MINERALOGICAL AND GEOCHEMICAL STUDIES ON THE SAKARO PRIMARY GOLD DEPOSIT (SIDAMO, SOUTHERN ETHIOPIA): ZONATION IN ORE BODIES AND HOST ROCKS

BY

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1993

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A thesis
presented to
the School of Graduate Studies
in partial fulfillment of the requirements
for the degree of Master of Science in Economic Geology

by

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June 1993

ACKNOWLEDGMENTS

The author wishes to thank Dr. Anatoli A. Sliouniaev for his continued inspiration and guidance in his course of post-graduate studies. Many of the ideas in these notes owe their origin to discussion with him. Sincere gratitude is extended to Profs. D. Turner and C. Gorgoni for their advice and encouragement in the early periods of the research. I would like to thank Prof. Getaneh Assefa, Chairman of the department of Geology and Geophysics and the Examining Board, Drs. Solomon Tadesse and Endale Ketefo, members of the same Examining Board, Prof. A. Peccerilo, referee and prof. R. Valera, external examiner for their constructive comments and suggestion. The thesis research have benefitted greatly from their suggestions, and their valuable comments have been incorporated in these revised notes.

Thanks are due to Mr. Ketema Taddess, Chief geologist of EIGS, Mr. Belay Desta, EIGS' ex-chief geologist, Mr. Bekele W/Michael, manager of EIGS/UNDP training project for their co-operation and will to solve encountered problems during the course of the study. I would like to thank Mr. Ayele Kebede, manager of AMEDP, Mr. Tesfayesus Mengistu, EMRDC Exploration department head, Mr. Admassu Mekete, ex-manager of AMEDP, Alemayehu Zewdu, head of Shakisso central laboratory and Zemene Asres, senior geologist for their selfless efforts in facilitating my field work. Without them it would have been impossible to get the required materials for the research in time. I am very grateful to Mrs. P. Sargent (British Council, Addis Ababa) for her help in improving the language of the thesis, Miss Rahel Eshete and Miss Menber Ashenafe for typing several drafts of this paper, and Miss Tigist Bekele for her kind help in tracing most of the diagrams. Staff members of the Geology and Geophysics department, EIGS/UNDP Training Project, EIGS Central Laboratory and EIGS computer center kindly offered me priorities in extensive use of their facilities.

I would like to give due acknowledgement to the school of Graduate studies and Ethiopian Institute of Geological Surveys for the use of their facilities, financial and logistic support throughout my post-graduate studies, Ethiopian Mineral Resources Development Corporation for allowing me to sample drill-cores, use duplicate rock-powder samples, assay data and documentations on the Sakaro deposit.

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ABSTRACT

The Sakaro deposit is a vein-type fault-hosted gold deposit in the Adola area, southern Ethiopia. It is composed of quartz veins up to 9.3 m wide which occupy fault planes along foliation and petrographic contacts in precambrian low-grade metamorphic rocks. The veins are gold-rich and sulfide-poor, forming a mineralized zone of 760 m in strike length and up to at least 150 m in vertical extent. Veins Nos. 1 and 2 are the richest shoots with an estimated total ore reserves of 760,800 tons capable of producing 2,551 kg of gold at an average grade of 3.4 g/t and 5.7 g/t respectively.

Geochemical and mineralogical studies of the ores and the host rocks reveal that the Sakaro deposit might include tungsten other than gold as a potential exploration target. Tungsten mineralization is the earliest to be formed. Tungsten content increases up to >1% in the ore veins and in the wall rocks (mainly in amphibolites proximal to the veins), forming a distinct zone that assumes W-As-Cu, a geochemical zone or wolframite-scheelite-iron sulfides zone, a mineralogical zone.

Gold is mostly associated with Ag and Pb, showing asymmetrical dispersion pattern that starts in the hanging wall side of the vein and decays towards the foot wall rocks. Its tight relation with Ag and Pb is expressed by forming a Au-Ag-Pb zone though it is also related at a lesser degree with other elements especially with Cu. Outward from this zone, Ag-Pb-Cu, W-As-Cu, and Fe-Co-Ni-Mo-Cu follow in respective distances from the ore veins toward enclosing rocks.

Gold distribution in the ore veins is controlled by thickness variation of the quartz fillings in both strike and dip directions, poor in swells and rich in constrictions. In the plane of the main vein, five ore columns are identified with marked contrast in gold mineralization: (1) obliquely running, EW dipping gold rich zone, (2) northerly trending, vertically dipping gold rich zone, (3) intermediate low gold zone, (4) oxidation zone, and (5) surficial weathering zone. The first two zones are ore shoots representing the fronts of gold depositing mineralizing fluids. Gold contents follow a systematic pattern of more or less regular course within and away from these fronts which otherwise are perceived as very irregular and erratic distributions. Moreover, statistical treatment on the metal content shows that gold distributions in populations separated according to the rock types and environments obey lognormal law, with mean values highest in ore veins, less in amphibolites, and least in mica schists.

Studies on the vein development reveal three distinct types of hypogene mineralization from veins margins to the center, of marcasite + chalcopyrite in the peripheral parts, galena + chalcopyrite + marcasite in the following portion, and sphalerite + high galena + chalcopyrite in the central part. Gold is present in all of the above associations, however, it is highly enriched in sphalerite-high galena-chalcopyrite zone, followed by hanging wall side marcasite-chalcopyrite zone, and least in foot wall side marcasite-chalcopyrite zone. The gold enrichment in sphalerite-high galena-chalcopyrite zone indicates the close association of Au, Ag, Pb, Cu and Zn. The selective enrichment of gold in the hanging wall side (marcasite-chalcopyrite) zone is most likely due to intense shear remobilization effects.

The veins display a crude ascending mineral sequence, from depth to the surface, of pyrrhotite, gold + galena + sphalerite + chalcopyrite + iron sulfides (productive zone), and marcasite. A descending sequence in the zone of weathering shows that Fe-hydroxides and Fe-disulfides grade downward where gold is enriched with secondary minerals of Pb, Cu, Zn. In the enclosing rocks, wolframite + scheelite + Fe-sulfides form a zone adjacent to the ore veins and marcasite + pyrrhotite + chalcopyrite in distal areas. These zones are in agreement with geochemical zones W-As-Cu and Fe-Co-Ni-Mo-Cu respectively.

Disulfidization process of iron monosulfides increases in the upper levels of the deposit and is more intense at the vein margins especially in the hanging wall side of the ore veins due to shearing which is also responsible for recrystallization of quartz at the vein selvages.

The vein mineralogy shows as the vein development is the result of multiple episodes of vein opening and filling characterized by wolframite-scheelite-quartz, sulfide-gold-quartz and disulfide-carbonate stages.

Statistical parameters of distribution of the components, ore geochemistry, peculiarities of horizontal (along the strike and across the thickness), vertical and three dimensional geochemical and mineralogical zonation of the mineralized rocks and the general sequence of formation of minerals in ores of the Sakaro deposit considered and proved in the thesis are the features of its genetic model. These features are also of practical importance for ore blending and further improvements of ore dressing technological schemes. They are of value and use in prospecting for similar mineral deposits in the region and their successful exploration.

1. INTRODUCTION

1.1. General

Ethiopia counts on gold as the most significant component of the country's mineral wealth. Its contribution to the national economy undoubtedly dominates the mining industry. Today, with regard to gold sources, the major significance in Ethiopia's mining scene is the discovery of primary and secondary (placers) deposits in the Adola area.

The Sakaro ore deposit is one of the primary gold sources discovered in the Adola Gold field so far. Moreover, it is considered to be one of the major gold-producing primary gold deposits next to Lega Dembi in the Adola area. For this reason, various studies conducted for different geological purposes on this deposit are worthwhile if can successfully be used as a guide in developing the known and also in prospecting for other similar deposits.

This research makes use of the results of the exploration of the Sakaro gold deposit (SGD), and deals with its geological features as well as its mineralization and alteration parameters based on the accumulated exploration results and recent observations and analyses made on core and trench samples. The emphasis is made on mineralogical and metal zoning of the deposit and its significance in prospecting, exploration and development. Also, an attempt is made to compare the characteristics of the deposit with other well known deposits of similar geological setting and model.

1.2. Location and accessibility

The project site is located within the so-called "Adola area" in Odo-Shakisso woreda, Jemjem awraja, Sidamo administrative region, southern Ethiopia. It is situated on the road-side along Shakisso-Megado road at 502 km post from Addis Ababa, or at 13 km post from Shakisso mining town. Specifically, the project site covers an area of about 700,000 sq. m with grid coordinates 3400-4100 m north and 2900-3900 m east (having approximate geographic coordinates between 5°42'25" -5°42'50" and 38°51'54" - 38°52'30"E) (Fig. 1).

From Shakisso town, Sakaro is accessible to four-wheel drive vehicles through 13 km long gravel road via Lega Dembi or Reji village. Moreover, non-surfaced roads, constructed during the mining and drilling activities, run over the area.

Shakisso town, in turn, is accessible from Addis Ababa either by a motor-vehicle or a plane. Using commercial or private vehicles, it can be reached by travelling over an aggregate distance of 489 km. The first 300 km run through the asphalted national highway until it bifurcates at Aposto. Thence, all weather gravel road leads to the town. The Shakisso town is also linked with Addis Ababa by air. Ethiopian Airlines offer two scheduled flights weekly from Addis Ababa.

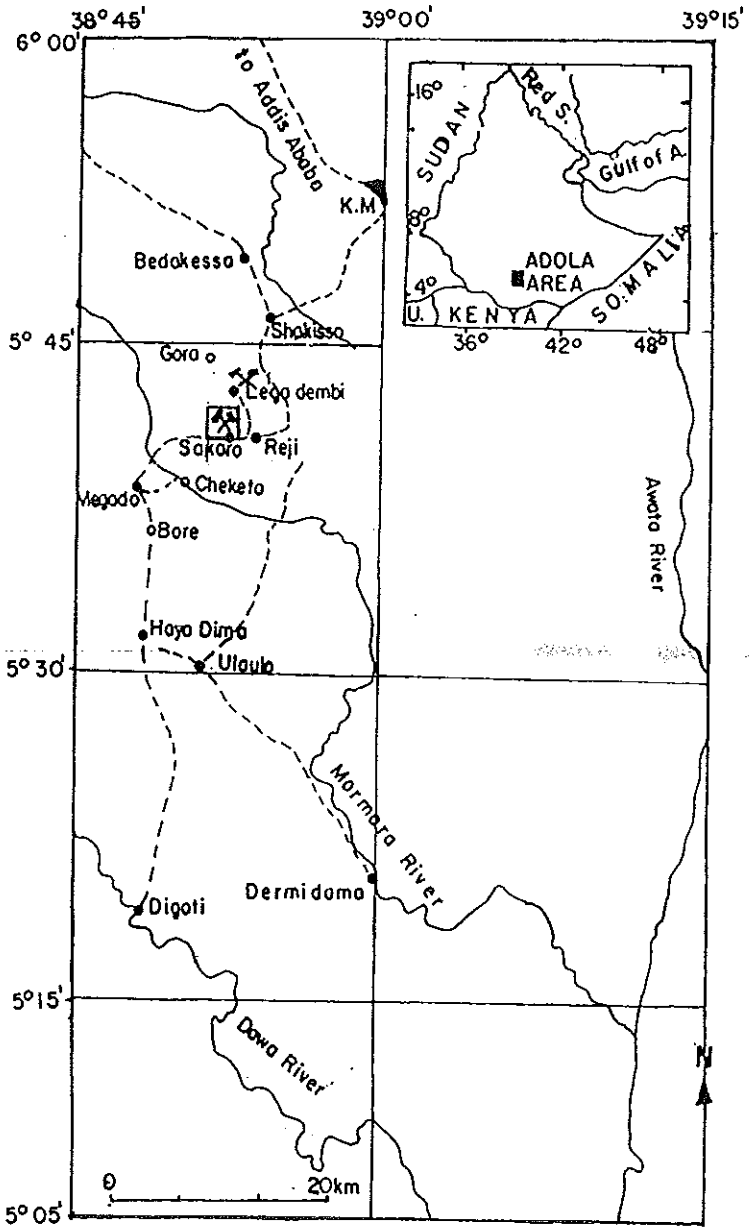


Fig ·1· Location map of the study area.

1.3. Physical features

The Sakaro area and its surrounding country is characterized by moderately elevated mountain masses of north-south trend that range from 1800 m at river bed to 2152 m above mean sea level (m.s.l.) with steep slopes and narrow V-like valleys.

The Sakaro hill which hosts the ore bodies has a summit at 2045 m. Seasonal streams, known as the west and the main Sakaro, drain south of this hill and join the Wollena stream, a tributary of the Mormora river.

The climate of the area is sub-tropical. It is characterized by two rainy seasons (Daniel, 1977). They are March-June and September - mid-November seasons. A rainfall data on the Adola area (Cooperation agreement in the Energy Sector between the Ministry of Mines and Energy, Ethiopian National Energy Committee (ENEC) and CESEN-ANSALDO/FINMECC ANICA GROUP, 1986) show that the area receives the highest precipitation in spring with a maximum in April and a relatively lower precipitation in autumn with a peak in October.

Vegetation in the study area is cleared due to the mining activity but in the surrounding country sparse to dense vegetation of tall trees and thorny bushes is present.

1.4. Human settlement

The local inhabitants, belonging to the Oromo-speaking Gujee tribe, reside in separate tukuls and villages scattered throughout the area. They earn their livelihood from cattle breeding and to a lesser extent from agriculture. The state-operated gold mine at Sakaro, like any other mine in the Adola Gold field, was getting mine labourers among people that came from different places of varied callings and ethnic origins, mainly Amharic- and Gedeo- speaking people.

At present, gold panning is widely practised in the Adola Gold field as a means of livelihood or self-improvement by the locals. It seems to be right, though not confirmed by the state policy, to a native (and new settlers) to pan/dig for gold in areas outside the state-operated mining places. Today, mining activity has escalated and has triggered an exodus of hundreds of people from different places of the nation hoping for a better prospect. A gold rush settlement has already began in the area, and in Sakaro, as one of the gold rush sites in the Adola area, hoards of people are engaged in mining activities.

1.5. Objective

It is a bit more than a decade ago that gold exploration in the Adola area branched out to include primary gold deposits in addition to placers. To this date, exploration activities for gold have been undertaken by various local- and foreign- based projects in the Adola area, especially for primary gold deposits. Research and development activities on the known primary gold deposits were also carried out in the Adola Gold field to help in developing exploration models, especially by

Training for Mineral Exploration Project (TMEP) which is a joint venture of United Nations Development Programme (UNDP) and Ethiopian Institute of Geological Surveys (EIGS). The development and refinement of both conceptual and explorational models will undoubtedly help in discoveries of other gold deposits in the future.

This thesis research deals with the mineral and metal zoning of ore bodies of the Sakaro deposit. By upgrading the available information on the distribution, associations and genetic relations of different minerals/metals, it will help in developing geologically sound exploration and genetic ore deposit models.

The research is concerned with the following objectives:

1. *Geochemical and mineralogical zoning in the Sakaro ore bodies and country rocks ; and the relation of the metal distribution and of the alterations to gold mineralizations in space and time;*
2. *The distribution of the mineral assemblages and their genetic relations;*
3. *Gold distribution and the controlling factors;*
4. *The zonation parameters and other geologic features of the deposit.*

1.6. Previous work

The Adola area has been studied by numerous investigators since the area became known for gold placers starting in the

1930's. An important contribution to the study of geology and mineralization of the Sakaro area dates back to the late 1970's. However, it shared the contribution of earlier works (Jelenc, 1966; Chater, 1971; Kazmin, 1971, 1972) at the regional scale.

In 1956-65, Jelenc carried out prospecting and exploration works for economic minerals (summarized in his book: Mineral Occurrences of Ethiopia, 1966), and particularly for gold in the Adola area, including feeder placers such as the ones of the Wollena creek which are partly enriched by the primary sources of the Sakaro area. By organizing the available scattered geological information, he produced the regional geological sketch map of the Adola area and has related mineral occurrences including gold placers to the geology of the area. In trying to establish the geological framework, he subdivided the Precambrian rocks of the Adola area into the Gariboro (lower unit) and Adola (upper unit) series . The Gariboro series comprises various gneissic rocks, whereas the Adola series, which also underlies the Sakaro area, includes the "green rocks", namely, amphibole and chlorite-talc-tremolite schists, phyllites, quartzites, sericite schists, sandstones and conglomerates.

Jelenc (1966) believed that the "green rocks" were the source of gold. This conclusion certainly promoted systematic exploration, but not of primary gold deposits for he didn't consider them to be economic. He assumed that the primary sources had been eroded away to enrich placer deposits.

Gilboy (1970) and Chater (1971) produced a 1:100,000 geological map of a part of the Adola area. The "green rocks" within the project site have also been studied by Chater (1971). For the first time, these investigators tried to reveal the structural and metamorphic history of the area and relate it to the evolution of the Mozambique Belt. Moreover, they have provided a three-fold lithostratigraphic subdivision which later was adapted by Kazmin (1972) and Kazmin et al. (1978) with minor modifications as the three complexes: Lower Complex (>2500 m.y.), high grade gneisses and migmatites; Middle Complex, metasediments of Lower to Middle Proterozoic; and Upper Complex, low grade metasediments and metavolcanics of Upper Proterozoic. AGEP (1979-81) adapted these complexes while producing a geological map of the Adola area (1:100,000 scale) and has recognized only the Middle and Upper Complexes which are identified as Upper Proterozoic rocks.

Kazmin (1971) has mapped the Shakisso area (Sakaro and its surrounding country) at the scale of 1:50,000 in trying to establish the possible sources of gold of some placers. As a result, he recommended some localities of veined zones for a detail study including the use of the diamond drillings. Those zones of quartz veins are: shear zone veins, veined zones along the contacts between metasediments and amphibolites, and veins along the contacts between gneisses and amphibolites.

Since 1979, under the Ethiopian Mineral Resources Development Corporation (EMRDC), the Adola Gold Exploration Project (AGEP) (1979-81) and later the Adola Mineral Evaluation and Development Project, AMEDP (1989 - up to now) have carried out the exploration works to assess the gold potential of the Sakaro area. The details of the exploration activities are summarized in Dorofeev et al. (1982) and Moudrov et al. (1991) respectively. The spectrum of exploration includes a detail geological mapping (1:2000, 1:1000, 1:500), geochemical (1:2000) and geophysical (magnetics, 1:2000; resistivity, 1:1000) surveys; trenchings (2730 meters) and pittings (9.9 meters); and diamond drillings (44 bore holes of 6056 meters in total). The detailed geological investigations started by AGEP (1979-81) enriched by AMEDP (1989-90) in underground information have provided a reliable estimate of the gold potential of the Sakaro deposit.

Giday (1980) has taken part in the delineation and understanding of the nature of the Sakaro deposit. He produced a 1:25,000 geological map of the Sakaro area, and considered the genesis of the Sakaro deposit within the frame of the Mozambique belt.

Since 1986, TMEP have had an interest on the Sakaro area. In 1986-87, an orientation survey was carried out on the Sakaro deposit to establish an exploration model that could be of use in further exploration. This survey was later changed to an exploration survey due to the finding of a geophysical anomaly. In 1987-88, the detailed grid survey at the Sakaro area aimed at following the extension of the known ore bodies resulted in recommending possible potential areas. In 1988-89, two bore-holes were drilled at East Sakaro (east of the known ore bodies) based on the overlapping of anomalous geochemical (Pb - 41 ppm, Cu - 120 ppm, Zn - 80 ppm, Ag - 2 ppm, As - 55 ppm) and geophysical (high IP and low resistivity) values (Last and Abdulwahab, 1988; Alazar, 1990a) and the core analyses show 6.7 ppm and 23.6 ppm Au (Matthias, 1989; Ayalew, 1991) as the highest readings respectively. The exploration work is still in progress in the area up to now to trace the ore zone.

Aster et al.(1988) conducted geochemical and mineralogical investigations of the disseminated sulfide mineralization and its association with primary gold in different rock units of the Adola Gold field. As a result, they have identified sulfide mineralization of those localities that include the Sakaro area (others are Ababido Gudba, Dawa/Digati and Reji) as having marked wall rock alterations. The sulfide mineralization was brought about by sulfidization of Fe-rich wall rocks where S introduction by mineralizing fluids caused consumption of Fe-oxides present in the host rock. They concluded that the mineralizing fluid supplied S and minor Ca but insignificant base metals. They further reasoned out that the process of sulfidization of Fe-rich wall rocks would be a very important cause of formation of primary gold deposits only if mineralizing fluids contained Au in solution. The authors recommended that since sulfide mineralization in these localities has a high probability of being connected with primary Au, these areas should get the highest priority in exploration for primary gold.

2. EXPLORATION AND MINING HISTORY.

In the late 1970's, economic and scientific interest on the primary gold mineralization has developed following the accidental discovery of the primary ore manifestations at Sakaro and Dermi Dama localities in 1975. Thus, these findings were used as incentives, and a government-run exploration project - AGEP - was set up to assess and prospect the mineral resources potential of the Adola Gold field. As a result, 40 auriferous quartz-vein occurrences and deposits were revealed (Shiferaw et al., 1987); the Sakaro and Lega Dembi being considered as major discoveries.

The exploration history of the Sakaro area is an integral part of investigations in the Adola area for the reason that it occurs in the Adola greenstone belt. This belt is the major gold source of the main productive Ethiopian Gold fields (Sidamo, Wollega, Eritrea). Since 1936 the Adola area is known for its gold. Mining has developed since then from intensive labour gold panning of river valleys and plains to mechanized placer mining and open pit and underground methods to extract primary gold ores. Exploration technique has also developed from a traditional and simple empirical approach to a systematic and integrated survey to locate hidden deposits. Recently, a number of researches were carried out on known deposits - the Sakaro deposit being one of them - to establish a more sound exploration technique (exploration models) by integrating the different characteristics of the deposits.

Three periods are known in the mining history of the Adola area (Shiferaw et al., 1987): the first period (late 1930's-early 1950's) is known for gold rush which followed the discovery of placer gold in Bedakessa valley. The second period (the early 1950's - 1978) is characterized by the rapid decline of gold production, expansion of mineral prospecting activities, and development in manual-mechanical mining operations. The third period begun in 1979 is marked by the discovery of primary economic minerals such as gold and rare metals, the development of large scale mining and a slight revival in gold production.

In 1975, as indicated earlier, gold lodes in Sakaro were discovered accidentally by hand miners who were working on placers of the Sakaro river valley. Later gold was traced to a quartz vein outcropping on the slope of the Sakaro hill. Following the discovery, mining of the eluvial-diluvial placers is activated. According to Moudrov et al. (1991), in 1986-91, 895.7 kg of gold was mined out by the Adola Gold Development Enterprise (AGDE) which is the body of EMRDC, partly from the diluvial sediments and partly from the oxidized part of the main vein. According to the estimates of the above authors, 505.8 kg of gold was produced from 77.5 thousand tonnes of ore at an average grade of 6.7 g/t. The reserves of the Sakaro diluvial placer is estimated at 299.1 kg (Grechanic et al., 1988).

Since 1979 exploration and research works have been carried out in the Sakaro ore manifestation by a number of individuals and groups (AGEP, 1979-81; Giday, 1980; Dorofeev et al., 1982; TMEP, 1986 - up to now ; Last and Abdulwahab, 1988; Aster et al., 1988; Grechanic et al., 1988; Alazar, Masresha and Zerihun, 1989; AMEDP, 1989 - up to now; Alazar, 1990a; Ayalew, 1990, 1991; Moudrov et al., 1991; Zerihun and Ayalew, 1992) with the aim of upgrading the deposit either in economic aspect or as exemplum. The detailed survey mainly by AGEP and AMEDP delineate two main ore bodies, namely, Vein No. 1 and Vein No. 2 with an estimated total gold reserves of 2551 kg. Vein No. 1 is calculated to yield 653.4 thousand tonnes of ore which will give 1939.9 kg of gold at an average grade of 3.4 g/t whereas vein No. 2 has 107.4 thousand tonnes ore reserve to produce 612 kg of gold at an average grade of 5.7 g/t.

3. METHODS AND MATERIALS.

3.1. Field works and office study

The investigations at the SGD started (prior to the field work) during the office study in Addis Ababa by a review of the data of the previous works which include maps and reports. Preliminary examination was done and tentative number of case bore-holes and their likely general position with respect to the ore bodies was discussed, and the optimum number of samples for different laboratory analyses have been determined. The review of geologic and assay data available in the archives of AMEDP at Shakisso were also carried out before the field work was started to determine the number of drill-cores and trenches for the purpose of the research.

Geological maps of the SGD and of the open pit at scale of 1:1000 and 1:500 respectively, and their respective sampling plans and sections at 1:500 scale, with core logs and fire assay data that were available provided sufficient information to start with. Fire assay data of 2588 samples from 24 bore-holes and 38 trenches were analyzed at Shakisso central laboratory and were used for the research purpose. For the study of trace and minor elements, and major oxides, 16 bore-holes of 2425 m length were selected out of the available 44 bore-holes of 6056 m length and 30 trenches of 1018 m length were selected out of 56 trenches of 2730 m in such a way as to cover regularly the whole vein system of the deposit. Drill-cores of the 16 bore-holes were checked against the available logs. Alteration zones, mineral associations, textural varieties, macrostructures and contacts between the different rock units were investigated in the field. Totally, 2050 samples were collected for thin and polished sections, silicate analyses and spectral multi-element analyses. Out of these, 1589 samples of rock powders each weighing 50-100 gram were taken from the Shakisso central laboratory duplicate samples. These are powders from trench channel samples and the split halves of the core samples, each representing approximately a one-meter length.

Traverses were taken at 50 m interval on each exploratory line across the strike of the ore body and country rocks, in order to verify the geological map of the deposit and to investigate the field features of the rock units, alteration zones, intensity of weathering, mineral assemblages and macro- and meso-structures of the rocks. Grab samples were selected from the quartz veins exposed by trenches, and textural variations and indications of mineralizations were also recorded. Core samples for thin and polished sections and silicate analyses were taken from the core by splitting further the available halves into halves i.e. one-fourth of a core at intervals to represent variations in alterations, mineralization and different rock units. The numbering and description of the samples were done right on the spot.

3.2. Analytical methods.

Gold contents in the samples were determined at the Shakisso central laboratory using Fire assay technique (taking about 20 gram of a sample) after the reduction of the rock samples by crushing and grinding into -80 mesh fractions. The detection limit of gold reported varies between 0.1 and 0.3 g/t. However, in the statistical treatment of the data, the detection limit is arbitrarily assigned to 0.1 g/t Au. Elements other than gold such as Ag, W, As, Pb, Cu, Mo, Co, Ni, V, Ti and Mn were determined by Optical Emission Spectrometry (OES) method at the central laboratory of EIGS. Though analysis for Zn, Te, Se and S is also helpful, it has not been carried out because of appropriate analytical instrument. The analytical procedure for those elements determined by OES was the spectrochemical analysis where rock powders of -200 mesh size, 15-25 grams of a representative sample, were excited in DC-arc and the spectra emitted by the excited atoms were recorded photographically, and the records consequently were interpreted semiquantitatively. The detection limits (at the minimum wavelengths) reported for the above elements are 0.3, 60, 30, 3, 0.5, 0.5, 3, 10, 3, 10 and 0.5 ppm respectively. Major oxides were also determined at the same laboratory by atomic absorption methods after attacking the representative samples (0.2 gram) by different chemicals, adding fluxes (LiB_2O_7 + LiB_4O_7) and fusing the materials in platinum crucible at 950°c.

Moreover, the collected fresh grab samples were processed for the purpose of mineralogical studies. The sample preparation procedure included splitting by cutting using different diamond blades and preparing slabs which were then ground using a diamond disc and aluminum oxides of variable grit (400, 600, 1200). Thin section preparation was done by mounting the slides on slabs using epofix materials and then resecting and further grinding until the appropriate thickness was achieved, which was 0.03 mm. Polished sections were prepared from ground slabs by a polishing machine using different diamond pastes (which are 6, 3, 1, and 1/4 micrometers), polishing disks and a diamond-polishing lubricant.

3.3. Methods of geochemical and mineralogical studies.

The mineralogical and geochemical data were analyzed using the facilities available at the AAU and EIGS. Statistical treatment of the geochemical data, preparation of content-variation graphs and other element distribution graphs as a preliminary base for the interpretation of the geochemistry of the Sakaro ore elements were done with the use of soft ware programs, mainly "LOTUS", "FREELAN" and "PROBPLOT", and personal computers. The universal reflected and transmitted light microscopes were used to identify and to observe the distribution, associations, paragenesis and zonation of ore minerals and alterations of the rocks of the SGD.

4. BACKGROUND.

4.1. Regional environment and metallogeny.

The association of certain mineral deposits with specific geological environment clearly indicates that they are interrelated. If the right correlation between a geological setting and a mineral deposit can be found, the search for other similar deposits can be more effectively directed (Clifford, 1973). The Adola area is known mainly for gold and rare metals mineralizations. These two mineralizations fall into two distinct low-grade Proterozoic domains (greenstone belts) of metavolcanic-metasedimentary rocks and mafic-ultramafic-felsic rocks respectively, within the basement rocks (gneiss-migmatite complex) of the Adola area (Fig. 2). Various authors attached different names to the belts formed by these rocks; such as "Upper Proterozoic fold belts", "Megado graben-synclinal and Kenticha anticlinal zones", "Adola fold and thrust belts", "Adola greenstone belts" and so forth. Many successful works have been done to determine the mineral potential of the Adola area, by AGEP (1979-81) in particular. The first attempt to relate the mineral occurrences in the Adola area to the geology was made by Jelenc (1966). Later, AGEP (1979-81) systematized the mineral occurrences into metallogenic provinces that included rare metal and gold belts. Recently, TMEP (1989) subdivided the Adola area into provinces that included gold mineralizations of different genetic types, MOR-sulfides (Fe, Cu, Pb, Zn,...) and oxides (Mn, Fe,...), old pegmatites (Mo, Ti, Sn?, W, Li) and young pegmatites (Be, Ta, b, Ti,...).

The litho-structural map (structural provinces) (Fig. 2) of Baraki et al. (1989) examine the geologic settings of the gold and the rare metals fields in the Adola area. The fields are identified as a metavolcanic-metasedimentary and a mafic-ultramafic belt respectively. They are affected by NS-trending regional anticlinal and synclinal structures which are overprinted by tight to isoclinal folds and shear zone tectonics and fracture systems.

The gold mineralization in the metavolcanic-metasedimentary belt is concentrated in low-to-medium grade metamorphic domains (greenschist-to-amphibolite transition facies) of mafic rocks, felsic volcanoclastic rocks and clastic sediments occupying a NS-trending and fault-bounded synclinal zone. It is separated from the low-grade metamorphic domains of the mafic-ultramafic sequence and granite-pegmatite complex (mafic-ultramafic belt) anticlinal zones by a tectonic belt of gneissic rocks of lower-to-upper amphibolite facies which are largely devoid of gold and/or rare-metal mineralizations.

Different models of evolution are proposed by various researchers for the Adola area to explain the regional geologic environment of the present setting in relation to the proposed still controversial models of formation of the Proterozoic fold belts in Africa i.e. ensialic model and plate tectonic model. Therefore, we would like only to indicate that the Adola area which is part of the Pan-African belt is also a component of the general problem under discussion today.

4.2. Regional geologic setting.

The SGD lies within the northeastern part of the folded metavolcanics and metasediments (Fig. 2). The rocks form a metavolcanic-metasedimentary belt that consists of amphibolites of volcanic and plutonic origin, metapyroclastic rocks, graphitic schists, and metasediments derived from pelites, psammites, and conglomerates with amphibolite and gneissic clasts (TMEP, 1989; Baraki et al., 1989). Of these, the rocks that underlie the Sakaro area have been identified as the Chakata formation by Kozyrev et al. (1982), and is 4080 m in thickness. The Chakata formation is the lower unit of the low grade volcano-sedimentary successions (greenstone belt) of Late Proterozoic age, designated as the Upper Proterozoic fold belt or Upper Complex (Kazmin, 1972). Kozyrev et al. (1982) divided the Upper Complex into a lower, mainly volcano-sedimentary (Chakata formation) and sedimentary (Finkilcha formation) sequence, which is called the Adola group, and an upper, mainly coarse clastic sedimentary sequence, the Kajimiti beds, overlying unconformably the Adola group.

The metavolcanic-metasedimentary belt is the only important source of gold in the Adola area. Its relationship to the older basement rocks is tectonic. NS-running faults/thrusts separate this low grade terrain from the older gneissic terrain, thus forming the youngest tectonic block in the area. This tectonic block is 120 km long and 4-14 km wide north-south running linear belt (Shiferaw et al., 1987). The rocks are deformed to tight to isoclinal folds complicated by younger fault/ fracture systems of EW, NE, and EW trends.

The geotectonic style of the fold belt including the environment of deposition and stratigraphy of the underlying rocks, within the framework of the Panafrican-Mozambique belt, are still open to discussion. Some authors (Gilboy, 1970; Chater, 1971; Giday, 1980; Kozyrev et al., 1982; Woldai, 1990; Hailu and Kinetebeb, 1990) considered the Adola area to be the northern extension of the Mozambique belt, and proposed that a predominantly vertical tectonic style of basement deformation, with accumulation of supracrustal sequences in restricted linear features in line with the views of Holmes (1951), Cahen and Snelling (1966), Clifford (1973), Warden and Horkel (1984). Kozyrev et al. (1982) termed the tectonic block formed by the Upper Complex as the Megado graben-syncline. The ultramafic bodies that mark the tectonic suture of the Megado graben-syncline, according to the above authors, indicate an emplacement along deeply seated faults. Kazmin, Shiferaw, and Tilahun (1978) favour the view that the Adola area represents a transition from a development of narrow rift-like ocean to intra-plate ensialic basins, i.e., the ophiolitic bodies may represent small scale ensimatic accretion or slices of oceanic crust with a large scale ensialic reworking of crustal material. De Wit and Senbeto (1981), Baraki et al. (1989), Baraki and Hundie (1989), Ayalew (1990) and Bisrat (1993) explain plate tectonic processes and describe the ophiolites and the volcano-sediments as oceanic settings in accordance to Wilsonian tectonic cycle or the plate tectonic models suggested for Northeast Africa by Gass (1977, 1981), Shacklton (1979), Vail (1976), Greenwood et al. (1980) and Seife M. Berhe (1990). From the above described contrasting models it follows that, the ultramafic-mafic rock associations are either intrusives or slices of oceanic crust. These rocks are represented by serpentinites and talc-tremolite rocks, metagabbro, gabbro amphibolite, diabases and other basic varieties of rocks. These rocks are found mainly in the eastern part of the Sakaro deposit forming a north-south running massif. The supporters of fault with deep-seated origin consider that it could also have an influence in the formation of ore deposits.

Within the deposit area, the metavolcanics and the metasediments, which dip 50-85° toward west, mainly contain micaceous schists that are metamorphosed in greenschist to lower amphibolite facies (Giday, 1980; Dorofeev et al., 1982; TMEP, 1989), and are represented by the upper subformation and upper member of middle subformation (Moudrov et al., 1991) respectively. The amphibolites are described as being consisted of hornblende or, actinolitic hornblende, plagioclase (albite-oligoclase), zoisite, epidote-clinozoisite, quartz, garnet, sphene and trace magnetite or ilmenite. They are frequently found interbedded with the micaceous schists. The micaceous schists are mainly mica (quartz-mica) schists with graphitic interbeds. The mica schists consist of biotite, sericite, quartz and albite, locally enriched with graphite. Local enrichment in silica due to metasomatic effects grades the schists into mica and graphitic quartzites.

In the amphibolites, north of the deposit occur discordant quartzite and granitic gneiss (Giday, 1980). The granitic gneiss is mapped as granodioritic/tonalitic gneiss (TMEP, 1989; Ayalew, 1990; Moudrov et al., 1991). This unit truncates both the amphibolites and the micaceous schists, and also occurs as patches within the amphibolite east of the mine area, forming the peak of Chechebo ridge (TMEP, 1989). Moreover, the lens of kyanite-staurolite schist developed at the contact zone of the micaceous schists with the tonalite gneiss is observed to east of the Sakaro creek. Thus, the truncation of the amphibolites and the micaceous schists together with the development of kyanite-staurolite schists at the contact with the metatonalite indicates that this unit is originally intrusive which has intruded into the metavolcanic-metasedimentary units (TMEP, 1989). Pegmatite veins and lenticular bodies of gabbro diabase and altered ultramafics occur in the southern part of the deposit, some of which (bodies of gabbro diabase) are associated with the ore hosting structure. The contacts of these bodies with the country rocks are tectonized and dipping generally westward.

4.3. Geology of the Sakaro deposit.

The Sakaro deposit is a vein type gold deposit. The veins strike northeast and dip at 45-80° (Dorofeev et al., 1982) towards northwest (Fig. 3). The mineralized quartz veins accompanied by swarms of veinlets and stringers are associated with fault channels and fractures, forming a complex system termed the Sakaro quartz veins zone (SQVZ) (Dorofeev et al., 1982). The SQVZ seems to have dominating structural control in its localization, thereby the shape of the ore bodies. Low magnitude fractures of downthrust type and shear downthrust discontinuities of northeasterly trend, confined to the contact between the schists and amphibolites of the Chakata formation, form a zone that split out in the southwesterly direction to give a typical horse-tail structure (Moudrov et al., 1991).

The Sakaro ore bodies are mainly quartz, containing partings, streaks and fragments of the altered wall rocks particularly graphite. The marginal parts of the ore bodies are shattered and fractured due to the shear effect, forming a banded ore variety owing to the alternating distribution of the ore minerals and rock-forming minerals. The dominant wall rocks exposed in the open pit are amphibolites in the hanging wall side, northwest of the ore body and mica schists which at places are carbonaceous (graphitic) in the foot wall side, southeast of the ore body. Moudrov et al. (1991) have identified variably silicified and graphitized litho-units of quartz-micaceous and quartz-feldspar-mica schists, and schistose and massive varieties of amphibolites. At the northeastern part of the deposit a southern part of the batholith of felsic or intermediate composition (Giday, 1980; TMEP, 1989; Ayalew, 1990;

Moudrov et al., 1991) is observed intruding the host rocks of the Sakaro deposit.

The two main quartz bodies, vein No. 1 and vein No. 2, account for the major portion of the reserves of the SGD. They are generally tabular, lenticular or else complex, varying in thickness from less than 1 m to 9.3 m, 40-150 m in known depth, and 760 m strike length. According to Moudrov et al. (1991), vein No. 1 is the main ore body that has distinct contact with the contrasting lithologies, and evidences of shearing effects. It strikes N65E and dips at 55-75 NW, and is 300 m in strike length. Vein No. 2 feathers the main ore body and has the same strike length, striking N45-50E and dipping 64-78° towards northwest. The other ore bodies are 0.5-3.0 m thick quartz veins, which are vein shoots of vein No. 1, with few tens of meters in strike length and pinching at shallow depth, hosted in quartz-mica schists. The feathering structure of the ore body is accompanied by minor fractures related to the fold of NNE plunge. In the south, the ore hosting structure changes its orientation to nearly north-south and is associated with bodies of gabbro diabase.

5. GEOCHEMISTRY OF THE ORES

5.1. General

In the SGD, gold occurs mainly in quartz veins and stringers, as native gold and/or in association with other minerals. The metals enriched with Au include Ag, Pb, Cu, As, W, Mo, Co, Ni, V and Mn. To relate the chemical properties of these elements to their geologic behaviour, the elements are classified into groups according to the Goldschmidt's (1937; 1954) geochemical classification. Goldschmidt (1937; 1954) after studying the distribution of elements in the earth (through meteorites, smelter products, natural rocks and sulfide ores), grouped elements into siderophiles, chalcophiles, lithopliles and atmophiles (see Table 1). Accordingly, the Sakaro ore elements are classified into the following groups:

(1) Lithophiles - Mn-Ti-V;
(2) Siderophiles - Co-Ni-Mo-(W)-(Mn)-Au;
(3) Chalcophiles - Cu-Pb-Ag-(Au)-(Ni-Co)-(Mo);

Some of the elements in the above mentioned classification show affinity with more than one group. Those elements are given in parentheses under the group with which they have secondary affinity.

Mason (1966) stated that in general, the classification of an element as lithophile, chalcophile, or siderophile refers to

Table 1. Goldschmidt's geochemical classification of elements (from Krauskopf, 1979. Introduction to Geochemistry, Table 20-4, p. 471)

Siderophiles	Chalcophiles	Lithophiles	Atmophiles
Fe Co Ni	Cu Ag (Au)*	Li Na K Rb Cs	H N (C) (O)
Re Rh Pd	Zn Cd Hg	Be Mg Ca Sr Ba	(F)(Cl)(Br)(I)
Re Os Ir Pt Au	Ga In Tl	Al Se Y REE#	Inert gases
Mo Ge Sn C P	(Ge) (Sn) Pb	(C) Si Ti Zr Hf	
(Pb) (As) (W)	As Sb Bi	Th (P) V b Ta	
	S Se Te	O Cr W U (Fe)	
	(Fe)(Mo)(Re)	Mn F Cl Br I	
		(H)(Ti)(Ga)(Ge)(N)	

* parentheses around a symbol indicate that the element belongs primarily in another group, but has some characteristics that relate it to this group. For example, gold is dominantly siderophile, but also appears in the chalcophile group because gold is often found in sulfide veins.

REE= rare-earth elements.

its behaviour in liquid-liquid equilibria between melts. This makes it fairly simple to predict possible patterns of behaviour in igneous rocks that are formed by the differentiation of a parent magma than in metamorphic rocks which could involve different conditions of crystallization. Lithophile trace elements may be expected to follow Goldschmidt's rules for camouflage, admission, and capture by the crystal lattices of the common minerals of metamorphic rocks, but for trace elements of chalophile or weakly lithophile character, electronegativity and the concentration of sulfide ions are probably more significant than ionic size in determining their ultimate deposition (Mason, 1966).

The ore elements of the SGD are analyzed from samples taken both from the ore bodies and the hosting metamorphic rocks (amphibolites and schists). The SGD is a high to medium temperature (420-180°C) hydrothermal deposit (Dorofeev et al., 1982), and the host rocks are metamorphosed to greenschist to amphibolite facies. Aster et al. (1988) consider sulfides as being originated by the sulfidation of the preexisting Fe-rich wall rocks by the mineralizing fluids which supplied only sulfur and minor calcium. Thus, it is presumed that during metamorphism and wall rock alterations or mineralizing fluid/wall rock interaction, the replacement of one mineral assemblage by another may have accompanied mobilization, redistribution and fractionation of both major and minor constituents and also liberation of ore-forming elements from the country rocks to the mineralizing solutions.

5.2. Geochemical characteristics of the ore elements

A review of the geochemical characteristics of the ore elements of the SGD seems proper as a base in the interpretation of the geochemical data obtained.

During the crystallization history of a silicate melt and sulfide mineralization, lithopile elements like Mn and Ti ionize readily and tend to form , or be associated with, silicate magmas. Chalcophile elements such as Cu, Pb, Ag form covalent bonds with sulfur, or with selenium or tellurium if these elements are present. Fe-group elements (or siderophiles) like Co, Ni, Mo and Au normally prefer the metallic bond characteristics and do not tend to form compounds with oxygen or sulfur, thus proving why some metals like gold commonly occur as native elements. The nature of the chemical bond in minerals is extremely important in determining the degree of association between pairs of elements (Levinson, 1974). Many details of the distribution, both in individual minerals and in rocks formed at different stages of differentiation, can be correlated with ionic properties such as size, charge, and tendency to form covalent bonds (Krauskopf, 1979). Many researches have been done in this respect to explain the various associations of elements, such as electronegativity, partition coefficients and crystal field theory. Since the distribution of any element is dependent to some extent on temperature, pressure, and the chemical environment of the system as a whole, the different groups of the ore elements overlap, as is shown by the occurrence of many elements in more than one category.

A review of the geochemical character of the ore elements in the SGD ores is discussed briefly below based on the publications of various authors (e.g. Goldschmidt, 1937, 1954; Rankama and Sahama, 1953; Betekhtin, 1964; Ramdhor, 1969; Boyle, 1979; etc.) to give a general picture for the understanding of their behaviour during the formation of the hydrothermal ores and host rocks, and the subsequent metamorphism and weathering of the rocks and ores containing them.

(1) Ti, Mn and V are abundant trace elements and are geochemically strongly lithophile. The elements are related to Fe in their chemical properties and are members of the Fe-family. They are oxyphile in the upper lithosphere and form a number of independent minerals or are found concealed in structures of rock-forming minerals.

(a) Ti forms independent minerals like ilmenite ($FeTiO_3$), rutile (TiO_2) and sphene $(CaTi)(O, OH, F)[SiO_4]$ which are found as accessory constituents of many rocks. In addition, it is concealed in the structures of pyroxenes, amphiboles, micas, etc. where the Ti-Si diadochic substitution is found predominating. During weathering, the most important Ti minerals particularly ilmenite and rutile are stable. Ti in ferromagnesian minerals is brought into solution during weathering, but is promptly hydrolyzed and incorporated into the hydrolyzates. Studies on many gold-quartz deposits indicate as

Ti accompanies gold mainly in minerals such as leucoxene, rutile, ilmenite, sphene as alteration products in the host rocks during primary mineralizations. These minerals also associate gold in placers as a consequence of their stable character and high specific gravity.

(b) Mn is strongly a lithophile metal and it has some chalcophile tendencies. Nearly all minerals contain manganese and it is also found as an independent mineral. In its independent silicate minerals, Mn occurs exclusively in the form of Mn^{2+} ions. In its oxides, Mn, however, is often present as Mn^{3+} ions and still more commonly as Mn^{4+} ions. Minerals such as wolframite particularly hubnerite $Mn[WO_4]$ are rich in Mn (5-15 percent MnO) . It is also found incorporated in sulfides such as sphalerite where the highest content occurs in those formed at higher temperatures. Hydrothermal veins often carry rhodochrosite or siderite high in Mn (mangansiderite). The replacement of Fe^{2+} by Mn^{2+} is the most common and geochemically the most important among other diadochic substitutions. Thus, biotite contains up to 1% and hornblende - 0.3% MnO. Mn generally accompanies Au in hypogene deposits mainly in the form of manganiferous carbonates. In most of the known gold deposits in the world, much of the Mn in alteration zones and gold ores appears to have been contributed by the nearby host rocks. The presence of supergene manganese minerals in the oxidized zones of gold deposits are important in the migration of gold. Oxides of Mn tend to adsorb and/or coprecipitate gold from solution and as a result gold will be enriched in the oxidized zone. On the other hand, MnO_2 and some other oxides aid in the formation of chlorine ($4HCl + MnO_2 \text{--->} MnCl_2 + 2H_2O + Cl_2$) which complexes with gold ($Au + Cl_2 \text{--->} [AuCl_4]^-$) and renders it mobile. Thus, in the presence of chlorides and sulfuric acid, gold may be mobilized and may migrate downward to the zone of reduction where some of the elements are precipitated in the native state or incorporated in the secondary sulfides.

(c) V occurs in three stable oxidation states as V^{3+}, V^{4+} and V^{5+}. All these, particularly V^{5+}, show a tendency to form complexes with oxygen and partly with sulfur. These facts account for the relatively large number of V-minerals in general and for the extensive possibilities of diadochic substitution of various elements in mineral structures by V. V is largely found in magnetite and Ti-minerals. Pyroxenes, amphiboles, micas etc. also carry some V as V^{4+} and V^{5+} ions, which replace Fe^{3+} and Al^{3+}. The possibilities of migration and concentration of V as volatile compounds and in hydrothermal solutions is not yet known. V is present in some hypogene gold deposits in sericite, roscoelite, pyrite, apatite, magnetite, ilmenite and leucoxene. It is reported that gold ores rich in tellurides frequently have higher than average amounts of V either in pyrite or in the vanadiferous micas. However, the reason for the relationship between Te, V, and Au is not yet clear.

(2) Co and Ni are members of the Fe-family and are the closest

relatives of Fe in the periodic system. Geochemically, Co and Ni are strongly siderophile, however, Co is notably less siderophile than Ni. Nonetheless, the observations on the occurrences of Co and Ni in the upper lithosphere show that these metals possess chalcophile tendency. Along with their siderophile and chalcophile character, Co and Ni also posses lithophile tendency.

Ni is one of the typical elements of the pyrrhotite ($Fe_{1-x}S$) - pentlandite ($(Fe, Ni)_9S_8$) assemblage. On the other hand, considerable Co but very little Ni enter into pyrite which crystallizes late from the sulfide melt. In hydrothermal sulfides the Co:Ni ratio is high and often even greater than 1, and thus Co may predominate over Ni. Generally speaking, Co has a considerable higher tendency to remain in residual solutions than Ni. Co substitutes for Fe in the pyrite structure and may also be incorporated in sphalerite. Sphalerites formed at high temperatures are rich in Co. In metalliferous veins, Co and Ni form a number of sulfide and arsenide minerals (e.g. cobaltite, CoAsS; niccolite, NiAs etc.). Also, a number of minerals of Co and Ni as hydroxides, arsenates, sulfates and carbonates are known in the weathering environment (e.g. spherocobaltite, $CoCO_3$; erythrite, $Co_3(AsO_4).8H_2O$; annabergite, $Ni_3(AsO_4).8H_2O$, etc.). In most types of gold deposits, Co and Ni accompany Au but generally only in trace or minor amounts. In most hypogene deposits, Co and Ni are a constituent of pyrite, pyrrhotite, chalcopyrite, arsenopyrite and tennantite-tetrahedrite in which they are present in amounts up to 100 ppm. Co- and Ni-sulfides and arsenides are relatively rare in gold deposits. In gold placers, they are found as a trace or minor amounts in a number of heavy minerals (e.g. pyrite, arsenopyrite, magnetite, etc.) that accompany gold.

(3) Mo and W, according to their positions in the periodic table, are closely related to each other and their chemical properties are much alike, but they show notable difference in their geochemical behaviour. The general geochemical character of Mo is siderophile, with a definite chalcophile tendency. W is strongly lithophile, with a weak siderophile tendency, but no chalchopile behaviour at all. In the presence of a considerable content of Mo during the crystallization of sulfides, it readily collects all sulfur available to form molybdenite, MoS_2, and consequently sulfides of other metals may be formed only if there is still sulfur available. W also forms the sulfide (tungstenite, WS_2) but it is rare in nature. W is preferentially present in rocks as tungstates (e.g. wolframite, $(Fe, Mn)[Wo_4]$, scheelite, $Ca[WO_4]$, etc.). The radii of Mo^{4+} and W^{4+} are equal, therefore, the two ions are able to replace each other in mineral (for example, in chillagite $Pb[(Mo,W)O_4)]$, powellite, $Ca[(Mo,W)O_4])$. A number of molybdates and tungstates are also known as minerals containing the elements like Cu, Pb, Zn, Fe, Ca, Al.

In gold deposits, Mo is commonly associated with Au but is generally present only in small amounts. Molybdenite is the only common hypogene Mo mineral found in gold deposits. Traces of Mo may also occur in some of the sulfides and in scheelite in gold deposits. W is nearly a universal associate of gold in its hypogene deposits as scheelite. Wolframite and its varieties, such as ferberite and hubnerite are less frequent but in places may be relatively abundant. Scheelite and wolframite concentrate with gold in placers. However, in the presence of oxidizing water that contains H_2SO_4 or dissolved Na, K or Mg salts, both minerals are slowly dissolved yielding a variety of supergene W-bearing minerals.

(4) Cu is a relatively abundant element as compared with the other heavy metals. Very little Cu, if any, is generally present in the silicate phase, whereas the Cu content in the metal phase is reasonably high and the sulfide phase may contain still more Cu. Therefore, Cu geochemically is mainly chalcophile, but not without a siderophile tendency. Cu shows a high affinity for sulfur and is one of the most typical constituents of sulfide ores. The observations made in copper-ore smelters show that Cu, among the sulfide-forming elements, has one of the highest affinities for sulfur which in decreasing order is found to be: Mn-Cu-Ni-Co-Fe-Sn-Zn-Pb-Sb-Ag. Sulfides and sulfosalts are the most important Cu minerals. However, the metal is found rather regularly as a constituent of the early-separated sulfides in hydrothermal deposits. Cu occurs as a constituent of a great variety of sulfides and sulfosalts which show pronounced variations in their composition, manner of occurrence, and parageneses with Ag, Ge, Sn, Pb, Fe, Ni, Co, and still other

metals. In the weathering environment Cu forms a number of minerals such as sulfates, carbonates, arsenates silicates and phosphates. In all types of gold deposits, Cu is a constant associate of Au, varying in amount from traces to a few percent. The most common Cu minerals in gold deposits are chalcopyrite, enargite, chalcocite and tetrahedrite-tennantite. In the oxidation zone of some gold deposits a number of secondary Cu minerals accompany Au.

(5) As readily combines with sulfur, selenium and tellurium and form sulfosalts, arsenides with various heavy metals, preferably Cu, Fe, Ni, and Co. Generally having a chalcophile tendency, As is also found enriched in the meteoric iron, therefore, is also siderophile. The greatest number of As minerals such as arsenopyrite (FeAsS), cobaltite (CoAsS) and others are found in the hydrothermal stages. In most types of gold deposits, there is a marked coherence between As and Au. The most common As minerals are arsenopyrite and tennantite-tetrahedrite. Other As-bearing sulfosalts are common in certain deposits. In alteration zones of gold-quartz veins, As is also observed in relatively large amounts in some deposits that increase when the deposit is approached. Oxidation of primary As-bearing minerals yield a variety of supergene arsenates and basic arsenate-sulfates, the most commonly found being scorodite.

(6) Pb shows both chalcophile and siderophile tendency. Pb has

a tendency to form numerous sulfides, selenides, sulfosalts, phosphates, arsenates and silicates. Pb sulfides are often found enriched in hydrothermal deposits. At low temperature it has affinity for sulfur whereas at intermediate and high temperatures it occurs exclusively as oxygen-bearing compounds. Pb is also known as the most important silver-containing mineral (up to 2% Ag). Pb is a universal associate of Au in all types of its deposits. Galena is the principal Pb mineral in all primary epigenetic gold deposits. In the oxidation zone, Pb (in supergene Pb-bearing minerals) is enriched with Au.

(7) Au and Ag. Au, Ag and Cu all belong to the same sub-group of the periodic system. Therefore, the manner of occurrence of Au and Ag in the upper lithosphere notably resembles that of Cu. Cu and Ag are occur mostly combined with sulfur, partly, with selenium in the form of various sulfides and selenides. In spite of its siderophile character, Au follows Ag and Cu in the upper lithosphere as a sulfophile. However, it doesn't form any independent sulfide mineral. Au accompanies Se and, particularly, Te and becomes enriched together with these elements. It is found in nature in the native state, alloyed with Ag (electrum) and platinum metals, and as tellurides in many sulfide deposits.

Ag occurs as a native metal and also forms ore minerals combined with sulfur, arsenic, and antimony. The most important Ag mineral is argentite (Ag_2S). In gold deposits, the most common Ag-bearing mineral is tetrahedrite-tennantite. It also occurs in galena from which it is extracted as by-product. Galena formed at high and intermediate temperatures are richer in Ag than those crystallized at low temperature. Native Ag is usually contains Au, Cu and other metals.

The most important Au-tellurides are calaverite ($AuTe_2$) and sylvanite ($AuAgTe_4$). Like native Ag, native Au is always impure. Ag, Cu, Fe and Pt metals are the foremost admixtures. In the simultaneous occurrence of a sulfide and an arsenide phase, Au, because of its siderophile behaviour, is preferentially concentrated in arsenides, which possess a pronounced metal-like character. Likewise, Au, as a siderophile element, prefers the metal-like minerals of the pyrite and marcasite- loellingite groups. It is generally associated with pyrite and arsenopyrite.

Au and Ag differ notably in their behaviour during weathering. Like Cu, Ag is brought into solution as sulfate. In the cementation zone of ore deposits, Ag, is reprecipitated as chlorides, sulfides or sulfates. Au is chemically more inert than Ag and since its compounds are readily reduced to metal, it remains largely in the native state and becomes concentrated in the resistates. Au dissolved from gold ores in the zone of oxidation is redeposited in the cementation zone, in which a secondary enrichment may sometimes take place.

The behaviour of various elements during the crystallization history of a silicate melt and sulfide mineralization is summarized in Table 2. It shows the timing and tendency of elements in mineral formation, thereby expected zonation. Some elements tend to form their own minerals and some tend to

Table 2. Comparison of the known behaviour of various elements during silicate melt crystallization with the behaviour postulated for chalophile elements during sulfide mineral deposition (from Taylor, 1963, in symposium on problems of post magmatic ore deposition, Table 1, p. 311).

Type of Element	Igneous rocks	Metallic Sulfide deposits
-Abundant elements that make up major minerals	Si,Al,Fe,Ca,Na,K,O	Fe,Cu,Zn,Pb, S, As, (Co,Ni)
-Rare elements that tend to concentrate in latest stages of crystallization, there by forming separate minerals of their own.	Li,Be,B,Cs,Rb, Ta,U,F,Sn,W,Th, Rare earths	Au,Ag,Sb,Hg Te,Se, (Bi)
-Rare elements that readily enter into the structures of major minerals, and therefore do not concentrate in latest stages of crystalization.	Ga,Ge,Cu,Ni,Co,Zn Sr,Ba,V,Sc,Er,Mn, Pb, Ti	Cd, Tl, In Ge, Sn, Ga, Mn, V, (Co,Ni)
-Rare elements that form very insoluble mineral species, and therefore crystallize relatively early as minor (accessory) minerals.	Zr, P, Ti, Cr, S	Mo, Bi

be partitioned into the structures of major silicate or sulfide minerals. Therefore, in an ore-bearing solution responsible for the present sulfide-gold quartz formation of the SGD, Fe-Cu-Pb-As and possibly Co-Ni form major minerals at an early stage of mineralization. Au and Ag are some of the relatively rare elements that tend to concentrate mainly in latest stages of mineralization that can form insoluble mineral species, and therefore can crystallize relatively easily as minor minerals if abundant. Generally, Mo-Co-Ni do not occur in sulfide mineralization forming their own separate minerals. Mn, V and even Mo, Co and Ni readily enter into the structure of sulfide minerals, and therefore do not concentrate in latest stages of crystallization. Mo is one of the elements that can form insoluble mineral species and therefore can crystallize relatively early as minerals if abundant. Generally, Mo-Co-Ni do not form their own minerals if they are minor constituents.

A generalized paragenetic sequence of heavy metals (Lindgren, 1933) is Fe-Ni, Co (if abundant) - Zn-Cu-Pb-Ag-Au; and the order of deposition of the non-metals is S-As-Sb-Se, Te. The most abundant tend to be earlier and the rarest elements tend to be late (Taylor, 1963). Taylor by compiling 550 mineragraphic determinations of paragenetic sequences in ore deposits throughout the world carried out a statistical treatment if differences in the order of sulfide mineral deposition could be consistently correlated with the chalcophile element composition of an ore deposit. In most of the deposits Fe sulfides appear as the earliest in the paragenesis which agrees with the observations that Fe is far more abundant in hydrothermal ore deposits than any other heavy metal. The low relative abundance of Au- and Ag-bearing minerals is also correlated with their late deposition from an ore-forming solution. But deposition of minerals like molybdenite and bismuthnite can be explained by their relative solubilities. They are one of the most insoluble sulfides that, irrespective of their low abundance, occur early in paragenetic sequences and relatively close to the presumed source of ore fluids.

5.3. Distribution of the elements in ores and enclosing rocks.

The content variation diagrams (Fig. 4-29) illustrate the spatial distribution of the elements in the ore and country rocks of the SGD, and also the types of the metal associations qualitatively. The spatial distribution and the mutual associations of the elements is not consistent throughout the deposit, thereby indicating the complex conditions during ore deposition. During the mineralizing process, anomalous concentration of metals by hydrothermal fluids near the ore body and channel ways obviously always takes place. Apart from the leaching of elements along portions of the path of the ore-forming fluids and hydrothermal alterations of minerals in the wall rocks, various stages of mineralization and remobilization of ores with tectonic/structural complications could have led to the superimposition of ore minerals in the SGD, thereby responsible for its observed geochemical complexity.

In the interpretation of the geochemical response of the minor and trace elements in content variation diagrams, emphasis is given on the variation trends rather than the absolute values of the contents. Thus, the geochemical characteristics of the individual elements and the observed geochemical dispersion is considered on the basis of the geochemical signatures of the mineralization which is the effect of the operating geological process during and after the ore formation. In describing the importance of spatial patterns of elements, Govett (1983) stated that geochemical deviations from "normal" are relatively uninformative, and that only variation trends within a region, district, or an area are of practical importance. He also stated that apart from the problem of establishing even a local background for many elements, a number of more subtle, but extremely useful, anomalies lie within so-called background changes and identification of these types of anomalies is generally possible only through the recognition of spatial patterns of relative enrichment or depletion.

For the general purpose of comparison a range of average abundances of elements to be expected in common rocks like that in the SGD is given from publications (see Table 3), however, neither these data, nor similar data from other sources, can be used as background values (Govett, 1983), which must be established in each region and area as part of the exploration programme.

A total of 1859 number of complete analyses for Ag, W, As,

Table 3. Abundance of elements in common rocks (extracted from Govett, 1983, Rock Geochemistry in Mineral Exploration, Vol. 3, Appendix 2)

Element	Symbol	Atomic number	Atomic weight	Mafic (range)	Mica schists
		Major and minor elements (wt%)			
Manganese	Mn	25	54.938	0.124-0.147	0.09
Titanium	Ti	22	47.90	0.56-1.80	0.59
		Trace elements (ppm)			
Gold	Au	79	196.9665	0.0003-0.018	(0.001-0.057)
Silver	Ag	47	107.868	0.1	0.3
Lead	Pb	82	207.2	0.76-10.2	30
Copper	Cu	29	63.546	47-160	30
Arsenic	As	33	74.9216	0.28-20	(3.2-18)
Tungsten	W	74	183.85	0.27-6.3	(1.5-3.8)
Molybdenum	Mo	42	95.94	0.6-2.8	(0.7-2.0)
Cobalt	Co	27	58.9332	37-50	20
Nickel	Ni	28	58.71	69-530	50
Vanadium	V	23	50.9414	50-400	70

Note: When data is missing for mica schists, range values for shales are used and are indicated in parentheses

Pb, Cu, Mo, Co, Ni, V, Ti, Mn (OES) and Au (Fire assay) have been made for this study. The representative data of OES analyses are given in Appendix I. Core logs and surface sampling plan (AMEDP) are used to illustrate the geology and distribution of the above mentioned elements. Geochemical dispersion pattern of the elements is shown across the strike and thickness and along the dip of veins and wall rocks.

5.3.1 Spatial distribution of metals

The effect of mineralization and hydrothermal alteration can be detected in the distribution of some ore bodies and wall rocks of the SGD.

(1) Fe-group elements (Co-Ni-Mo-V-Mn-Ti) show enrichment in the wall rocks, enhanced at the periphery of the deposit (e.g. Fig. 15, 24, 26). The width of this zone is 10-80 meters from the ore veins (down-hole distance) to hanging and foot wall rocks. In case of the foot wall side, it may include a zone of depletion near the ore veins until it attains the maximum concentrations. The enriched zone is generally well seen in the hanging wall rocks (amphibolites), however, the background values of these metals in both the amphibolites and mica schists are similar: Co - 5-10 ppm, Ni - 20 ppm, Mo - 3 ppm, V - 20 ppm, and Mn and Ti - 200 ppm. The enriched zone with these metals has enhanced values above the background values with Co - >80, Ni - >320, Mo - >12, V - >320, Mn and Ti - >1600. The selective

enrichment of these metals in the wall rocks could be ascribed to the effect of wall rocks and ore-bearing solutions interaction. Since regional metamorphism doesn't affect the original trace element composition of rocks (Shaw, 1954), variations are not expected to occur in the regionally metamorphosed host rocks of the SGD, except in account for their lithologic variation. However, the same background values of the Fe-group metals in mica schists and amphibolites are observed due to the presence of the ferromagnesian minerals in both of these rocks. Thus, the maximum concentration of these elements in the wall rocks is due to the hydrothermal alteration which could enhance the background values of these metals in these rocks or remobilization and concentration of existing sulfides. The effect of the hydrothermal alteration is evident by actinolite-chlorite-biotite (hanging wall side) and sericite-chlorite-biotite (foot wall side) assemblages in the wall rocks near the quartz veins. Actinolitization, chloritization, biotitization, carbonatization and silicification are the main alteration types in the wall rocks (Moudrov et al., 1991) that are responsible for liberation and reconcentration of Fe-group metals from the country rocks. Many researches on hydrothermal alteration effect (e.g. Boyle, 1979; Barnes, 1979; Park and MacDiarmid, 1975; Fyfe and Kerrich, 1982) often indicate that wall rocks adjacent to ore bodies are profoundly changed in composition as a result of the penetration of the ore fluids into the rocks. Hydrothermal alterations are the result of an interaction of ore solution and wall rocks involving addition and substraction of metals either to the wall rocks or to the ore solution. Commonly, the elements added by the ore solutions are Si, C, Mg, Na, K, Ca and Fe (Krauskopf, 1979). Thus, apart from the remobilization of earlier sulfides, the breakdown of high temperature ferromagnesian minerals to actinolite-chlorite-biotite assemblage accompanies liberation of some of the metals which are more than the amount to be accommodated in latter minerals. The excess amounts, thus, form local maxima in the altered country rocks. In quartz veins, they generally have low concentration, showing mostly a negative correlation to ore-forming metals like Au-Ag (Fig. 15). Therefore, the prevailing tendency of the Fe-group elements towards the wall rocks than the ore bodies might be explained by their behaviour to be partitioned more to solids than solutions. However, rarely do they show peaks that are localized or extended to a vein (Fig. 26), which could be described by a multi-stage character of deposition of metals as sulfides from solutions, or the solutions character to deposit these metals at a single stage at various depths sometimes to the veins when the physical and temperature conditions favour deposition of minerals of these metals. The other alternative is that they could be admixtures of sulfides of other metals. Thus, they possibly could have formed their own minerals or occurred as traces in major sulfides of the deposit (see Table No. 2). Their peaks are entirely absent, at least for most of the elements, in the ore (ore vein No.1), in the primary environment, and are exclusive only to the oxidizing and surficial environments (Fig. 5, 8, 9, 11, 16, 17, 20, 22, 25, 26). Therefore, their exclusive enrichment in the secondary environment indicates that those metals occurred as traces in major sulfides in quartz veins. The sulfides are not stable in the oxidizing environment. Their disintegration have favoured for the observed peaks of these trace metals which is not found in the primary environment. It follows that their anomalous concentrations in the zone of weathering are due to the oxidation and leaching of pre-existing sulfides and silicates that appear to have released metals which have become secondarily fixed in the upper levels of the deposit.

Sometimes extensive anomalies of Mo-Co-Ni occur up to 150 meters down hole (Fig. 7, 10) with discrete spikes in mica schists that do not seem to be primary dispersion related to the emplacement of the veins in strict sense. However, when the vein (ore vein No. 1) passes its way to the rocks underlying the Sakaro area it horsetails, therefore, could have impregnate these rocks which show high contents of these metals with sulfides. The vein shoots are shallow in depth (see section 4.2) and of variable thickness that range from a few cm to a maximum at the ore vein No. 2 (7 m) where it branches off ore vein No. 1. These vein shoots are found emplaced in mica schists, and therefore, are responsible for the observed anomalies of the above metals seen localized mostly to the mica schists. These high contents could, of course, be enhanced further in the weathering and oxidizing environments of the vein shoots and mica schists.

Since metals of sulfide ore minerals may be converted into insoluble compounds stable under surface conditions (oxides, carbonates, sulfates, silicates) or may be taken into solutions (Krauskopf, 1979), each of the Fe-group elements with strong peaks at the present surface and in the oxidized part of the vein could form minerals stable under surface conditions such as molybdates, vanadates, oxides and hydroxides of other minerals or their own.

(2) W shows discrete spikes distributed in the ore veins (e.g. Fig. 17, 26, 29) or at the contact of the ore veins with the country rocks (e.g. Fig. 17, 18, 29) or in the country rocks (e.g. Fig. 9, 11, 22, 24). The maximum concentration (up to >10,000 ppm) is seen either in the ore veins or near the veins in the wall rocks. The exceptions are the low magnitude concentrations that show discrete narrow spikes which could occur anywhere in the country rocks. The geochemical dispersion of W is confined to the enclosing rocks 20 meters thick (down-hole distance). Those low order peaks found scattered in the country rocks are considered anomalous based on the assumption that the local background for W is below the detection limit which is 60 ppm. The assumption is based upon that (i) most of the samples (84.13%) analyzed for W show contents below the detection limit of the spectrochemical analysis which is described above as 60 ppm and (ii) from publications the W content of unmineralized similar (to the SGD) rocks (see Table No. 3) in the world show a range 0.27-6.30 ppm. Though the

second point is undependable, for the reasons that it is the regional background and it is not obtained from the area under discussion, it could be used for comparative purposes. To make the assumption more satisfactory, it seems sensible to allow a range that the local background would fluctuate. Qualitatively, 60-100 ppm is selected and it turns out to be in agreement spatially with the local background variations of the metals it is commonly associated with (e.g. Fig. 9).

The geochemical dispersion of W in the country rocks is controlled by fractures which are actually healed by quartz veinlets and stringers. The peaks are sharp and narrow spatially related to similar peaks of the chalcophile elements (e.g. Fig. 6, 77, 11, 18) especially with As-Cu-Pb. The enrichment of W in the wall rocks near or/and at the contact with the ore bodies and in the ore veins is also spatially related with chalcophiles (Ag-Pb-Cu). Thus, these associations point to the possible relations of W ore minerals in space with sulfides of the above chalocophile elements. W-bearing minerals can be deposited from an ore-bearing solution in the form of sulfides or oxides. However, tungsten sulfide known as tungstate (WS_2) is so rare even for detailed mineralogical study (Betekhtin, 1964), therefore, oxygen compounds of W are the only expected minerals. W also shows zones of enrichment in the wall rocks near the veins and a depletion in the veins (e.g. Fig. 10), like the Fe-group (Co-Ni-Ti-V-Mn) elements. Thus, this similar behaviour shown by these metals which are known to form high temperature minerals indicates that they are subjected to the same depositional environment.

(3) Chalcophiles (Cu-Pb-Ag-(Au)-(Ni-Co)-(Mo))

(a) Cu has a local background of 200 ppm within the hanging and foot wall rocks. Its geochemical dispersion can be flat (e.g. Fig. 13, 21, 23, 24, 29), or with peaks confined to the veins (e.g. Fig. 9, 12, 15, 17, 19) or extended to wall rocks like the Fe-group elements (e.g. Fig. 5, 6, 13, 14, 16, 17, 22, 28). Its dispersion in the wall rocks varies in extent from the ore veins between the limits shown by W-As to that of the Fe-group elements. In most of the cases its peaks are not strong and are usually enhanced above the background values in 400-800 ppm range. It has wide dispersion pattern spatially associated with Fe-group elements which show significant enrichment in the wall rocks and to Ag and Pb which are confined to a vein. This indiscriminate association of Cu to metals that form earlier sulfides and also to metals of sulfides that crystallize later from the hydrothermal solutions is known in nature in the association of complex Cu-Fe sulfides with Fe-sulfides, galena and others.

(b) Ag and Pb show similar geochemical dispersion patterns. These elements are mostly confined to the ore veins and are found within 5-10 meters (down hole distance) from the ore veins in the wall rocks (e.g. Fig. 12, 14, 15, 16, 17). The background values are 10-50 ppm and 1 ppm for Pb and Ag respectively. The intensive peaks of both Ag and Pb are confined mostly to the contacts of the ore veins and wall rocks, with an enhanced values above the background in the range of 200-10,000 ppm (Pb) and 3-300 ppm (Ag). Spatially they are closely associated exhibiting similar dispersion patterns, thus, suggesting the affinity of the metals to occur together along the hydrothermal fluid channel ways and in the ore veins.

(c) The dispersion pattern of Mo-Co-Ni as chalcophiles is described in the discussion of the spatial distribution of the Fe-group elements.

(4) Au occurs spatially associated in most of the cases (75%) with Ag and Pb. Except for a very few spikes in the wall rocks which are controlled by fractures healed by thin quartz veinlets and stringers. The above three metals are enriched in the ore veins and at the tectonic/lithologic contacts with the wall rocks. Their dispersion pattern is mostly asymmetrical (e.g. Fig. 12, 15, 24) with steep side (elevated values) at the contact of vein with the hanging wall rocks (amphibolites) and a gentler slope towards the foot wall rocks (mica schists). Though Au is tightly related to Ag and Pb sometimes it show significant values (up to 3 g/t) where the values of Ag and Pb are low (e.g. Fig. 5, 8 24). The background value of Au is taken as 0.1 which is also the detection limit of the metal by Fire assay. Its meximum concentration ranges from 28.2 ppm in the primary environment to

52.2 g/t in the oxidizing environment and 32.4 g/t in the zone of weathering. The behaviour of gold in these environments will be discussed in detail in section 5.6.

5.3.2 Metal associations.

The spatial relations between the ore metals have been already described in section 5.3. But we need to know how variable the relationships between the metals are in different environments and how strongly the metals are tied together in these environments. To achieve this goal, thereafter, the metal associations, the relationship between the ore elements is quantified with respect to the different depositional environments observed in the SGD.

Correlation coefficient matrices for ore elements in the ore veins and wall rocks are given in Tables 4-7. In calculating the correlation coefficients, the ore veins and wall rocks are grouped into those which occur (1) in the weathering (supergene) and (2) in the primary (hypogene) environments. Rocks in each environment is further subdivided into wall rocks/veins of ore vein No. 1 and wall rocks/veins of ore vein No. 2. Ore vein No. 2 is a system of veins which are vein shoots from ore vein No. 1. As a result of the above groupings, we do have the correlation matrices which are categorized into four main groups, namely, 1) in sample suites of fresh rock samples of ore vein No. 1 and wall rocks, 2) in sample suites of weathered rock samples of ore vein No.1 and wall rocks, 3) in sample suites of fresh rock samples of ore vein No. 2 and wall rocks and 4) in sample suite of weathered rock samples of ore vein No. 2 and wall rocks. The metal contents in the mixtures of ore veins and wall rocks are omitted from the calculation of correlation coefficients. Therefore, the bias introduced in the inter-element relationships could be avoided, however, it should be noted also that some significant relations that could occur at the veins/wall rocks contacts are missing.

The correlation coefficients show a range from positive significant correlations to negative significant correlations between the elements that show enrichment-depletion relations. When the elements show significant correlations they are typed bold in the tables for an easy reading. Based on the correlation coefficients given in the tables a discussion on element inter-relationships is given below.

(1) Au - In the SGD Au is found with significant correlations with Ag, Pb, Cu, Mo and rarely with As, W, and Ni. Au in most cases, as can be deduced from the above mentioned inter-element relations is found associated with Ag, Pb, Cu .

Au and Ag show significant correlations in ore vein No.1 and in mica schists, whereas in vein No. 2 and amphibolites they show the least correlations. In ore vein No. 1 equivalent correlation coefficients are present both in fresh rocks (r = 0.52) and weathered rocks (r = 0.54) samples. The best significant correlation is seen in fresh rock samples of mica schists (r = 0.82). This relation decreases in the weathered rock samples to r = 0.25. In the mica schists of ore vein No. 2 r = 0.66 in fresh rock samples and r = 0.49 in weathered rocks. It can be generalized that there is a tendency to decrease Au-Ag relation from the primary environment towards the secondary environment in wall rocks, and with almost constant relation in sulfide gold-quartz veins. A decrease of Au-Ag relation in weathered rock samples could be due to the mobility differences of these metals in solutions. In oxidizing and surficial environments, Ag is mobile both in acidic and neutral solutions whereas Au is immobile (see table 8). The strong correlations of Au and Ag in mica schists and the absence of (or weak) correlation in amphibolites confirms the spatial relation of Au and Ag described in section 5.3 as they have a steeper slope at the contact of the ore veins and wall rocks and a wider decreasing geochemical dispersion in mica schists.

Au and Pb show significant correlations in weathered samples of ore vein No. 1 (r = 0.41) and in fresh samples of ore vein No. 2 (r = 0.76). In the ore vein No. 1 and its hanging wall rocks (amphibolites) there is a general tendency of increasing (r = 0.09 for fresh samples and r = 0.46 for weathered samples) relations in the surficial environment, whereas the strength of the relation between these metals decrease at the surface for ore vein No. 2 (r = 0.76, -0.01 for fresh and weathered samples respectively) and foot wall rocks (mica schists) (r = 0.59, 0.46 for fresh and weathered varieties respectively). Au and Pb like Au and Ag show significant correlations in foot wall rocks which are more tight than in hanging wall rocks for the similar

Table. 4. Correlation coefficient matrices for ore elements of the Sakaro gold deposit in sample suites of weathered rock samples of ore vein No. 1.

Sulfide-gold-quartz vein (sample size=57)

	Au	Ag	W	As	Pb	Cu	Mo	Co	Ni	V	Ti	Mn
Au	1.00											
Ag	**0.54**	1.00										
W	-0.10	0.13	1.00									
As	-0.11	-0.13	**0.57**	1.00								
Pb	**0.41**	**0.60**	0.06	-0.07	1.00							
Cu	**0.20**	0.13	0.01	-0.03	**0.30**	1.00						
Mo	-0.16	0.00	**0.38**	**0.34**	0.04	0.12	1.00					
Co	-0.01	-0.08	0.01	0.05	0.07	**0.34**	-0.11	1.00				
Ni	-0.04	-0.13	0.10	**0.25**	-0.06	**0.32**	-0.11	**0.49**	1.00			
V	-0.13	-0.04	0.06	0.11	0.08	**0.41**	**0.47**	**0.24**	0.06	1.00		
Ti	-0.18	-0.11	0.00	0.14	-0.11	-0.04	**0.30**	0.06	0.13	**0.54**	1.00	
Mn	0.10	-0.02	0.12	0.03	**0.21**	**0.29**	-0.06	**0.26**	0.08	-0.01	0.08	1.00

Amphibolites (sample size=100)

	Au	Ag	W	As	Pb	Cu	Mo	Co	Ni	V	Ti	Mn
Au	1.00											
Ag	0.13	1.00										
W	0.02	**0.32**	1.00									
As	0.12	0.10	**0.20**	1.00								
Pb	**0.46**	**0.68**	**0.25**	**0.29**	1.00							
Cu	0.04	**0.54**	**0.28**	**0.30**	**0.33**	1.00						
Mo	**0.49**	**0.31**	-0.09	0.11	**0.62**	0.04	1.00					
Co	-0.09	0.08	0.07	-0.07	-0.11	0.14	-0.15	1.00				
Ni	-0.07	0.03	0.10	**0.24**	-0.01	**0.39**	-0.02	0.18	1.00			
V	0.11	**0.24**	0.00	-0.11	-0.07	**0.38**	0.03	**0.45**	**0.28**	1.00		
Ti	-0.12	-0.09	-0.15	-0.05	-0.07	-0.13	-0.06	0.15	-0.22	0.03	1.00	
Mn	-0.10	-0.11	-0.16	-0.14	-0.11	-0.17	-0.06	-0.03	-0.25	0.02	**0.82**	1.00

Mica schists (sample size=78)

	Au	Ag	W	As	Pb	Cu	Mo	Co	Ni	V	Ti	Mn
Au	1.00											
Ag	**0.25**	1.00										
W	0.08	**0.54**	1.00									
As	0.04	-0.05	0.08	1.00								
Pb	0.09	**0.53**	**0.56**	**0.23**	1.00							
Cu	0.14	**0.44**	**0.40**	**0.25**	**0.70**	1.00						
Mo	-0.16	-0.12	0.01	-0.08	-0.09	0.19	1.00					
Co	0.18	**0.60**	0.10	-0.05	0.06	0.04	-0.17	1.00				
Ni	-0.11	0.11	0.01	0.11	0.14	**0.29**	**0.28**	0.12	1.00			
V	-0.15	-0.08	0.01	-0.06	0.15	0.17	**0.51**	-0.01	**0.40**	1.00		
Ti	-0.12	0.11	-0.10	-0.02	0.04	-0.06	**0.33**	0.11	0.06	-0.11	1.00	
Mn	-0.11	**0.71**	**0.36**	-0.10	**0.34**	**0.26**	-0.11	**0.46**	0.14	-0.02	**0.24**	1.00

Table. 5. Correlation coefficient matrices for ore elements of the Sakaro gold deposit in sample suites of fresh rock samples of ore vein No. 1.

Sulfide-gold-quartz vein (sample size=50)

	Au	Ag	W	As	Pb	Cu	Mo	Co	Ni	V	Ti	Mn
Au	1.00											
Ag	**0.52**	1.00										
W	-0.07	-0.03	1.00									
As	-0.07	-0.02	0.05	1.00								
Pb	**0.22**	**0.62**	-0.04	0.01	1.00							
Cu	**0.62**	**0.80**	0.09	-0.03	**0.71**	1.00						
Mo	**0.38**	0.16	-0.15	-0.08	0.13	**0.28**	1.00					
Co	0.05	-0.01	**0.38**	0.03	-0.06	**0.20**	-0.08	1.00				
Ni	**0.35**	**0.28**	0.03	0.04	0.01	**0.31**	0.14	**0.68**	1.00			
V	0.19	0.13	-0.10	-0.07	0.03	0.18	**0.22**	**0.36**	**0.51**	1.00		
Ti	0.07	0.05	-0.12	-0.06	0.02	0.10	0.13	**0.36**	**0.55**	**0.39**	1.00	
Mn	0.07	0.05	**0.40**	-0.01	-0.06	0.05	-0.10	**0.20**	**0.28**	0.10	0.03	1.00

Amphibolites (sample size=285)

	Au	Ag	W	As	Pb	Cu	Mo	Co	Ni	V	Ti	Mn
Au	1.00											
Ag	0.08	1.00										
W	0.01	0.04	1.00									
As	0.19	0.06	0.00	1.00								
Pb	0.09	0.09	0.07	0.00	1.00							
Cu	0.08	**0.24**	**0.26**	0.01	0.11	1.00						
Mo	0.09	-0.02	0.11	0.00	0.04	**0.27**	1.00					
Co	-0.07	-0.06	0.09	0.02	0.00	**0.23**	0.02	1.00				
Ni	-0.02	-0.05	-0.04	0.02	0.01	0.19	-0.01	0.15	1.00			
V	-0.07	-0.06	0.03	0.00	0.13	**0.46**	**0.25**	**0.44**	-0.24	1.00		
Ti	-0.04	-0.03	-0.07	-0.01	0.05	0.18	0.11	0.18	-0.07	**0.35**	1.00	
Mn	-0.06	-0.08	0.02	0.00	0.06	0.18	0.02	0.20	-0.22	**0.50**	0.42	1.00

Mica schists (sample size=171)

	Au	Ag	W	As	Pb	Cu	Mo	Co	Ni	V	Ti	Mn
Au	1.00											
Ag	**0.82**	1.00										
W	**0.29**	**0.33**	1.00									
As	**0.22**	**0.26**	**0.43**	1.00								
Pb	**0.43**	**0.43**	0.04	0.04	1.00							
Cu	**0.35**	**0.42**	**0.66**	**0.34**	0.19	1.00						
Mo	0.03	0.12	0.05	0.03	0.09	0.09	1.00					
Co	0.01	0.03	0.12	0.05	0.09	**0.53**	0.08	1.00				
Ni	-0.03	0.03	0.08	-0.01	-0.01	0.14	**0.46**	**0.40**	1.00			
V	-0.01	0.03	0.11	-0.01	0.04	**0.29**	**0.40**	**0.47**	**0.47**	1.00		
Ti	0.06	-0.05	-0.02	0.03	0.03	0.07	0.13	0.15	0.14	**0.37**	1.00	
Mn	0.01	-0.01	0.15	0.06	0.08	**0.23**	0.03	**0.45**	**0.39**	**0.34**	**0.22**	1.00

Table. 6. Correlation coefficient matrices for ore elements of the Sakaro gold deposit in sample suites of weathered rock samples of ore vein No. 2.

Sulfide-gold-quartz vein

(sample size=27)

	Au	Ag	W	As	Pb	Cu	Mo	Co	Ni	V	Ti	Mn
Au	1.00											
Ag	0.11	1.00										
W	-0.13	-0.14	1.00									
As	-0.10	-0.10	0.11	1.00								
Pb	-0.01	0.61	-0.05	-0.14	1.00							
Cu	-0.15	0.37	0.34	0.35	0.46	1.00						
Mo	0.59	0.54	0.19	-0.13	0.47	0.19	1.00					
Co	-0.06	0.92	-0.09	-0.06	0.66	0.46	0.50	1.00				
Ni	-0.13	-0.01	-0.09	0.02	-0.14	0.15	-0.12	-0.01	1.00			
V	-0.13	-0.10	0.60	0.63	0.00	0.29	0.18	-0.01	-0.01	1.00		
Ti	-0.12	-0.22	0.27	0.29	0.35	0.26	0.09	-0.13	-0.11	0.64	1.00	
Mn	-0.02	0.88	0.07	-0.11	0.64	0.43	0.52	0.95	-0.06	0.12	-0.02	1.00

Mica schists

(sample size=542)

	Au	Ag	W	As	Pb	Cu	Mo	Co	Ni	V	Ti	Mn
Au	1.00											
Ag	0.49	1.00										
W	0.00	0.08	1.00									
As	0.01	0.09	0.06	1.00								
Pb	0.46	0.46	0.04	0.07	1.00							
Cu	0.05	0.24	0.09	0.29	0.25	1.00						
Mo	0.21	0.15	0.06	0.11	0.09	0.09	1.00					
Co	0.02	0.34	0.07	0.07	0.19	0.22	0.16	1.00				
Ni	-0.02	0.01	0.13	0.17	0.01	0.37	0.01	0.13	1.00			
V	0.00	0.18	0.10	0.28	0.10	0.30	0.36	0.13	0.19	1.00		
Ti	-0.06	-0.09	0.03	-0.05	0.04	0.00	0.16	-0.04	0.07	0.29	1.00	
Mn	0.01	0.36	0.09	0.00	0.20	0.19	0.22	0.53	0.00	0.16	0.12	1.00

Table. 7. Correlation coefficient matrices for ore elements of the Sakaro gold deposit in sample suites of fresh rock samples of ore vein No. 2.

Sulfide-gold-quartz vein

(sample size=9)

	Au	Ag	W	As	Pb	Cu	Mo	Co	Ni	V	Ti	Mn
Au	1.00											
Ag	0.17	1.00										
W	0.02	-0.09	1.00									
As	0.09	-0.09	0.20	1.00								
Pb	0.76	0.76	0.07	-0.11	1.00							
Cu	0.49	0.60	0.43	-0.06	0.72	1.00						
Mo	0.39	-0.10	0.13	0.87	0.21	0.10	1.00					
Co	-0.14	0.24	0.79	0.34	0.10	0.50	0.19	1.00				
Ni	0.03	-0.01	0.99	0.21	0.00	0.48	0.15	0.85	1.00			
V	0.14	-0.07	0.97	0.29	0.04	0.48	0.29	0.84	0.99	1.00		
Ti	0.12	0.09	0.36	0.15	0.23	0.36	0.22	0.73	0.46	0.52	1.00	
Mn	0.03	0.08	0.94	0.18	-0.02	0.50	0.14	0.86	0.95	0.95	0.60	1.00

Mica schists

(sample size=219)

	Au	Ag	W	As	Pb	Cu	Mo	Co	Ni	V	Ti	Mn
Au	1.00											
Ag	0.66	1.00										
W	-0.03	0.02	1.00									
As	0.06	0.00	-0.01	1.00								
Pb	0.59	0.75	0.01	-0.03	1.00							
Cu	0.04	0.07	0.94	-0.06	0.07	1.00						
Mo	-0.14	-0.01	0.34	0.05	0.04	0.41	1.00					
Co	-0.16	0.00	0.36	0.08	0.08	0.36	0.28	1.00				
Ni	-0.01	0.01	0.03	0.23	0.23	0.01	0.08	0.52	1.00			
V	-0.23	-0.07	0.10	-0.04	-0.04	0.14	0.55	0.50	0.13	1.00		
Ti	-0.21	-0.09	-0.03	-0.12	-0.12	0.02	0.24	0.14	-0.04	0.33	1.00	
Mn	-0.14	-0.05	0.12	0.03	0.03	0.13	0.11	0.57	0.60	0.28	0.18	1.00

dispersion pattern that Pb shows to Au and Ag. The Au-Pb associations increase in the weathering environment in ore vein No. 1 and hanging wall rocks seems to be due to the secondary enrichment of these metals. However, in ore vein No. 2 and footwall rocks these metals show the opposite relation to the above mentioned favouring the leaching out of Pb even to the extent of enrichment - depletion relation that expressed, for example by r = 0.76 and r = -0.01 respectively.

Au and Cu have r = 0.62 in fresh samples of ore vein No. 1, r = 0.20 in weathered samples of ore vein No. 1, r = 0.49 in fresh samples of ore vein No. 2 and r = - 0.15 in weathered samples of ore vein No. 2. Cu like Pb is slightly mobile (see Table 8), and can therefore be taken into solution to the ground water table below the surface or migrated in solution at the surface. The same relations hold true for the foot wall rocks which have r = 0.43, 0.09, 0.59, 0.46 in fresh and weathered wall rock samples of ore vein No. 1 and ore vein No. 2 respectively. The exception is seen in hanging wall rocks with r = 0.09 in fresh rock samples and r = 0.46 at the surface which is a similar tendency observed in Au-Ag and Au-Pb relations due to the secondary enrichment.

Au and Mo show significant correlations in ore veins with r = 0.38 and r = 0.39 in ore vein No. 1 and ore vein No. 2 respectively, and r = 0.21 in weathered wall rocks of ore vein No. 2. Generally, Au and Mo are associated/related in veins, otherwise, they have very weak or negative correlations.

The strong correlation of Au with Ag, Pb, Cu and (Mo)

Table 8. Mobility of elements in surficial environments from Rose, Hawkes and Webb, 1979, Geochemistry in Mineral exploration, Table 2.3, p. 25).

Relative Mobility	Oxidizing conditions (pH = 5-8)	Oxidizing conditions (pH > 4)	Reducing conditions
Highly Mobile (K>10)	Cl,Br,I,S,Rn,He, C, Mo, B (Se, Te, Re?)	Cl, Br,I,S,Rn He, C, , B	Cl,Br,I,Rn,He
Moderately mobile (K=1-10)	Ca,Na,Mg,Li,F, Zn,Ag,U,V,As (Sr,Hg,Sb?)	Ca,Na,Mg,Sr, Li,F,Zn,Cd, Hg,Cu,Ag,Co, Ni,U,V,As, Mn,P	Ca,Na,Mg,Li, Sr,Ba,Ra,F, Mn
Slightly Mobile (K=0.1-1)	K,Rb,Ba,Mn,Si, Ge,P,Pb,Cu,Ni, Co(Cd,Be,Ra,In, W?)	K,Rb,Ba,Si,Ge, Ra	K,Rb,Si,P Fe
Immobile (K<0.1)	Fe,Al,Ga,Sc,Ti, Zr,Hf,Th,Pa,Sn, rare earths, Pt metals, Au(Cr, Nb,Ta,Bi,Cs?)	Fe,Al,Ga,Se, Te,Zr,Hf,Th, Pa,Sn,rare earths, Pt metals, Au,As Mo, Se	Fe,Al,Ga,Ti Zr,Hf,Th, Ra,Sn,rare earth, Pt metals,Au, Cu,Ag,Pb,Zn, Cd,Hg,Ni,Co, As,Sb,Bi,U,V, Se,Te,Mo,In, Cr, (Nb,Ta,Cs?)

suggests that as gold commonly associates with sulfides of these metals, and many studies have demonstrated that gold is preferentially concentrated in sulfide phases (e.g. Boyle, 1979; Taylor, 1963; Keays and Scott, 1976).

It can be generalized that Ag, Pb, Cu, Mo, As, W, Ni show strong correlation with Au in decreasing order. Thus, in geochemical survey of fresh and weathered rock samples, anomalous contents of Au, Ag, Pb, Cu and (Mo) might be used as indicator elements with decreasing importance in locating primary gold deposits of similar geological setting of the SGD.

(2) Ag shows significant correlations other than Au with Pb, Cu, Co, W, Mn, Mo and very rarely with As, Ni and V. Its relations with Mo, Ni, and V is confined only to surficial environment. In ore veins, Ag is associated with Pb and Cu except in weathered ores of vein No. 2 which include Co, Mn and Mo in addition to Pb and Cu. Ag and W show significant correlations only in foot wall rocks (r = 0.33, 0.54) and weathered hanging wall rocks (r = 0.32) of ore of vein No. 1. Ag and Co are found correlated in foot wall rocks of ore vein No. 1 and ore vein No. 2 with r = 0.96 and r = 0.34 respectively; and also in ore vein No. 2 with r = 0.24 (fresh samples of veins) and r = 0.92 (weathered samples of veins). Thus, generally the correlation of Ag with W and Co becomes more tight at the surface than in the primary environment indicating simultaneous enrichment by secondary processes. Ag, Pb and Cu show a decrease in correlation in weathering environments in sample suites of ore veins and wall rocks of ore vein No. 2, and

meanwhile, an increased relations in wall rocks of ore vein No. 1. Therefore, indicating both impoverishment and enrichment operations were active at the surface.

(3) Other than Au and Ag, Pb is found related to Cu, Mo, Mn, Ti and rarely with W, As, Co, Ni. Pb and Cu show significant correlations in all the environments, whereas, others are dominantly associated with Pb in the weathering environments. The strong relation of Pb with Cu (+ Au and Ag) has a genetic significance especially in the primary environment suggesting their deposition as sulfide phases.

(4) Cu shows significant correlations in addition to Au, Ag and Pb to W, As, Co, Ni, V, Mo, Mn, Ti. Except for Ti which is found correlated with Cu in weathered rock samples of ore vein No. 2, the others are found associated both in the primary and secondary environments. Since correlation coefficients tell us how uniformly the content variations of the elements behave and not necessarily peak relations, it seems necessary to recall the spatial relations of these elements described in the previous section. Co, Ni, V, Mn and Ti are predominantly seen with elevated values in the wall rocks, therefore, the significant correlation of these metals with Cu in ore veins (except ore vein No. 2) show their common insignificant presence or variations in trace amounts in other sulfides. Thus, those valid correlation coefficients seem to be typical for wall rocks and ore vein No. 2. These metals show the strongest correlation in

ore vein No. 2 and moderate to weak correlations in wall rocks. Since these metals are known to form sulfides (Co, Ni) or traces in sulfides at an earlier stage of crystallization of hydrothermal solutions, the significant correlation of Cu with these metals might also indicate a superposition or/and deposition of Cu-Fe-sulfides with Fe-sulfides (e.g. pyrrhotite, pyrite, marcasite etc) that can contain the above elements in trace amounts. For example, according to Betekhtin (1964), pyrrhotite ($Fe_{1-x}S$) sometimes has minor admixtures of Cu, Ni, Co and occasionally of Mn and Zn (the first three metals are usually present in the form of chalcopyrite or pentlandite inclusions).

(5) Mo is correlated in addition to those elements mentioned before, with V, Ti, Co and Ni. It shows the best correlation with V and is found related in all environments. In the zone of weathering, the strong correlation of Mo and V could be explained through their ability to form molybdates and vanadates. However, their strong correlations in the primary environment is mainly due to their presence in traces in sulphide phases.

(6) As is a non-metal and its correlation with the ore-forming metals could indicate the presence of arsenides and sulfarsenides. It shows significant correlations with Cu, W, Ni, V, Mo, Pb and rarely with Au, Ag and Co. Its association with Cu and W is stronger than with the other elements, thus, indicating

the common occurrence of Cu-Fe arsenides (such as grey ores (the minerals of tennantite- tetrahedrite group- ($Cu_{12}(As,Sb)_4S_{13}$)), enargite (Cu_3AsS_3), arsenopyrite (FeAsS)) in association with tungsten minerals such as scheelite ($CaWO_4$) and wolframite ($(Mn,Fe)WO_4$). Thus, since these minerals are formed at high temperature, they could have crystallized together in the earliest stages of mineralization, therefore, they exhibit the observed strong correlations. The other metals could form traces in these minerals for the reason that they are weakly correlated. For example, according to Betekhtin (1964) isomorphous admixture of MoO_3 up to 10% could occur in scheelite. Grey ores can have a ranges of elements that include Ni, Co, Mn, and arsenopyrite can have admixtures of Co, Ni and Sb.

(7) W shows significant correlations with all metals. However, it is tightly correlated with Cu and As, and occasionally at a lesser degree to Co, Mn, Ag, Pb, Mo, V and Au. The W-Cu and W-As correlations are in favour of the observed spatial association of W with chalcophiles and it indicates the possible crystallization (or enrichment) of ore metals of these metals from an ore solution earlier than Au-Ag-Pb in the form of oxides, sulfides, arsenides and sulfarsenides (see above).

(8) Others: Co-Ni are found closely correlated with V, Mn and rarely with Mo and Ti. The strong relation of Co-Ni-V-Mn is in accordance with Goldschmidt's classification of these metals

by their geochemical affinity for metallic iron. Mn and Ti show significant correlations only in few cases, mostly showing no correlations. It seems that the strong relation of these metals in the wall rocks is due to their presence in silicate structures as traces than in sulfides.

5.4 Metal zonation

The zonation of metals and paragenesis (sequence of deposition) in the SGD will be discussed in this section based on the spatial distribution and associations of the metals discussed in sections 5.2 and 5.3.

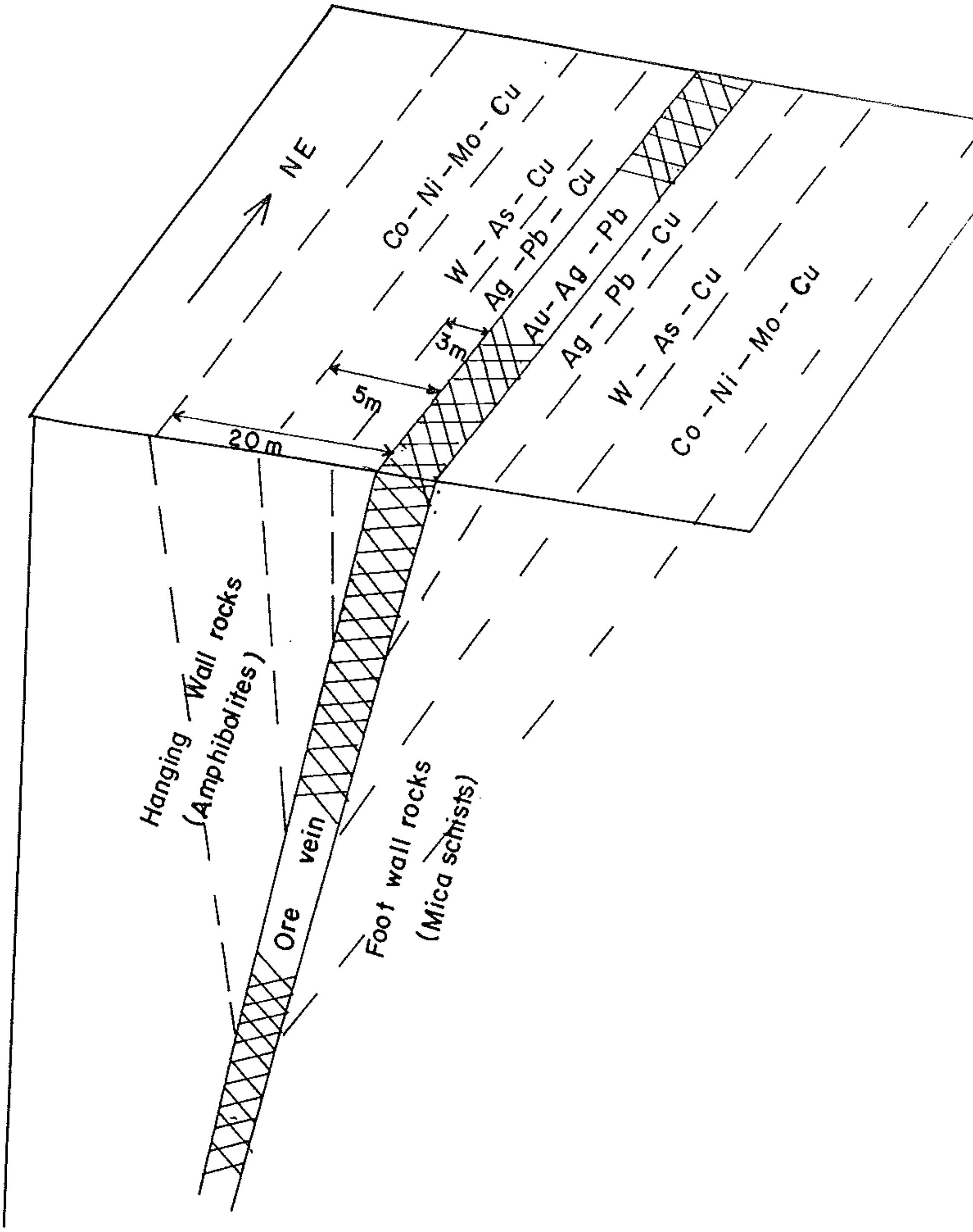
The study of the spatial distribution of ore metals and minerals is a widely used exploration method in the world to outline the zones of metals or/and minerals of commercial interest at regional, district, and mine scales. Sliouniaev (1992) suggested that, with particular reference to AGF, an approach from the point of view of zonal (in three dimensions) distribution of minerals and elements of economic importance, and also of the elements-isomorphic admixtures to the main mineral forming elements that produce the so-called "hidden zonation" as one of the mostly reliable and universal qualitative (or semi-quantitative) approaches in solving the problems of finding, measuring relative prospects and priority rating of mineral deposits.

Since paragenesis and zoning are closely related and in many places result from the same process (Park, 1963), the sequence of deposition of the Sakaro ore metals and their zonal patterns are treated as related subjects. Park (1963) in his reply to J. Kutina described a revised definition of zoning as "zoning in ore deposits is any regular pattern in the distribution of minerals or elements in space; it may be shown in a single ore body, in a mineral district, or in a large region. Although zoning is related to the spatial distribution of elements and minerals, both time and space must be considered in the study of zonal phenomena. The term paragenesis, as used in the United States, is the distribution in time, or sequence of, numbers of elements...".

The ore metals of the SGD do have variable associations, however, based on the predominating distributions and associations of the elements, a general scheme of their zonal arrangement is outlined (Fig. 30). In places where there are no assay values extrapolations are made from the known ones. Moreover, when delineating the zones the maximum width, is considered.

The zonal patterns of the ore metals from that proximal to the veins outward to distal areas is Au-Ag-Pb, Ag-Pb-Cu, W-As-Cu, Mo-Co-Ni-Cu. Some of the elements, for example Cu, appear in more than one zone in significant quantities, therefore, their zonal range is considered.

Au-Ag-Pb zone is confined to the quartz veins forming an ore of commercial interest. This zone also includes Cu and Mo which are excluded for their minor occurrence. Horizontal zoning of the metals shows that from this zone outward to the wall rock,



Fig·30· A schematic draw of metal zonation in the Sakaro gold deposit.

Ag-Pb-Cu zone follows. This zone has a lateral width of 3 m on each side of hanging and foot wall rocks. Then W-As-Cu zone follows with a limit of about 5.0 m from the ore veins. The widest of all is Mo-Co-Ni-Cu zone which is within 20 m from the ore veins. The above zones could be larger in vein shoots and the host rocks (mica schists). The zonal pattern of the elements is asymmetric, narrow in the hanging wall side and wider on the foot wall side. This is explained by differences in permeability providing the access to the mineralizing solutions. Mica schists give much more space for the wall rock-fluid interaction along schistosity planes than do the amphibolites which behave in the same manner after shearing and fracturing.

It has been discussed in section 5.2 that metals follow certain order of deposition from an ore solution and according to Lindgren (1933) this sequence is generalized as Fe-Ni-Co-Zn-Cu-Pb-Ag-Au. Considering Fe as the most abundant metal in sulfides (Taylor, 1963), though no analysis is available in the Sakaro case, the possible paragenetic sequence of the Sakaro ore elements will be (W - Au?) - (Fe-Co-Ni-Mo-Au) - (Cu-Pb-Ag-Au) - (Au, Ag). Several generation of gold is possible from the variable spatial association of the metal, even though most of it was probably introduced with Cu-, Pb-, and Ag- minerals. It has been seen in many types of ore deposits that the oldest gold has the same age as wolframite, tourmaline, rutile, and the youngest gold has the same age as lead-antimony-sulfosalts, or even zeolites (Ramdhor, 1969).

Since Cu is found associated with the first three of the metal groups as is shown in zonal pattern of the elements, it seems that there were at least four stages of mineralization in the first two of which (W-As-Cu, Fe-Co-Ni-Mo-Cu) Cu-sulfides are crystallized at the latest stage or are superimposed on earlier ore minerals. It should be taken into account that alteration and remobilization during metamorphism could affect the existing sulfide minerals and those which are crystallized at the late stage are easily mobilized and superimposed on the earlier sulfides. This interaction of the mineralizing solution and wall rocks certainly do influence on the zonal pattern of the metals.

Wall rock alterations and concomitant ore deposition are a process of irreversible chemical exchange between hydrous solutions and adjacent wall rocks. Certain components are selectively leached from wall rocks and are added to the fluid, and other components (including the ore metals) are selectively taken up by wall rocks (or form coating on the wall rocks) and are removed from the hydrothermal fluid. The net result depends on the physical conditions at the wall rocks-fluid interaction interface, on the composition of wall rocks and fluid, and on the relative amounts of fluid and wall rocks involved in the exchange process (Rose et al., 1979).

Apart from the alteration effect that accompanies the hydrothermal process, the observed zonal pattern of the metals is a result of mineralizing activity which narrows its front with time (with compositional changes of the fluid) in depositing Fe-sulfides (that could have traces of Co-Ni-Mo) and probably sulfides of Co-Ni and Mo at the earliest stage followed by W minerals and sulfarsindes (e.g. arsenopyrite, $FeAsS_2$), and sulfides of Cu (e.g. chalcopyrite, $CuFeS_2$), Pb (galena, Pbs) and Ag (e.g. argentite, Ag_2S), and (at the latest stage) native metals of Au and Ag and tellurides.

5.5 Frequency distribution of gold

To understand the frequency distribution of gold, in the SGD, 2364 gold assays are grouped according to the hosting rock types and depositional environments. The rock types are sulfide-gold-quartz veins, mica schists, and amphibolites that consist of both massive and sheared varieties. These rocks are categorized in to two major groups i.e. those in the weathering environment and those in primary environment. Mixed samples, if any, are not considered in the distribution frequency histograms.

The distribution frequency of an element depends on its geochemical character, mode of occurrence in minerals, the distribution of minerals in rocks, and the conditions of formation and subsequent history of the rock (Govett, 1983). Thus, it is possible to speak about the mineralizing event by looking at the form of the frequency distributions. Ahrens (1954) shows that as minor and trace elements log-transformed concentrations are distributed approximately normally. However, there are exceptions to this rule that question its universal applicability (Shaw, 1961; Oertel, 1969; Tolstoy et al., 1965). Though the hypothesis of log-normal distribution by Ahrens

(1954) lacks universality, much of the work in exploration proves as elements distribution appears nearly log-normal than normal, and that useful results can be obtained by assuming log-normal behaviour (Tennant and White, 1965; Lepeltier, 1969; Miesch, 1977; Sincliar, 1974, 1976; Rose et al., 1979).

In the SGD as already mentioned above, population separation is done according to the rock types and depositional environments to distinguish the effect on the distribution of elements due to rock types, on the one hand, and those due to depositional and enrichment process effected by secondary processes in the oxidizing and surfical environments or by hydrothermal processes in deep seated environment on the other. As a result, in the frequency distribution histograms shown in Fig. 31, two population are identified in each rock unit, namely, the ore population and the background population.

Effective interpretation of geochemical data involves a consideration of multiple populations of data. From the survey, a log-normally distributed population of background samples may constitute one population. Samples near ore and affected by a dispersion involving the ore can be considered a second population. Samples related to certain rock types or unusual aspects of the environment may define additional populations. The samples related to ore usually have an approximately log-normal frequency distribution but with a higher mean and different standard deviations than the background samples. The background and ore populations commonly overlap, so that a completely satisfactory discrimination of background and ore samples is impossible. (Rose et al., 1979).

The distribution frequency of gold contents in all rock types in the SGD are positively skewed (Fig. 31). Examination of the histograms shows that both the wall rocks and quartz veins have a large peak representing background and a tail or second peak at higher values. The high gold contents are more frequent in weathered (channel) rock samples than fresh (core) rock samples. This indicates gold enrichment by the processes of weathering. Moreover, high gold contents are frequent in sulfide-gold-quartz veins than in wall rocks.

In plotting the histograms that show the frequency of gold contents, 23 classes with an interval of 2 ppm are selected to cover the range of most of the gold contents. However, those above the limit of the range <1 - 45 ppm are treated as an outliers, meanwhile an attempt has been made to make the outliers as few as possible. The frequency histograms are plotted against the upper class limits. The most frequent (mode) gold contents are those with <1 ppm and these modal concentrations are higher in the wall rocks than in the ore veins. Although gold contents and ranges are similar in all the rock types, there is a difference in the form of the distributions. The distribution pattern in the ore veins show a steady decaying pattern form from low towards high values whereas in the wall rocks there is a break in the distribution mostly seen between 3 and 5 ppm, thereafter, representing flat (or constant) distribution. The high gold values in the wall rocks which show a flat profile are actually

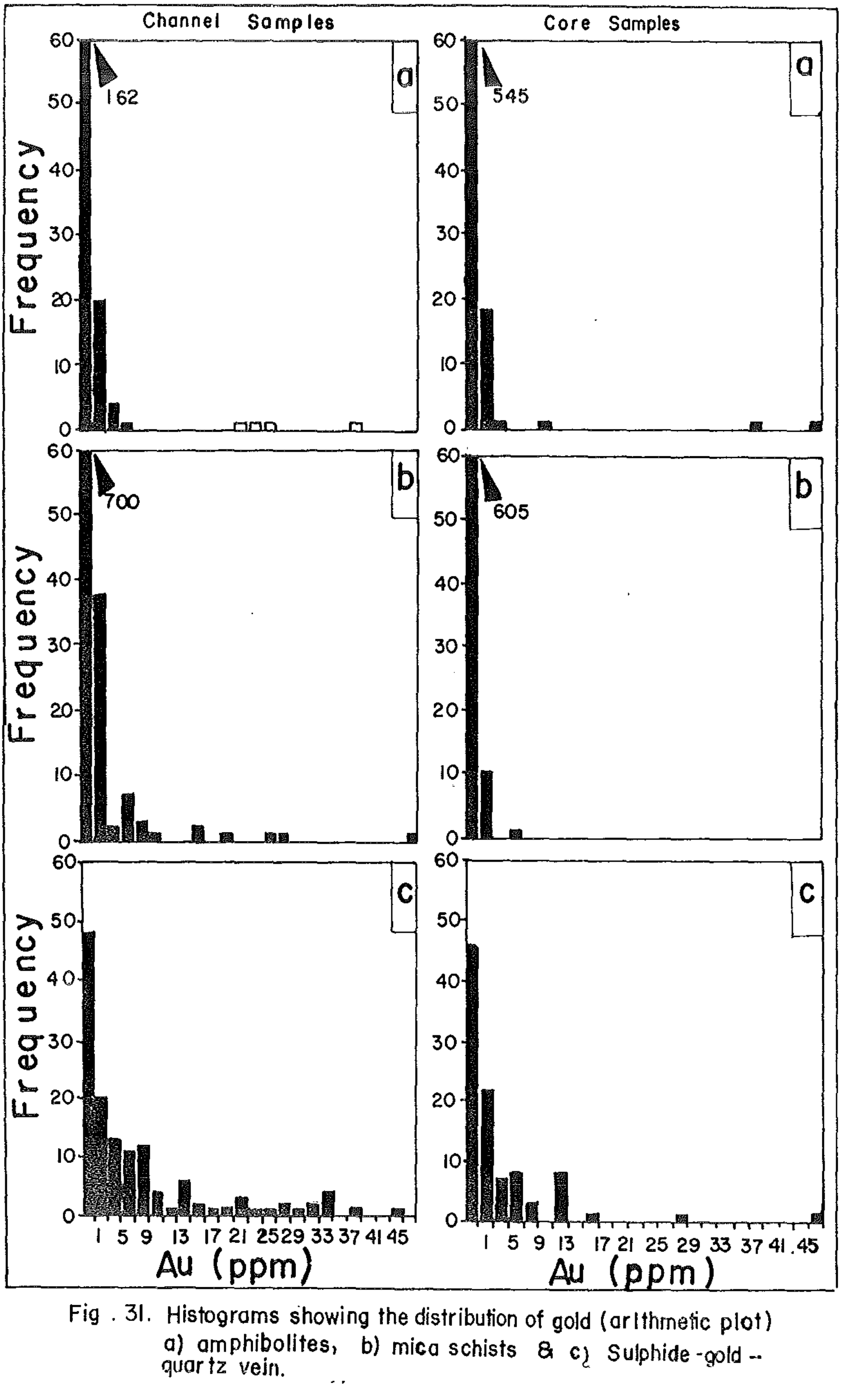


Fig . 31. Histograms showing the distribution of gold (arithmetic plot) a) amphibolites, b) mica schists & c) Sulphide-gold-quartz vein.

contents found spatially distributed near the ore veins (see section 5.3) that could represent a separate population.

The frequent gold contents - background population - are replotted in Fig. 32 in 10 classes with an interval of 0.1 ppm. The distribution is positively skewed in rock types with modal concentrations of <0.1 ppm (except in weathered ores which have 0.1-0.2 ppm). This value (0.1 ppm) has been selected as the background value for gold qualitatively based on the relative content variation during the discussions of the spatial distribution of elements.

To apply parametric statistics that characterize the distribution of gold contents and hence, population background, threshold and anomalous values, the frequency distributions which are positively skewed in the arithmetic plots in Fig. 31 should have to approximate normal distributions. Thus, the data shown have been transformed logarithmically to approximate a symmetrical bell shaped form, typical of the normal distribution. According to Lepeltier (1969), when values are lognormally distributed means that the logarithms of these values are distributed following a normal law (or Gauss'law) and this happens when a phenomenon is subject to a proportional effect, that is to say when independent initial cause of variations of the studied value take effect in a multiplicative way.

Thus, the data on gold contents are transformed to logarithm and plotted in 10 classes with log interval of 0.36 ppm (Fig. 33). As a result, the distribution approximate normal

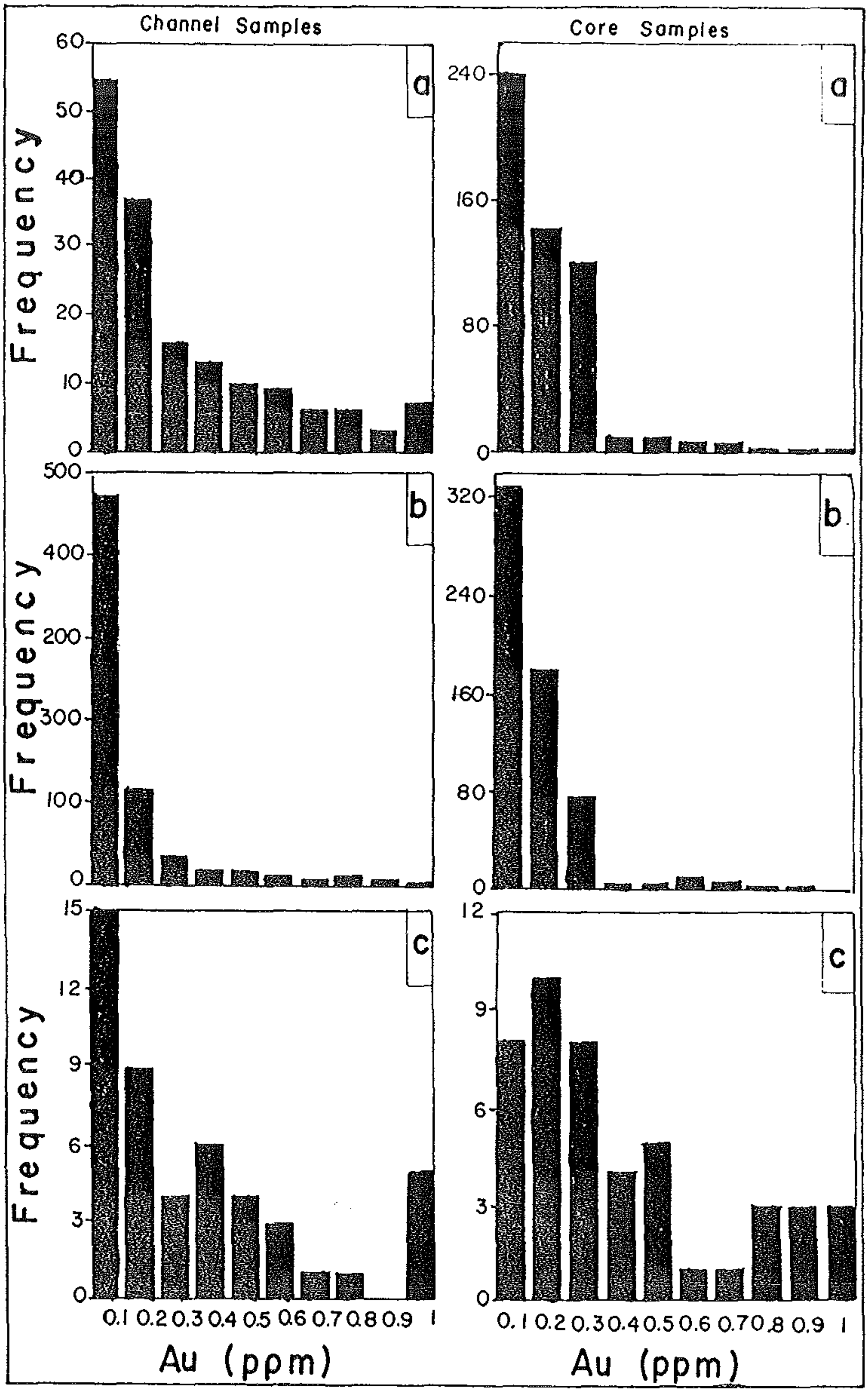


Fig.32. Histograms showing the distribution of frequent gold contents in a) amphibolite, b) mica schists & c) Sulphide-gold-quartz veins.

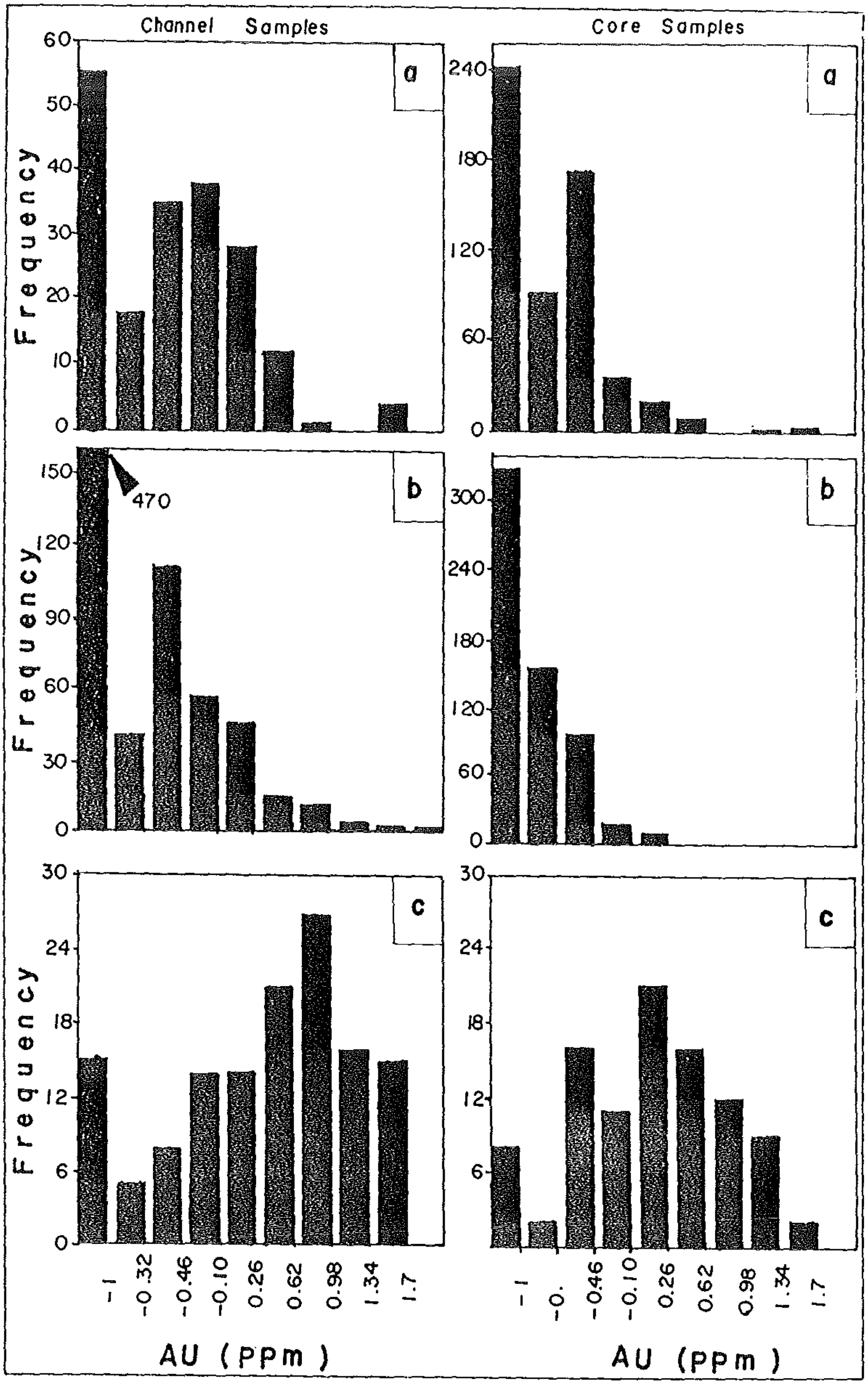


Fig.33. Log_{10} plot of Au contents in a) amphibolites ; b) mica-Schists; c) Sulphide - gold - quartz veins.

distribution in all rock types and environments though with variable degree. Therefore, the gold contents are distributed lognormally in the SGD which is in agreement to Ahrens (1954) hypothesis to the distribution of minor and trace elements. The peaks shown at the left-hand of each graph with a log value of (- 1) or antilog value of 0.1 ppm are a discrete spike that could represent a separate population.

In the $\log_{10}$ plot of gold contents (Fig. 33), the same range of values as in the arithmetic plots is adopted considering those above this limit as outliers. The best approximation of the normal distribution is seen in the core samples of ore veins and the least in the core samples of mica schists. In channel samples (weathered rocks) of ore veins, gold is slightly negatively skewed whereas in weathered mica schists and in both weathered and fresh amphibolites it is slightly positively skewed. Generally, a better lognormal distribution is seen in weathered rock samples except for the ore veins that have similar distribution in both fresh and weathered samples. This implies a better sorting (lognormally) in the distribution of gold contents is achieved by a secondary processes at the surficial environment. The slight positive skewness in the wall rocks due to the values greater than 0.98 (antilog 9.55 ppm) is due to the content related much to the immediate contact of the ore veins to wall rocks, and if these values are treated as an outliers the distribution frequencies appearance shall be improved.

A statistical summary of the gold distribution is given for both the arithmetic and $\log_{10}$ plots in Table 9. The mean gold contents (arithmetic plot) in ore veins is 7.17 ppm and 3.51 ppm for trench and drill-core samples respectively. The mean gold in wall rocks, for trench and drill-core samples respectively, is 0.55 and 0.16 in mica schists and 1.12 and 0.39 for amphibolites. Thus, mean gold contents are generally higher in trench samples than in core-samples as a result of the enrichment given by the processes operating at surficial environment. The ore veins as can be expected do have higher mean values than the wall rocks. A comparison of mean gold values shows that the amphibolites (hanging wall rocks) have higher values than the mica schists (foot wall rocks). This is in accordance with what has been discussed in the spatial distribution of elements (see section 5.3) that gold is distributed with the steeper slopes, thereby, high contents at the hanging wall side and gentler slopes (low contents) in foot wall rocks.

The mean gold contents found from the arithmetic plot is a close estimate of the average abundance of gold in the rocks though it could be biased by scattered high values. According to Govett (1983) the mean is a poor indicator of the concentration that most commonly occurs, and in determining background for positively skewed data a better approximation to the most commonly occurring value is the geometric mean which is the antilog of the arithmetic average of the $\log_{10}$ of the values. The geometric mean reduces the importance of a few values in a sample group and therefore is numerically less than the

Table 9. Statistical parameters of the gold distribution in major geologic units of the Sakaro gold deposit.

Rock units	N	X	G	s	Range
A. Trench Samples					
Sulphide-gold-quartz vein	135	7.17	2.06	9.84(.83)	<1-45.0
Mica schists (variably graphitic)	757	0.55	0.13	2.69(.54)	<1-51.3
Amphibolites (massive and schistose)	191	1.12	0.3	4.02(.6)	<1-37.8
B. Drill-core samples					
Sulphide-gold-quartz vein	97	3.51	1.15	6.26(.69)	<1-46.3
Mica schists (variably graphitic)	616	0.16	0.1	0.31(.36)	<1-5.5
Amphibolites	568	0.39	0.14	2.54(.44)	<1-45.6

N - sample size X - arthimetic mean G - geometric mean
s - standard deviation (.83) - antilog standard deviation

arithmetic mean, making it a useful indicator of background for most geochemical data.

The geometric means calculated for the ore veins and wall rocks of the SGD show they are significantly reduced in comparison to arithmetic means. They are generally small in wall rocks and are in the range of 0.1 - 0.3 ppm. In the ore veins, they are 2.06 ppm and 1.15 ppm in the trench and drill-core samples respectively. The standard deviation which is the measure of the scatter of the distribution is in the range of 0.36 - 0.83 for the lognormal distributions of gold in all rocks of the SGD. Since one of the aims of the interpretation of geochemical data is the recognition of an abnormal concentration of an element in a sample associated with mineralization compared to the concentration of an element in a similar sample material from a geologically comparable but non-mineralized situation (Govett, 1983), the anomalous gold values related to the mineralization process in the SGD should be discriminated. According to Govett (1983), an anomaly is defined conceptually as a chemical equilibrium caused by a mineralizing event. Hawkes and Webb (1962) give a method for calculating threshold (which is the upper limit of background population or the lowest anomalous value) as the mean plus 2 or 3 standard deviations in geochemical surveys. Accordingly, using the 2 standard deviations which is a widely used assessment of threshold in publications, the threshold values for the SGD is in the range of 1.03-2.49 g/t. However, it seems wrong to depend totally on the statistical results though they are useful in solving some geochemical problems. Govett (1983) shows the lack of universality of the 2 (or 3) standard deviation method of threshold assessment by an example that exceeds the highest value of the data set, thereby, missing an ore body which is shown in the spatial pattern of the values. Therefore, he emphasized that the most useful approach is to seek anomalous patterns rather than anomalous values. As pointed also by Cachau-Herreillat (1975), the selection of the mean plus 2 (or 3) standard deviations is arbitrary and doesn't have general applicability because only the characteristics of the background population are considered. For a detailed survey in which an appreciable proportion of ore-related samples is likely, this method is clearly not appropriate (Rose et al., 1979). Therefore, it seems proper not to give weight to the attempt to determine threshold values and depend on the relative variation of gold content in the SGD.

5.6 Zonal gold deposition in ore veins.

From the studies on the spatial distribution and zonation of the metals in the SGD, we were able to determine that gold is mostly localized to quartz fillings (or veins). However, there is a need to further study how gold is distributed within the veins for its practical importance in the exploration of ore deposits. According to Park and MacDiarmid (1975), seldom is an entire vein filled with ore, and the valuable constituents are usually concentrated in restricted zones, called ore shoots.

Thus, a detail study of gold contents in the Sakaro ore veins is important in revealing the zonal deposition character of gold which is vital in the mining of the gold ores. The mechanism of deposition and the origin of the zones is actually a broad subject that demands a knowledge on the controls (physical and chemical) of the mineralization. Much of it is probably out of the scope of this research, however, a discussion within the limit of our data is included.

The variation in gold mineralization within the volume of the ore veins at various levels has been followed in detail by the use of the metal content distributions and measurements of the quartz filling thickness. Gold assay values from 2043 vein samples taken by trenching and drilling across the apparent thickness of the ore veins at various levels were used in this study. The distribution of high gold values and the mean gold values (calculated in relation to the apparent thickness) in each crossings of the ore veins were compared and related to the thickness variations (Figs. 34 and 35) based on the data of the high gold contents, mean gold contents, total gold contents and apparent thicknesses along the strike and dip of the ore veins (Tables 10 and 11).

The high and mean gold contents show a similar distribution pattern along the strike and dip of the ore veins (see Figs. 34 and 35). According to Moudrov et al. (1991), no regulation is observed in the distribution of gold and there is no noticeable trend in high gold contents in "pinches" and "swells" of the vein structure. However, as a result of the

Table 10. Variation of gold highs and means along the strike of ore veins and their relation to veins thickness.

Ore vein No.1

Exploration lines	Trench numbers	Peak gold values (g/t)	Mean gold Content (g/t)	Apparent thickness (m)	Total gold Content (g/t)
1	1/2	34.60	13.10	9.00	117.95
0	700	9.90	2.49	6.40	16.20
0/A	0/A	20.00	10.75	4.00	43.00
A	A	25.00	12.95	2.00	25.90
A/B	A/B	27.00	9.04	11.00	99.40
B	701	22.40	9.13	11.50	105.00
C	702	31.80	6.15	19.50	119.85

Ore vein No.2

Exploration lines	Trench numbers	Peak gold values (g/t)	Mean gold Content (g/t)	Apparent thickness (m)	Total gold Content (g/t)
5/6	722	6.10	1.28	11.00	14.10
4	721	2.60	2.60	1.00	2.60
3	720	32.40	15.89	2.50	39.70
2/3	2/3	23.00	10.70	3.00	32.10
2	717B	0.10	0.05	1.00	0.05
1	1/2	27.20	7.66	5.00	38.30
0/1	700B	13.40	4.83	7.00	33.80

Table 11. Variation of gold highs and means along the dip of ore vein No. 1 and its relation to veins thickness.

Exploration lines	Bore-hole/ numbers	Peak gold values (g/t)	Mean gold values (g/t)	Apparent thickness (m)	Total gold content (g/t)
D	361	4.80	2.27	6.00	13.60
	355	10.20	2.81	9.00	25.30
	327	11.30	2.15	55.00	11.85
C	347	1.40	0.74	4.00	2.95
	346	13.00	9.47	3.00	2.40
	300	13.00	2.49	17.00	42.40
	702	31.80	6.15	19.50	119.85
D	324	11.10	3.31	4.50	14.90
	323	1.10	0.75	2.00	1.50
	322A	1.20	0.26	6.50	1.70
	701	22.40	9.13	11.50	105.00
A	348	28.20	8.78	4.00	35.10
	345	8.20	1.83	13.50	24.75
	314	6.50	3.52	2.50	8.80
	302	1.60	0.77	3.00	2.30
	A	25.90	12.95	2.00	25.90
	326	5.70	3.24	4.00	12.95
	344	7.10	2.42	4.00	9.70
	3A	5.10	1.34	5.00	6.72
	304	46.30	23.55	2.00	47.10
	700	9.90	2.49	6.50	16.20
1	308	6.20	2.63	6.25	16.45
	306	5.80	1.80	6.50	11.90
	305	5.20	1.29	11.00	14.15
	313A	52.20	16.03	6.50	104.20
	1/2	34.60	13.11	9.00	117.95

study, their distributions found related much to the thickness variation of the quartz filling, with high values at the thinner part and low values at the wider part of the veins. Therefore, the constrictions in the channel ways might have an effect during the hydrothermal fluid migration in decreasing pressure and thereby, precipitation of gold. Thus, the irregularities in the thickness as pinches and swells have directed the ore fluid to deposit the ore content at certain places in the veins. The Sakaro ore veins are formed along fault planes and fractures showing a pinch and swell character. The movement along these fractures and fault surfaces had separated structural foot wall and hanging wall of dissimilar rock units in ore vein No. 1 and at least locally in vein shoots (ore vein No. 2). Minor movement along curved fault surfaces causing pinching and swelling, according to Park and MacDiarmid (1975), caused the ore-bearing fluids to migrate through the more open parts of the fissures (the "swells") and to deflect around the tighter zones (the "pinches"), which as a result, rolls or changes in attitude of either the strike or dip of a vein commonly marks the beginning or end of an ore shoot. Therefore, the enriched and barren stretches in the Sakaro ore veins might have been originated by superimposed structures described above. In the distribution of gold contents along the dip of ore vein No. 1 (Fig. 36), the general enrichment seen up dip of the vein is not due to the thickness variation of the quartz fillings but rather is a result of environmental changes due to oxidation and weathering. However, thickness variation is observed functional in controlling the distribution of gold if comparison of gold contents is made with reference to each environment such as primary environment, oxidation zone and surficial environment.

An assessment of the distribution of high gold contents reveal that they are located at the wall rock side of the veins, especially to the hanging wall rock side of the veins (see Figs. 34 and 35). The selective enrichment of high golds to the wallrock sides of the veins might be the result of chemical control when the ore-bearing fluids travel through the channels created by favourable structural environment. The ore-bearing fluids continuously react with wall rocks through its way, decreasing the solubility of gold and thereby precipitating only along the chemically receptive part of the vein. The chemical reaction and solubility decrease of gold and other ore metals actually are the result of changes in pressure, temperature, oxidation potential, pH and activities of various complexing ligands (e.g. Park and MacDiarmid, 1975; Barnes, 1979; Seward, 1982; Fyfe and Kerrich, 1982). According to Barton (1959), since the solubilities of heavy metals change markedly in response to relatively small changes in composition of solutions, a solution that passes through a fissure may deposit the metals along a restricted portion of the vein where contamination by wall rocks has modified the solutions significantly. Therefore, the high gold contents deposition in the wall rock sides of the veins seem to be due to the favourable ground prepared by the chemical reactions of the ore fluid with the wall rocks.

A study on high gold content distribution in ore vein No. 1

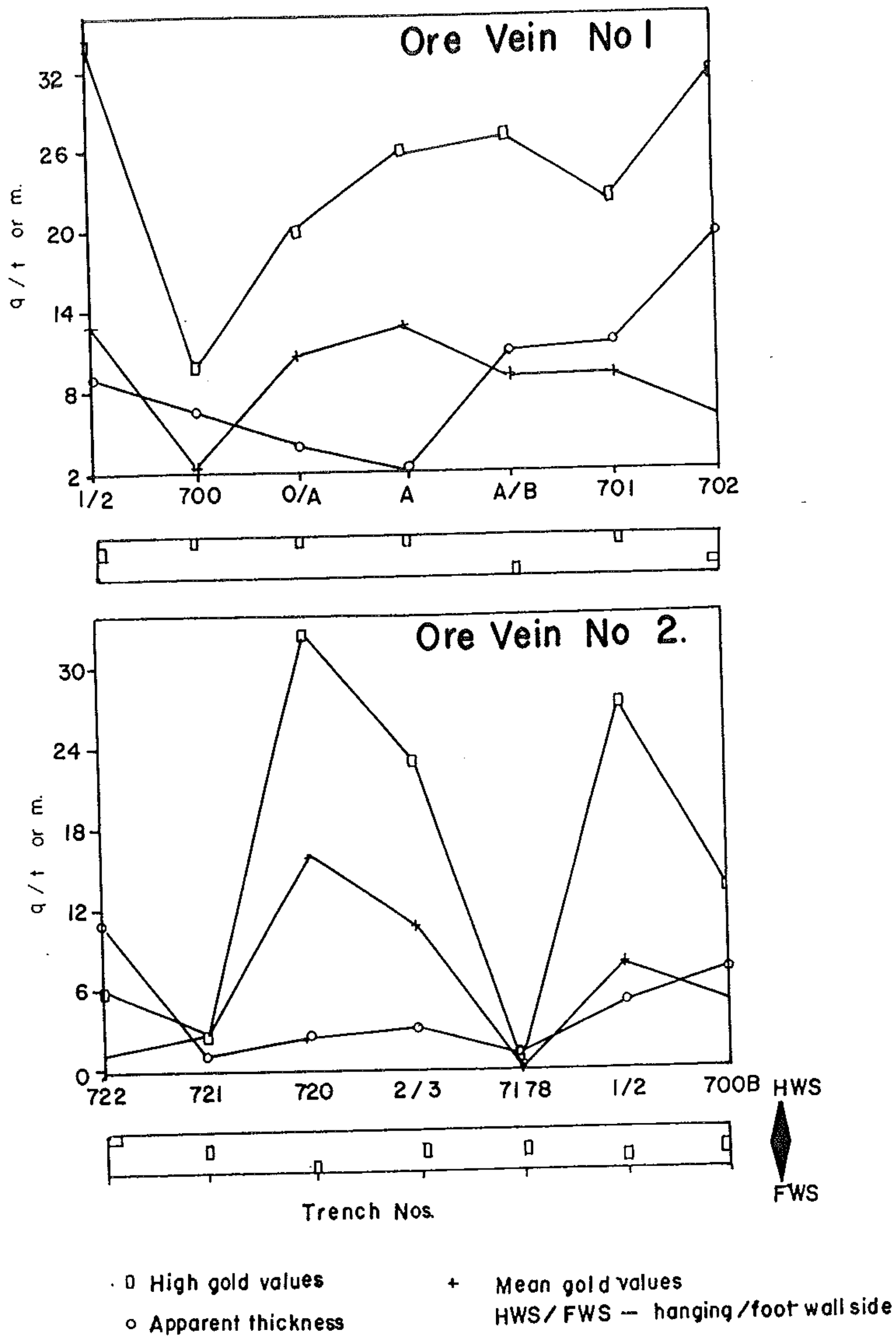


Fig. 34. Distribution of gold contents along the strike of the vein and its relation to thickness variation at the surface.

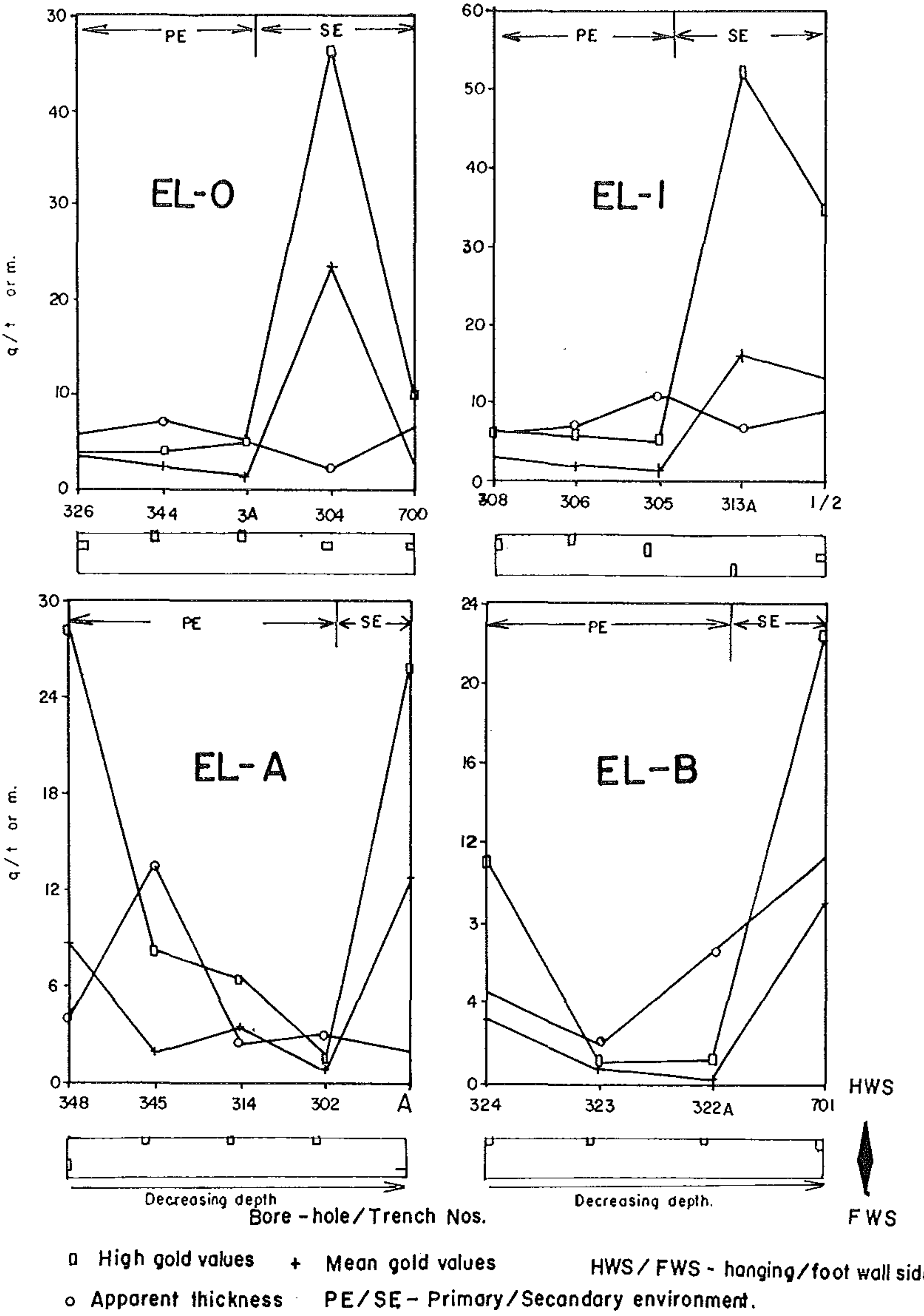


Fig. 35. Distribution of gold contents along the dip of ore vein No. I and its relation to thickness variation

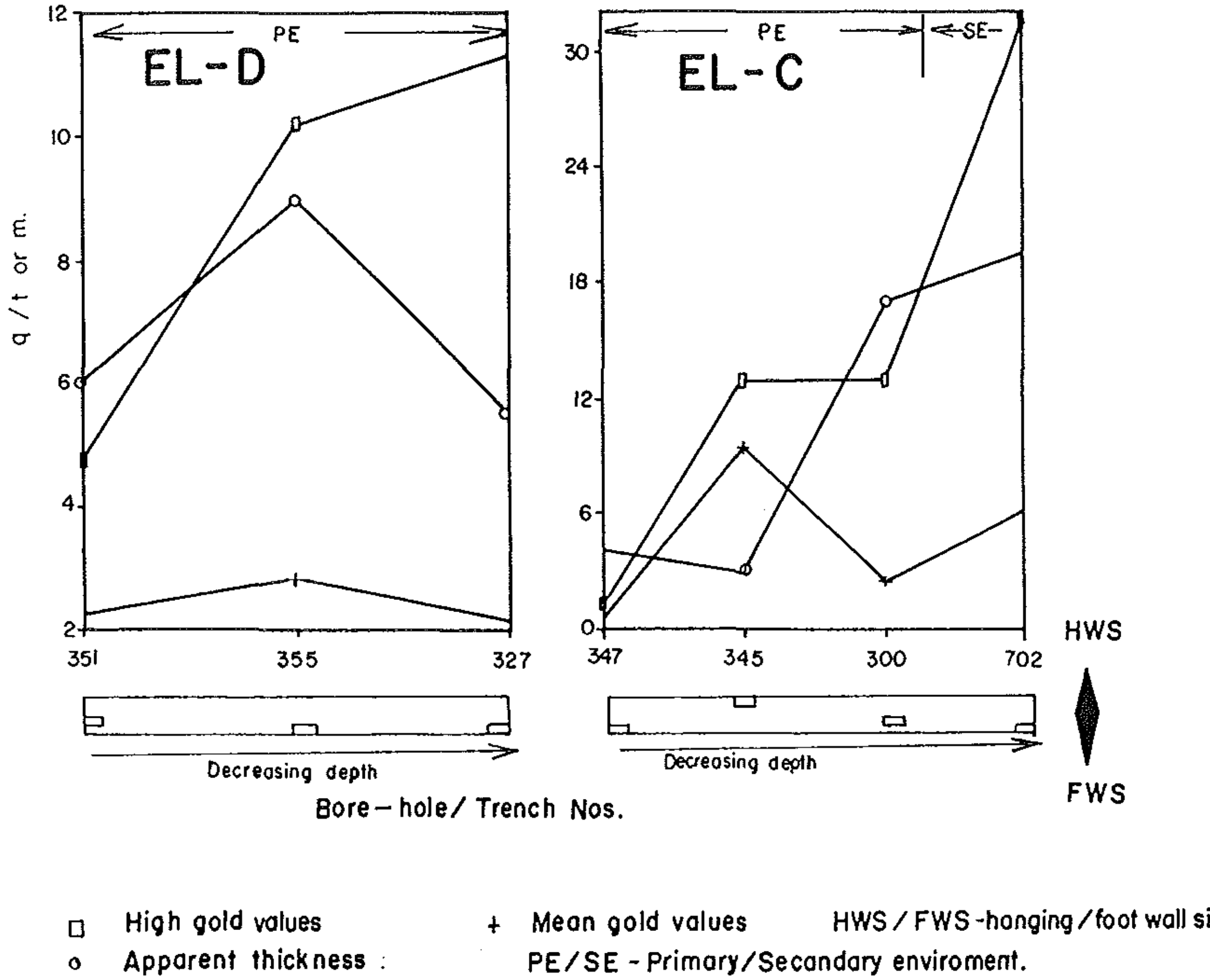


Fig. 35. (Continued)

which is the main body of the SGD, reveal that there are at least five zones with marked contrast in concentration of ore-mineralization (Fig. 36): (1) obliquely running, EW dipping gold rich zone, (2) northerly trending, vertically dipping gold rich zone, (3) intermediate low gold zone, (4) oxidation zone, and (5) surficial weathering zone. Two of the zones marked in the primary environment indicate that the ore-bearing fluids responsible for deposition of gold were migrating from a depth through the channels of (1) obliquely running zone, dipping, in EW direction and (2) a vertically dipping surface upward. Such localization of the ore content into ore columns and zones is a manifestation of the zonal structure of the vein (Moravek, 1963). The gold distribution within the volume of the vein is irregular; however, it follows a systematic pattern of more or less regular course within and away from the above mentioned ore zones. There is a regular increase in gold contents upward in these zones where the separation of the load with maximum ore content from an ore solution took place at the upper limit of the zones. In the intermediate zone, from these zones up to the weathering front which is the lower limit of the oxidation zone there is a regular decrease in metal content. In the zone of oxidation and weathering, enhanced values of gold occur due to the secondary processes of leaching and reconcentration. The gold content is found higher in the oxidation zone in comparison to the surficial environment. This enrichment of gold in the oxidation zone is a combination of a variety of processes, where gold is transported in complexes

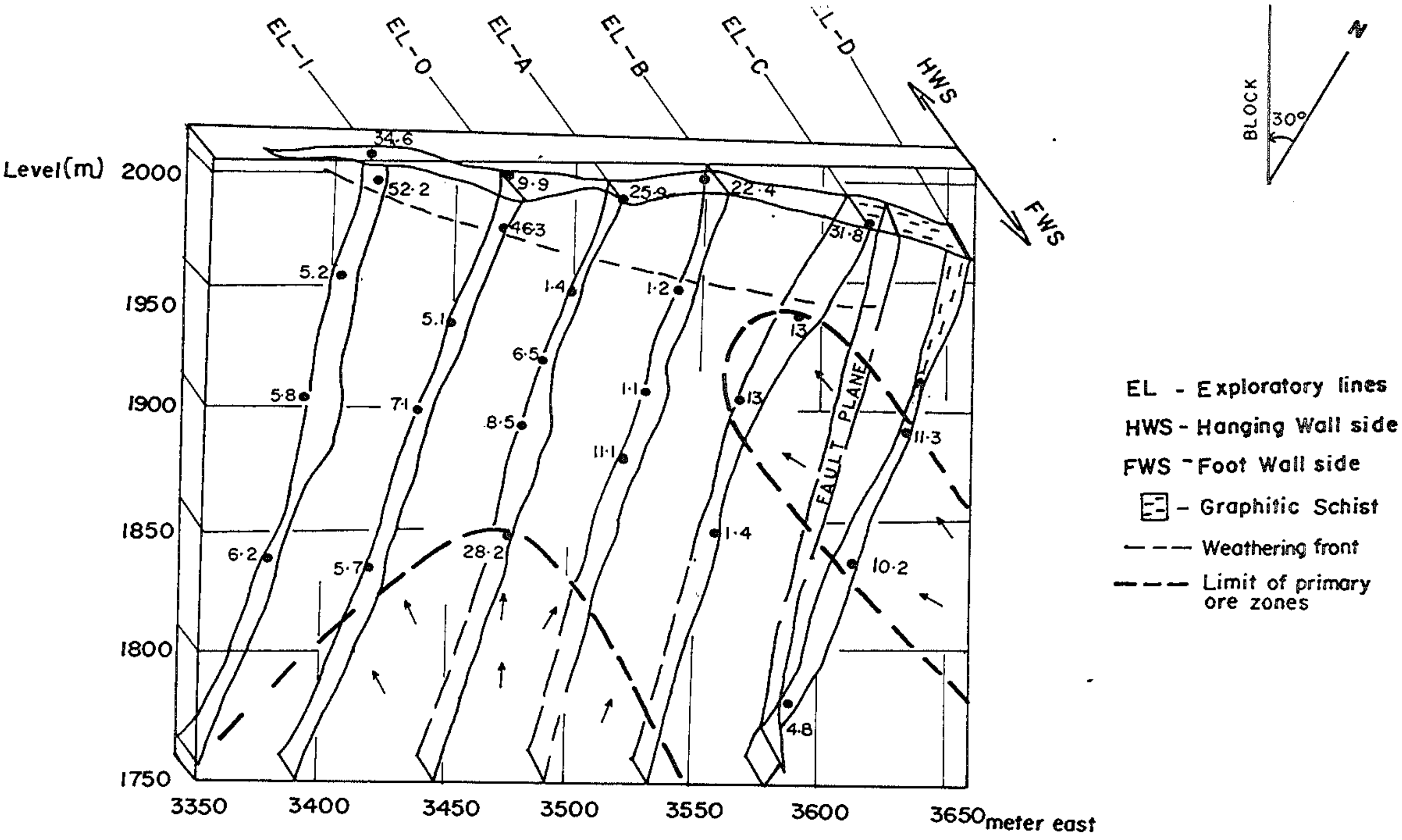


Fig · 36· Schematic draw of the zonal deposition of gold (not to scale). Gold contents are in g/t.

6. MINERALOGY AND PARAGENESIS

Individual mineral grains, ore minerals textures and ore-gangue minerals relations in the SGD were studied microscopically (in addition to the detailed field observation) using forty polished sections from core samples of ore veins and wall rocks taken at different depth intervals within 150 meters vertical depth. Various aspects of this subject have been discussed previously by Giday (1980), Dorofeev et al. (1982), Shiferaw et al. (1987), Aster et al. (1988) and Moudrov et al. (1991).

The ore-microscopic study on the vein mineralogy shows that mineralization is the result of multiple episodes of vein opening and filling characterized by massive and recrystallized quartz containing oxides, sulfides and carbonates (in small quantities) impregnating in and replacing rock-forming minerals. The main ore minerals identified are wolframite, scheelite, pyrrhotite, arsenopyrite, chalcopyrite, sphalerite, galena, marcasite and melnicovite-pyrite. These minerals have variable associations, structural and textural features.

Wolframite and scheelite occur as irregular coarse-grained aggregates, sometimes forming large masses in quartz and amphibolites, with impregnation micro-structure and replacement textures (Fig. 37). They occur mostly in quartz, siderite and amphiboles (actinolite) frequently associated with pyrrhotite. In places, scheelite grows at the expenses of wolframite. The crystallization of scheelite together or at the expense of

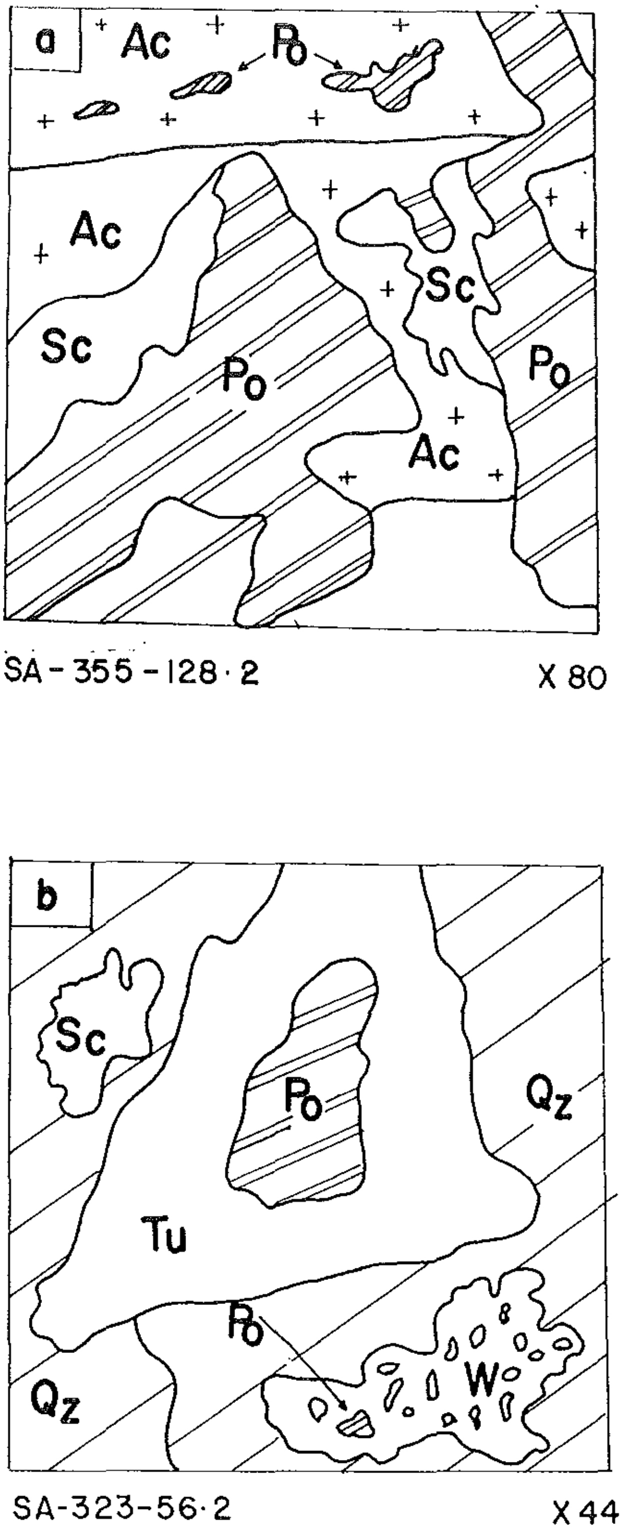


Fig. 37. Sulfides and oxides in silicate minerals. Impregnation micro-structure and replacment textures. a) Scheelite (Sc) and pyrrhotite (Po) replacing actinolite (Ac). b) Pyrrhotite, scheelite and wolframite (Wo) impregnations in quartz (Qz) and tourmaline (Tu).

Note: i) all sketches are made with nicols //;
ii) SA- Sakaro, 355- bore hole number, 128.2- depth (metres).

wolframite, according to Ramdhor (1969), takes place when changes occur in the Ca-concentration of the hydrothermal solutions. In some of the wolframite crystals, pyrrhotite aggregates are observed as young immigrant inclusions in hypogene domains indicating the paragenetic relation of tungsten-bearing minerals with iron sulfides.

Pyrrhotite (together with marcasite) is the most abundant sulfide mineral that occurs disseminated in quartz and alteration haloes in the host metamorphic rocks. It occurs as irregular aggregates associated with other sulfides inside quartz grains, where it is commonly rimmed by associated with chalcopyrite (Fig. 38). At the vein margins and in the upper levels of the deposit, it frequently occurs as inclusions in marcasite (Fig. 40, 43, 44) forming a relict texture. In the wall rocks of the SGD, it usually occurs as coarse-grained cataclastic aggregates and as fine aggregates in poorly developed bands near vein margins and also as micro-folds (Fig. 39). In the near-surface oxidation conditions, pyrrhotite is commonly corroded and replaced zonally by siderite and Fe-hydroxides (Fig. 41). Pyrrhotite, according to Ramdhor (1969), is the most easily destroyed of the iron sulfides, which shows signs of alteration in ore deposits observable to far greater depths than the other ore minerals. At the deeper levels of the deposit where pyrrhotite is found dominating over all other sulfides, lamellar exsolution intergrowths of hexagonal and monoclinic forms are found as polymorphic assemblage. The monoclinic pyrrhotite commonly forms bands or thin uniform

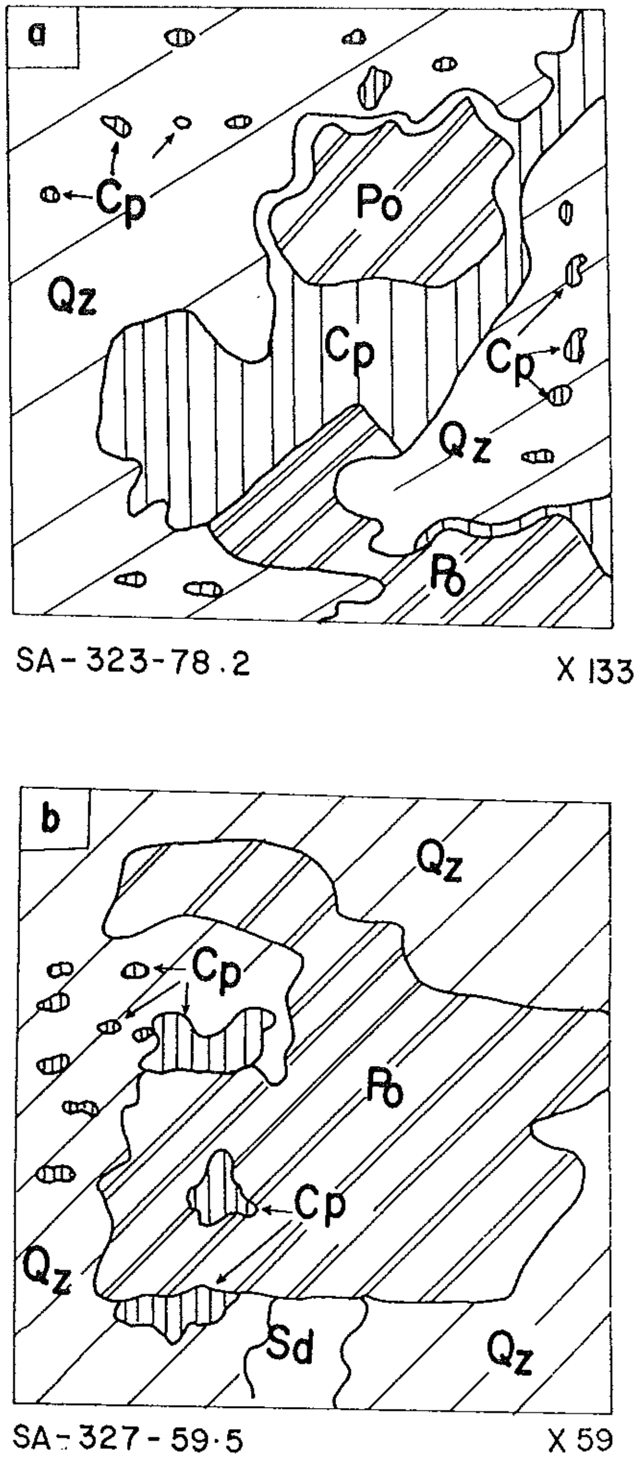


Fig. 38. Sulfides aggregate in quartz (Qz). Impregnation micro - structure. Replacment of quartz by pyrrhotite (Po) and chalcopyrite (Cp). Isometric drop-like inclusions of chalcopyrite in quartz and pyrrhotite. a) Rim-like texture - rims of chalcopyrite surrounding pyrrhotite. b) Chalcopyrite included in and at the grain boundary with pyrrhotite.

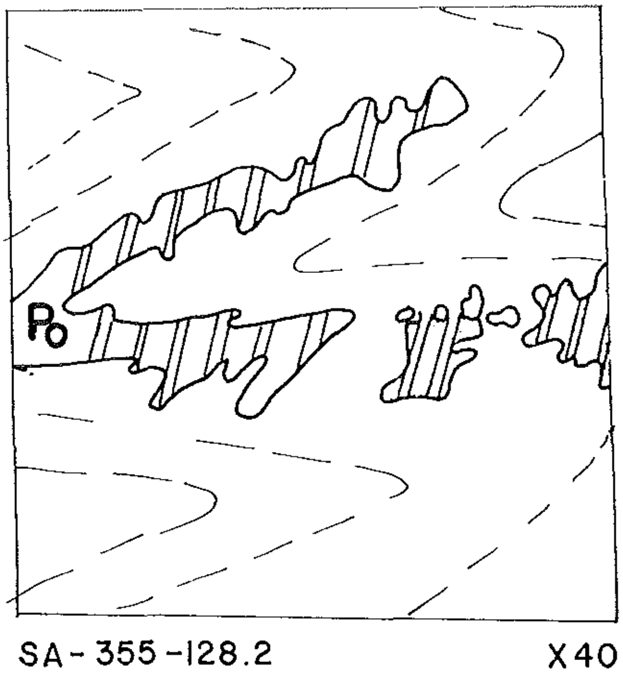


Fig. 39. Deformations (micro-folds) in pyrrhotite (Po) in biotite-amphibole schists.

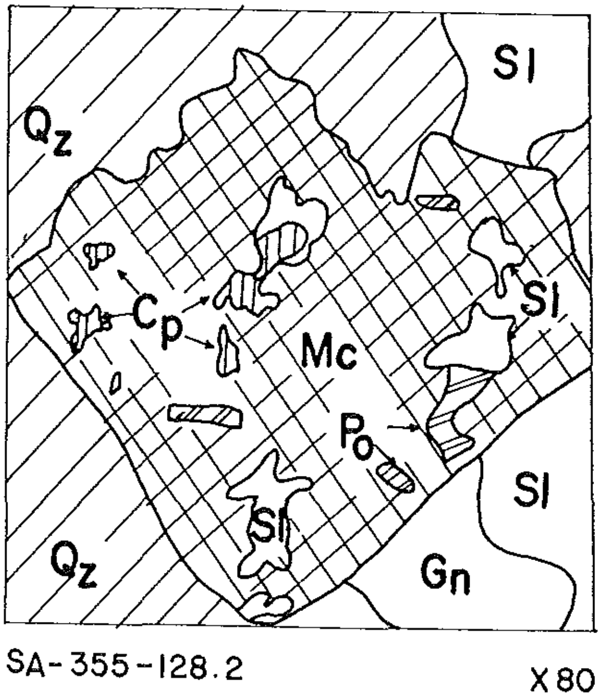


Fig. 40. Sulfides in quartz (Qz). Relict texture- relics of chalcopyrite (Cp), sphalerite (Sl) and pyrrhotite (Po) in marcasite (Mc). Sphalerite and galena (Gn) are outlining marcasite.

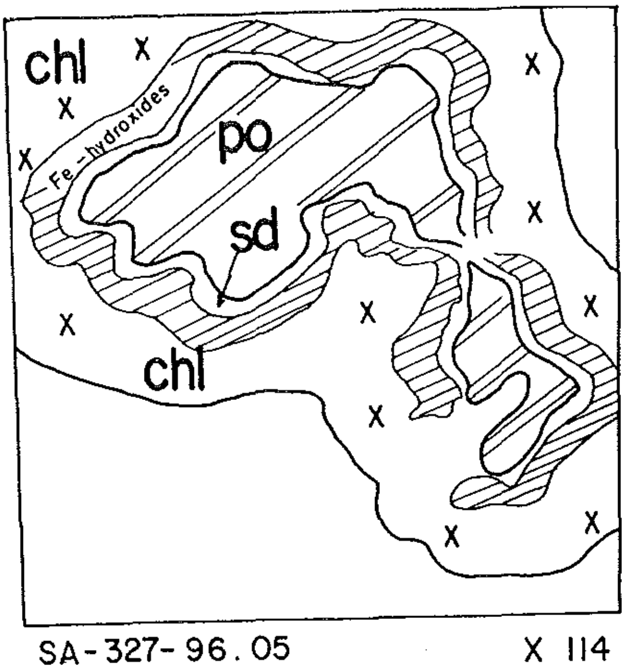
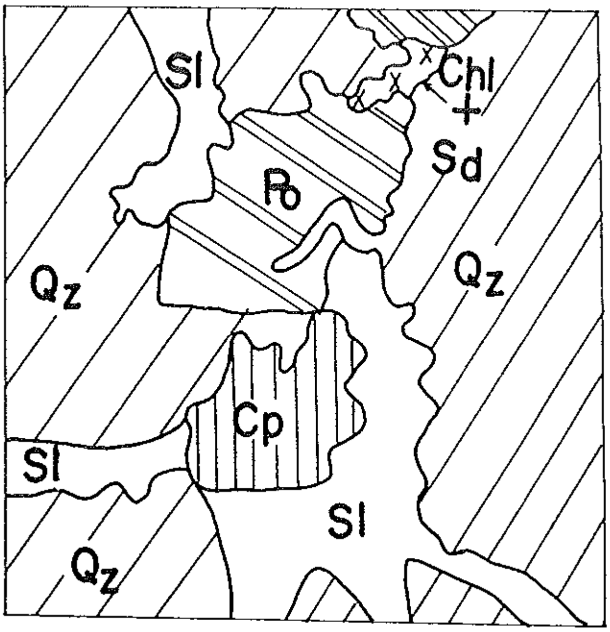


Fig. 41. Zonal micro-structure. Marginal replacment of pyrrhotite (Po) siderite (Sd) and Fe-hydroxides due to the near-surface oxidati

lamellae parallel to the base forming a darker component in the brighter hexagonal variety. The darkening (brown film) owes its origin to air etching which tarnish the monoclinic variety rather quickly. This property in the polymorphous group of pyrrhotite can be used as an indication of the monoclinic symmetry (Ramdhor, 1969). Such crystallographic changes from the high-temperature polymorph (hexagonal pyrrhotite) to low-temperature polymorph (monoclinic pyrrhotite) take place at about 307°C (Genkin, 1971).

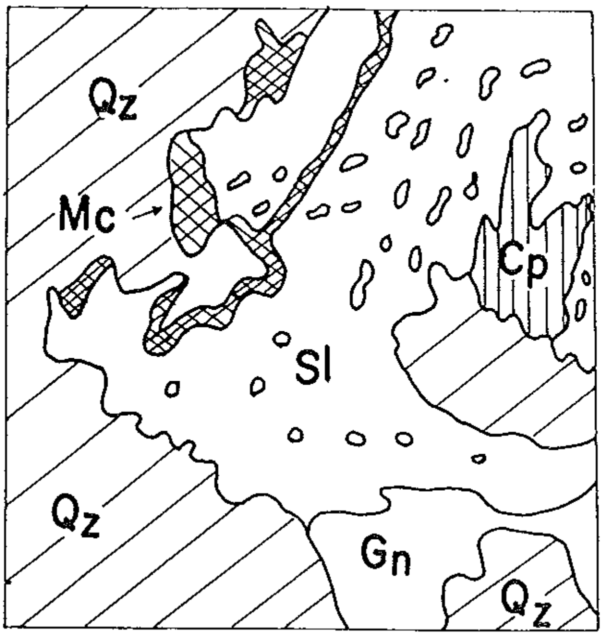
Arsenopyrite commonly occurs as euhedral to subhedral crystals with characteristic rhomb shape and also as anhedral aggregate with pyrrhotite, marcasite and chalcopyrite. Chalcopyrite is ubiquitous in the SGD being associated with all sulfides in quartz and host rocks. It occurs as medium grained aggregate commonly twinned and as tiny isometric drop-like grains in quartz (Fig. 38, 42b, 42c, 43). It is also observed frequently forming rounded oval or rod-shaped exsolution (?) bodies in sphalerite, some of which formed by collection crystallization are granular (Fig. 42b). In its association with galena, sphalerite and marcasite, it is commonly developed at the grain boundaries as intermittent occasional grains and replacing (or filling) galena along the cleavage planes (Fig. 43). Not infrequently it is also found as rims (possibly coating) and inclusions in pyrrhotite (Fig. 38). It is also observed included in marcasite, which sometimes together form aggregates of tiny grains (recrystallites) in siderite matrix (Fig. 40, 44d). From the wide occurrence of chalcopyrite and the spectrum of its association in the ore minerals assemblage together with the micro-structures and textual information (impregnation, exsolution (?) and replacement textures), it is possible to suggest that chalcopyrite was present in all periods of mineralizations in the sulfide stage of vein development. This is in agreement with Ramdhor's (1969) veiws, who suggests that chalcopyrite may precipitate during all the stages of ore formation, and that very often it is difficult to decide whether a given texture is due to a specific geologic process.

Sphalerite occurs as irregular anhedral masses with galena, chalcopyrite, pyrrhotite and marcasite in quartz, with irregular grain boundaries and impregnation and veinlet-like micro-structures (Fig. 42a). It commonly contains exsolutions (?) chalcopyrite (Fig. 42b, c). Grains of sphalerite with chalcopyrite and pyrrhotite are also observed included in marcasite where relict structures of the sulfide aggregates is preserved (Fig. 40). In places marcasite rims and infiltrates sphalerite (Fig. 42b) "replacing" it slightly along grain boundaries and cleavage cracks. It seems that the marcasite that has rimmed and penetrated sphalerite is the result of the disulfidization of the monosulfides of iron which may have originated by exsolution of FeS from sphalerite and migrated towards the grain boundaries. Ramdhor (1969), attributed the lack of sufficient Fe in sphalerite, which is expected to have high iron substitution for zinc, to exsolution from sphalerite and migration of iron sulfide into crescent shaped marginal areas of the sphalerite joining galena and other ore minerals.



SA-306-159·6 X 47

Fig. 42a. Sulfides aggregate in quartz (Qz) . Micro - structure a replacment textures: anhedral grains of sphalerite (Sl), pyrrhotite (P and chalcopyrite with irregular grain boundary, broken and displaced alo a micro-fracture. Siderite (Sd) and chlorite (Chl) as open space fillin between the minerals.



SA-3A-100.7 X40

Fig. 42b. Sulfides aggregate in quartz (Qz). Micro-structure, exsolution (?) a replacment textures: sphalerite (Sl) with emulsion-like inclusions chalcopyrite (Cp) in association with galena (Gn). Sphalerite is rimmed a penetrated with marcasite (Mc).

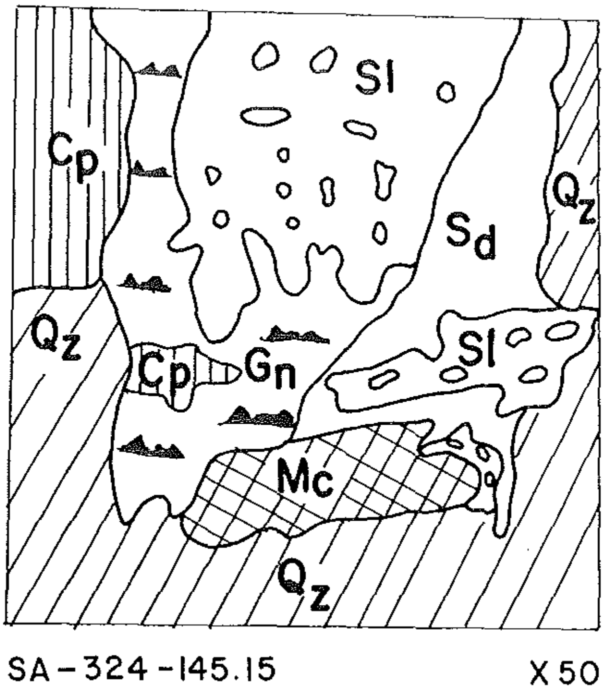


Fig. 42c. Sulfides aggregate in quartz (Qz). Exsolution (?) and replacme textures: sphalerite (Sl) with blebs of chalcopyrite (Cp), galena (Gn) wi chalcopyrite at the grain boundary and filling its cleavage plan associated with late marcasite (Mc) and siderite (Sd).

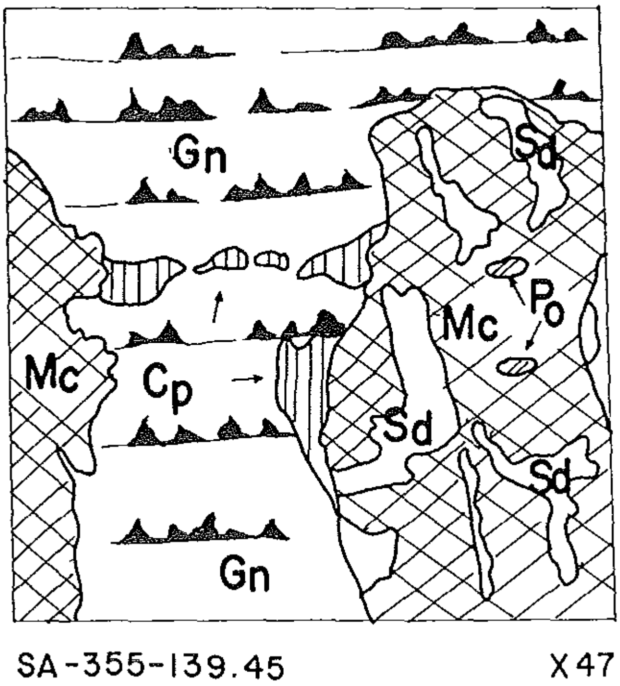


Fig. 43. Aggregate of sulfides. Relict and replacment textures: relics pyrrhotite (Po) in marcasite (Mc); chalcopyrite (Cp) healing the cleava planes in galena (Gn) and as intermittent occasional rims along the gra boundary of galena with marcasite.

Galena occurs as coarse grained anhedral masses with irregular grain boundaries impregnated in quartz, often with triangular pits following the cube planes of cleavage. It is commonly associated with sphalerite, chalcopyrite and marcasite (Fig. 40, 42b, 42c, 43). It contains chalcopyrite infills along its cleavage planes (Fig. 42c, 43). In places, galena is observed smeared into sphalerite along fractures. This feature is common in ore deposits where galena is associated with brittle ore minerals whose plasticity is conspicuously low compared to the plasticity of galena (Ramdhor, 1969).

Marcasite occurs as crystal aggregates arranged in clusters, impregnated and replacing silicate minerals in veins and host rocks (Fig. 44). The grains are well interlocked, sometime lath-shaped (Fig. 44b), commonly associated with pyrrhotite, chalcopyrite, galena and sphalerite. Frequently it is associated with melnicovite-pyrite (grains with fine porous blackish powder), which is a mineral much similar in chemical composition to marcasite. Marcasite is a dominant mineral at the vein margins and in the upper levels of the SGD. It contains inclusions of quartz , pyrrhotite , sphalerite and chalcopyrite (Fig. 42), relics of pyrrhotite in marcasite being much common. Marcasite is sometimes fractured forming broken hard bodies, with cross-cut and veinlet-like micro-structures containing siderite and Fe-hydroxides (Fig. 44a - f).

Microstructures, relict and replacement textures indicate that marcasite including melnicovite-pyrite and siderite were formed at a later stage during the decomposition of sulfides.

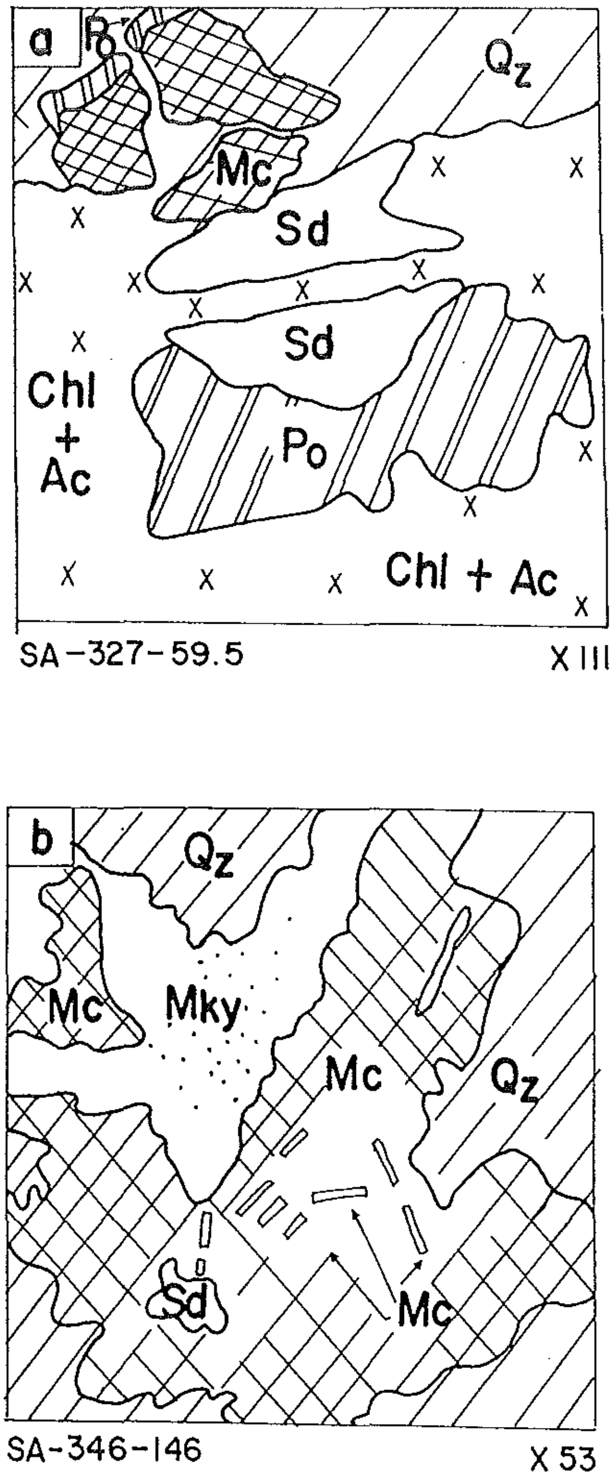


Fig. 44. The products of disulfidization of monosulfides (of the minerals pyrrhotite group) . a) Marcasite (Mc) replacing pyrrhotite (Pseudomorphs of marcasite laths, melnicovite-pyrite (Mky) and sideri after pyrrhotite.

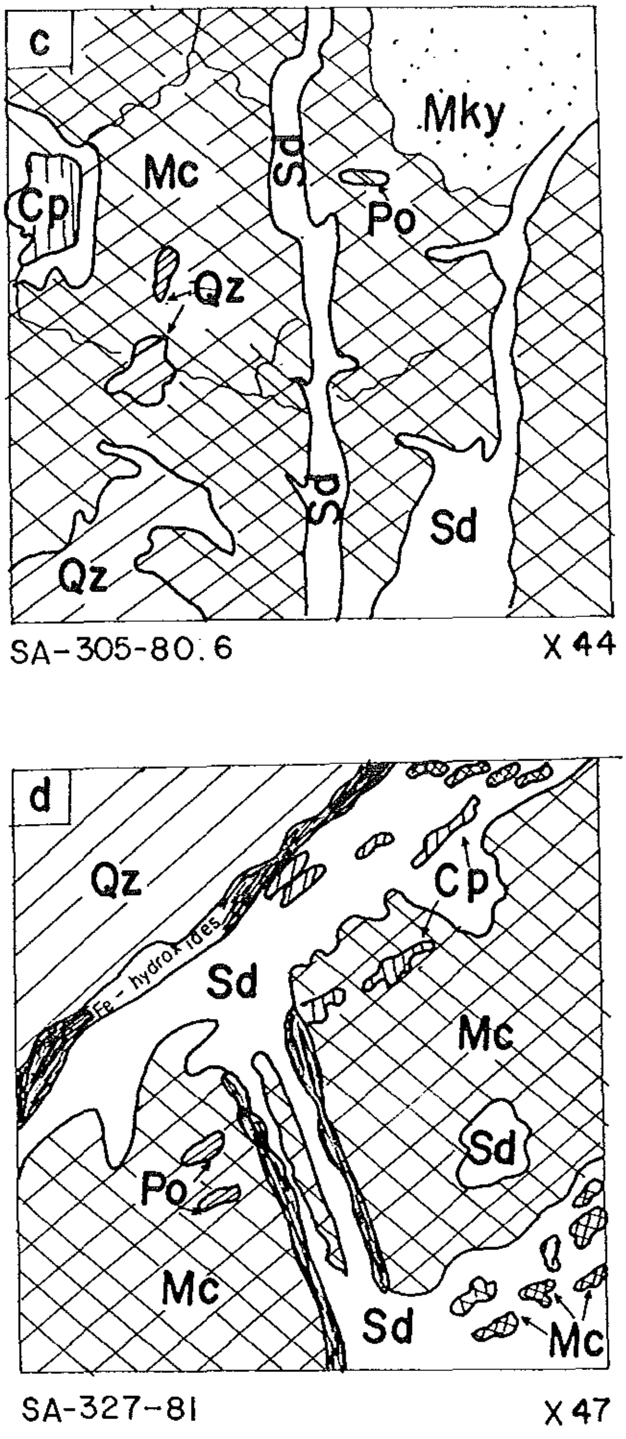


Fig. 44 (cont'd.) c) Marcasite , fractured, with cross - cut micro-structur containing siderite, and inclusions of quartz (Qz) and pyrrhotite d) Oxidation of Fe - monosulfides , inclusions of pyrrhotite ar chalcopyrite (Cp) in marcasite; tiny grains of chalcopyrite and marcasit in siderite matrix.

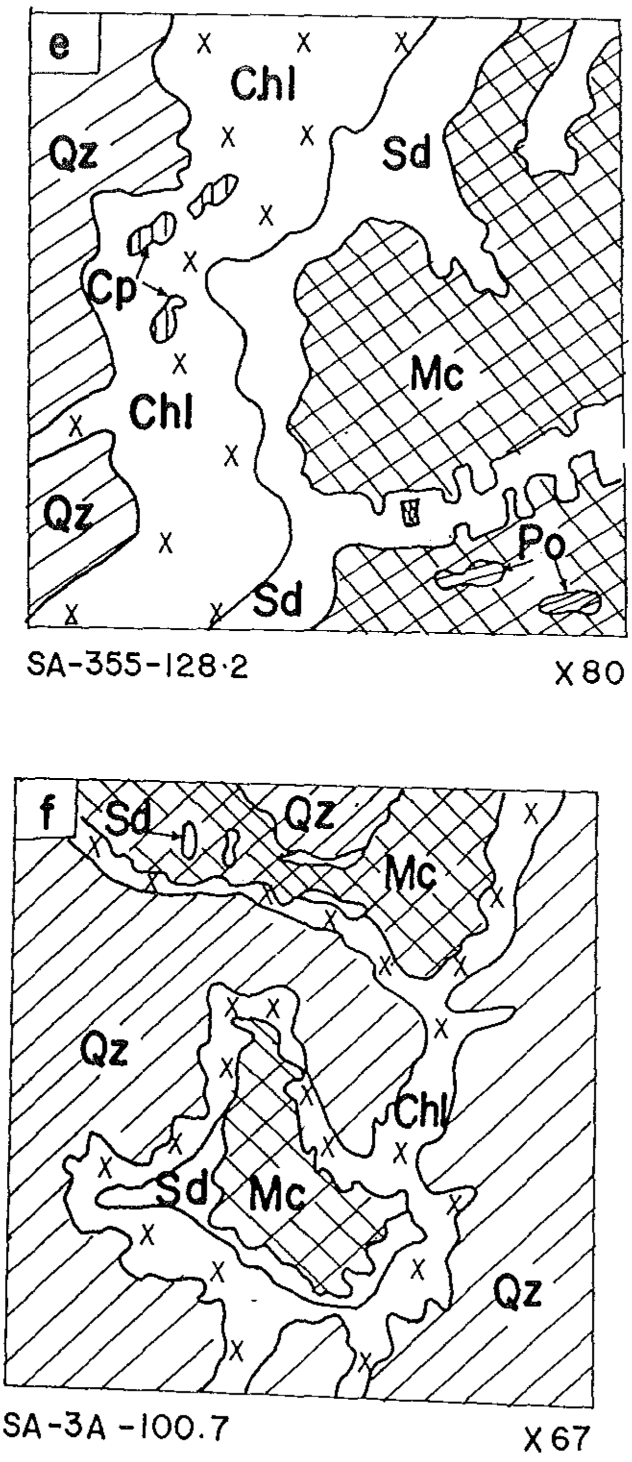


Fig. 44(cont'd) e & f) Cross-cut micro-sructure and rim-like texture: rims of siderite around marcasite grains in chlorite (Chl) and quartz.

The pyrrhotite inclusions that form relict texture in marcasite give good evidence of replacement processes. Thus, marcasite and melnicovite-pyrite are the products of the disulfidization processes of iron monosulfides where transformation of pyrrhotite that start along the cleavage openings and cracks progress as in leaching away and replacing pyrrhotite leaving only the presently observed inclusions. Disulfidization of Fe-sulfides takes place in acid solutions at moderate to low temperatures (Ramdhor, 1969). However, the presence of small amounts of siderite in the ore veins indicated that CO_3 was present in the solutions. Thus, the transformations, disregarding the intermediate products, can be expressed as $2Fe_{1-x}S + CO_3$ ---> $FeS_2 + FeCO_3$. Fe-hydroxides are common alteration products of Fe-sulfides in near-surface oxidation condition where weathering produces $FeSO_4$, or limonite and H_2SO_4 as end products (Ramdhor, 1969). Supergene siderite could be formed together with the Fe-hydroxides from a solution that carries $FeSO_4$ and CO_3.

In the genetic systematization of the ore minerals, the microtextures and microstructures examined were used as clues to determine the sequence of mineral deposition. Since determining the order of deposition is seldom simple and requires an examination of many thin and polished sections from samples taken at widely scattered locations within the deposit (Park and MacDiarmid, 1975), the mineral paragenesis established here will serve only as a general temporal relation of the ore minerals in the SGD. The hypogene minerals of the SGD are the result of discontinuous surges of ore-bearing fluids where the mineralized fissure could have been repeatedly opened by tectonic activity in the vein development.

There are at least four stages of mineralization in the SGD that can be broadly categorized into three i.e. wolframite-scheelite-quartz stage, sulfide-gold-quartz stage and disulfide-carbonate stage.

Wolframite-scheelite-quartz stage is the earliest mineralization where wolframite followed by scheelite are possibly deposited together with quartz. They are spatially associated with sulfides especially with Fe-sulfides and arsenopyrite in the mineralized country rocks and hydrothermal quartz veins. Both wolframite and scheelite could overlap the deposition of sulfides and gold in time and space. In hydrothermal deposits wolframite is found in close association with arsenopyrite, sphalerite, chalcopyrite and in paragenesis of intrusive gold veins; and at still lower temperatures with siderite and galena (e.g. Nevdorf, Harz, Germany) and in enargite bearing veins (e.g. Butte, Montana) (Ramdhor, 1969). Therefore, overlapping in space and time is possible if slight changes in temperature, pressure and chemistry of the transporting fluids occur during the normal course of deposition resulting in reversals or interruptions of the crystallization of the processes (Park and MacDiarmid, 1975).

The sulfide-gold-quartz stage follows the wolframite-scheelite mineralizations and is characterized by multiple pulsation system that deposits minerals of different chronologic

7. MINERAL ZONING

7.1. General

Mineralogical data on the primary ore minerals of the SGD were plotted on the vertical projection of ore vein No. 1 and on the geological cross-sections to characterize the distribution of ore minerals in the ore veins and the enclosing rocks respectively. As a result, it has been proven that the ore minerals show both lateral and vertical zoning which might be of considerable importance in mine development (ore blending). The zones are generalized, and particularly, the vertical zonation is partially described partly on the theoretical basis due to insufficient sampling density and lack of samples from considerable depth (below 1800 m level). Undoubtedly, the further refinement of the zonal pattern of the ore minerals could be achieved with a more dense sampling grid. Any detection of zonal pattern whether epigenetic or hypogenetic is important in economic geology because it helps to predict changes in mineralization patterns during the development and mining of a deposit (Park and MacDiarmid, 1975). Thus, the sulfide mineralization in the SGD is related to gold rich zones making them relevant in gold prospecting.

7.2. Zoning

In ore vein No. 1, lateral zoning of hypogene ore minerals for 150 meter vertical depth (levels 1950 - 1800 m), show three distinct types of mineralizations that form four parallel zones with inclined boundaries that become vertical in the upper levels (Fig. 45). The zonal depositional pattern of gold overlaps the zones of all sulfide minerals indicating its presence everywhere in the vein plane in association with all types of sulfides that form the ore zones. Nonetheless, a classification of the high gold values with respect to the primary ore mineral zones into four blocks show a clear picture of the gold distribution in relation to the ore minerals.

(1) Marcasite-chalcopyrite (Mc-Cp) zones occupy the peripheral parts of the vein along its strike, in both northeast and southwest directions at the vein pinch-outs. The zones consist of marcasite as a major (>75%) ore mineral and includes chalcopyrite, pyrrhotite and melnicovite-pyrite as minor (<10%) constituents. Pyrrhotite occurs here only as relics in marcasite irrespective of the depth variations, thereby, indicating the transformation of pyrrhotite to disulfides due to superimposed structural effect which is shearing in this case. The Mc-Cp zones, therefore, indicate an extent where the shear effect is felt, at least, in the foot wall side of the vein. The zones are in agreement with the occurrence of a fine-grained (recrystallized) quartz which is described at the selvages of the vein by Dorofeev et al. (1982) and Moudrov et al. (1991). The high gold grades are 5.2 - 6.2 g/t in the foot wall side zone and 11.3-13.0 g/t in the hanging wall side zone. The higher values in the latter case is probably due to the higher

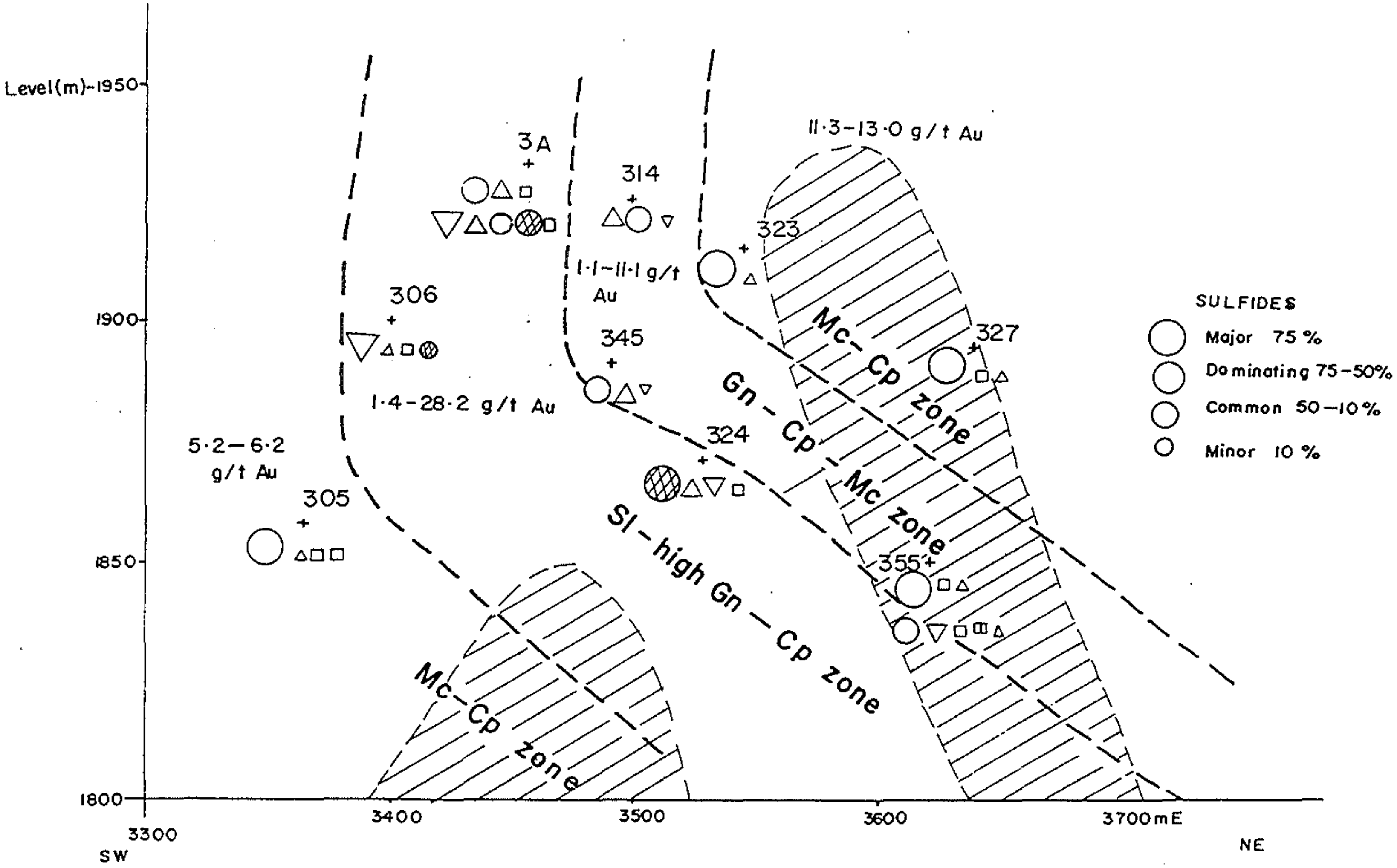


Fig-45-Scheme of primary zoning of hypogene ore minerals in ore vein No.I of the Sakaro gold deposit. ○Marcasite(Mc) □ Pyrrhotite△Chalcopyrite (Cp) ▽galena(Gn) ⊗ Sphalerite (Sl)⊞Melnicovite Pyrite ▨ Gold rich zone 305—Bore-hole number.

remobilization effect as a result of intense shearing.

(2) Sphalerite-high Galena-Chalcopyrite (Sl-high Gn-Cp) zone. This zone is rich in galena and chalcopyrite, and is the only zone that contains sphalerite. Galena and sphalerite constitute 50-75% and chalcopyrite 10-50% of the sulfides correspondingly. Pyrrhotite is present as minor constituent at all levels and marcasite is found only in the upper levels of the zone as replacement mineral. It is the widest (100 - 200 m) zone of all and occupies the central part of the vein. It is rich in gold with the highest grade reaching 28.2 g/t. The mineralogical association of sphalerite, high galena and chalcopyrite with high gold, therefore, proves the close association of Au-Ag-Pb-Cu-Zn,Fe. However, geochemical data for Zn is missing for this zone (and SGD as a whole) because the analyses have been made using OES which has a low detection limit (100 ppm) for Zn.

(3) Galena-Chalcopyrite-Marcasite (Gn-Cp-Mc) zone is found at the northeast of the vein below the Mc-Cp zone forming a narrow (about 50 m wide) zone. The zone contains chalcopyrite and marcasite in equal proportions and pyrrhotite, melnicovite-pyrite and galena as minor constituents. Pyrrhotite occurs as grains in sulfide aggregates and also as inclusions in marcasite, therefore, disulfidization process of mono-sulfides is not complete in this zone in comparison with the Mc-Cp zone. Thus, Gn-Cp-Mc zone could represent rather a transitional zone from Mc-Cp zone to Sl-high Gn-Cp zone. The presence of this transitional zone only in the northeastern part of the vein

pre-erosional vein apex which had been located below a paleosurface. The zone contains only FeS_2 (marcasite). However, much of it is eroded away, and the left over is altered by secondary processes which has replaced it by another zone; namely, oxidation zone.

(4) Zone 4 is an oxidation zone which is bounded by present day surface and oxidation zone bottom. It is a zone where supergene alterations of the primary ore minerals take place. The zone contains FeS_2 (marcasite + melnicovite-pyrite) and Fe-hydroxides; and within its lower levels secondary minerals of Cu, Pb, Zn and Au are found. The highest grade of gold in this part of the zone reaches 52.2 g/t.

Ore minerals in the enclosing rocks of the SGD were plotted with their relative proportion in nine bore-holes that are sunk at different points along the strike of the vein (Fig. 47). As a result, the ore minerals show similar distribution pattern along the dip of the vein in sections along different exploratory lines that are laid perpendicularly to the strike of the vein and host rocks. The distribution of the ore minerals are systematized in two broad zones i.e. marcasite - pyrrhotite - chalcopyrite zone and wolframite - scheelite - Fe-sulfides zone. The zones are established by taking wolframite and scheelite as index minerals. This is done for the understanding of the paragenetic relations of Fe-sulfides and W-minerals on the one hand and on the other a probable economic significance of W. If a scheme of classification based on mono- and di-sulfides had been adopted a similar pattern to that of the

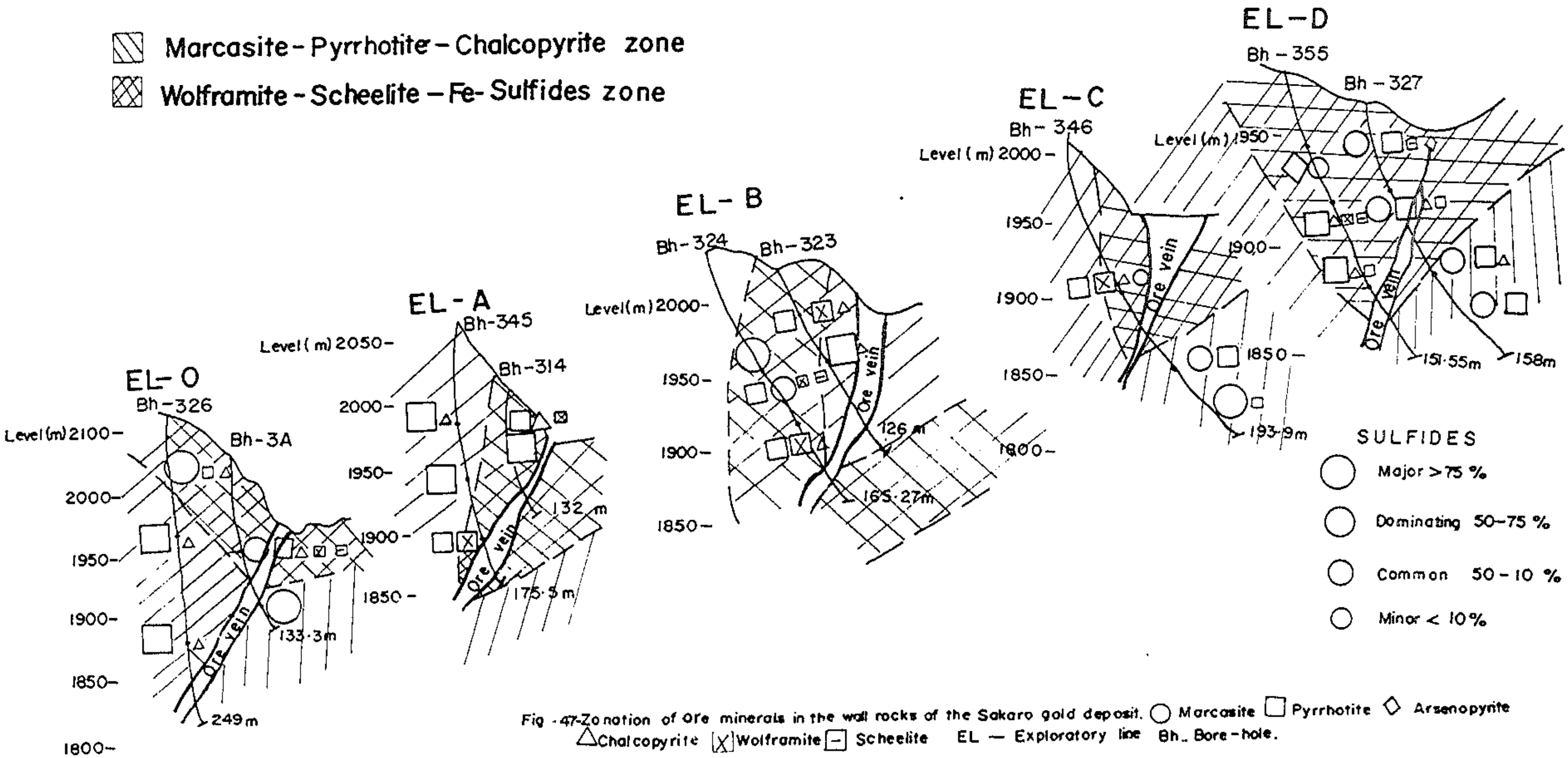


Fig - 47-Zonation of Ore minerals in the wall rocks of the Sakaro gold deposit. ○ Marcasite □ Pyrrhotite ◇ Arsenopyrite △Chalcopyrite ☒Wolframite ⊟ Scheelite EL — Exploratory line Bh.. Bore-hole.

9. TUNGSTEN MINERALIZATION.

The Adola area has a long mining history for gold and recently also for rare (Ta, Nb) metals. Exploration for the above mentioned metals in the area is still in progress. Though much has been done to understand the mineral potential of the area, especially by AGEP (1979-81) and TMEP (1986-89) there is still a demand for a continued effort in mineral assessment and exploration to upgrade the mineral wealth of the area. Thus, exploration targets that include metals other than gold and rare metals might possibly lead to discoveries of other deposits of different nature. One of these is a possibility of finding W-mineralization in the Adola area. This possibility has been suggested recently by Getaneh, Sliouniaev and Solomon (1992) based on the preliminary data of assay values (0.1 - 0.2 %) on the drill-core samples of the SGD and on the genetic interpretation of the geological settings (quartz veins, amphibolites, physical-chemical conditions of metamorphism and tungsten-bearing minerals) significance for looking for tungsten as ore-component in gold-bearing ores. As a result, the authors recommended that further sampling of the ores of the area and wastes of the gold-producing plant at Lega Dembi might be carried out to prove the availability of tungsten accumulations of commercial value.

The presence of tungsten in the SGD was reported first by Dorofeev et al. (1982). However, it was considered as having no commercial value. Nevertheless, the results of an approach based

Table 12. Tungsten contents(>0.006%) in core samples of the Sakaro gold deposit

Cont'd.

Serial number (Data code)	Bore-hole number-Sample number	Sampling interval (m)	Sampling length (m)	W (%)
95	305-20	88.70 - 90.20	1.50	0.01
96	305-23	93.30 - 94.80	1.50	0.01
97	305-26	97.00 - 98.50	1.50	0.01
98	305-42	118.20 -119.45	1.20	0.03
99	305-44	121.00 -122.50	1.50	0.01
100	305-46	124.00 -124.80	0.80	0.01
101	305-47	124.80 -125.65	0.85	0.01
102	305-48	125.65 -126.15	0.50	0.01
103	340A-1	33.20 - 34.20	1.00	0.02
104	340A-2	34.20 - 35.20	1.00	0.01
105	340A-4	36.20 - 37.20	1.00	0.01
106	340A-8	40.20 - 41.20	1.00	0.01
107	319-6	7.50 - 9.00	1.50	0.06
108	319-10	13.50 - 14.50	1.00	0.02
109	319-11	14.50 - 15.50	1.00	0.02
110	319-12	15.50 - 16.50	1.00	0.03
111	319-13	16.50 - 17.70	1.20	0.02
112	319-15	18.70 - 20.00	1.30	0.02
113	319-16	20.00 - 21.60	1.60	0.01
114	319-17	21.60 - 23.00	1.40	0.01
115	319-20	26.00 - 27.50	1.50	>1.00

Note: (1) Analytical method is O.E.S., (2) The analyses are made at the Central Lab. of E.I.G.S.

Table 13. Tungsten contents(>0.006%) in surface samples of the Sakaro gold deposit

Serial number (Data code)	Trench number-Sample number	Sampling interval (m)	Sampling length (m)	W (%)
1	702A-1	0.00 - 1.00	1.00	0.01
2	702A-2	1.00 - 2.00	1.00	0.01
3	702A-3	2.00 - 3.00	1.00	0.02
4	702A-4	3.00 - 4.00	1.00	0.02
5	702A-5	4.00 - 5.00	1.00	0.01
6	702A-6	5.00 - 6.00	1.00	0.01
7	702A-7	6.00 - 7.00	1.00	0.02
8	702A-8	7.00 - 8.00	1.00	0.02
9	702A-9	8.00 - 9.00	1.00	0.01
10	702A-10	9.00 - 10.00	1.00	0.01
11	702A-13	12.00 - 13.00	1.00	0.01
12	702A-14	13.00 - 14.00	1.00	0.02
13	702A-15	14.00 - 15.00	1.00	0.01
14	702A-17	16.00 - 17.00	1.00	0.01
15	702A-18	17.00 - 18.00	1.00	0.01
16	702A-19	18.00 - 19.00	1.00	0.02
17	702-2	21.00 - 22.00	1.00	0.02
18	702-3	22.00 - 23.00	1.00	0.01
19	702-4	23.00 - 24.00	1.00	0.01
20	702-5	24.00 - 25.00	1.00	0.01
21	702-6	25.00 - 26.00	1.00	0.01
22	702-7	26.00 - 27.00	1.00	0.01
23	702-12	31.00 - 32.00	1.00	0.01
24	702-13	32.00 - 33.00	1.00	0.01
25	702-15	34.00 - 35.00	1.00	0.01
26	705-14	26.00 - 28.00	2.00	0.01
27	701A-6	5.00 - 6.00	1.00	0.01
28	701A-7	6.00 - 7.00	1.00	0.01
29	701A-9	8.00 - 9.00	1.00	0.01
30	701A-10	9.00 - 10.00	1.00	0.01
31	701A-11	10.00 - 11.00	1.00	0.03
32	701A-12	11.00 - 12.00	1.00	0.03
33	701A-13	12.00 - 13.00	1.00	0.05
34	701A-15	14.00 - 15.00	1.00	0.01
35	701A-16	15.00 - 16.00	1.00	0.01
36	701A-17	16.00 - 17.00	1.00	0.01
37	701A-18	17.00 - 18.00	1.00	0.01
38	701A-20	19.00 - 20.00	1.00	0.15
39	700B-1	34.00 - 35.00	1.00	0.03
40	700B-2	35.00 - 36.00	1.00	0.03
41	700B-3	36.00 - 37.00	1.00	0.03
42	700B-4	37.00 - 38.00	1.00	0.01
43	700B-5	38.00 - 39.00	1.00	0.01
44	700B-6	39.00 - 40.00	1.00	0.01
45	700B-7	40.00 - 41.00	1.00	0.01
46	700B-8	41.00 - 42.00	1.00	0.01
47	700B-9	42.00 - 43.00	1.00	0.01
48	700B-10	43.00 - 44.00	1.00	0.02
49	700B-11	44.00 - 45.00	1.00	0.01
50	700B-22	55.00 - 56.00	1.00	0.01
51	700B-25	58.00 - 59.00	1.00	0.01
52	700B-28	61.00 - 62.00	1.00	0.01
53	717A-6	4.75 - 5.75	1.00	0.01
54	717A-17	15.75 - 16.75	1.00	0.01
55	717B-2	49.75 - 50.75	1.00	0.01
56	717B-8	55.50 - 56.50	1.00	0.01
57	717B-9	56.50 - 57.50	1.00	0.01
58	717B-16	63.50 - 64.75	1.25	0.03
59	717B-21	69.50 - 70.50	1.00	0.01
60	717B-22	70.50 - 71.00	0.50	0.01
61	717B-23	71.00 - 72.00	1.00	0.01
62	719-20	19.25 - 20.25	1.00	0.01
63	719-21	20.25 - 21.25	1.00	0.01
64	719-22	21.25 - 22.25	1.00	0.02
65	721-28	31.75 - 33.75	2.00	0.01
66	721-41	49.50 - 50.50	1.00	0.01
67	721-42	50.50 - 52.50	2.00	0.01
68	721-53	66.50 - 67.50	1.00	0.01
69	721-61	74.50 - 75.50	1.00	0.01
70	721-67	80.50 - 81.50	1.25	0.01
71	721-68	81.50 - 82.50	1.00	0.01
72	721-69	82.50 - 83.50	1.00	0.01
73	721-71	84.50 - 85.50	1.00	0.03
74	721-72	85.50 - 86.50	1.00	0.02
75	721-74	87.00 - 88.00	1.00	0.03
76	721-76	89.00 - 90.75	1.75	0.01
77	722-33	32.00 - 33.00	1.00	0.01
78	722-36	35.75 - 36.75	1.00	0.01
79	722-40	39.75 - 40.75	1.00	0.01
80	722-46	46.00 - 46.75	0.75	0.01
81	722-49	49.00 - 50.25	1.25	0.01
82	722-55	55.25 - 56.25	1.00	0.01
83	724-2	0.75 - 1.75	1.00	0.01
84	724-4	2.75 - 3.75	1.00	0.01
85	724-6	4.75 - 5.75	1.00	0.01
86	724-18	16.50 - 17.00	0.50	0.01
87	724-19	17.00 - 17.50	0.50	0.03
88	724-33	30.25 - 31.25	1.00	0.01
89	724-49	47.25 - 48.25	1.00	0.01
90	724-64	62.00 - 62.25	1.25	0.01
91	724-88	84.00 - 85.00	1.00	0.02
92	724-89	85.00 - 86.00	1.00	0.01
93	724-108	104.00 - 104.50	0.50	0.01
94	724-109	104.50 - 105.25	0.75	0.01

Note. (*) analytical method [illegible]

Table 13. Tungsten contents(>0.006%) in surface samples of the Sakaro gold deposit

Cont'd.

Serial number (Data code)	Trench number-Sample-number	Sampling interval (m)	Sampling lengt (m)	W (%)	Serial number (Data code)	Trench number-Sample-number	Sampling interval (m)	Sampling length (m)	W (%)
95	728A-2	0.75 - 1.75	1.00	0.03	138	727A-21	145.25 - 146.25	1.00	0.01
96	728B-10	59.00 - 60.00	1.00	0.03	139	727-1	146.25 - 147.25	1.00	0.03
97	728B-11	60.00 - 61.00	1.00	0.10	140	727-6	151.25 - 152.25	1.00	0.01
98	728B-12	61.00 - 62.00	1.00	0.03	141	727-9	154.25 - 155.25	1.00	0.01
99	728B-13	62.00 - 63.00	1.00	0.01	142	727B-34	213.75 - 214.50	0.75	0.30
100	728B-14	63.00 - 64.00	1.00	0.01	143	739-10	0.50 - 1.00	0.50	0.01
101	728B-15	65.00 - 66.00	1.00	0.02	144	739-9	1.00 - 1.50	0.50	0.01
102	728B-19	69.00 - 70.00	1.00	0.01	145	738-24	1.00 - 2.00	1.00	0.02
103	728B-20	70.00 - 70.50	0.50	0.01	146	738-23	2.00 - 3.00	1.00	0.03
104	728B-21	70.50 - 71.50	1.00	0.01	147	738-18	7.00 - 8.00	1.00	0.02
105	728B-27	76.00 - 76.50	0.50	0.01	148	738-15	10.00 - 11.00	1.00	0.02
106	728B-31	79.50 - 80.50	1.00	0.01	149	737-19	3.75 - 4.75	1.00	0.01
107	728B-42	90.50 - 91.50	1.00	0.01	150	737-18	4.75 - 5.50	0.75	0.01
108	728B-44	92.50 - 93.00	0.75	0.01	151	737-17	5.50 - 6.50	1.00	0.10
109	725-11	9.50 - 10.25	0.75	0.01	152	737-16	6.50 - 7.50	1.00	0.10
110	725-12	10.25 - 11.25	1.00	0.01	153	737-15	7.50 - 8.50	1.00	0.20
111	725-13	11.25 - 12.00	0.75	0.01	154	737-14	8.50 - 9.50	1.00	0.02
112	725-14	12.00 - 13.00	1.00	0.02	155	737-13	9.50 - 10.50	1.00	0.10
113	725-15	13.00 - 13.75	0.75	0.01	156	737-7	15.25 - 16.25	1.00	0.06
114	725-16	13.75 - 14.50	0.75	0.01	157	737-6	16.25 - 17.25	1.00	0.06
115	725-17	14.50 - 15.25	0.75	0.02	158	736-19	0.00 - 1.00	1.00	0.05
116	725-18	15.25 - 16.00	0.75	0.03	159	736-18	1.00 - 2.00	1.00	0.02
117	725-19	16.00 - 16.75	0.75	0.02	160	736-17	2.00 - 3.00	1.00	0.06
118	725-20	16.75 - 17.50	0.75	0.01	161	736-16	3.00 - 4.00	1.00	0.03
119	725-21	17.50 - 18.25	0.75	0.03	162	736-15	4.00 - 5.00	1.00	0.02
120	725-22	18.25 - 19.00	0.75	0.02	163	736-14	5.00 - 6.00	1.00	0.10
121	725-23	19.00 - 19.75	0.75	0.02	164	736-13	6.00 - 7.00	1.00	0.01
122	725-24	19.75 - 20.75	1.00	0.02	165	736-12	7.00 - 8.00	1.00	0.03
123	725-25	20.75 - 21.75	1.00	0.02	166	736-11	8.00 - 9.00	1.00	0.10
124	725-26	21.75 - 22.75	1.00	0.01	167	735-12	0.00 - 1.00	1.00	0.06
125	725-27	22.75 - 23.75	1.00	0.01	168	735-10	2.00 - 3.00	1.00	0.06
126	725-28	23.75 - 24.75	1.00	0.01	169	735-9	3.00 - 3.50	0.50	0.06
127	725-29	24.75 - 25.50	0.75	0.01	170	735-8	3.50 - 4.50	1.00	0.15
128	725-30	25.50 - 26.50	1.00	0.01	171	735-6	5.50 - 6.25	0.75	0.01
129	725-32	27.50 - 28.50	1.00	0.01	172	735-5	6.25 - 7.00	0.75	0.01
130	725-33	28.50 - 29.50	1.00	0.01	173	735-3	8.00 - 8.75	0.75	0.01
131	725-34	29.50 - 30.50	1.00	0.01	174	734A-20	0.00 - 1.00	1.00	0.03
132	725-35	30.50 - 31.25	0.75	0.02	175	734A-19	1.00 - 2.00	1.00	0.03
133	725-36	31.25 - 32.00	0.75	0.02	176	734A-16	3.00 - 4.00	1.00	0.02
134	725-37	32.00 - 32.50	0.50	0.03	177	734A-15	4.00 - 5.00	1.00	0.02
135	727A-12	137.00 -137.75	0.75	0.01	178	734A-11	8.00 - 9.00	1.00	0.02
136	727A-16	140.50 -141.50	1.00	0.01	179	734A-10	9.00 - 10.00	1.00	0.06
137	727A-20	144.25 -145.25	1.00	0.01	180	734A-9	10.00 - 11.00	1.00	0.03

Note: (1) Analytical method is O.E.S., (2) The analyses are made at the Central Lab. of F.I.G.S

Table 14. Industrial tungsten deposits (from Kuzvart and Bohmer, 1978. Prospecting and Exploration of Mineral Deposits, Table 9, p. 3)

Type	Form	Economic mineral	Metal content in %	Percentage of world reserves	percentage of world production	Examples
1. Skarn	layers and veins at the granitoid-carbonate contact	scheelite0	0.3-6.0 WO_3	60 (WO_3)	55 (WO_3)	Sang Dong (S. Korea), Ingichke (USSR), USA, Mexico Brazil
2. Hydrothermal (with quartz)	veins at the granitoid contact	wolframite	0.4-4.0 WO_3	30 (WO_3)	25 (WO_3)	Burma, China Dzhida (USSR), Cinovec (Zinnwalde CSSR)
3. Placers	eluvial-colluvial cover, alluvium	wolframite	0.01(min.) WO_3	10 (WO_3)	20 (WO_3)	China, Dzhida (USSR)

Maximum content of impurities: P - 0.03 to 0.2%, S - 0.3 to 3%, As - 0.04 to 0.2%, Sn - 0.08 to 1.5%, Cu - 0.1 to 0.22%.

the geological and geochemical environments of the SGD with skarn type tungsten deposits formed at the contacts of carbonate rocks of different compositions and acidic intrusions. Though further research is required to formulate a model on the origin of tungsten in particular, and on the origin of the Sakaro ore veins in general, it is possible to suggest a general statement on possible mechanisms. One of these is a metamorphic secretion model for vein genesis (Boyle, 1979) and W-mineralizations where metals required for forming tungsten-bearing minerals i.e. Ca, Fe, Mn, etc. are taken out from the amphibolites and added to the mineralizing solutions by orogenic and metamorphic processes. The other alternative is the possible connection of the mineralization with an intrusive body. The geological map of the SGD (see Fig. 3) shows that the Sakaro area underlies amphibolites and metamorphic schists which are interpreted as a sequence of volcano-sedimentary origin under regional scale (AGEP, 1979-81; TMEP, 1986-89). At the northeastern part of the deposit an amphibole-plagioclase gneiss (TMEP, 1989) which is considered as an intrusive of tonalitic (TMEP, 1989; Ayalew, 1990) or granodioritic (Moudrov et al., 1991) composition intrudes through the volcanogenic sequence which is mainly amphibolites with some graphitic interbands. Thus, the metatonalite /metagranodiorite could have served in controlling the thermal gradient (locally) and possibly as a metal source in Au- and W- mineralizations.

According to Boyle (1979) tungsten is a nearly universal associate of gold in its hypogene deposits and is observed with a content range of few parts per million to more than 5000 ppm in auriferous deposits: skarn type deposits (2 - 1000 ppm), gold-quartz veins (2 - 5000 ppm), and polymetallic deposits (< 2-1000 ppm). Moreover, the author stated that rich shoots of scheelite or wolframite may occur in all of these gold deposits and some have been mined for their tungsten content at a grade range of 0.05 to 0.75 percent WO_3. In the SGD, tungsten content is even more than the range mentioned above, with an upper limit of > 10,000 ppm. Therefore, an effort directed to locating the W-bearing ore shoots in the SGD, undoubtedly will promote the appraisal of the relative prospects of the tungsten mineralization.

Studies on zonation show that tungsten highs and tungsten-bearing minerals are found adjacent to the ore veins in the wall rocks and also in quartz veins (see Fig. 30 and Fig. 47). Paragenetic study show that quartz, tungsten and gold (?) were deposited together during the earlier period of mineralization. Moreover, supergene enrichment of tungsten as tungstite (H_2 WO_4) and as tungstates (WO_4) in association with gold, arsenates, sulfates, carbonates and hydroxides of other metals in the oxidation zone were reported by Moudrov et al. (1991). Therefore, the oxidation zone and placers that may include tungstite, wolframite and scheelite might be one of the targets in exploration for tungsten mineralization.

The studies on tungsten mineralizations so far conducted could be used as a ground in prospecting and exploration for tungsten in the SGD and AGF. Calc-silicate-bearing assemblages and various metasedimentary and metavolcanic rocks with dilatant structures in the AGF are the possible sites of tungsten mineralization. It is also discussed in various publications that tungsten is mined with gold as a commodity in auriferous-tungsten deposits of variable nature including shear zone gold [Au(Ag,W)]. As regard to SGD, a better analytical technique, sampling that considers veins, wall rocks, the nearby "intrusives" and eluvial - alluvial heavy concentrates; and a study on the zonal distribution of supergene minerals in the oxidation zone could upgrade tungsten as a mineral for future use.

10. CONCLUSIONS AND RECOMMENDATIONS.

According to the proposed scheme of the research, the geochemical and mineralogical studies conducted on the SGD allow the following conclusions to be made:

Conclusion related to geology.

(1) Having taken into consideration the data on the geological features of SGD obtained by different researchers up to now (the reports and publications are referred to in the thesis), it might be concluded that the Sakaro deposit is a fault-hosted mesothermal vein-type gold deposit. The enclosing metamorphic rocks are of the Upper Proterozoic age and are metamorphosed in greenschist to lower amphibolite facies. The dominant wall rocks exposed in the mine working are amphibolite in the hanging wall side, northwest of the mineralized zone, and mica schists which at places are graphitic in the foot wall side, southeast of the mineralized zone. The mineralization forms a zone that has a typical horse-tail structure. The two main quartz bodies i.e vein No. 1 and vein No. 2 constitute the larger part of the vein shoots of the zone and also account for the major portion of the reserves of the SGD.

Conclusions related to distribution, associations and zonation of metals.

(2) Spatial distribution and content variation trends of elements (Au, W, Ag, Pb, Cu, As, Mo, Co, Ni, V, Mn, Ti) from 1859 samples of the SGD indicate metals in the wall rocks and ore veins are either enriched or depleted as a result of mineralizing fluid and wall rock interactions. Liberation of metals and enrichment by the secondary fixation in the supergene environment are due to weathering processes.

(3) The metals enriched with Au in the SGD include Ag, Pb, Cu, Mo, As, W and Ni in decreasing order. The qualitative and quantitative inter-element relations show that Au has significant correlations with Ag, Pb, Cu, Mo and rarely with As, W, and Ni. The strong correlation of Au, with Ag, Pb and Cu suggests that as gold commonly is associated with sulfides of these metals.

(4) In most of the cases (75%), Au occurs spatially associated with Ag and Pb. The metals i.e Au, Ag and Pb are enriched in the ore veins and at the tectonic/lithologic contacts with the wall rocks. Their dispersion pattern is mostly asymmetrical with steep side (elevated values) at the contact of vein with the hanging wall rocks (amphibolites) and a gentler slope decreasing values towards the foot wall rocks (mica schists). Though Au is tightly related to Ag and Pb, sometimes, however, it shows significant values (up to 3 g/t) where the values of Ag and Pb are low.

(5) Based on the predominating distributions and associations of the elements the general sequence of metal zones in the SGD from the veins outward in the wall rocks are Au-Ag-Pb, Ag-Pb-Cu, W-As-Cu, and Fe-Co-Ni-Mo-Cu respectively.

Conclusions related to frequency distribution of gold

(6) The distribution frequency of 2364 gold assays from ore veins and enclosing rocks in the SGD show that their distribution is positively skewed. Examination of histograms show that high gold contents are more frequent in ore veins than in wall rocks. Both the quartz veins and wall rocks have a large peak (mode) representing background and a tail at higher values. The high gold contents are more frequent in weathered rock samples rather than fresh rock samples indicating gold enrichment by the process of weathering.

(7) Although gold contents range is a similar pattern in all rock types, there is a difference in the form of the distribution. The frequency distribution of gold in the ore veins shows a steady decreasing pattern from high towards low ones, whereas in the wall rocks there is a break in the distribution mostly seen between 3 and 5 ppm, thereafter, representing flat distribution. The most frequent gold contents are those with < 1 ppm, and these modal concentrations are higher in the wall rocks than in the ore veins.

(8) The frequency distribution of gold approximate normal distributions in all rock types and environments when the data on gold contents are transformed to logarithms. The best approximation of the normal distribution is seen in fresh ore veins and the least in fresh mica schists. Generally, a better lognormal distribution is seen in weathered rock samples. In the ore veins, however, the distribution is nearly similar in both hypogene and hypergene environments.

(9) The arithmetic and geometric means of gold in rocks of the SGD is high in ore veins, low in amphibolites and least in mica schists. The mean values are greater in the weathering environment in the respective rocks for the enrichment given by the processes operating at the surficial environment.

Conclusions related to zonal structure of the ore veins

(10) Studies on gold assay values from 2043 vein samples at various levels, along the strike and dip of the ore veins in relation to the thickness variation of the quartz fillings reveal that high and mean gold contents are related much to the thickness variation of the quartz filling with high values at pinches and low values at swells.

(11) An assessment of the distribution of high gold contents across the thickness of the ore veins reveal as they are mostly located to the wall rock sides of the veins, especially to the

hanging wall rock side.

(12) In the distribution of gold contents along the dip of ore vein No.1, the general enrichment seen up the dip of the vein as a result of environmental changes due to oxidation and weathering. However, thickness variation is functional in controlling the distribution of gold when the comparison is made with reference to each environment such as primary, oxidation and surficial environments.

(13) Distribution of gold in the volume and along the strike of the main ore body (ore vein No. 1) of the SGD reveals five ore columns with marked contrast in the ore mineralization. They are (1) obliquely running, EW dipping gold rich (up to 28.2 g/t) zone, (2) northerly trending, vertically dipping gold rich (up to 13 g/t) zone, (3) intermediate low gold (1.1-11.1 g/t) zone, (4) oxidation zone (up to 52.2 g/t Au) and (5) surficial weathering zone (up to 34.6 g/t Au). The first three ore zones are hypogene mineralizations.

(14) The east-west and northerly trending ore zones identified in ore vein No. 1 represent the fronts (channels) of migration of the mineralizing fluids responsible for gold deposition. Their upper surfaces (or apexes) represent locations where the loads or maximum concentrations are separated from solutions. The trends of the zones indicate that the ascent of the solutions is from east and north along a tectonically

predetermined path.

(15) Gold distribution within the volume of the ore vein is irregular. However, it follows a systematic pattern of more or less regular course within and away from the fronts of mineralization. There is a regular increase in gold contents upward until a level where maximum ore content is separated from solution. From these zones up to the weathering front, in the intermediate low gold zone, there is a regular decrease in the metal content.

Conclusions related to vein mineralogy

(16) The vein mineralogy shows that the mineralization is the result of multiple episodes of vein opening and filling characterized by massive and recrystallized quartz containing oxides, sulfides and carbonates (in small quantities) with impregnation micro-structures and replacement textures. Besides gold, the main ore minerals identified are wolframite, scheelite, pyrrhotite, arsenopyrite, chalcopyrite, sphalerite, galena, marcasite and melnicovite-pyrite.

(17) Microstructures, relict and replacement textures indicate that marcasite, melnicovite-pyrite and siderite are products of disulfidization processes of iron monosulfides. The effect of disulfidization is much more pronounced at the vein selvages due to shearing (rejuvenated tectonic activity).

Conclusion related to paragenesis

(18) The general paragenetic sequence of the hypogene minerals of the SGD in the younging direction is (1) wolframite-scheelite-quartz stage, (2) sulfide-gold-quartz stage and (3) disulfides-carbonate stage. The minerals sequence from early to late stages of crystallization is wolframite + scheelite in early stage, arsenopyrite + pyrrhotite + gold in early sulfide stage, chalcopyrite + sphalerite + galena + gold in late sulfide stage, and marcasite + melnicovite-pyrite + siderite in disulfides-carbonate stage.

Conclusions related to mineral zoning

(19) In ore vein No. 1, lateral zoning of hypogene minerals display three distinct types of mineralization that form four parallel zones. The general mineral sequence from vein margins to the center is marcasite + chalcopyrite (in peripheral zones) galena + chalcopyrite + marcasite (transitional zone) and sphalerite + high galena + chalcopyrite (central zone).

(20) According to gold enrichment in sulfide zones, priorities in decreasing order are (1) Sl - high Gn - Cp zone (1.4 - 28.2 g/t), (2) Mc - Cp (HWS) zone (11.3 - 13.0 g/t), (3) Gn - Cp - Mc (transitional) zone (1.1 - 11.1 g/t) and (4) Mc - Cp (FWS) zone (5.2 - 6.2 g/t).

(21) Enrichment of galena, chalcopyrite and sphalerite with gold in the central zone in the ore vein proves the close association of Au - Ag - Pb - Cu - Zn.

(22) A presence of a transitional (Gn - Cp - Mc) zone only in the northeastern part of the ore vein indicates a higher intensity of shearing on the hanging wall side of the vein.

(23) The general vertical hypogene mineral zoning in ore vein No. 1 is pyrrhotite (zone 1) in the lower portions, chalcopyrite + galena + sphalerite + gold + iron mono - and di - sulfide (zone 2 - productive zone) in the upper portions.

(24) The general mineralogic zoning in the enclosing rocks from that distal to proximal to the ore veins is marcasite + pyrrhotite + chalcopyrite, and wolframite + scheelite + Fe - sulfides.

Conclusions related to tungsten

(25) Tungsten assays on 1859 samples of the SGD indicate tungsten content in the range 0.006 - > 1.000%. The maximum concentrations (> 1%) are found in the ore veins and near the veins in the wall rocks (amphibolites). Its geochemical dispersion in the country rocks is controlled by fractures which are healed by quartz fillings.

(26) Qualitative and quantitative correlations reveal that W is tightly related to Cu and As.

(27) Mineralogical studies reveal that in the primary ores of the SGD both wolframite and scheelite are the source of tungsten.

(28) Studies on metal and mineralogical zonation show that tungsten-highs and tungsten-bearing minerals are found in veins and in the wall rocks adjacent to the ore veins mainly in amphibolites, forming W-As-Cu and wolframite - scheelite - Fe-sulfides zones respectively which are in complete agreement.

(29) Paragenetic studies reveal that as tungsten bearing minerals (wolframite and scheelite) are the earliest minerals formed in the SGD.

RECOMMENDATIONS

Recommendations related to gold

(30) In geochemical survey of fresh and weathered rock samples in the Sakaro area and in others of similar geologic setting, anomalous contents of Au, Ag, Pb, and Cu might be used as indicator elements with decreasing importance.

(31) An identification of a zone formed by Ag-Pb-Cu in

exploration target areas might indicate that a gold deposit is in the vicinity.

(32) In the SGD, gold enrichment observed in the wall rocks especially at the lithologic/tectonic contact with the ore veins is worth considering in ore zone delineation in the SGD (and in exploration in other areas) because the significant gold values existing outside the ore veins might add to ore reserves.

(33) The ore elements identified and mineralization styles of gold in pinches and swells should be considered in the SGD while preparing constant ore grades for a gold mining industry.

(34) In ore blending, ore zones (lateral + vertical) identified in the SGD are of helps in expecting certain mineral assemblages.

(35) In the processing technology, the products of disulfidization processes and the vertical zonal changes of sulfides are helpful to know the solubility differences of minerals while recovering gold. Therefore, more studies need to be conducted on zonation in the oxidation zone and at depth.

(36) The vertical and lateral mineral zoning covers a 150 meters vertical range, and is generalized from limited number of samples. Therefore, further research with more dense sampling grid that include samples below 1800 m level will improve the

zonal patterns.

(37) The ascending direction of the mineralizing fluids indicate a possible relation of the mineralization with the nearby batholith (tonalitic intrusion), at least in controlling the local thermal gradient. To elucidate the origin and history of the hydrothermal fluids and the role of the intrusion, further studies on fluid compositions , alterations, metamorphic effects and age determination should be conducted.

Recommendations related to tungsten.

(38) Tungsten contents (up to > 1%) of the SGD are encouraging when compared to gold deposits in the world that produce tungsten as by-product at 0.05 - 0.75% WO_3. Therefore, more studies should be conducted in the Sakaro area on tungsten and tungsten-bearing minerals in the placer, primary and supergene deposits.

(39) Tungsten might be one of the metals for future production that may add to Ethiopia's mineral wealth. Therefore, tungsten should also be expected and explored in areas of similar geologic setting to that of the Sakaro area.

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endix 1. Representative assay data of channel and core samples of SGD

rial mber ata de)	Sampling interval (m)	length (m)	number (trench)	Au g/t	Pb ppm	Cu ppm	Ag ppm	As ppm	Mo ppm	W ppm	Ti ppm	V ppm	Co ppm	Ni ppm	Mn ppm
1	0.00 - 1.00	1.00	702A-1	1.30	100	300	0	0	0	100	200	30	60	150	200
2	1.00 - 2.00	1.00	702A-2	0.70	100	300	0	0	0	100	200	30	60	200	200
3	2.00 - 3.00	1.00	702A-3	1.00	200	300	0.3	0	0	200	500	30	60	150	200
4	3.00 - 4.00	1.00	702A-4	1.10	200	300	0.3	60	0	200	300	30	50	200	200
5	4.00 - 5.00	1.00	702A-5	1.30	200	300	0.3	60	0	100	300	20	30	150	200
6	5.00 - 6.00	1.00	702A-6	0.70	100	300	0.3	60	0	100	200	30	20	150	200
7	6.00 - 7.00	1.00	702A-7	0.60	200	500	0	0	0	200	600	20	20	200	200
8	7.00 - 8.00	1.00	702A-8	0.50	200	500	0	0	0	200	1000	20	20	200	200
9	8.00 - 9.00	1.00	702A-9	0.80	50	300	0	0	0	60	500	20	15	200	200
10	9.00 - 10.00	1.00	702A-10	0.20	30	300	0	0	0	60	500	20	3	100	200
11	10.00 - 11.00	1.00	702A-11	0.50	20	200	0	0	0	0	1000	20	3	60	200
12	11.00 - 12.00	1.00	702A-12	0.70	20	200	0	0	0	0	600	20	3	30	200
13	12.00 - 13.00	1.00	702A-13	0.60	100	300	0.3	60	0	100	300	20	6	50	200
14	13.00 - 14.00	1.00	702A-14	1.10	60	200	0	60	0	200	300	20	10	100	200
15	14.00 - 15.00	1.00	702A-15	1.00	30	200	0	0	0	60	2000	30	6	150	300
16	15.00 - 16.00	1.00	702A-16	0.80	20	300	0.3	0	0	0	300	20	3	60	200
17	16.00 - 17.00	1.00	702A-17	1.50	20	300	0	600	0	100	300	20	60	150	200
18	17.00 - 18.00	1.00	702A-18	2.80	60	800	1	300	0	100	200	20	3	150	200
19	18.00 - 19.00	1.00	702A-19	2.40	300	1500	0.5	300	0	200	1500	30	3	20	500
20	19.00 - 20.00	1.00	702A-20	6.80	300	1000	0.5	300	0	0	300	30	6	200	200
21	20.00 - 21.00	1.00	702-1	1.80	200	300	0	0	0	0	200	10	0	20	200
22	21.00 - 22.00	1.00	702-2	1.90	600	2500	3	300	0	200	500	30	3	300	300
23	22.00 - 23.00	1.00	702-3	2.10	100	150	1	300	2	100	500	20	0	10	200
24	23.00 - 24.00	1.00	702-4	3.50	100	200	0	0	0	100	300	20	6	100	200
25	24.00 - 25.00	1.00	702-5	3.40	600	300	.2	60	0	60	600	20	3	15	200
26	25.00 - 26.00	1.00	702-6	1.10	600	600	1	600	0	60	500	20	3	30	200
27	26.00 - 27.00	1.00	702-7	1.40	1000	1000	5	600	0	100	500	20	3	30	200
28	27.00 - 28.00	1.00	702-8	1.00	600	150	3	60	0	0	300	10	6	10	200
29	28.00 - 29.00	1.00	702-9	3.20	600	100	20	60	1	0	200	10	6	10	200
30	29.00 - 30.00	1.00	702-10	23.70	200	100	30	0	1	0	200	10	3	10	200
31	30.00 - 31.00	1.00	702-11	0.40	30	200	0	0	0	0	200	30	6	200	200
32	31.00 - 32.00	1.00	702-12	0.15	100	100	2	0	6	60	600	20	0	10	200
33	32.00 - 33.00	1.00	702-13	1.00	600	150	1	0	3	100	300	10	3	10	200
34	33.00 - 34.00	1.00	702-14	7.20	1000	150	5	0	2	0	200	20	6	10	200
35	34.00 - 35.00	1.00	702-15	5.00	300	300	5	100	5	100	200	10	6	10	300
36	35.00 - 36.00	1.00	702-16	31.80	500	300	10	100	1	0	200	20	6	10	500
37	36.00 - 37.00	1.00	702-17	22.70	800	500	2	100	3	0	200	20	6	20	1000
38	37.00 - 38.00	1.00	702-18	7.40	800	500	2	100	0.5	0	200	20	6	10	1000
39	38.00 - 39.00	1.00	702-19	0.60	50	60	0	0	3	0	200	10	0	3	200
40	40.00 - 41.00	1.00	702-21	3.50	200	150	0	60	2	0	300	10	6	10	200
41	41.00 - 42.00	1.00	702-22	0.20	200	200	0	600	2	0	500	10	10	10	200
42	42.00 - 43.00	1.00	702-23	0.40	50	100	0	0	2	0	2000	10	0	10	200
43	43.00 - 44.00	1.00	702-24	0.50	100	150	0	0	3	0	600	10	0	100	200
44	44.00 - 45.00	1.00	702-25	0.20	60	150	0	0	2	0	600	10	0	30	200

Note: 1) Complete analyses are available with the author (or at [illegible] and CIGS Cent. lab.).

endix I. Representative assay data of channel and core samples of SGD

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rial ber ata ce).	Sampling														
	interval (m)	length (m)	number (B.H.)	Au g/t	Pb ppm	Cu ppm	Ag ppm	As ppm	Mo. ppm	W ppm	Ti ppm	V ppm	Co ppm	Ni ppm	Mn ppm
45	180.00 -181.00	1.01	326-1	0	200	0	0.05	0	3	0	500	300	20	30	2000
46	181.00 -182.60	1.60	326-2	0	150	0	0.05	0	0	0	300	150	20	20	1500
47	182.60 -183.75	1.15	326-3	0	150	0	0.05	0	5	0	300	150	10	10	1500
48	183.75 -184.90	1.15	326-4	0	300	0	0.05	0	5	0	500	200	20	20	1500
49	184.90 -186.05	1.15	326-5	0	100	0	0.05	0	2	0	500	200	15	20	1500
50	186.05 -187.20	1.15	326-6	0	200	0	0.00	0	3	0	300	150	15	20	1000
51	187.20 -188.40	1.20	326-7	20	20	0	0.25	0	0	0	500	150	15	20	1500
52	188.40 -189.60	1.20	326-8	0	300	0	0.25	0	3	0	1000	200	15	20	1500
53	189.60 -190.80	1.20	326-9	30	200	0	0.25	0	0	0	1000	300	20	60	2000
54	190.80 -192.00	1.20	326-10	0	150	0	0.25	0	0	0	500	300	20	20	1000
55	192.00 -193.20	1.20	326-11	0	100	0	0.25	0	0	0	500	300	20	20	1000
56	193.20 -194.30	1.10	326-12	0	100	0	0.25	0	0	0	500	200	10	20	1500
57	194.30 -195.35	1.05	326-13	0	20	0	0.25	0	0.5	0	500	200	10	20	1500
58	195.35 -196.45	1.10	326-14	0	60	0	0.25	0	3	0	200	10	0	10	200
59	196.45 -197.55	1.10	326-15	10	30	0	0.25	0	2	0	200	10	0	10	200
60	197.55 -198.65	1.10	326-16	15	150	0	0.25	0	30	0	300	60	10	10	300
61	198.65 -199.75	1.10	326-17	10	100	0	0.25	0	3	0	300	30	10	10	200
62	199.75 -200.85	1.10	326-18	15	150	0	0.25	0	1	0	200	20	0	10	200
63	200.85 -202.20	1.35	326-19	6	200	0	0.25	0	1	0	600	200	30	10	600
64	202.20 -203.20	1.00	326-20	6	200	0	0.25	0	30	0	300	200	20	10	500
65	203.20 -204.20	1.00	326-21	6	200	0	0.25	0	1	0	600	300	20	10	1500
66	204.20 -205.20	1.00	326-22	6	200	0	0.25	0	0.5	0	600	300	30	20	1500
67	205.20 -206.20	1.00	326-23	0	200	0	0.25	0	0	0	600	300	20	10	1500
68	206.20 -207.30	1.10	326-24	3	150	0	0.25	0	1	0	1000	300	30	200	1500
69	207.30 -208.80	1.50	326-25	6	200	0.5	0.25	0	0	0	600	300	30	30	2000
70	208.80 -209.90	1.10	326-26	10	100	0	0.25	0	2	0	300	30	10	10	300
71	209.90 -211.00	1.10	326-27	15	30	0	0.25	0	3	0	200	20	0	10	200
72	211.00 -212.30	1.30	326-28	20	30	0	0.25	0	3	0	200	20	0	10	200
73	212.30 -213.40	1.10	326-29	0	150	0	0.25	0	1	0	500	300	30	20	1500
74	213.40 -214.50	1.10	326-30	20	150	0	0.25	0	0	0	600	300	30	20	1500
75	214.50 -215.60	1.10	326-31	10	300	0	0.25	0	2	0	1000	30	20	20	1500
76	215.60 -216.75	1.15	326-32	30	150	1	0.25	0	3	0	600	30	3	10	300
77	216.75 -217.90	1.15	326-33	3	150	0	0.25	0	2	0	1000	200	20	20	1000
78	217.90 -219.05	1.15	326-34	3	150	0	0.25	0	1	0	600	200	20	10	500
79	219.05 -220.20	1.15	326-35	0	150	0	0.25	0	0	0	600	200	30	15	1000
80	220.20 -221.40	1.20	326-36	20	150	0	0.25	0	1	0	1000	200	20	30	2000
81	221.40 -222.60	1.20	326-37	20	200	0	0.25	0	5	0	600	300	30	200	1000
82	222.60 -223.75	1.15	326-38	10	150	0	0.25	60	5	0	600	300	30	200	1500
83	223.75 -224.90	1.15	326-39	10	200	2	0.25	60	5	0	600	300	30	200	1500
84	226.05 -227.20	1.15	326-41	3	200	0	0.25	0	3	0	300	150	10	100	600
85	227.20 -228.40	1.20	326-42	10	200	0	0.30	0	20	0	600	300	15	200	1000
86	228.40 -229.60	1.20	326-43	20	200	0	0.70	0	20	0	500	200	10	150	300
87	229.60 -230.50	0.90	326-44	600	300	30	5.70	60	2	60	500	30	10	60	200
88	230.50 -231.40	0.90	326-45	100	800	200	0.83	60	2	100	500	100	15	150	300
89	231.40 -232.20	0.80	326-46	30	200	3	3.20	0	10	0	600	200	10	100	300

ote: 1) complete analyses are available with the author (or at AHEDP and CTGS Cent. lab.).

Appendix I. Representative assay data of channel and core samples of SGD

Cont'd.

Serial number (Data code)	Sampling			Au	Pb	Cu	Ag	As	Mo	W	Ti	V	Co	Ni	Mn
	interval (m)	length (m)	number (B.H.)	g/t	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
90	232.20 -232.70	0.50	326-47	10	150	0	2.50	0	1	0	1500	30	6	60	300
91	232.70 -234.05	1.35	326-48	50	150	6	0.30	0	2	60	600	60	10	30	300
92	234.05 -235.40	1.35	326-49	30	150	2	0.25	0	3	60	500	100	3	20	300
93	235.40 -238.35	1.70	326-50	30	150	3	0.25	0	6	600	500	150	10	100	300
94	238.35 -238.35	1.25	326-51	30	150	0	0.05	0	10	0	1000	150	3	60	300
95	239.60 -241.00	1.40	326-53	20	150	0.5	0.05	0	2	0	1500	150	10	60	300
96	241.00 -242.00	1.00	326-54	50	150	0.3	0.05	0	3	0	1500	200	15	30	600
97	242.00 -243.00	1.00	326-55	10	150	0	0.05	0	2	0	1000	100	10	30	1000
98	243.00 -244.00	1.00	326-56	20	150	0	0.05	0	3	0	1000	200	15	30	300
99	244.00 -245.00	1.00	326-57	10	100	0	0.05	0	1	0	2000	200	30	10	600
100	245.00 -249.00	4.00	326-58	6	20	0	0.05	150	15	0	300	200	60	600	600
101	0.00 - 1.50	1.50	304-1	10	300	0	0.05	0	0	0	200	60	15	10	200
102	1.50 - 3.00	1.50	304-2	6	300	0	0.05	0	0	300	200	60	20	15	200
103	3.00 - 4.50	1.50	304-3	0	300	0	0.05	0	0	0	200	60	30	15	200
104	4.50 - 6.00	1.50	304-4	0	300	0	0.05	0	0	0	300	100	30	10	200
105	6.00 - 7.50	1.50	304-5	0	300	0	0.05	0	0	0	200	100	30	10	300
106	7.50 - 9.00	1.50	304-6	0	300	0	0.05	0	0	300	200	60	30	10	300
107	9.00 - 10.50	1.50	304-7	6	500	0	0.05	0	0	0	300	60	30	15	200
108	10.50 - 12.00	1.50	304-8	0	300	0	0.05	0	0	0	300	60	20	10	200
109	12.00 - 13.50	1.50	304-9	0	300	0	0.10	0	0	0	200	30	20	10	200
110	13.50 - 15.00	1.50	304-10	0	300	0	0.05	0	0	0	200	30	20	10	200
111	15.00 - 16.50	1.50	304-11	0	300	0	0.05	0	0	0	200	100	30	10	300
112	16.50 - 18.00	1.50	304-12	0	300	0	0.05	0	0	0	300	100	30	30	300
113	19.50 - 21.00	1.50	304-14	0	800	0	0.10	0	0	0	300	100	30	30	300
114	21.00 - 22.50	1.50	304-15	0	300	0	0.05	0	0	0	300	150	30	30	300
115	22.50 - 24.00	1.50	304-16	0	150	0	0.05	0	0	0	300	200	30	100	300
116	24.00 - 25.50	1.50	304-17	0	150	0	0.05	0	0	0	300	150	20	20	300
117	25.50 - 27.00	1.50	304-18	0	150	0	0.05	0	0	0	300	150	20	20	300
118	27.00 - 28.50	1.50	304-19	0	200	0	0.05	0	0	0	300	200	30	100	300
119	28.50 - 30.00	1.50	304-20	0	150	0	0.05	0	0	0	300	150	20	30	300
120	30.00 - 31.50	1.50	304-21	0	150	0	0.05	0	0	0	500	200	30	10	600
121	33.00 - 34.50	1.50	304-23	0	150	0	0.05	0	0	0	200	100	30	30	300
122	34.50 - 36.00	1.50	304-24	10	150	0	0.40	0	0	0	300	20	20	10	600
123	36.00 - 37.50	1.50	304-25	0	150	0	0.30	0	0	0	200	100	30	20	300
124	37.50 - 39.00	1.50	304-26	30	200	0.3	0.50	60	0	60	500	200	20	10	1000
125	39.00 - 40.50	1.50	304-27	300	100	0.3	0.25	0	0	300	1500	200	20	10	2000
126	40.50 - 42.00	1.50	304-28	30	300	2	2.00	0	0	600	1000	200	20	15	200
127	42.70 - 44.00	1.30	304-30	2500	2500	300	46.30	0	10	600	500	150	30	200	300
128	44.00 - 45.50	1.50	304-31	20	150	1	0.25	0	0.5	100	600	600	20	30	1000
129	45.50 - 46.50	1.00	304-32	200	150	6	0.30	0	2	200	1000	600	30	100	1000
130	46.50 - 47.30	0.80	304-33	200	300	10	0.50	0	3	600	600	200	20	100	300
131	47.30 - 48.80	1.50	304-34	200	2000	20	1.50	800	10	11000	600	200	30	150	600
132	48.80 - 50.30	1.50	304-35	300	2000	20	1.70	800	10	11000	600	300	30	100	600
133	50.30 - 51.80	1.50	304-36	1500	2000	30	2.00	800	10	600	300	150	20	60	300
134	53.30 - 54.80	1.50	304-38	20	150	2	0.25	0	3	100	600	300	20	30	600
135	54.80 - 56.30	1.50	304-39	30	150	15	0.55	60	20	200	600	200	10	200	300

Note: 1) Complete analyses are available with the author (or at AMEDP and EIGS Cent. lab.)

pendix I. Representative assay data of channel and core samples of SGD

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rial mber ata de)	Sampling interval (m)	length (m)	number (B.H.)	Au g/t	Pb ppm	Cu ppm	Ag ppm	As ppm	Mo ppm	W ppm	Ti ppm	V ppm	Co ppm	Ni ppm	Mn ppm
136	56.30 - 57.80	1.50	304-40	200	150	10	0.60	0	3	600	1000	150	10	200	300
137	57.80 - 59.00	1.20	304-41	200	300	30	0.60	0	10	100	1000	150	10	200	300
138	59.00 - 60.30	1.30	304-42	300	300	10	0.30	0	10	600	600	200	20	300	1500
139	60.30 - 61.00	0.70	304-43	600	200	60	1.70	100	0.5	0	300	30	6	30	300
140	61.00 - 62.20	1.20	304-44	200	200	60	0.25	0	0.5	0	1500	20	10	60	300
141	62.20 - 63.70	1.50	304-45	600	300	60	0.25	60	0	0	600	10	10	30	200
142	63.70 - 64.70	1.00	304-46	30	150	1	0.25	0	0	0	200	6	0	10	200
143	64.70 - 65.70	1.00	304-47	10	200	0	0.25	0	0	0	200	3	0	10	200
144	65.70 - 67.20	1.50	304-48	50	150	0.5	0.25	0	2	0	1000	100	10	60	300
145	67.20 - 68.70	1.50	304-49	30	150	0.3	0.25	0	6	0	1000	100	10	60	300
146	68.70 - 70.20	1.50	304-50	30	150	0.3	0.25	0	3	0	1500	100	10	60	300
147	70.20 - 71.70	1.50	304-51	30	150	0.3	0.60	0	3	0	1000	100	10	60	300
148	71.70 - 73.20	1.50	304-52	30	150	0	0.25	0	2	0	600	100	10	60	300
149	73.20 - 74.70	1.50	304-53	20	150	0	0.25	0	6	0	1500	100	10	100	300
150	74.70 - 76.20	1.50	304-54	30	150	0	0.25	0	3	0	1000	100	10	100	300
151	76.20 - 77.70	1.50	304-55	20	150	0	0.25	0	2	0	1000	100	10	60	300
152	77.70 - 79.20	1.50	304-56	50	150	0	0.25	300	2	0	1000	100	10	60	300
153	79.20 - 80.70	1.50	304-57	30	200	0	0.25	800	6	0	1500	200	10	150	300
154	80.70 - 82.20	1.50	304-58	60	200	0	0.25	0	6	0	600	100	10	100	300
155	82.20 - 83.70	1.50	304-59	30	200	0	0.25	0	10	0	1500	200	10	100	300
156	83.70 - 85.20	1.50	304-60	50	150	0	0.25	0	6	0	1000	150	10	60	300
157	85.20 - 86.70	1.50	304-61	60	200	0	0.25	0	2	0	600	100	10	60	300
158	86.70 - 88.20	1.50	304-62	30	200	0	0.25	0	3	0	1000	100	10	60	300
159	88.20 - 89.70	1.50	304-63	60	200	0	0.25	0	3	0	1000	150	10	60	300
160	89.70 - 91.20	1.50	304-64	30	300	0	0.25	0	5	0	1000	150	10	150	500
161	91.20 - 92.70	1.50	304-65	30	300	0	0.25	0	3	0	500	100	10	60	300
162	92.70 - 94.20	1.50	304-66	20	150	0	0.25	0	2	0	500	100	10	30	300
163	94.20 - 95.70	1.50	304-67	10	100	0	0.25	1200	0	0	300	60	3	20	300
164	95.70 - 96.70	1.00	304-68	30	150	0	0.25	0	15	0	600	300	10	150	300

Note: 1) Complete analyses are available with the author (or at AMEDP and EIGS Cent. lab.).