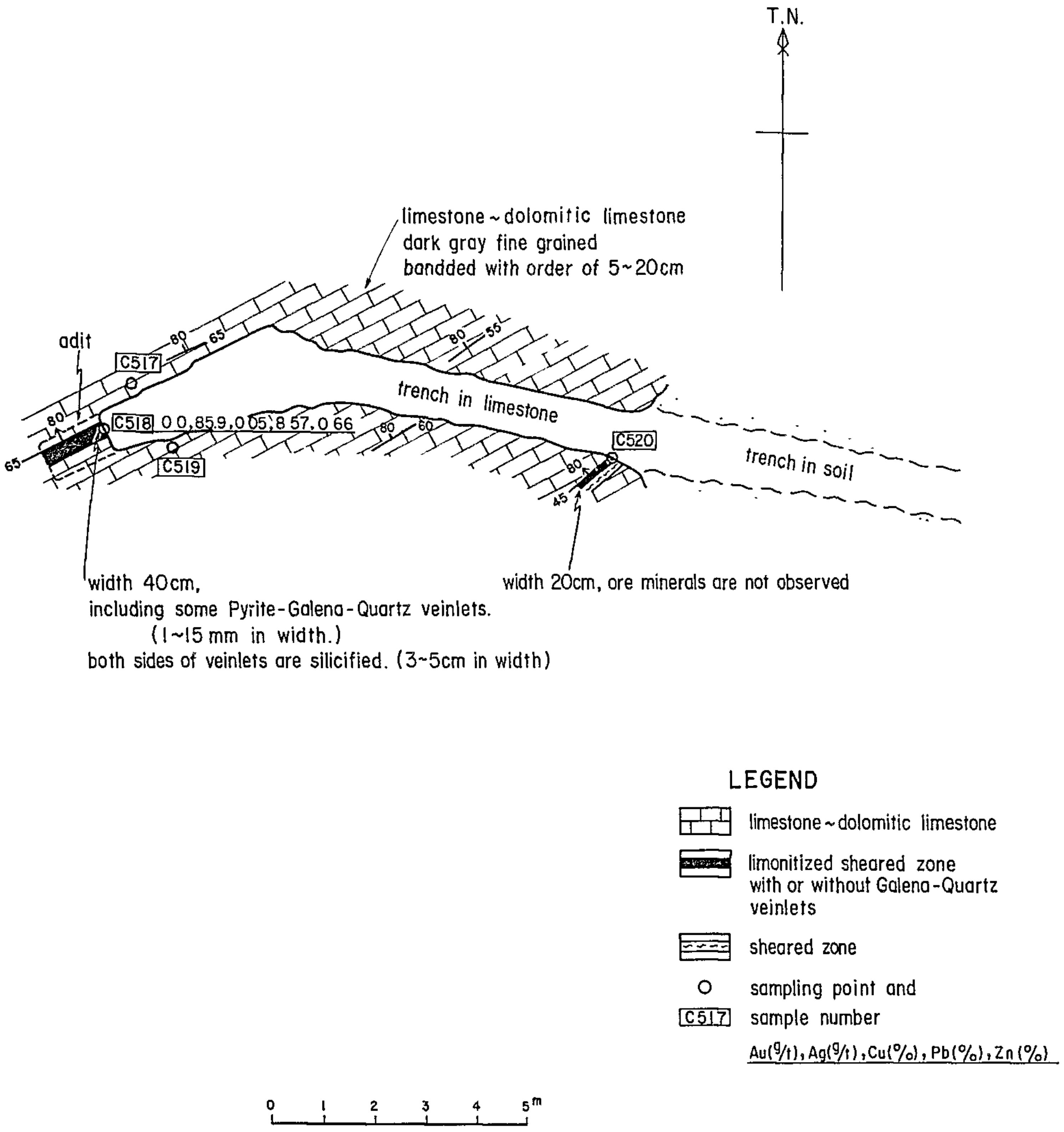


Fig. I—7—1 Geological Sketch of Trench in Espirito Santo Deposits

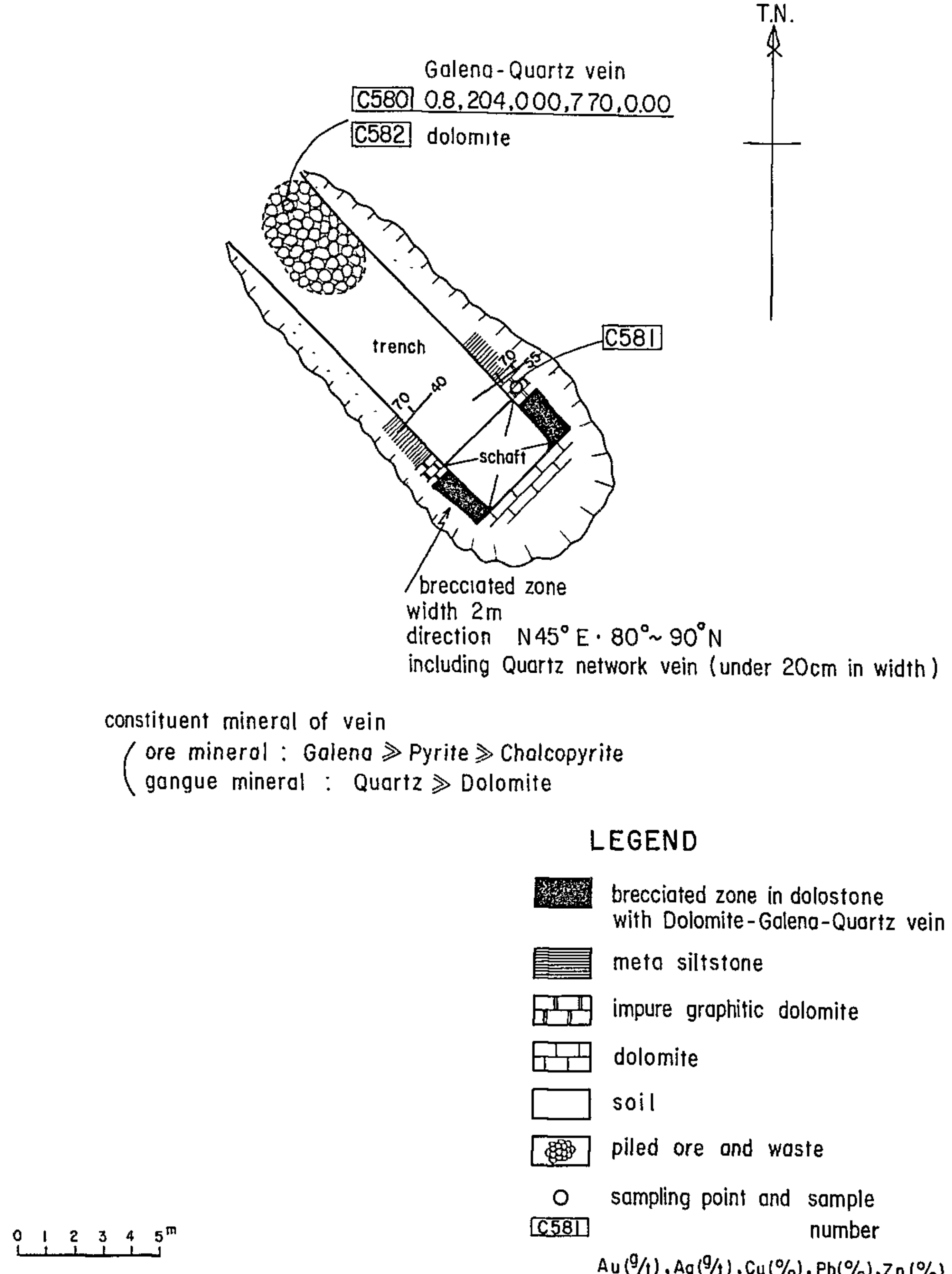


Fig. I—7—2

Geological Sketch of Trench in Monjolinho de Sebastião Deposits

appear to warrant economical operation, and the operation has been suspended. The whole amount of ore produced in the past is several hundreds tons (C.P.R.M., 1975).

Geology

Geology in the surrounding area of ore deposits consists of carbonate rocks of the Açungui III formation. The carbonate rocks mainly consists of calcareous dolomite to dolomite ($AIIIL_3$dol), having a thickness of about 1,000 meters.

The ore deposits occur in the intertrappen limestone and are stratigraphically positioned about 620 meters upward from the bottom of the $AIIIL_3$ member. The wall rock of the footwall is limestone, and the hanging wall dolomitic limestone, both showing dark gray tint and fine-grained texture. These rocks have a fairly distinct bedded structure with width of five to 20 centimeters of each unit.

The area occupies a common limb of the Calabouço syncline and the Serra Manduri anticline, both belonging to the first order, and is positioned, at the northwestern limb of the Espirito Santo anticline of the third order. The strata show the general strike of N50°E and dips of 50° to 80° to the northwest.

Ore deposits

The ore deposits are vein-type deposit emplaced in the shear zone in limestone, striking N65°E and dipping 80° to the northwest. Several pyrite-galena-quartz veins one to 1.5 centimeters wide are observed in the limonite stained shear zone about 40 centimeters wide approximately parallel to the bedding of limestone.

Grayish silicified parts three to five centimeters wide are formed on both sides of the quartz vein in which druses are found.

A shear vein is observed on the southern wall of the trench, striking N45°E and dipping 80°NW. It intersects the bedding plane in a low angle, in which about 20 centimeters of the hanging-wall is strongly limonitized and no ore minerals including galena could be found.

These ore veins seem to have been formed after the completion of metamorphism.

The result of microscopic observation of ore sample is as follows:

Galena = hematite > cerussite > pyrite = covelline

Galena has been replaced by cerussite at the rim and along the cleavage.

Hematite replaces galena and pyrite which show fine-grained platy or oolitic textures.

Small amount of fine-grained covelline is found in the cerussite aggregate.

Euhedral or anhedral pyrite is observed in galena or in the aggregate of cerussite and hematite.

The assay result of ore sample is as follows:

Au g/t	Ag g/t	Cu %	Pb %	Zn %
0.0	85.9	0.05	8.57	0.66

(b) Monjolinho de Sabastião deposit

The ore deposits are located on a small hill on the left bank of Córrego Manimiano about four kilometers to the east-southeast of the Espirito Santo deposit.

To reach to the deposit, a branch road of Expirito Santo truck road leads southward from Barrio das Cadoclos, about 1.5 kilometers, to the end of the road. Further walking of about 1.5 kilometers toward the south is required to reach to the vicinity of the deposit.

Observation of the trench and a part of the entrance of a shaft can be made at present, but the ore can be observed only at the pile of ore (Fig. I–7–2). The operation is stopped at present, and several tons of ore was produced in the past.

Geology

The geology of the area consists of carbonate rocks ($AIIIL_3$), meta quartz sandstone ($AIIIS_3$) of the Açungui III formation and dykes diabase intruded into the above rocks.

The ore deposits are embedded in the carbonate rocks situated about 400 meters upward from the bottom of $AIIIL_3$. The best rock of the ore deposit consists of gray, fine-grained massive dolomite. Toward the hanging-wall of dolomite, the rock changes to meta siltstone intercalated with a pelitic bed about 0.8 meters between them.

The host rock strikes N40° to 55°E and dips 70°NW.

The ore deposit is located on the northwestern limb of the Serra Manduri anticline of the first order of the area, which is also positioned on the southeastern limb of the Espirito Santo syncline of the third order. The Manjolinho fault runs on the west of ore deposit very closely to it.

The strike and dip of the carbonate rocks are N40° to 60°E and 70°NW in general respectively.

Ore deposit

The ore deposit is composed of stockwork quartz vein in the brecciated zone of dolomite. The brecciated zone is about two meters wide with strike of N45°E and dip of 90°NW parallel with the bedding of dolomite. The quartz vein is less than 20 centimeters in width, being exposed on the surface of wall of the vertical shaft could not be observed detail.

By the maicroscopic observation, relative amount of ore minerals of galena $\gg$ pyrite $>$ chalcopyrite are recognized in the pile stock.

Galena shows an occurrence of irregular veins or spots, and the gangue minerals are com-

posed of mainly quartz accompanying with dolomite.

The brecciated zone was traced along the vertical shaft for more than 10 meters, but it has not been traced laterally along strike.

The assay grade of an ore sample are as follows:

Au g/t	Ag g/t	Cu %	Pb %	Zn %
0.8	204	0.00	7.70	0.60

(c) Agua da Limeida showings

Summary of the mineral showings

According to C.P.R.M. (1975), five mineral showings occur distributed in one to two kilometers to the east to the northeast of the Monjolinho de Sebastião deposit. It is located.

Most of the oil adits and outcrops have been buried in the ground, and difficult to find them out again.

In this survey, the outcrops of barren quartz and ore float were observed at two places located in the southern part out of the five showings mentioned above.

Geology and ore deposit

The geology of the area consists of carbonate rocks ($AIIIL_2$) and meta siltstone ($AIIIS_2$) of the Açungui III formation, and diabasic dykes intruded into the above rocks.

The ore deposits occur in limestone or dolomite of the $AIIIL_2$ member.

Stratigraphically, the mineral showings are located almost in the axial part of the Serra Manduri anticline which is situated between the Figueira fault and the Monjolinho fault. The four mineral showings in the northwestern part occur in $AIIIL_2$ and distributed in a top horizon, 500 ~ 700 meters, of the member.

C.P.R.M. (1975) reported that the ore deposits were composed of silver-copper-lead-quartz vein of NW–SE system. The barren quartz veins observed this time showed the strike of N55°E and dip of 85°SE in one outcrop, and strike of N55°E and dip of 75°NW with vein width of 0.5 to three centimeters. These are the veins almost parallel to the bedding.

In the surrounding area of the mineral showings, abundant pieces of float of quartz vein, two to 20 centimeters, are scattered. Galena, chalcopyrite and pyrite were observed by the naked eye, and quartz is the only gangue mineral.

The result of microscopic observation of the ore samples is as follows:

C–501

Small amount of galena fills the interstices of gangue minerals, and sometimes occurs as small aggregate with a sharp relief.

C–592

Chalcopyrite > pyrite = chalcocite = covelline

Chalcopyrite fills the interstices of gangue minerals and shows a very rough surface. It contains some round pyrite and is irregularly replaced by the mixture of chalcopyrite and digenite. Covelline is rearely found at the boundary of the mixture of digenite and chalcopyrite.

The assay grades of ore samples are as follows:

	Au g/t	Ag g/t	Cu %	Pb %	Zn%
C–591	0.4	554	0.06	12.09	0.00
C–592	0.0	16.8	0.11	0.14	0.00

(d) Other mineral showings

Three small mineral showings were confirmed in this survey along Rio Iporanga. All these are quartz-calcite vein in $AIIIL_2$ or $AIIIL_3$ with the width of several centimeters, and are low grade lead oxide ore.

The assay result of the ore samples are as follows:

	Au g/t	Ag g/t	Cu %	Pb %	Zn %
C–596	0.0	3.2	0.01	0.15	0.00
E–571	0.0	5.8	0.00	0.02	0.01
E–620	0.0	5.2	0.00	0.03	0.01

(4) Eastern Part of Itaoca Area

The Santo Antonio do Pavão deposit is the only lead deposit distributed in the area. In the southern part of the Itaoca area, however, some copper showings are known in the Açungui II formation in addition to the fluorite deposit in the $AIIIL_2$ member reported in the first year of the survey.

o Santo Antonio do Pavão deposit

Summary of the deposit

It is located on the northern slope of a mountain with an altitude of 400 to 500 meters above sea level about seven kilometers to the east of Itaoca.

A road extends from Itaoca to the entrance of the Pavão plantation, from where a truck road leads to the entrance of the Santa Marina Adit II with the distance of about two kilometers. Six prospecting adits are found in the deposit, and about seven tons of ore were produced until 1954. The operation is suspended at present.

Geology

The geology of the surrounding area of the ore deposit is composed of mica schist

(AIIIS$_1$ ps) and carbonate rocks (AIIIL$_2$ ls) of the Açungui III formation. These members have been intruded by the Itaoca granite mass.

The strike of the AIIIL$_2$ ls member, the host rock of the ore deposit, varies from N–S to N20°E with the dips of 60° to 80° NW and showing a thickness of 800 meters.

The rock facies are roughly divided into two categories. The lower part consists of thin alternating beds of dark gray medium-grained limestone and gray to dark gray medium-grained chlorite-sericite schist, and the upper part gray to dark gray, medium to coarse grained massive limestone.

Very small amount of pyrite is impregnated in the upper limestone, which has partly become coarse-grained limestone of marble-like appearance at the contact with granite.

The ore deposits are emplaced in the lower part of the AIIIL$_2$ ls, member and in limestone immediately above the upper boundary of it.

The deposits are situated on the northwestern limb of the Foqouilha anticline continued from the Serra Manduri anticline.

Ore deposits

The ore deposits are vein type, and the trends of fracture of the veins are classified into three systems such as (1) strikes of N70°E to E–W and dips of 60° to 80° NW, (2) strike of N–S to N20°W and dips of 80° to 85°NE and (3) strike of N60°W and dips of 30° to 80°NE.

The system of (1) is observed in the Santa Marina I and II adits, 80 meters and 130 meters in length, in the eastern part of the area of deposits.

In the Santa Marina II adit, the intersection of the veins striking N70°E and E–W has been prospected by a winze. The fractures has been filled with only calcite and no ore minerals are found.

Several those fractures of N–S to N20°W (2) occur in the Santo Antonio adit (the length of adit is 100 meters), in which only calcite is observed. The width of the vein is 10 centimeter in maximum.

The fractures of N69°W system (3) is observed in the Nova Esperança adit in the western part of the deposit, and has been mineralized. The maximum strike length of the veins is 30 meters with the width of five to 20 centimeters of swelling and pinching.

The ore minerals observed by the naked eye are galena and pyrite with subordinate amount of chalcopyrite and sphalerite Gangue minerals are calcite and small amount of quartz.

The result of microscopic observation of the ore sample (B–622) is as follows:

Pyrite > galena

Pyrite is mostly coarse grained, and displays anhedral crystal form, which includes fine-grained galena and gangue minerals. Cracks filled with gangue minerals have irregularly penetrated pyrite crystals.

Assay grades of the ore sample are as follows:

B–622

Au g/t	Ag g/t	Cu %	Pb %	Zn %
0.0	51.9	0.06	4.29	0.06

1–2–3 Measurement of Lead Isotopes

By the survey of the first year in the Vale do Ribeira lead ore province, the type of ore deposit have been classified into two types such as Perau type embedded in the calc-silicate rocks of the Açungui I formation and Rocha type in the carbonate rocks of the Açungui III formation (JICA and MMAJ, 1918).

In the second year's study, involving southern part of the Vale do Ribeira, the lead isotopes of galena taken from the Perau mine and the Rocha mine were measured two sample each.

As the result of plotting the measurements of isotope value on the ore growth curve of Cumming and Richards (1976), two gropes wer clearly differentiated, and indicating that the Perau type is plotted in the neighbourhood of 1,400 m.y. and the Rocha type is plotted in the 1,100–1,200 m.y. (JICA and MMAJ, 1982).

In the present survey area, involving northern part of the Vale do Ribeira, the Rocha type mines such as Furunas, Lageado and Espirito Santo mine are known well.

In the present study, to examine synthetically lead ore deposit of the Perau type and the Rocha type in the whole area of the Vale do Ribeira, twenty galena samples from whole mines have been collected and measured isotopes (Fig. I–8).

Measurement values of these samples are shown in Table I–3, and are plotted on the ore lead grouth curve of Cumming and Richards (1976) shown as Fig. I–9, the result, however, is quite similar as the result of mentioned above. There is no contradiction that the Perau ore deposit had been sedimented syngenetically with host rocks, because of coincidence age of host rocks, the other hand, as the age of the Rocha type ore depisit is more older than age of activity of granite, although approximated to the age of host rock, therefore the vein type ore deposit in the area can be considered that the base metal had been precipitated with host rocks and concentrated to the fractures in the host rocks of these ore deposit in the later stage.

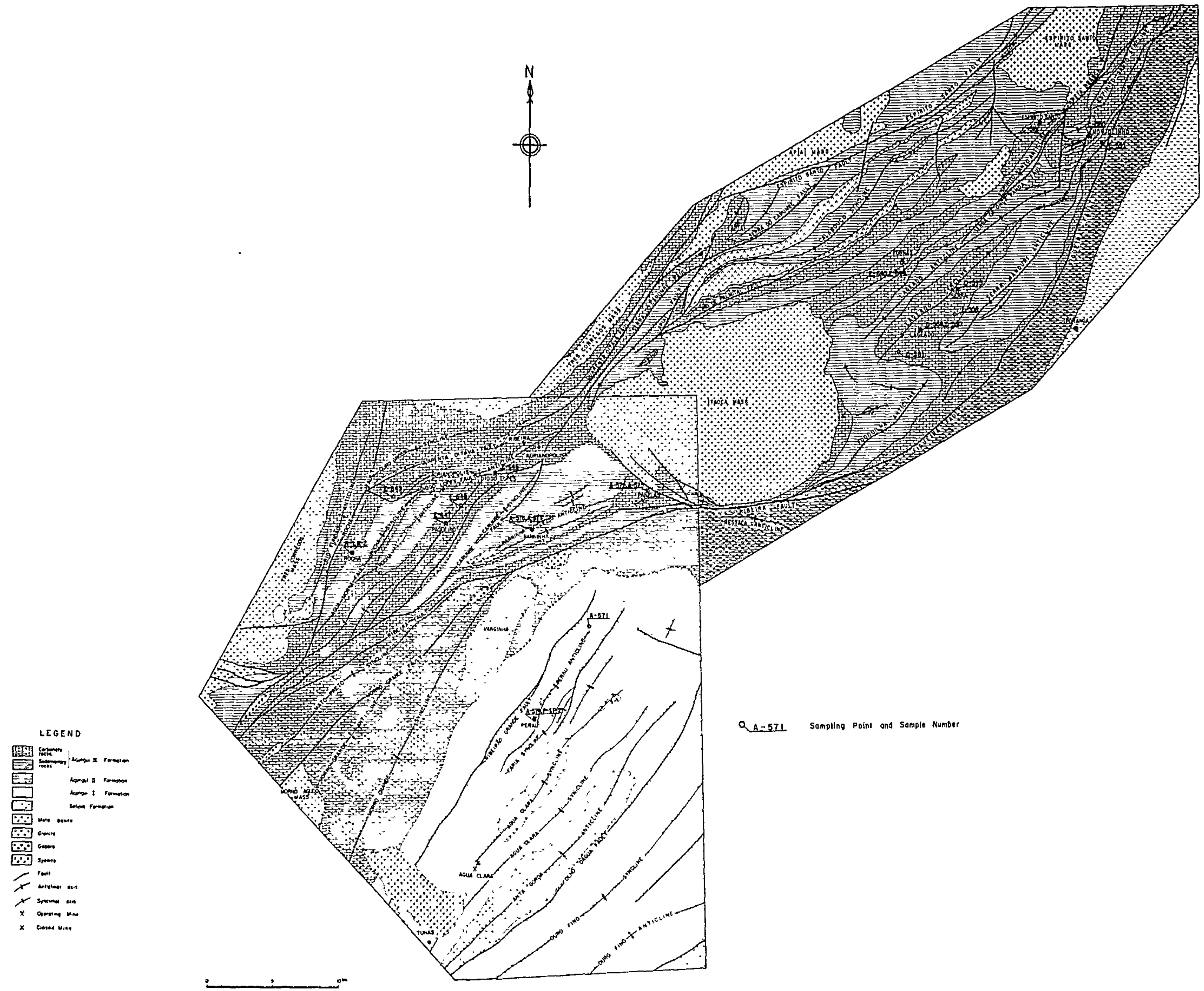


Fig. Ⅰ−8 Location Map of Galena Samples for Pb Isotopic Analysis in Project Area

Table I —3 Results of Pb Isotopic Analysis

Deposite type	No	Sample No.	Location	Ore Name	Isotopic Relation		Isotopic Age (m.y.)
					Pb 207/Pb 204	Pb 206/Pb 204	Cumming and Richards (1975)
Perau type	1	A–574	Perau Mine G2+8–S	Pyrite-Galena Ore	15.49	16.20	1440
	2	A–571	Canoas	Galena Ore	15.51	16.24	1420
	*A	P–1	Perau Mine	Galena Ore	15.51	16.24	1420
	*B	P–2	Perau Mine	Galena Ore	15.56	16.31	1380
Rocha type	3	A–572	Panelas Mine 110+26 mL	Galena Ore	15.48	16.66	1180
	4	A–573	Panelas Mine 110+34 mL	Galena Ore	15.47	16.66	1180
	5	A–576	Barrinha Mine	Pyrite-Galena Ore	15.54	17.09	950
	6	A–577	Barrinha Mine	Pyrite-Galena Ore	15.51	17.04	980
	7	C–518	Espirito Santo	Hematite-Galena Ore	15.49	16.52	1260
	8	C–580	Monjolinho de sebastiao	Galena Ore	15.57	17.20	890
	9	C–591	Agua da Limeira	Galena Ore	15.53	16.89	1060
	10	D–581	Lageado-Serra: Boa Ventura	Galena Ore	15.55	16.91	1050
	11	D–588	Lageado-Serra: Nova Esperança	Pyrite-Galena Ore	15.54	16.99	1010
	12	D–590	Lageado-Serra: Santa Nova G–5	Pyrite-Galena Ore	15.51	16.93	1030
	13	D–595	Lageado-Serra: Jaguatirica	Serussite-Galena Ore	15.53	16.97	1020
	14	1–508	Lageado-Serra: Aberto do Leao	Galena Ore	15.54	16.97	1020
	15	E–643	Furnas Mine	Pyrite-Galena Ore	15.57	17.27	850
	16	E–644	Furnas Mine	Galena Ore	15.51	16.95	1030
	17	E–646	Diogo Lopes Mine	Serussite-Galena Ore	15.45	16.62	1210
	18	E–647	Paqueiro Mine	Galena Ore	15.52	16.87	1070
	19	E–648	Bueno Mine	Galena Ore	15.50	16.61	1210
	20	E–649	Onça II	Galena Ore	15.51	16.85	1080
	*C	R–1	Rocha Mine	Galena Ore	15.54	16.91	1050
	*D	R–2	Rocha Mine	Galena Ore	15.51	16.84	1080

*A ～ D after Phase II

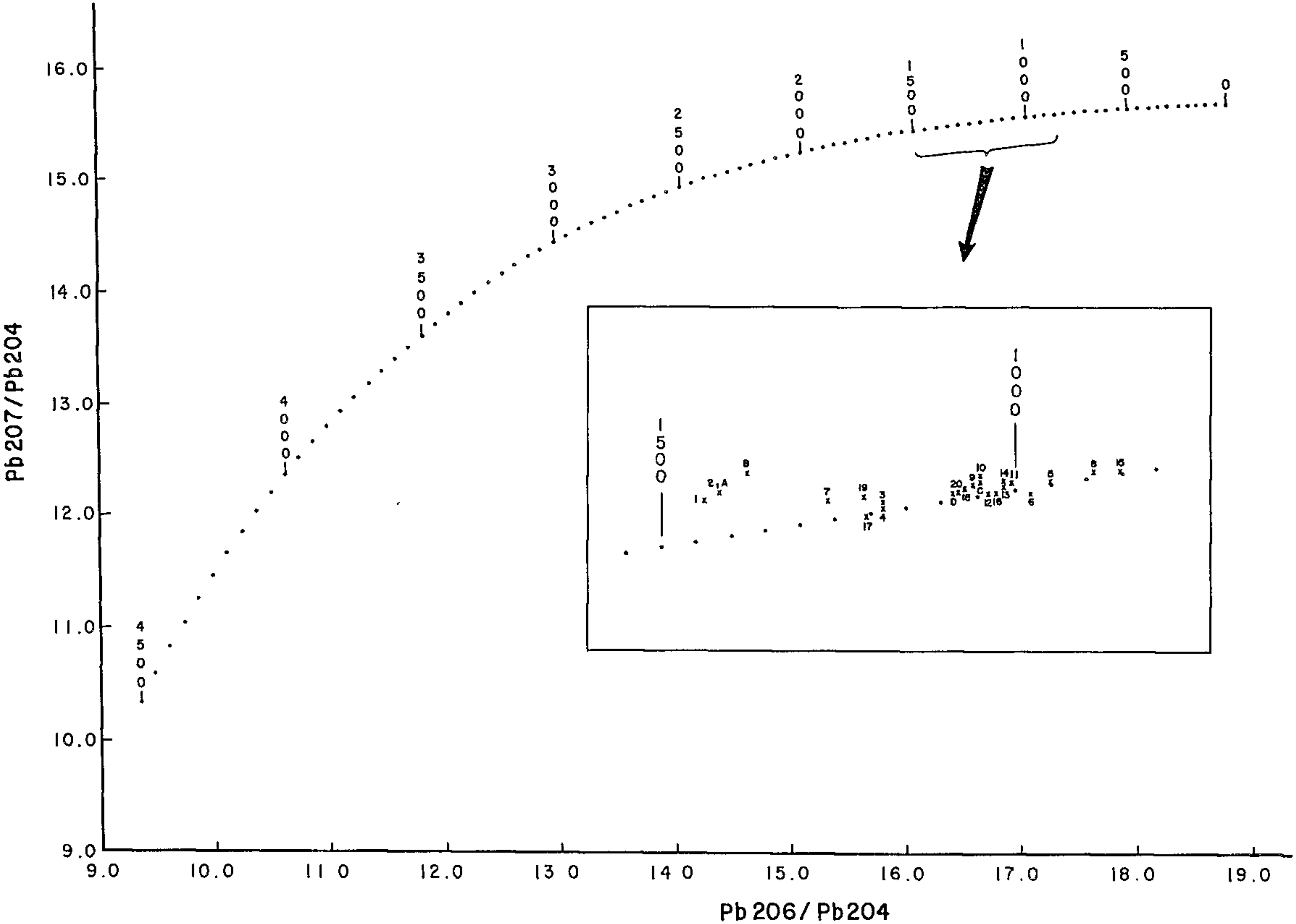


Fig. I —9 Pb Isotopic Age by Ore Lead Growth Curve of Cumming and Richards (1976)

1–2–4 Microanalysis of Carbonate Rocks

(1) Purpose of Chemical Analysis

Numerous lead ore deposits occur in the carbonate rocks of the Açungui III formation distributed in the area. In the past, it had been considered that the same ore horizon was repeatedly exposed by folding. As the result of survey of this time, stratigraphical classification of the carbonate rocks and geological positioning of the lead deposits were clarified.

In the area of the second year, the analysis of base metals (Cu, Pb, Zn, and Ag) in the host rock ($AIIIL_2$) of the ore deposits of the Rocha mine was made, the result of which led to the assumption that very high content of silver in the country rock of the Rocha mine compared with the mean value of general carbonate rocks reported by Turekin and Wedepohl (1961), might be an important characteristic to indicate that the rock might be the host of the ore deposit (JICA and MMAJ, 1982).

The content and distribution of microelements in the carbonate rocks have also been treated as a means for estimation of the sedimentary environment (Davis, P.J., 1972).

As mentioned in the above, microanalysis of the carbonate rocks is considered to be effective for estimating the indicator elements of lead mineralization and for investigating the field of emplacement of metalliferous ore deposits.

(2) Method of Sampling, Assay Component

The Açungui formation distributed in the area is interbedded with the carbonate rocks of three horizons such as L_2, L_3 and L_4.

Many lead deposits occur in these carbonate rocks, espeically the Lageado ~ Serra deposits occur in L_2 as well as the Furnas and the Espirito deposits occur in L_3.

To investigate ore deposit in the area, L_2 and L_3 are the important host rocks of lead ore deposits.

For the purpose of knowing the geochemical characteristics of carbonate rocks of these horizons, sampling of the rocks was made to take the samples homogeneously from the area underlain by all the carbonate rocks (PL I–6).

One hundred and twenty samples of carbonate rocks sampled were analyzed by atomic absorption analytical method and wet assay method on 15 components such as Cu, Pb, Zn, Ag, Co, Ni, Mn, Ba, Sr, F, CaO, MgO, Na, K and I.R. (Table A–5).

(3) Interpretation of Assay Result

Histogram was made from the assay data obtained for each component, then multivariate analysis was made to estimate the mineralization and the sedimentary environment. Feed back of single component analysis was made on the elements considered to be important

from the above result, resulting in to extract the anomalies of lead mineralization.

Fig. I–10 shows the flow chart from the sample planning to the extraction of anomalies.

(a) Histogram

All the assay data were converted to logarithm and the histograms were produced putting the maximum value and the minimum value on both end of the axis of abscissas, the interval of which was divided into 20 classes.

Fig. I–11 shows the histogram for each element of Cu, Pb, Zn, Mn, Ba, F, Na, K and I.R. which showed a shape relatively close to normal distribution among all the components. Table I–4 shows the mean ($\bar{x}$) and the standard deviation (σ) of each component of the whole lot.

The histograms obtained are composed of plural populations. The reason of this is because it is considered that it is the effect of various factors acted compositely.

Those of the six components such as Ag, Co, Ni, Sr, Ca and Mg did not show any normal distribution because of the abundant values below the limit of detection in the analysis and because limestone and dolomite were analyzed having been put together.

(b) Multivariate analysis

As analitical method which is in order to explining the characteristics of variable quantities, shown by multivate data, and to finding out a scientific simplicity by hypothetical variation and small representative variation, the factor analysis is the best method.

Cluster analysis was also used as a supplementary means in order to make clear the relationship between each component.

Table I–5 shows correlation coefficient between each component.

As the result of factor analysis on 120 samples and 15 components, varimax method, by computor (NEC 8801), four factors were extracted (Table I–6).

Those of more than 0.4 of factor loading extracted are I.R.–K–Ba–Na–Cu–Zn–Ni as factor 1, Pb–Ag–Zn as factor 2, Cr–Ca as factor 3 and Mg–f as factor 4.

Table A–6 shows the marks obtained for each factor of the samples.

In order to get hold of correlation of each component visually, a dentrogram of Ward's method by cluster analysis is shown in Fig. I–12. It shows that two groups of factor 1 and 4 and those of factor 2 and 3 are connected together in short distances.

The factor analysis does not show the relative ratio of quantity of the individual elements.

In order to get hold of the relative distribution of concentration for each of L_2, L_3 and L_4, the elements of relatively high factor loading were selected, and the cumulative curves

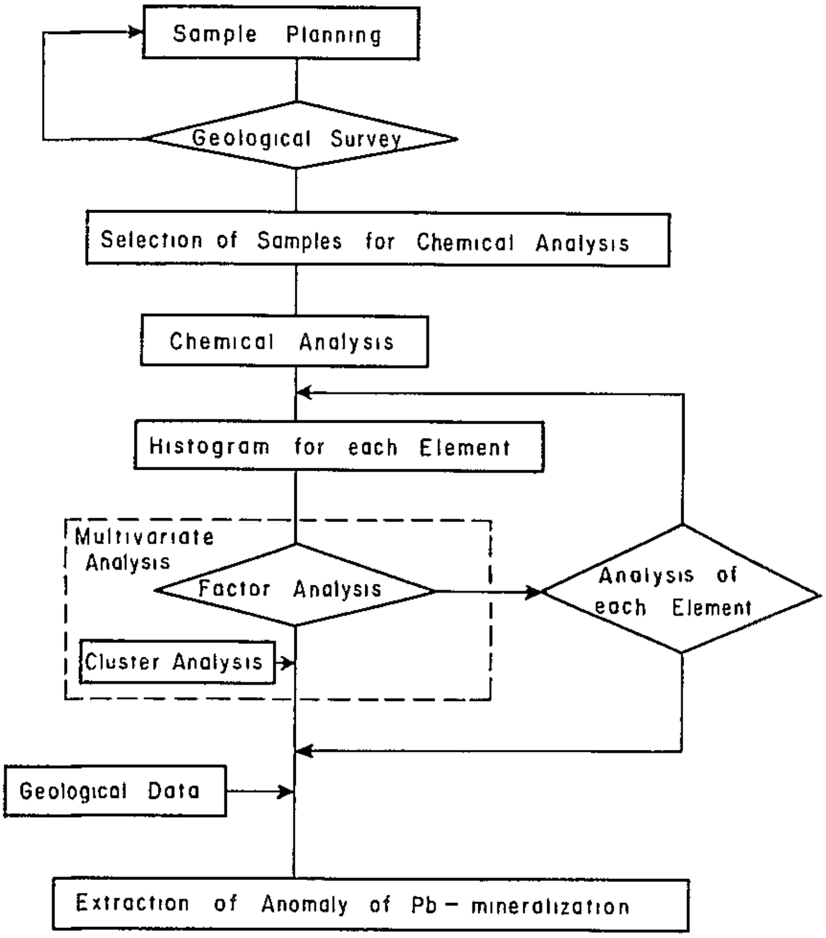


Fig I–10 Flow Chart of Statistical Analysis

Table I–4 Mean and Standard Deviation of Geochemical Data of Carbonate Rocks in Survey Area

Element	Max	Min	Mean 10^{x}	S D 10^{σ}	$10^{x+\sigma}$	$10^{x+2\sigma}$	Unit
Cu	240	3	6 10	2 63	16 0	42 2	
Pb	5400	5	17 10	2 49	42 6	105 9	
Zn	920	3	10 52	3 05	32 1	98 2	
Ag	12 0	0 5	0 53	1 44	0 76	1 10	
Co	20	3	3 62	1 51	5 5	8 3	ppm
Ni	55	3	5 06	2 17	11 0	23 9	
Mn	7400	6	183 23	4 51	826 0	3723 9	
Ba	2400	10	124 74	2 81	349 9	981 7	
Sr	2300	5	553 35	2 74	1517 1	4159 1	
F	2750	50	328 85	2 62	861 0	2254 2	
CaO	55 4	0 1	33 88	2 12	71 8	152 1	
MgO	19 3	0 3	2 71	3 39	9 2	31 1	
Na	0 75	0 03	0 07	2 45	0 17	0 42	%
K	1 80	0 03	0 16	3 24	0 52	1 68	
I R.	97 1	0.3	8 07	3 54	28 6	101 2	

I R insoluble residues

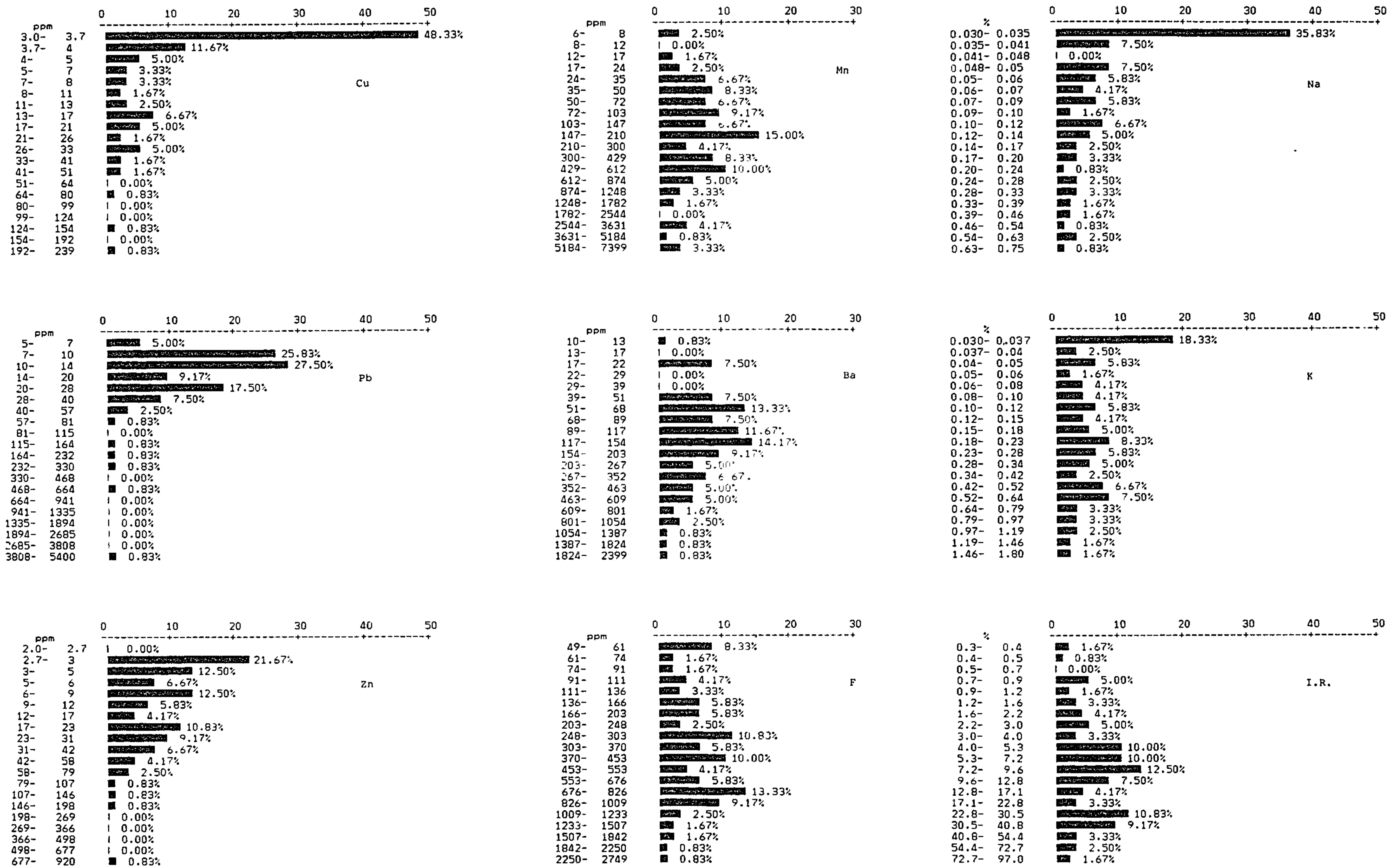


Fig. I—11 Histogram for Cu, Pb, Zn, Mn, Ba, F, Na, K, and I.R. of Geochemical Data of Carbonate Rocks in Survey Area

Table I–5 Correlation Matrix

	Cu	Pb	Zn	Ag	Co	Ni	Mn	Ba	Sr	F	Ca	Mg	Na	K	I.R.
Cu	0 714														
Pb	0 348	0.722													
Zn	0 671	0 389	0 705												
Ag	0.278	0 722	0 340	0 722											
Co	0.678	-0 033	0 456	-0 070	0 840										
Ni	0.718	-0 047	0 689	-0.090	0 840	0 840									
Mn	0 557	0 167	0 705	0 241	0 465	0 614	0 705								
Ba	0 548	0 007	0 504	0 060	0 527	0 582	0 464	0 711							
Sr	-0.304	0 108	-0.276	-0 031	-0 234	-0 269	-0 288	-0 101	0.646						
F	0 299	-0.000	0 415	0 037	0 326	0 489	0 183	0 428	-0 069	0 609					
Ca	-0 479	0.171	-0 343	0 054	-0 365	-0 432	-0 221	-0 328	0 646	-0.208	0.646				
Mg	0 222	-0 074	0 423	-0 141	0 314	0 502	0 353	0 127	-0 442	0 504	-0 234	0 504			
Na	0 481	-0 073	0 406	-0 121	0 492	0 550	0 350	0 552	-0 176	0 347	-0 340	0 312	0 613		
K	0 664	0 080	0 644	0 066	0 560	0 704	0.555	0 711	-0 129	0 609	-0.388	0 327	0 606	0 813	
I R	0 566	-0 050	0 636	0 028	0 412	0 612	0 627	0.672	-0 253	0 479	-0 567	0 312	0.613	0 813	0.813

I R insoluble residues

Table I–6 Factor Loading of Geochemical data of Carbonate Rocks in Survey Area

	Factor Loading			
Element	Factor 1	Factor 2	Factor 3	Factor 4
Cu	0 480	0 365	–0 272	0 055
Pb	-0 030	0 843	0 143	0 001
Zn	0 468	0 474	–0 220	0 380
Ag	0 021	0 842	–0 030	–0 099
Co	0 327	–0 058	–0 126	0 123
Ni	0 467	–0 016	-0 180	0.377
Mn	0 404	0 340	–0 234	0 241
Ba	0 761	0 046	–0 033	0 025
Sr	0 005	–0 008	0 803	–0 196
F	0 466	–0 031	0 056	0 599
CaO	-0 367	0 093	0 715	-0 011
MgO	0 095	-0 062	-0 276	0 682
Na	0 602	-0 112	–0 125	0 149
K	0 809	0 112	–0 057	0 288
I R	0 837	0 051	–0 300	0 202

I R insoluble residues

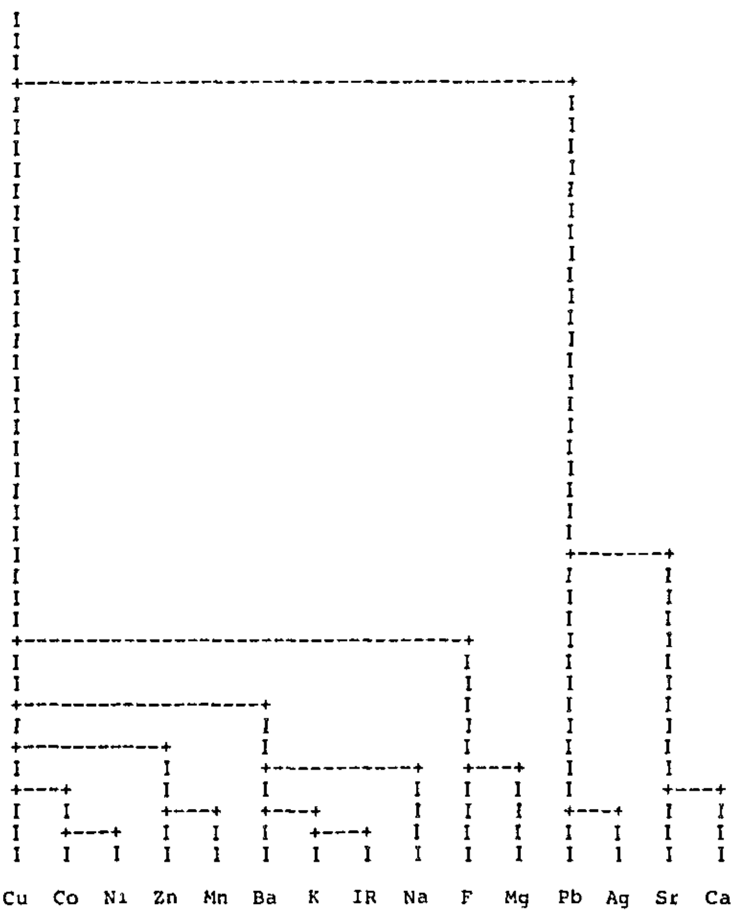


Fig. I–12

Dendrogram by Cluster Analysis of Geochemical Data of Carbonate Rocks

were produced (Fig. I–13).

The number of samples used for every horizon were 59 in L_2, 48 in L_3 and 13 in L_4. Although these were not many enough for the reliability to be obtained sufficient for the analysis by statistical method, the rough tendency can be known from the above.

The examination of each factor characteristic is made in the following.

Factor 1 (I.R.–K–Ba–Na–Cu–Zn–Ni–F–Mn)

The factor is composed mainly of the insoluble consisting of SiO_2, and Al_2O_3, Na or K as clay minerals and Ba added to them. In addition, subordinate amount of Cu, Zn, Ni, F and Mn is also contained. The synthesis of these leads to the assumption of reducing sedimentary environment with abundant impurities.

PL.I–7–1 shows the figure of factor shown in separate three stages of factor scores of each sample classified into categories such as more than 0 and less than 0.5, more than 0.5 and less than 1.0, and more than 1.0.

The figure shows that the factor scores of 0 ~ 0.5 are observed in all the horizons of L_2, L_3 and L_4, espeically it is distributed in the surrounding area of the L_2 and L_3.

In Fig. I–13, 50% of cumulative frequency curve is supposed to be the background, Ba and Na are approximately equal in amount in L_2 and L, though a little large in L_4, while K and Mn show no great difference between the horizons. Mn, although it seems to be affected to the carbonate rocks of $AIIIS_2$ member, because manganese oxide stains were observed, no difference can recognized between the horizons.

Factor 2 (Pb–Ag–Zn)

The factor is coincide with the metalliferous elements (Pb–Ag–Zn) of ore deposits such as Furnas, Lageado and Espirito Santo, and it seems to be the factor of mineralization.

The factor scores are classified same as factor 1, and factor score map is shown as PL. I–7–1. The factor 2 overlapped with factor 1, and arrenging high score near the known deposits.

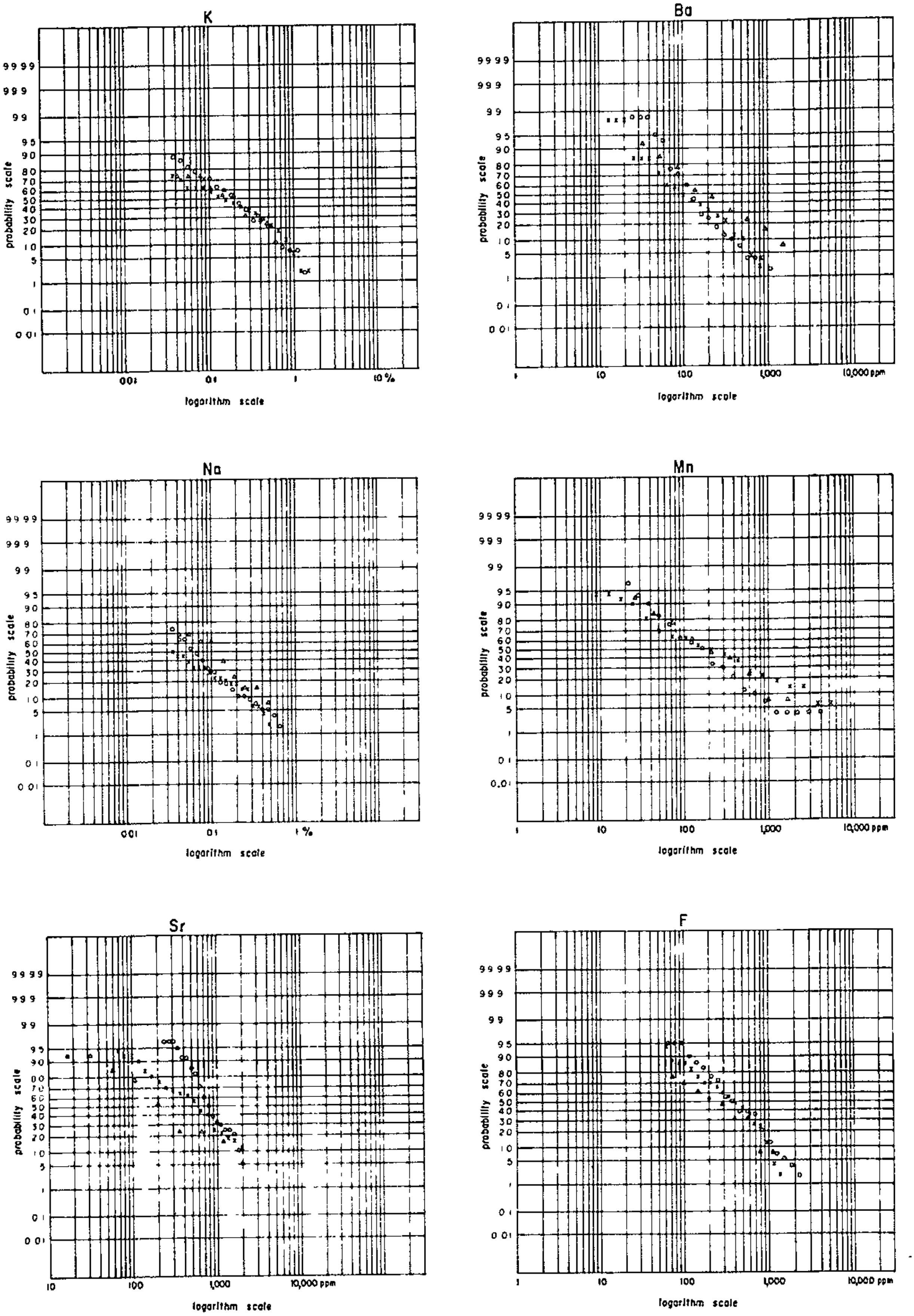
Among Pb, Ag and Zn, many values of Ag below the limit of analysis impossible for statistical treatment.

The anomalies of Pb and Zn based on the mean (M) and the standard deviation (S.D.) obtained from Table I–4 are shown as follows.

Pb t_1 = M + 0.5 S.D. = 27.0 ppm

t_2 = M + S.D. = 42.6 ppm

t_3 = M + 2 S.D. = 105.9 ppm



○A III L2
×A III L3
△A III L4

Fig. 1–13 Cumulative Frequency Distribution of K, Ba, Na, Mn, Sr and F of Each Horizon of Limestone

Zn $t_1 = M + S.D. =$ 32.1 ppm

$t_2 = M + 2\ S.D. =$ 98.2 ppm

$t_3 = M + 3\ S.D. =$ 299.9 ppm

Pb anomaly is classified into three categories of weakly anomalous zones (more than 27.0 ppm and less than 42.6 ppm), medium anomalous zone (more than 42.6 ppm and less than 105.9 ppm) and strongly anomalous zone (more than 105.9 ppm), and anomaly map is shown as PL I–8.

Zn anomaly is classified into the weakly anomalous zone (more than 32.1 ppm and less than 98.2 ppm), medium anomalous zone (more than 98.2 ppm and less than 299.9 ppm) and strongly anomalous zone (more than 299.9 ppm).

The anomalous zones in PL I–8 are coincide with the areas of factor 2 of L_2 and L_3 of PL I–7–1.

Fig. I–14 shows simplified map of the synthesis of Pb anomaly and factor 2 based on the above, which shows that the anomalous zones are well coincide with the known ore deposits such as Furnas, Lageado and Espirito Santo.

The reason that Pb anomalous zone can not be observed inspite of factor 2 is distributed in L_4 on a small scale, is considered to be only a little high content of Pb in L_4 compared with the Pb content in ordinary carbonate rocks as reported by Turekian and Wedepohl (1961).

On the other hand, Pb content in L_2 and L_3 shows the values more than double those in ordinary carbonate rocks.

Factor 3 (Sr–Ca)

Two modes of existence of Sr is considered, the one is to replace a part of Ca in the crystal lattice of $CaCO_3$ and the other is to occur in impurities. Although, as to the latter, it is merely shown in factor 1, it is likely that the mode of existence of the former is shown.

The factor 3 is considered, therefore, to be the factor to characterize the crystallographic character of $CaCO_3$, that is, the petrographic character of the carbonate rocks. Factor score map is shown as PL I–7–2.

Sr shows obvious difference in its content depending on the limestone of each horizon as shown in Fig. I–13. Namely, the amount of its content more increased in limestone in the lower horizon, and it is likely that the difference of characters of rock is indicated.

Factor 4 (Mg–F)

It is considered that this factor is the one that characterizes the dolomite. Because of the correlationship between factor 4 and factor 1 shown by the cluster analysis, it is considered that a part of dolomite was deposited primarily under the reducing sedimentary environ-

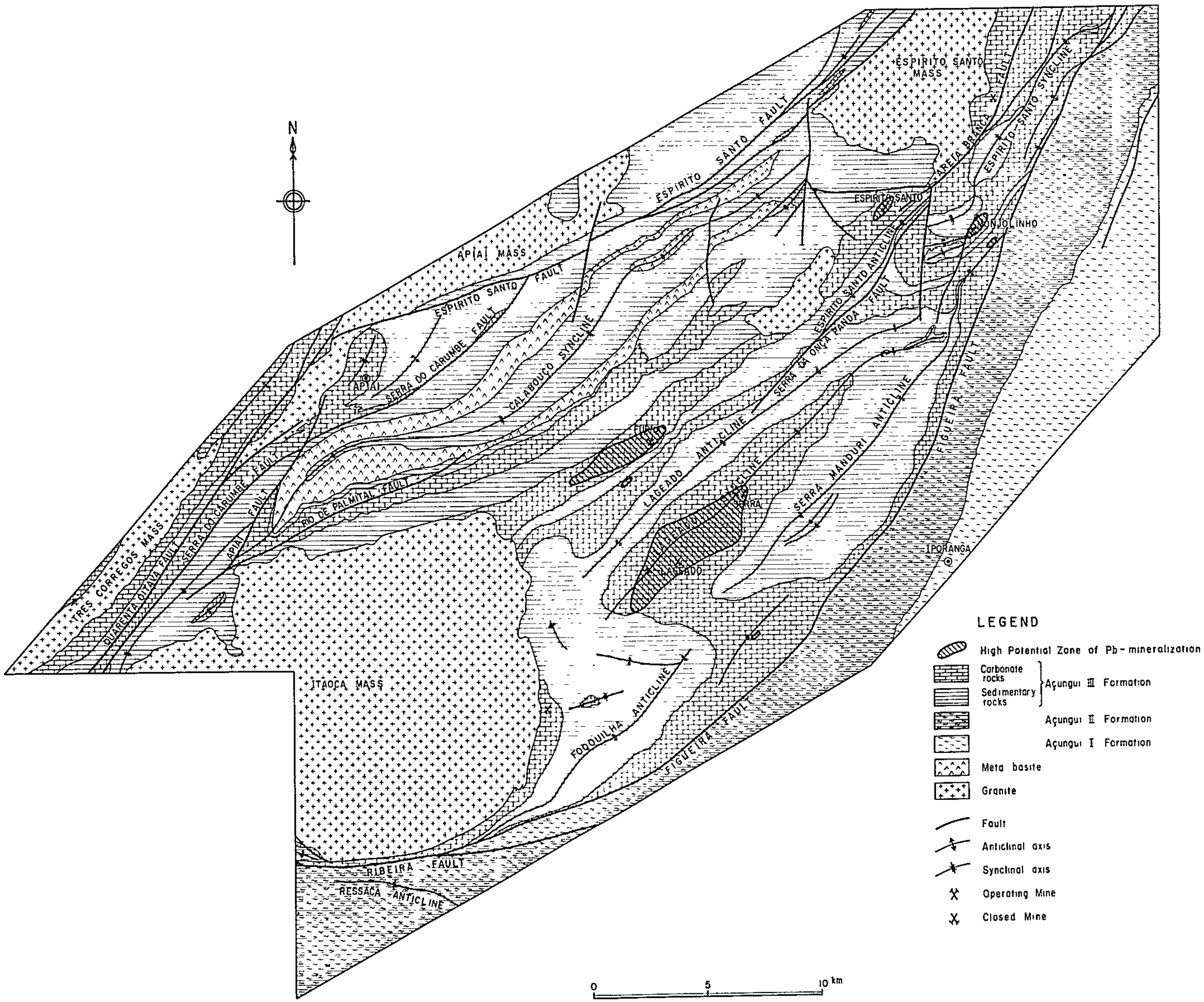


Fig. I —14 High Potential Zone of Pb-Mineralization in Survey Area