The use of stream sediment and soil sampling media for tungsten exploration geochemistry around Doi Mok, northern Thailand

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In searching for concealed mineral resources, the objective is to find dispersions of elements or compounds in geochemical media, which may indicate mineralization. Stream sediments are widely used in regional survey to pinpoint the existence of mineralizations, whereas different soil horizons are extensively used for detailed survey to delineate the boundary of mineralizations. In this investigation, the comparative studies of two layers of stream sediment, of 4 soil horizons on base of slope, and of 2 soil horizons in one particular area are undertaken.

An area in the vicinity of the tungsten deposit at Doi Mok in northern Thailand was chosen. Top and basal stream sediment samples were taken simultaneously from 148 sampling sites. A total of 79 samples each of A1, A2, B and C horizon on the slope base were taken simultaneously from 45 sampling sites. In an area around a tailing dam, A1 and B horizon soil samples were taken from 576 sites. Totally 108 composite samples were collected from 34 sites in the tailing dam.

All types of samples were assayed for W, Cu, Zn, As, Mo, Sn, Ni, Fe, Ca, Ti and K by XRF. The analytical data were treated by univariate and multivariate methods.

The dispersions of the anomalies, revealed by the basal stream sediment samples were greater than those revealed by the top stream sediment samples. Some minor potential mineralizations, detected by the basal stream sediment samples, failed to be detected by the top stream sediment samples.

If there are any mineralizations in bedrock, expectedly, the anomalies will be detected in the C horizon samples. In this study, the results obtained from all horizons in both slope base soil and detailed soil surveys are more or less similar.

The univariate and multivariate methods yielded, to some extent, identical results.

The amount of 1600 tons WO_3 was calculated to be available in the tailing material which once was counted as the disposal from the mine.

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Contents

Introduction

Mineral exploration, in the past, was carried out largely by prospectors and geologists who tended to concentrate their efforts on outcrops or related expressions of mineralization. This resulted in the discovery of many ore bodies, most of which could possibly be recognized visually.

Essentially, the era of visual observation is drawing to a close and probably most of the world's obvious mineral deposits have been found. Hence, there is a need for a radical, imaginative, new approach to mineral exploration, which geochemistry, along with other sciences such as geophysics, is attempting to fulfil (Levinson 1974).

In searching for concealed mineral resources, the objective is to find dispersions of elements or compounds sufficiently greater than normal to be called an anomaly, which, it is hoped, may indicate mineralization of economic value (Levinson 1974). Therefore, most applied geochemistry depends on attempting to trace the results of partial destruction of ore bodies which could be traced back to its source, i.e. mineralization (Derry 1971).

In this investigation, an effort has been made to search for the most efficient, rapid, simple and cheap sampling media, for tungsten exploration geochemistry in tropical rainforest terrain in northern Thailand. An area was chosen for this purpose in the vicinity of the tungsten deposit at Doi Mok, northern Thailand.

Two categories of sampling media are studied, namely stream sediments for regional survey and soils for detailed survey. In addition, evaluation of a tungsten resource in a tailing dam and determination of the efficiency of analytical method by X-ray fluorescence spectrometry (XRF) are also undertaken.

Literature review

Development of exploration geochemistry

After the introduction of the biogeochemical-enrichment principle by Goldschmidt (1937), vegetation samples were successfully employed for metallic mineral explorations by Brundin (1939) in Sweden, Rankama (1940) in Finland, Vogt (1942) in Norway, Kovalevskiy (1966) in U.S.S.R. and later by Warren (1972) in Canada, and Quin & Brooks (1974) in New Zealand. Basic principles and applications of biogeochemistry are invaluably compiled in the text books by Brooks (1972 and 1983) and Kovalevskiy (1979).

For reconnaissance surveys, inorganic stream sediment surveys were used almost exclusively to delineate targets for follow-up work. Especially in areas of moderate to strong topographic relief and well-developed stream drainage as in Norway, inorganic stream sediment samples were first used in 1954. It soon became the most extensive sampling medium for regional surveys (Bölviken 1967). In the neighbouring countries, Sweden and Finland, this sampling medium was employed selectively in areas where soils are partly residual and the terrain has a fairly strong relief (Brotzen et al. 1967). The organic stream sediments were studied and compared with the inorganic stream sediments, and were found to be more reliable and sensitive than the inorganic ones (Brundin & Nairis 1972; Selinus 1983b).

Pedogeochemical prospecting (e.g. till, soil geochemical prospecting) was conducted in the early 1950's to trace boulder and mineralized particle fans in Fennoscandian countries. The method was applied both in regional and detailed surveys (Brotzen et al. 1967; Bölviken 1967; Nikkarinen & Björklund 1976; Brundin & Bergström 1977; Lindmark 1977 and Toverud 1977 and 1982). In glaciated terrain of Fennoscandia and north America, humus geochemical prospecting was proved to be a possible sampling medium for pinpointing submineralizations lying under glaciated deposits (Boyle & Dass 1967; Bölviken 1967; Kauranne 1967; Chowdhury & Bose 1970; Kovalevskiy 1976; Kokkola & Penttilä 1976; Kokkola 1977; Nuutilainen & Peuraniemi 1977; Toverud 1977 and Silakul 1984).

Lithogeochemical prospecting based on systematic sampling of weathered or fresh rocks was first undertaken on a selective basis in the 1950's. Some types of rock surveys had been developed to the point of routine application by the 1960's, particularly in the U.S.S.R. (Rose et al. 1979). In Sweden, where most of the easily accessible ores have been found this method has been used since the 1970's and is expected to be the main method in the future for searching for deep-seated blind ore bodies (Selinus 1981).

Another factor that stimulates the development of exploration geochemistry is analytical chemistry. The emission spectrographic method was used in 1932 by Soviet geologists in the first large-scale exploration programmes (Levinson 1974). In the late 1940's, a rapid, simple colorimetric method was introduced in Canada (Boyle & Smith 1968). The development of atomic absorption spectrometry in the late 1950's permitted rapid, accurate, sensitive and relatively interference-free analysis of many elements of interest. Gas chromatography is an extremely sensitive method of searching for hydrocarbons (Boyle & Smith 1968). X-ray fluorescence spectrometry has been demonstrated to be a rapid, high precision and easy analytical method for multielement analysis of most elements with atomic weights equal to or greater than Na (Rose et al. 1979 and Fletcher 1981). Thirty-five elements can be analysed simultaneously for lithogeochemical prospecting, as used by the Geological Survey of Sweden (Selinus 1983a).

The final stages in geochemical exploration are statistical analysis and presentation. In the past, the volume of data was often small and the numerical description, analysis and plotting of the data could be carried out by manual methods. It is rather common in this decade that large numbers of samples are encountered (especially in regional prospecting) and numerous elements are assayed simultaneously. The use of computers makes it possible to treat this large volume of data, easily and rapidly.

The purpose of statistical analysis is to ascertain the relationship between single element or multielement distributions and the existence of ore deposits. Treatment of single element data (also called univariate data) has been proved to be quite simple and can be done manually (Ahrens 1957; Tennant & White 1959; Williams 1967; Lepeltier 1969; Bölviken 1971; Parslow 1974; Sinclair 1974, 1976 and 1983 and Rose et al. 1979). The treatment of multielement data (also called multivariate data) requires complicated mathematical calculations for which the computer has proved to be of great advantage. This multivariate data treatment is nowadays widely used in geochemical explorations (Garrett & Nichol 1969; Cadigan & Stuart-Alexander 1972; Jöreskog et al. 1976; Selinus 1981, 1983a and 1983b; Santos Oliveira 1982 and Howarth & Sinding-Larsen 1983).

Exploration geochemistry in tropical terrain

Tropical rain forests which cover 15 per cent of the earth's surface may bear considerable mineral potentials by analogy with similar geological settings better exposed in other climatic zones, e.g. in areas of glaciated terrain (Matheis 1980). Most of the tropical rainforests lie in developing countries where indigenous exploration, capital and expertise are scarce and there is general political instability (Singh 1980).

Not unexpectedly, many geochemical exploration programmes in various developing countries have been jointly financed and aided by the United Nations Developing Programme (UNDP) since 1960's (Lepeltier 1971).

Matheis (1980), one geochemist among others who participated in geochemical exploration studies in tropical terrain, has shown that soil, at a depth of 60 cm from the upper B horizon in areas around the Guyana Shield and in Nigeria can be used not only for mineral exploration targets but also as a tool in geological reconnaissance mapping.

Singh (1980) from a prospecting programme in Guyana, concluded that geochemistry as a reconnaissance tool in regional surveys should start with stream sediment silt sampling and that a detailed soil sampling grid should be established only in anomalous areas.

Thailand, as part of the tropical rainforest regions has been explored geologically for mineral deposits since the end of the 1880's (Hallet 1890). Mineral prospecting, using conventional geological methods was carried out intermittently before World War II. The first remarkable regional, geological-mineralogical investigation was made by Professor B. Högbom from the University of Uppsala in 1912 (Högbom 1914).

Long-term geological investigation programmes began in 1946 after the establishment of the Geological Surveying Division of Thailand in 1941. In collaboration with American geologists from the United States Geological Survey and the United States Bureau of Mines, the Thailand division undertook in 1949 the first systematic geological reconnaissance study of the known mineral deposits (Brown et al. 1951).

Suwanasing (1963), Bleakly & Workman (1964) and Cratchly & Workman (1966) were, among others, pioneers who applied geochemical methods to mineral prospecting in Thailand. Till now, these methods are extensively employed for prospecting in high mineral potential areas (Jacobson et al. 1969; Baum et al. 1972; Sektheera et al. 1981 and Snansieng 1983).

Geochemistry of tungsten

Notable concentrations of tungsten are unambiguously linked to igneous processes, where a crystallizing magma contains significant tungsten. This metal is concentrated in water-rich residual solution (Krauskopf 1970).

In precipitation of tungsten minerals, scheelite is preferable to wolframite in environments of abundant calcium (Horsnail 1979). However, Bryzgalin (1960) made an experimental study and concluded that scheelite which is formed in skarn does not obtain calcium from only marble but it can also obtain calcium released from pyroxene, amphibole and calcic plagioclase.

Most major ore deposits are associated with granitic rocks but the tungsten shows no preference for particular rock compositions in the range from diorite to alkaline granite (Krauskopf 1970).

Major tungsten deposits can be grouped into five broad categories (Horsnail 1979): skarns, hydrothermal veins and stockworks, porphyries, volcanogenic deposits, and brines and hot springs.

Skarns are the most common form in which economic deposits of tungsten occur. The characteristic features of skarn tungsten occurrences are:

1) tungsten generally occurs as scheelite within a calc-silicate gangue;
2) pyrrhotite, chalcopyrite and sphalerite are often present;
3) the host rock is generally a carbonate sediment;
4) an intrusive rock, generally a more basic member of the granitic series, is frequently associated; and
5) the mineral body is generally small and of irregular shape; it often occurs near original high points of the intrusive.

Hydrothermal tungsten deposits are those in which the tungsten minerals occur within or adjacent to quartz veins. The veins may form discrete lodes, vein swarms or stockworks. Tungsten is present mainly as wolframite, but scheelite may also occur in such deposits. Cassiterite, arsenopyrite and bismuthinite are frequent associates of wolframite in hydrothermal tungsten deposits.

Porphyry-type tungsten deposits are genetically related to igneous rocks, particularly granitic porphyries, yet do not form skarn bodies or discrete vein systems. Sphalerite, arsenopyrite, chalcopyrite, galena, cassiterite, molybdenite, bismuthinite and native bismuth may associate with tungsten of this type.

In volcanogenic tungsten deposits, tungsten occurs as scheelite and some of these deposits occur in environments that are largely free from calcium carbonate, and appears to have more volcanogenic than skarn affinities. Associated metallic minerals include pyrrhotite, chalcopyrite, molybdenite, bismuthinite, and some silver and gold are present.

An example of the tungsten-bearing brine deposits occurs at Searles Lake, California (Horsnail 1979). It is believed to be comprised of salts, derived in Pleistocene time. Tungsten in the brine is thought to exist as a large heteropoly ion and the tungstate is complexed with boron, arsenic or phosphate, and probably originated through leaching of mineralized material.

Once tungsten deposits are exposed to the atmosphere, they are subjected to weathering and erosion. Especially under conditions of high average annual rainfall, high mean annual temperature, and the profuse drainage of the tropical rain forests, these processes will take place rapidly and deeply.

Although chemical weathering proceeds rapidly and deeply, leaching is restricted to Mg, Ca, Na, K and partly to Si. Most of the trace elements retain more or less their bedrock concentrations throughout the dispersion processes (Matheis 1980).

Wolframite and scheelite are relatively insoluble within the pH range of most natural surface waters (Horsnail 1979). However, in the zone of weathering, particularly in tropical conditions, the dispersion and migration of tungsten does not start with fresh primary mineral but with the products of their alteration, namely anthoinite, ferritungstite, hydrotungstite, meymacite and tungstite (Varlamoff 1971).

The alteration strongly affects the mechanical resistance of wolframite and scheelite, so that they cannot survive for more than some hundred metres of alluvial transportation. The products will be dispersed and transported for distances of kilometres to tens of kilometres and are mixed with the finest products of the river silts and soils. The coarse wolframite and scheelite are possibly concentrated in river beds over some hundred metres near the primary deposits (Varlamoff 1971).

Hence, alluvial placer deposits of wolframite, scheelite and their alteration products are less common, probably because the fragility leads to their breakdown into fine particles with consequent wide dispersion (Horsnail 1979).

Previous tungsten exploration

To obtain general views on applications of geochemistry in tungsten explorations, some case histories are summarized in accordance with various types of sampling media.

Concentration of weathering resistant heavy minerals by panning of stream sediments is probably the oldest method used by man in the recovery and prospecting of ores (Brundin & Bergström 1977). Concentration of heavy minerals can also be effected by jigging and floating in heavy liquid. Tungsten mineral grains in heavy mineral concentrates can be counted under the microscope. Scheelite is easily recognized in ultraviolet light. Hence, the tungsten content in stream sediments can be expressed in grains per unit of the original sample. This method is called the mineralometric method (Brundin & Bergström 1977). It has been proved to be sensitive in regional surveys in Pakistan and Greece by Zeschke (1961), in Ireland by Steiger (1977), in Greenland by Hallenstein et al. (1981) and in Portugal by Santos Oliveira (1982).

Determination of the tungsten content can also be made by conventional chemical analysis (colorimetry) and instrumental chemical analysis (X-ray fluorescence spectrometry–XRF). Colorimetry has long been used for tungsten analysis in various kinds of geochemical material (Jeffery 1955; Mukherjee 1955; North 1956; Ward et al. 1963; Bowden 1964; Stanton 1966, 1970 and 1976; Quin & Brooks 1972 and Welsch 1983). However, colorimetry gives high sensitivity but is time-consuming, whereas XRF has the advantages of convenience, rapidity and reproducibility of the samples (Jenkins & De Vries 1972 and Fletcher 1981).

Cachau-Herreillat & Prouhet (1971) obtained satisfactory results by using colorimetry for the analysis of stream sediment samples from the French Pyrénées, even if Santos Oliveira (1982) found colorimetric analysis of the minus 80-mesh fraction of stream sediments to be less advantageous than mineralometric method.

Contrary to the other workers, Brundin & Nairis (1972) and Brundin & Bergström (1977) considered that inorganic stream sediment samples were inadequate for prospectings in central and northern Sweden, whether mineralometric or chemical methods were used for analysis. They introduced organic stream sediments as a substitute for inorganic ones.

During the Quaternary glaciation, the continental ice sheet distributed loosened parts of ore from the ore body, partly as boulders and often in the shape of a fan. The boulders can be transported several tens of kilometers from their source in the bedrock (Brundin & Bergström 1977). These facts have made boulder tracing a very important method for ore exploration, particularly in Fennoscandia (Hedström 1894; Sauramo 1924; Grip 1953; Nikkarinen & Björklund 1976 and Lindmark 1977).

In the same manner as boulders, smaller ore fragments and weathering resistant ore grains in glacial till are also distributed from the ore body in the shape of a fan. Therefore, tracing the distribution of heavy minerals in till can also disclose indications of mineralization (Dreimanis 1957; Lee 1963 and Shilts 1971 and 1973). This method was employed for regional surveys in Sweden (Brundin & Bergström 1977 and Toverud 1977), while in Finland it was used as a follow-up method to preceding boulder tracing surveys (Nikkarinen & Björklund 1976 and Lindmark 1977) and stream sediment surveys in Greenland (Hallenstein et al. 1981).

To delineate the mineral deposit in the final stage of geochemical exploration, apart from glacial till, soils from different horizons were employed by Kovalevskiy (1966) in U.S.S.R., Cachau-Herreillat & Prouhet (1971) in France, Quin & Brooks (1974) in New Zealand, Steiger (1977) in Ireland, Toverud (1977) in Sweden and Rogers (1980) in Australia. Nevertheless, Kovalevskiy (1966) and Quin & Brooks (1974) made investigations of plant samples and compared them with soil samples. Kovalevskiy (1966) suggested the use of older plant organs or branches rather than leaves. Quin & Brooks (1974), however, found that it was possible to use composite samples of shallow-rooting vegetation such as tussock grass and fern in tungsten biogeochemical exploration.

Test area

General description

The test area for the investigation of stream sediment samples is situated in the vicinity of the well-known scheelite deposit of Doi Mok, 100 km north-east of Chiang Mai (Fig. 1). It comprises the west slope of the north–south trending mountain range

Fig. 1. Location of the investigated area.

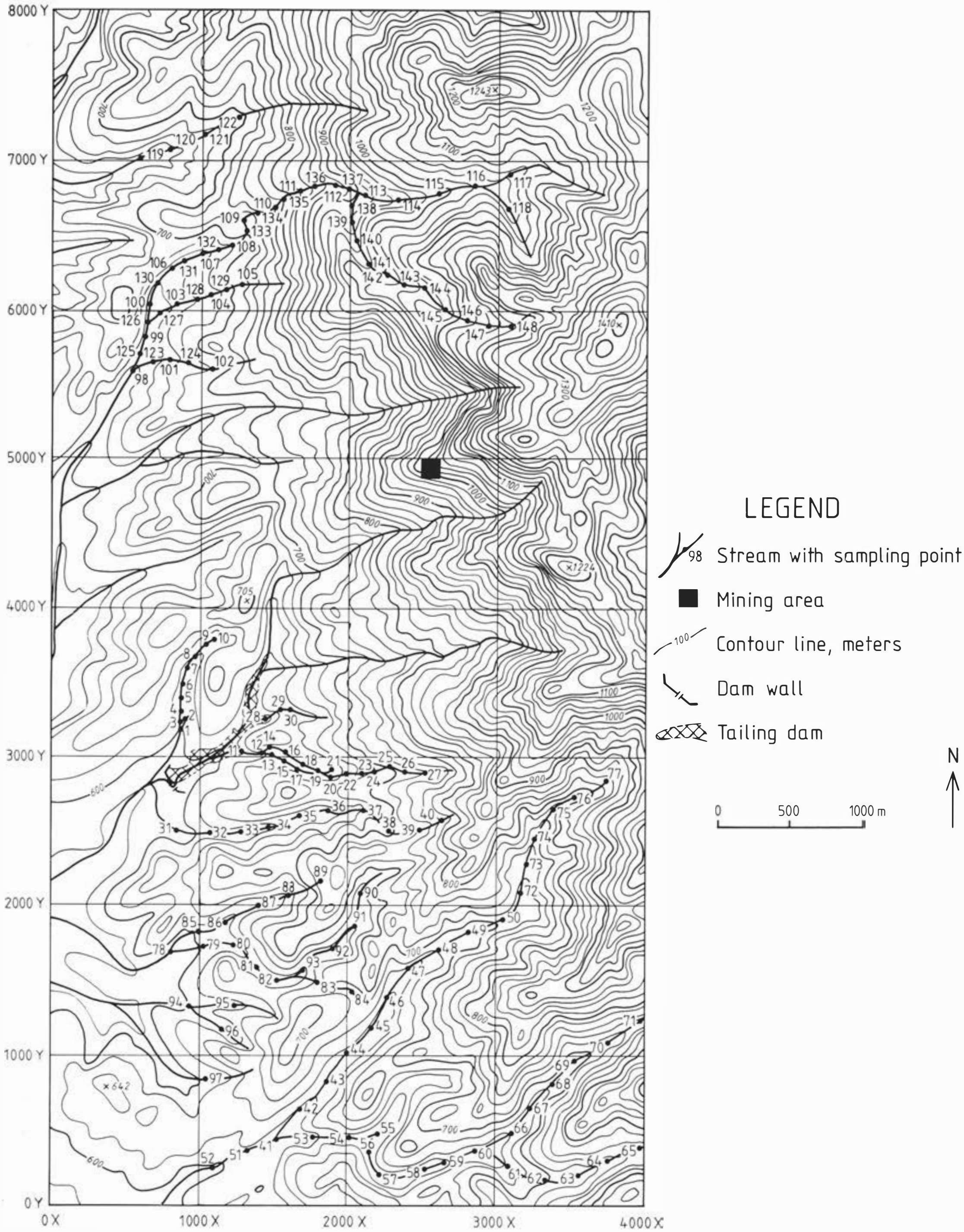


Fig. 2. Topographic map of the investigated area for stream sediment and slope base soil samples.

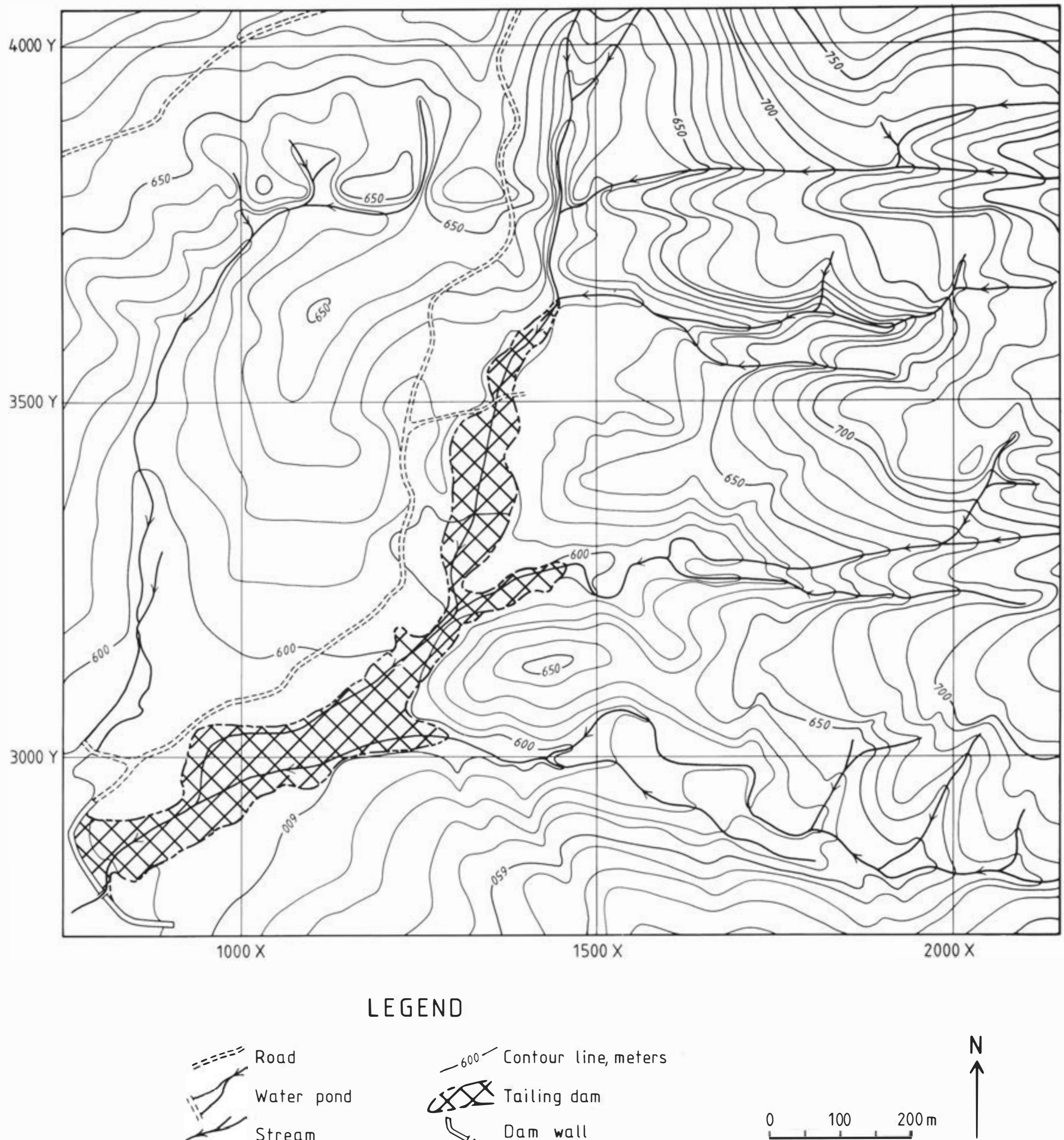


Fig. 3. Topographic map of the investigated area for detailed soil samples, including location of tailing material reservoir.

to form the eastern flank of Wiang Pa Pao valley (Fig. 2). Tailing disposal from the mining area was drained down along a major stream, flowing along the southern slope, and deposited in a tailing dam, shown in Figs. 2 and 3. The area around the tailing dam was subjected to detailed soil sample investigation (Fig. 3).

The forest in the area is constituted of perennial trees, mostly of deciduous types, bamboo trees, shrubs and grasses. During 1951–1975, the mean annual temperature was 24.6°C and the average annual rainfall 179.5 cm.

Stream drainage patterns are controlled by geological structures. The north–south and east–west

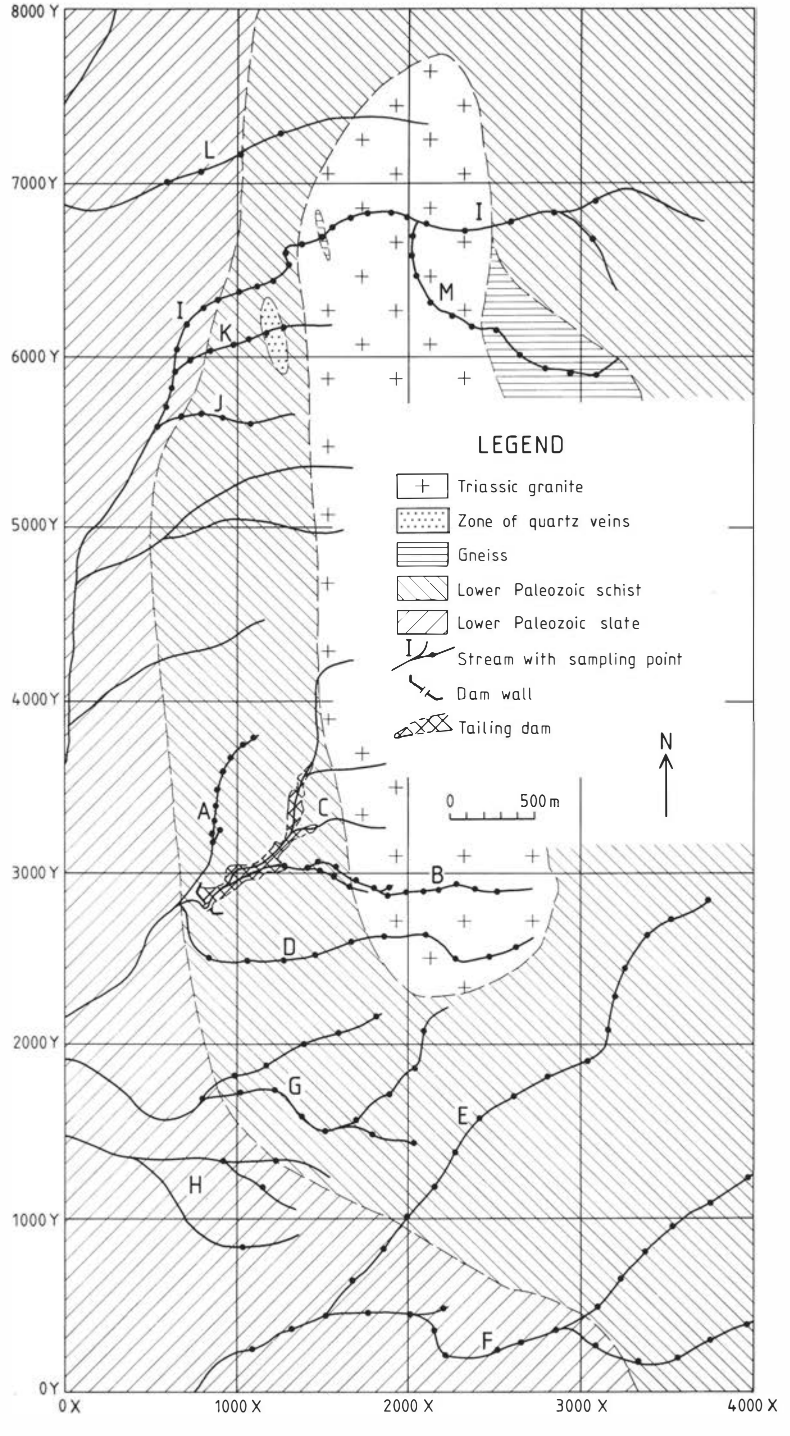


Fig. 4. Geologic map of the investigated area for stream sediment and slope base soil samples.

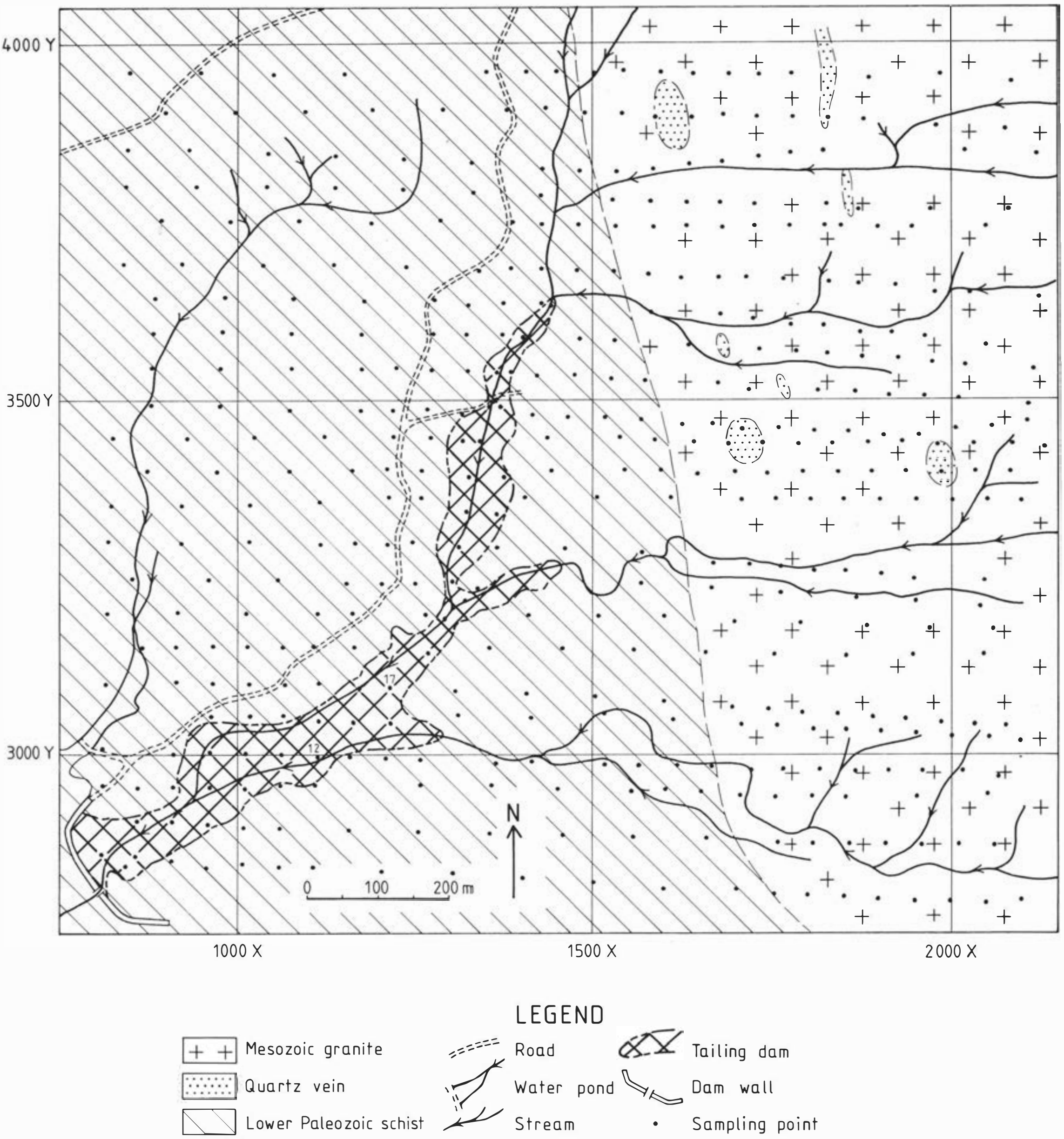


Fig. 5. Geologic map of the investigated area for detailed soil samples.

flowing directions along fault zones are evident (Fig. 1).

The average 17 degree slope angle along the streams portrays the high relief topography of the area, thus V-shaped valleys are predominant. When the streams approach gentle slopes of floodplains at the foot of the mountains, the streams loose their transporting capacity and meander with the development of terraces on the banks. Terrace-like deposits of stream sediments can also be found below the junction of tributary streams.

Geology

The north–south striking valley of Wiang Pa Pao is a graben-like structure, enclosed by two parallel mountain ranges. Both are cut by cross faults, which now are indicated by valleys trending approximately east–west.

The investigated area is characterized by a small intrusion of possibly Mesozoic biotite granite (Braun et al. 1976) and low-grade contact metamorphosed Lower Paleozoic sedimentary rocks (Baum et al. 1972; Chuaviroj et al. 1978; Jivathanond 1981, Charoensri 1982 and Asanachinda & Chantaramee 1984). Formation of marble, skarn and schist was observed near contact zones of granite on the eastern margin of the granite body in the mining area (Jivathanond 1981). Slate was found in the outer rim further away from the granite batholith. Gneiss and quartz veins crop out in the northern part of the geological map in Fig. 4. To avoid possible contamination from the mining area, both geochemical and geological studies in the neighbourhood of the mine were evaded. Several quartz veins are shown on the geological map of the detailed soil sampling area (Fig. 5). Their general trending is approximately in a north–south direction.

Mineralogical studies of the scheelite deposit in the mining area were carried out on two different occasions by Baum et al. (1972) and Jivathanond (1981). They, more or less, agreed that there are three types of mineralizations:

1) Scheelite in quartz veins. They may exist as a single vein with frozen walls or many parallel closely spaced spurs. Scheelite is associated with arsenopyrite and pyrite. The occurence of dense parts, consisting of a mixture of contact silicates, indicates the nearby marble contact.

2) Scheelite in fracture zones. Scheelite is found in or near zones of jointing in granite and consists of veins 10 cm wide. On either side, decomposed granite is irregularly impregnated by scheelite. The associated minerals are quartz, arsenopyrite, pyrite, pyrrhotite, chalcopyrite, sphalerite and a small amount of galena.

3) Scheelite in skarn. According to its nature, this type of deposit consists of irregular and differently sized intergrowths of various Ca-silicates and ore minerals. Scheelite occurs as an impregnation and as aggregates sometimes exceeding 50 kg. Minerals associated with scheelite include arsenopyrite, pyrite, pyrrhotite, chalcopyrite, sphalerite and galena.

Strong relief, high average annual rainfall and high mean annual temperature are characteristics causing deep weathering of bedrock, letting a great volume of surface water run off and producing a high rate of erosion and percolation of the area. Undoubtedly, humus derived from leaves and forest litter is swept down the slope and/or leached through underlying minerogenic soil.

In conditions of abundant meteoric water, soil profiles in this area are well developed into 4 distinct horizons, A1, A2, B and C (Fig. 6).

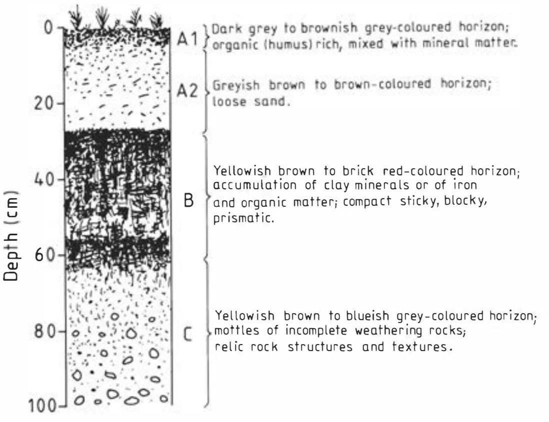


Fig. 6. Diagramatic representation of soil profile, showing the principal A1, A2, B and C horizons (Modified after Rose et al. 1979).

The uppermost A1 horizon is characterized by a variation of colours from dark grey to brownish grey depending on the proportion of humus in the mixture with minerogenic soil. There are possibilities of accumulation of soluble material derived from underlying horizons by evaporation of soil moisture, capillary rise of water, chelation and by the persistence of chemically resistant minerals in situ, for instance scheelite, wolframite, cassiterite and gold, in the regolith, as residual products.

The subsequent sandy A2 horizon is strongly leached. The colour varies from greyish brown, with a small amount of humus, to brown due to iron hydroxide. Insoluble minerals tend to be most frequent in this horizon.

B horizon is constituted of colloidal silicates, humus, Al-oxides, Fe-oxides, Mn-oxides and clay minerals which together result in a variation of colours from yellowish-brown to brick-red. It is possible that B horizon may also gain material by the precipitation of soluble material derived from underlying horizon by groundwater circulation (Rose et al. 1979).

The constituents of C horizon are mostly weathering products of parent rocks. Organic matter is at a minimum in C horizon, which usually contains less clay and is lighter in colour than the B horizon. Mottles of incomplete weathering rocks are general characteristics of C horizon and relic rock structures and textures are also more commonly preserved than in the overlying horizons.

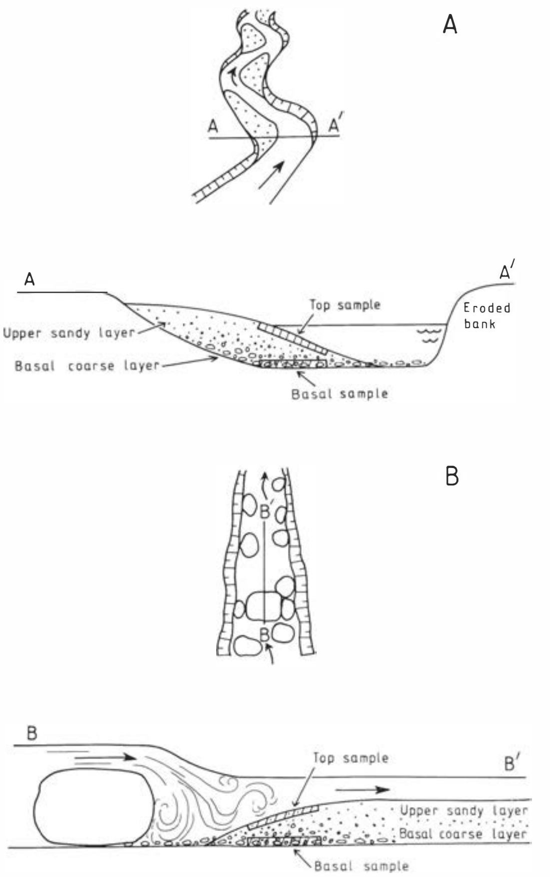


Fig. 7. Bird's eye view of meandering (A) and straight stream (B). Water flows in the direction of arrows. Cross sections of meandering stream at A–A′ and of section B–B′ display positions of samples (indicated by boxes).

Stream patterns in the investigated area can be defined roughly as meandering or straight ones (Fig. 7). Secondary flow conditions promote the deposition of sediments at the inner side of meander bends and behind boulder obstructions. Sediments are sorted in such a manner that coarser rock fragments and heavy mineral grains together are deposited first in the basal layer, and finer rock fragments and mineral grains of lesser density are gradually deposited.

Evidently, meanders and boulders act as natural tools to pan heavy minerals out of other sediments. When heavy minerals are distributed in drainage systems, they are accumulated at the inner curve of meanders and behind obstructing boulders.

Previous mining activity in the area

Mr. E. Carlsson, the former chief geologist of STORA (Stora Kopparbergs Bergslags Aktiebolag) who was responsible for evaluating the mining area at the time of establishing the Thai-Swedish Mining Co., Ltd., has kindly written the history of the mining area.

After the deposit was discovered early in 1970, it became a great attraction to trespassers who dug and pitted illegally down to a depth of 40 m. Scheelite ore was subsequently concentrated by manual panning.

The lodgings of thousands of trespassers appeared and a big village developed on the mountain slope in and around the mining area. Stores, food shops, gambling-houses, a small temple etc., were available in the village. The movement was similar to the Wild West in the USA. Eventually, the area was undermined without any control. A big subsidence of soil occurred in 1973 and several men were killed. Later, a landslide destroyed most of the village; hundreds of men were burried under masses of soil.

The concessionaire tried to install law and order, and in 1979 the mining right was enforced. Then proper mining techniques were introduced.

The total production in the period 1970–1978 was at least 5000 tons of scheelite.

Thereafter, underground mining was put in operation; several drifts were made by the Sirithai Scheelite Thailand Co., Ltd. Compared with the activities in the years 1970–78, scheelite ore was extracted on a smaller scale. The ore was sold first to Ekman & Co., Ltd., and later to Stora Kopparberg Trading AB.

The production declined drastically, and in 1981 a prospecting staff led by E. Carlsson was sent from STORA to prospect for potential mineralizations in drifts and residual soil deposits by diamond drilling. Several new ore zones were discovered after this diamond drilling programme was effected.

The Thai-Swedish Mining Co., Ltd was established in 1983 as a joint venture of STORA and Sirithai Scheelite Thailand Co., Ltd. Since 1984, a new concentration plant, with a capacity of 100000 tons/year, has been constructed.

With the advice of Mr. Carlsson, the present investigation was planned, discussed and finally executed.

Field work

Stream sediment samples

For the detection of mineral dispersions in stream drainage patterns, selection of too large a sampling interval may give rise to ambiguity of significant dispersion halos. A sampling interval of between 200 and 300 m has been employed in various parts of the world (Cachau-Herreillat & Prouhet 1971; Brundin & Nairis 1972; Singh 1977 and Sektheera et al. 1981).

In this study, stream sediment samples were taken generally at intervals of 300 m, but in areas of great interest the interval was reduced to 150 m.

To obtain optimum homogeneity of samples, stream sediments were always taken from mineral accumulation spots at the inner curve of meanders or behind boulders. Two distinctive layers, displayed in Fig. 7, i.e., upper sandy layer and basal coarse layer were simultaneously sampled using average weights of 500 and 1000 g respectively. Samples from the upper sandy and the basal coarse layers are termed "top stream sediment samples" and "basal stream sediment samples" respectively.

On the immediate surface (<1 cm depth) of the upper sandy layer, samples were collected from 5 regions in an area of one square meter, one being taken from each corner and the fifth from the centre. They consisted of varying proportions of sand, silt and humus. The position of basal stream sediment samples can be recognized by the accumulation of gravel on the stream bed.

At the beginning of 1983, in an area of approximately 20 km^2, stream sediment samples were taken from 122 sampling sites along streams. Later in 1984, 26 complementary sampling sites were added to a high potential area. Topographical surveys, using a compass and measuring tape, and geological surveys along stream channels were also carried out in conjunction with the sampling programmes. Sampling sites and their numbers are shown in Fig. 2.

Slope base soil samples

For comparative studies of mineral dispersions in soil at the base of slopes and the corresponding stream sediment, an area of one square metre was cleared on the slope above the previous stream sediment sampling site. A slab of surface soil 1 cm thick was cut by a hoe from each corner and one from the center of the area. Approximately 500 g of the sample were collected in a plastic bag and labelled A1 horizon slope base soil sample.

Subsequently, the slope was dug vertically down to bedrock, if possible, but if not, down to C horizon was considered to be satisfactory. The profile was studied; thus individual horizons could be recognized. Samples from A2, B and C horizons were taken by the channel sampling method described by Parks (1957). The same amount of sample, 500 g, was collected separately from each horizon.

The sampling sites on the base of slope were always located on rather steep slopes to avoid extreme weathering depths of bedrock and therefore too great a depth of profiles. Care was also paid to the morphology of the area to insure that the sampling material consisted of residual soil and not transported soil. The average depth of the boundaries between two adjacent horizons, A1, A2, B, C and bedrock were 6, 28, 61 and more than 111 cm respectively.

Normally, samples were taken from both sides of the slopes in V-shaped stream valleys. When the streams reached the foot of the mountains, the stream valleys extended laterally to become U-shaped with deposition of terraces on either side. In these cases, one sampling site on the slope was available. Seventy-nine slope base soil samples from each of the horizons were taken from 45 sites along streams.

Detailed soil samples

There is a controversy concerning the most suitable soil horizon for exploration geochemistry. Brotzen (1967) among others, stated that C horizon was preferable to B horizon, while Boyle & Dass (1967) have proved that humus samples from A0 horizon gave better contrasts than samples from B horizon. Humus samples were preferred to till samples for tungsten exploration by Toverud (1977) and used successfully for sulphide mineral exploration by Silakul (1984). Quin and Brooks (1974) found that the upper B horizon samples were better than the plant samples for geochemical prospectings in areas adjacent to scheelite deposits in New Zealand. Remarkably, these controversies concern mostly areas of glaciated terrain. There is not yet any report of comparative studies of different soil horizons in tropical terrains.

The purpose in detailed surveys was to outline mineralized areas and pinpoint the mineralizations with the greatest possible precision, preparatory to physical exploration by trenching, pitting, drilling and underground work. In order to localize the mineralization, a relatively close sample spacing, normally between 1 and 100 m was arranged on a rectangular grid basis or on transverse lines across the mineralization trend (Cachau-Herreillat &

Prouhet 1971; Quin & Brooks 1974; Singh 1977; Toverud 1977; Snansieng 1983 and Silakul 1984).

The author carried out detailed comparative studies of soil samples from A1 and B horizons in an area of approximately 1 km^2 (Fig. 3). Sample locations were situated on a rectangular grid, each approximately 50 m x 50 m (Fig. 5). Samples from A1 horizon were taken in the same way as on the bases of the slopes as mentioned above. Samples of B horizon were taken simultaneously using a steel gouge auger. The depth to the upper boundary of B horizon is on an average 28 cm in 576 sampling sites, the variation lying between 10 and 60 cm. Each of the A horizon samples collected, weighed approximately 300 g and the B horizon samples 150 g.

Detailed topographical and geological mappings were also carried out at the same time as the sampling programme.

Note that the A2 and C horizons were neglected in this investigation, since the A2 horizon seems to be inappropriate for geochemical sampling due to the high effects of leaching and percolation, which cause the mobilization of many elements from this horizon. And it was not possible to reach C horizon at every sampling site by the steel gouge auger which is only 1 m long.

Tailing material samples

Tailing material which had been disposed from the mine, was transported along the stream and deposited in a tailing dam 2.5 km southwest of the mine (Figs. 2 and 3).

In dry areas, an Edelman auger was used to drill down to groundwater level, then a suction auger proceeded further to reach the greatest depth of 4 m, the full length of the auger. It was difficult to drill deeper than the gravel bed. The suction auger was used directly in wet areas. Composite samples were collected by the augers at every meter penetrated. The total 108 samples were taken from 34 sampling sites, located on a grid basis in connection with that of the detailed soil samples (Fig. 5).

To study the grain-size distribution of the tailing material, supplementary samples were taken from site 12. This was located in the middle of the lower part of the tailing dam (Fig. 5) and was expected to yield representative samples of the tailing material. A percussion drill was used which could reach to the bottom of the dam at a depth of 6 m.

Laboratory work

The effects of sample matrix on XRF analysis were tested by taking a portion of scheelite ore which was crushed and ground, then sieved through a 0.075 mm screen: grains finer than 0.075 mm were divided into 6 portions. One portion was not milled, the other five were milled by an agate-pulverizer for 15, 30, 60, 90 and 120 minutes respectively.

Two of the A1 horizon detailed soil samples, A73 and A116, which have relatively low concentrations of W, were sieved to obtain grains finer than 0.075 mm, grains between 0.03–0.075 mm and grains finer than 0.03 mm.

Some 3.5 g of each sample, followed by cellulose powder to reinforce the samples were pressed into a holder under a pressure of 0.5 t/cm^2. The sample was assayed for its content of W, Cu, Zn, As, Mo, Sn, Ni, Fe, Ca, Ti and K using XRF, Phillips PW 1410/1710, at the Department of Analytical Chemistry of the University of Uppsala. The content of these elements was obtained directly in a semi-quantitative unit (counts) and stored for further statistical analysis by a personal computor.

The estimated W contents of scheelite ore at different milling time are shown by bar charts in Fig. 8. The estimated content in the unmilled portion and that milled for 15 minutes was the same but increases as the milling time increases. The optimum estimation is obtained at the milling time of 90 minutes. The estimated amount at 90 minutes or longer is 11 % greater than in the unmilled portion.

The estimated W content in grains of different sizes of samples A73 and A116 are shown by bar charts in Fig. 9. In both samples, the estimated content in grains finer than 0.075 mm and grains between 0.03 and 0.075 mm are more or less identical. The estimated content in grains finer than 0.03 mm,

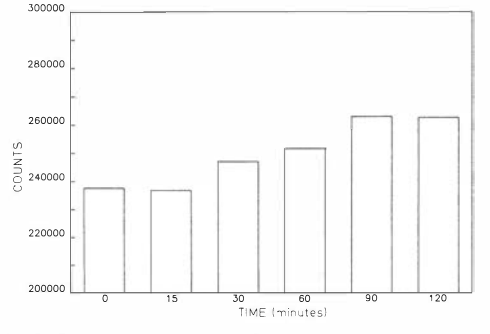


Fig. 8. Diagram showing the estimated W contents, in counts, of scheelite ore milled for 0, 15, 30, 60, 90 and 120 minutes.

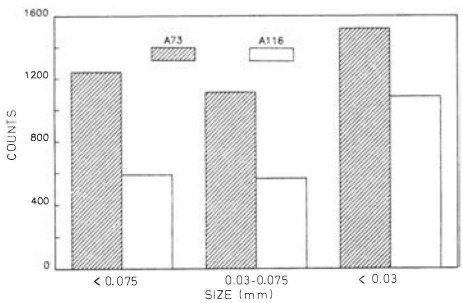


Fig. 9. Diagram showing the estimated W contents, in counts, in grains finer than 0.075 mm down to grains finer than 0.03 mm of samples A 73 and A 116 of Al horizon detailed soil samples.

however, increase by 22 and 84 % in samples A73 and A116 respectively.

From the milling test, it can be assumed that XRF is more efficient at detecting the W content in finer grains than in coarser grains. The sieving test demonstrates that the estimated W content in the grains finer than 0.03 mm is much higher than in the coarser grains. Nevertheless, samples of grains finer than 0.075 mm are preferred in this investigation, since it is too difficult and time-consuming to carry out dry sieving of grains finer than 0.03 mm.

All the samples from the field were dried in air. The Department of Geological Sciences, Chiang Mai University, Thailand kindly made its facility available for this investigation. Clumps of the samples were broken down suitably by passing them through a hammer mill, the screen of which had been removed to avoid crushing the grains unnecessarily. Since the samples were not really crushed, computation of possible contamination from the mill can be neglected. To obtain representative, fine grained and homogeneous subsamples, they were sieved through a screen with an aperture of 0.075 mm.

Samples from sites 12 and 17 in the tailing dam were divided into two portions. The first was ground in a shatter box for two minutes. The second was sieved through a series of screens with apertures of 0.075, 0.175, 1.0 and 2.0 mm. The weight of each fraction was recorded. Each group of particles larger than 0.075 mm was ground in a shatter box for 2 minutes.

Subsequently, all samples, after the preparation stage, were analysed by XRF for the content of W, Cu, Zn, As, Mo, Sn, Ni, Fe, Ca, Ti and K.

To calibrate from semi-quantitative unit (counts) to ppm, fifty samples of various concentrations and all types of samples were analysed for W content by colorimetry, as described by Welsch (1983). A non-linear relationship between XRF data and colorimetric results is encountered. This relationship can be explained by the equation

$$\log_{10} Y = 1.125 \log_{10} X - 1.44,$$

where Y = number of ppm
and X = number of counts.

Hence, using this equation quantitative estimations of W, in ppm, can be obtained.

A professional laboratory, Analytica AB, analysed ten samples of various concentrations for the content of W, Cu, Zn, As, Sn and Ca. Our results are in good accord with the concentrations of W obtained by Analytica AB. Concentrations of the other elements were also used to calibrate from semi-quantitative unit to ppm.

The calibration for the content of Mo, Ni, Fe, Ti and K were done by the standard addition method at the Department of Analytical Chemistry of the University of Uppsala.

Treatment and presentation of analytical data

Basic statistics

Virtually, if the frequency distribution of raw data is said to be normal, that means the skewness of the distribution is equal to zero. In many cases a logarithmic transformation of raw data provides a normal form to the frequency distribution, in which case the data are said to be lognormal (Sinclair 1983).

To investigate the forms of the frequency distributions of element contents in all sampling media

Table 1. Skewnesses of frequency distributions of element contents, in ppm and log ppm values, of 148 top and basal stream sediment samples.

Element	Top stream sediments		Basal stream sediments	
	ppm	log ppm	ppm	log ppm
W	4.37	0.94	8.06	0.79
Cu	1.26	0.17	3.99	−0.13
Zn	4.19	1.37	1.18	−0.06
As	2.78	−0.09	2.37	−0.18
Mo	9.47	0.55	−0.58	−1.97
Sn	4.81	0.99	7.82	0.73
Ni	2.30	1.09	1.45	0.36
Fe	−0.19	−1.21	−0.10	−1.47
Ca	2.78	−0.25	6.92	−0.17
Ti	−0.55	−1.19	−0.16	−1.04
K	−0.14	−0.95	−0.56	−1.37

Table 2. Skewnesses of frequency distributions of element contents, in ppm and log ppm values, of 79 Al, A2, B and C horizon slope base soil samples.

Element	A1 horizon		A2 horizon		B horizon		C horizon	
	ppm	log ppm	ppm	log ppm	ppm	log ppm	ppm	log ppm
W	5.60	−0.51	7.41	−0.51	7.82	−0.06	8.04	−0.35
Cu	3.68	0.82	1.99	0.06	2.31	0.17	3.28	0.34
Zn	3.48	1.61	3.44	1.67	1.88	0.74	1.55	0.59
As	3.33	0.06	3.16	0.14	3.36	0.34	3.36	0.22
Mo	0.33	−0.35	0.20	−1.29	−0.04	−2.06	1.18	−0.66
Sn	1.91	−0.10	2.44	−0.09	3.52	0.18	3.64	0.38
Ni	2.70	1.62	3.16	1.43	3.08	1.50	2.34	1.30
Fe	1.06	−0.03	1.24	−0.19	0.50	−0.52	0.35	−0.74
Ca	2.68	0.62	4.96	0.87	7.26	1.35	5.61	1.60
Ti	2.56	1.36	2.92	1.38	2.94	1.44	2.76	0.91
K	−0.24	−1.36	−0.46	−1.83	−0.51	−2.32	−0.54	−1.94

that they approach whether normal or lognormal forms, the skewnesses of the raw data values and the log transformation values of element contents were calculated and listed in Tables 1−4.

It is evident that the frequency distributions of most element contents in stream sediment, slope base soil and detailed soil samples approach lognormal form (Tables 1−3) whereas the distributions of most element contents in tailing material approach normal form (Table 4).

Hence, the element contents of stream sediment samples, slope base soil samples and detailed soil samples were converted logarithmically and then calculated for means and standard deviations. The means, and mean plus and minus standard deviations were subsequently converted to ppm and presented in Tables 5−7. The maximum values and minimum values of all the elements are also presented.

The element contents of tailing material, in ppm, were calculated directly for means and standard deviations. The means, mean plus and minus standard deviations, maximum values and minimum values of all the elements are presented in Table 8.

Advanced statistics

The main objective in exploration geochemistry is to discover the single element or multielement distributions that relate to mineralization. In this study, the probability graphs method is employed for the treatment of single element distribution (univariate data) and the factor analysis method for multielement distribution (multivariate data).

Probability graphs. − Probability graphs were established on the principle that most of the frequency distributions of element contents in geochemical materials approach closely to lognormality, and a cumulative lognormal frequency distribution will plot as a straight line on a log probability paper (Ahrens 1957; Sinclair 1976). The first to recognize the potential of cumulative probability graphs in treating geochemical data were Tennant and White

Table 3. Skewnesses of frequency distributions of element contents, in ppm and log ppm values, of A1 and B horizons detailed soil samples.

Element	A1 horizon		B horizon	
	ppm	log ppm	ppm	log ppm
W	2.90	0.30	2.94	−0.20
Cu	1.60	−0.01	1.37	−0.16
Zn	1.09	0.01	2.73	0.52
As	2.43	−0.15	4.14	0.31
Mo	6.09	−0.58	1.94	−0.58
Sn	0.79	−0.77	0.75	−0.71
Ni	0.76	0.29	1.45	0.69
Fe	0.69	−0.13	0.54	−0.57
Ca	4.50	−0.12	2.67	0.00
Ti	0.41	−0.05	0.22	−0.77
K	−0.46	−1.09	−0.25	−3.21

Table 4. Skewnesses of frequency distributions of element contents, in ppm and log ppm values, of 108 tailing material samples.

Element	Tailing material	
	ppm	log ppm
W	−0.02	−2.41
Cu	0.88	0.12
Zn	−0.84	−1.37
As	−0.27	−2.11
Mo	−0.39	−1.35
Sn	1.16	−1.83
Ni	0.60	−0.05
Fe	0.08	−0.76
Ca	0.08	−1.37
Ti	0.31	−0.11
K	0.81	0.60

in 1959. Since then the method has been modified and used extensively (Williams 1967; Lepeltier 1969; Bölviken 1971; Parslow 1974 and Sinclair 1974, 1976 and 1983). This method described in detail by Sinclair (1976) has been employed in this investigation for the treatment of W contents in all types of sampling media. It must be pointed out, however, that Björklund (1983) conducted an experiment based on ideal data and concluded that the application of cumulative probability graphs for geochemical data may not be valid.

As shown in Tables 1–3, the frequency distributions of W contents in all types of sampling media approached closely to lognormality. Hence, W contents in ppm were converted to logarithmic (base 10) values and subsequently were tabulated into class intervals lying between a quarter and half the standard deviation. The number of classes was limited to between 10 and 20. Cumulative percentages were computed from high to low values and plotted as solid dots against lower class limits. Smooth curves were drawn through the plotted points (cf. Sinclair 1976).

Several tabulations and plots with different numbers of classes were made for each of the sampling media to obtain the best form of the curve. Tabulations of 15 classes seem to be the best fit for all media.

Cumulative probability plots of W contents for all media, namely, top and basal stream sediment samples; A1, A2, B and C horizon slope base soil samples and A1 and B horizon detailed soil samples are displayed in Figs. 10–17.

All cumulative probability curves were arbitrarily partitioned into 5 sections in order to detect every possible individual population. Each population tends to form a straight section of the cumulative curve and the location can be recognized readily by inflections of the curve. Each of the partitioned populations was depicted as a straight line drawn through open circles.

Partitionings were conversely checked by ideal combination of constituent populations at particular ordinates. The sums were plotted in the diagrams as open triangles. They coincide almost exactly with the smooth cumulative curve. Thus, they indicate that partitioned straight lines represent reliably constituent populations of the whole data values.

In cases where overlapping of two adjacent populations occur their overlapping extremities are more or less mutual mixtures of each part. Probability graphs of all sampling media evidently show

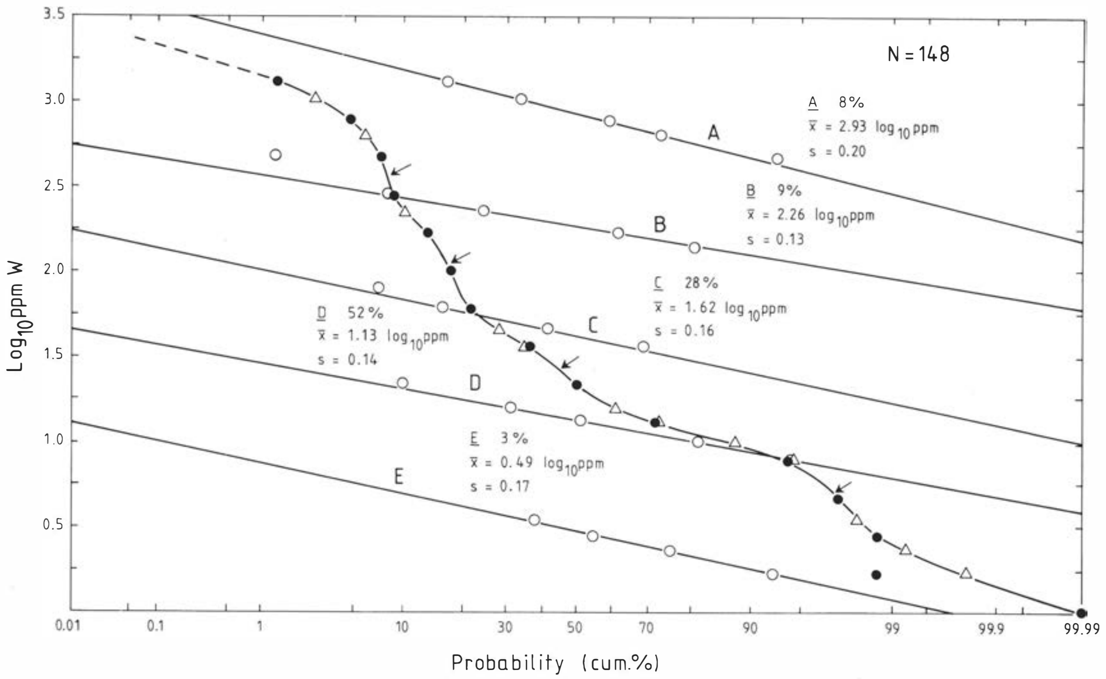


Fig. 10. Partitioned probability plot of 148 W analyses of top stream sediment samples. Original data are plotted as black dots, open circles are estimated partitioning points, open triangles are check points obtained by ideal combination of partitioned populations A, B, C, D and E. Inflection points are shown by arrow heads.

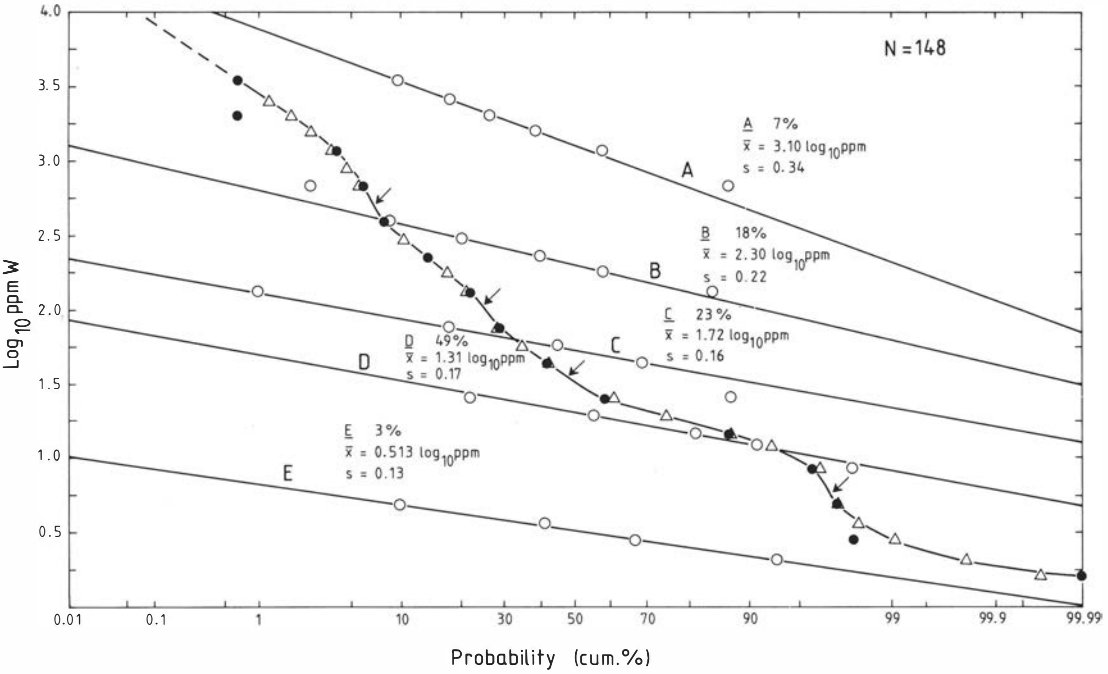


Fig. 11. Partitioned probability plot of 148 W analyses of basal stream sediment samples. See Fig. 10 for explanation of symbols.

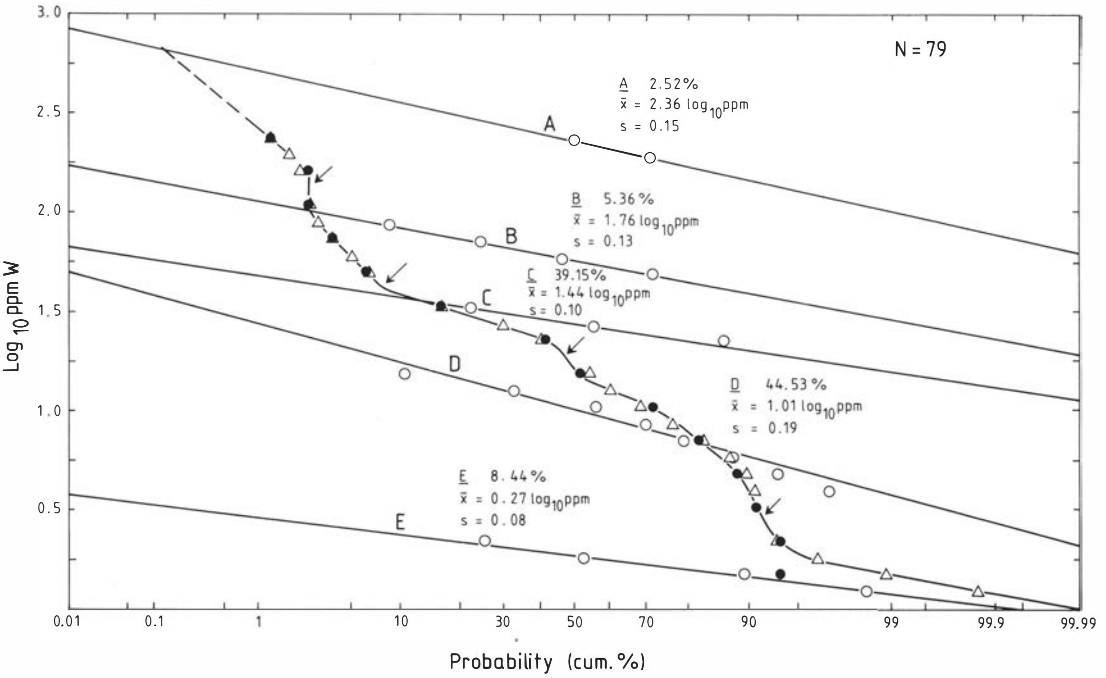


Fig. 12. Partitioned probability plot of 79 W analyses of A1 horizon slope base soil samples. See Fig. 10 for explanation of symbols.

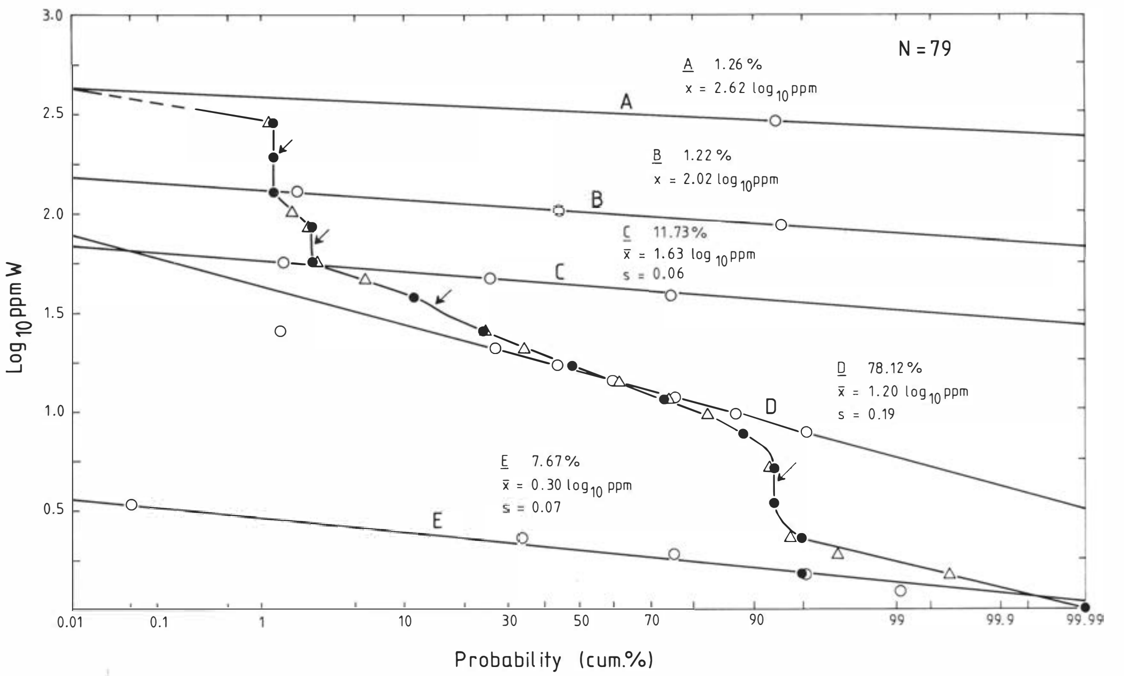


Fig. 13. Partitioned probability plot of 79 W analyses of A2 horizon slope base soil samples. See Fig. 10 for explanation of symbols.

this phenomenon. However, attention will be restricted to anomalous populations only.

Population A (anomalous) and B (background) of top and basal stream sediment samples (Figs. 10 and 11) overlap to some extent. Therefore, two thresholds were necessary to distinguish anomalous from background values. These thresholds were taken arbitrarily at the 99th cumulative percentile of population A and 1st cumulative percentile of population B.

Thresholds for eliminating anomalous from adjacent background populations in all soil sampling media (Figs. 12–17) can be recognized readily by natural breaks of concentration, displayed by gaps in some classes of the frequency distributions. Threshold values for distinguishing the rest of the populations were estimated from the ordinate values of the inflection points, indicated by arrow heads.

Mean values of each population can be estimated directly as the ordinate value corresponding to the 50th percentile. The values of mean, mean plus and minus one standard deviation, in $\log_{10}$ ppm, can be read fairly precisely by ordinate values that correspond to the 16th and 84th percentiles respectively.

Statistical parameters and threshold values of stream sediment samples, slope base soil samples and detailed soil samples are converted to ppm and listed in Tables 9, 10 and 11 respectively.

Ultimately, each population of the stream sediment and slope base soil samples is coded distinctly on the maps by different sizes of solid circles, shown in Figs. 18–23. Each population of the detailed soil samples is depicted by distinctive linear patterns in Figs. 24 and 25. The proportions of each constituent population were presented as cumulative percentiles with accurate two decimal numbers which could be read from the abscissa values of the thresholds (Figs 10–17). They were listed in the same manner as the cumulative probability curves were constructed, i.e. starting from the high concentrations.

Correlation and factor analysis. – As the contents of W, Cu, Zn, As, Mo, Sn, Ni, Fe, Ca, Ti and the K content in stream sediment, slope base soil and detailed soil samples tend to be lognormally distributed, they were transformed logarithmically in order that meaningful statistical parameters could be computed. It was unnecessary to transform the element contents of tailing material, since they were already normally distributed.

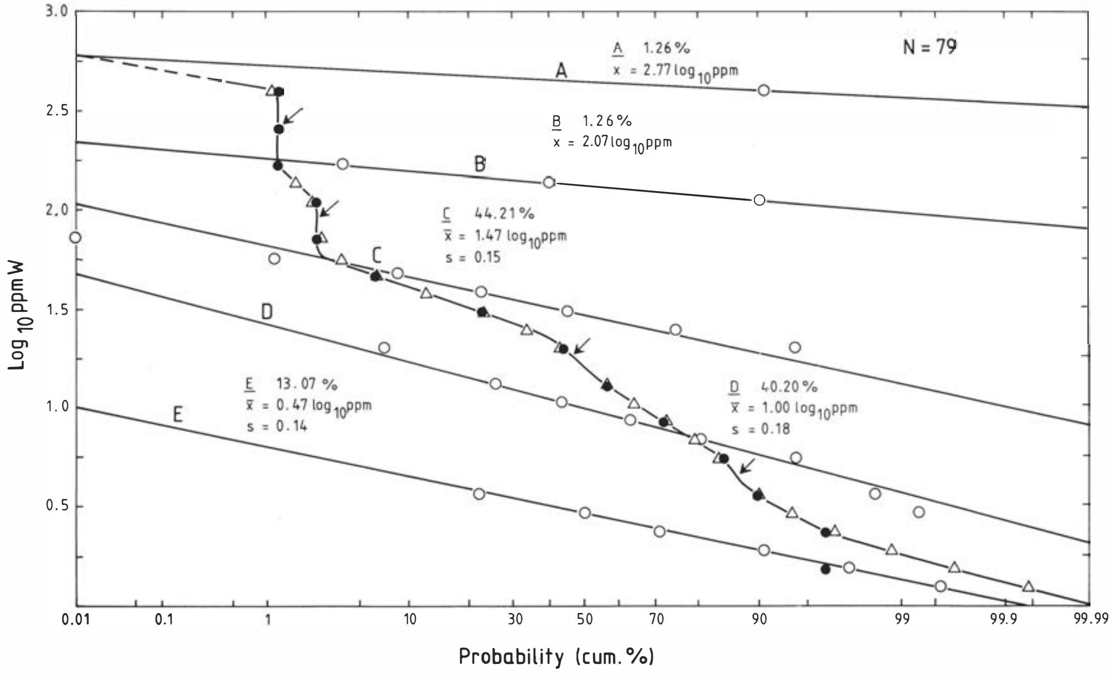


Fig. 14. Partitioned probability plot of 79 W analyses of B horizon slope base soil samples. See Fig. 10 for explanation of symbols.

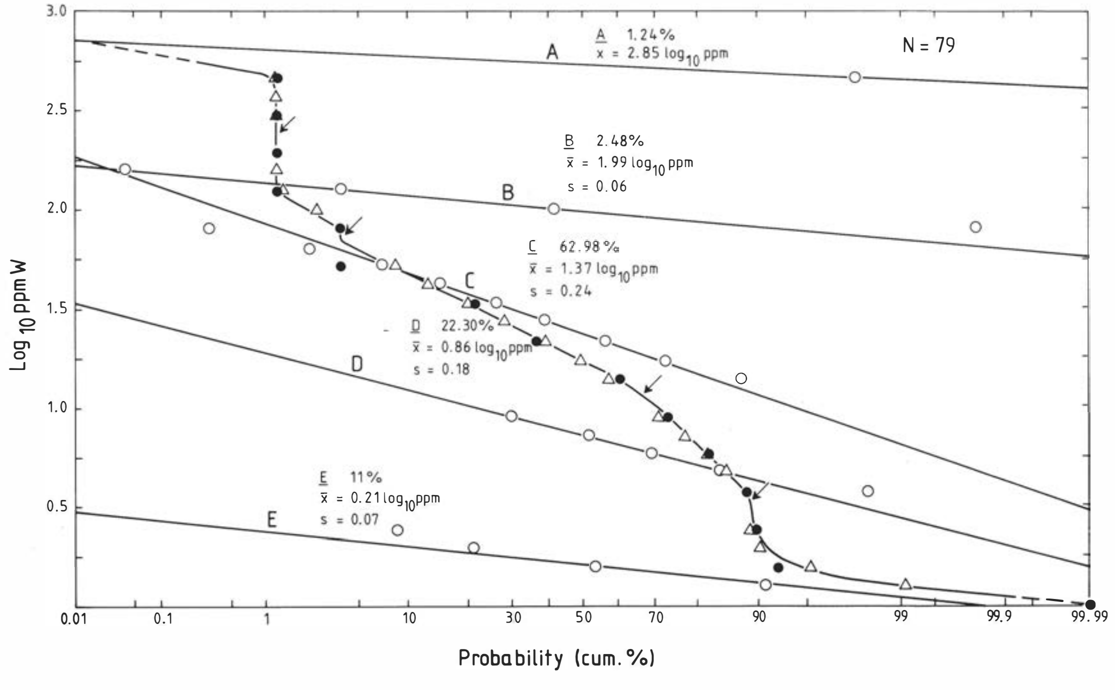


Fig. 15. Partitioned probability plot of 79 W analyses of C horizon slope base soil samples. See Fig. 10 for explanation of symbols.

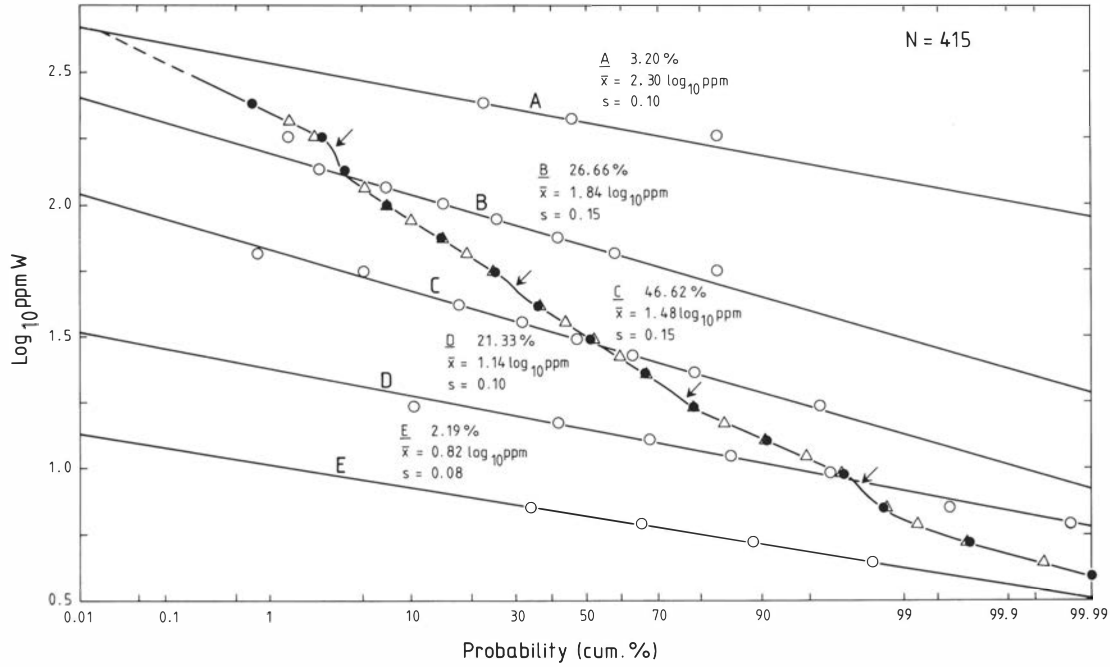


Fig. 16. Partitioned probability plot of 415 W analyses of A1 horizon detailed soil samples. See Fig. 10 for explanation of symbols.

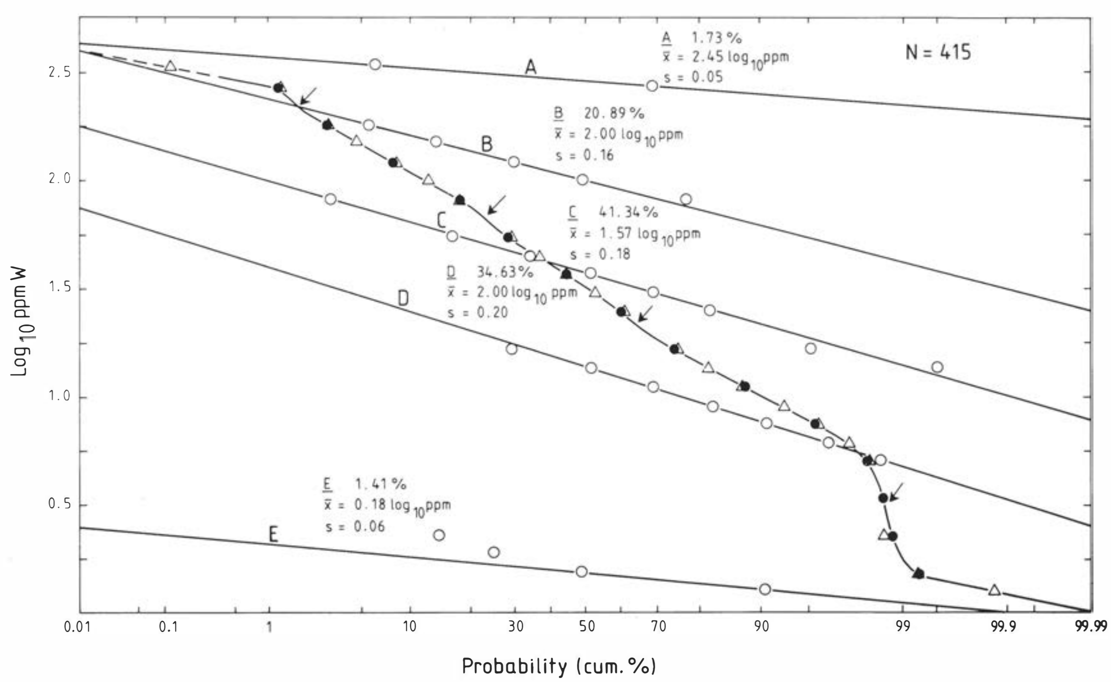


Fig. 17. Partitioned probability plot of 415 W analyses of B horizon detailed soil samples. See Fig. 10 for explanation of symbols.

The interrelations of the element contents were established by the computation of correlation coefficients for each pair of element contents. A perfect sympathetic correlation will yield a coefficient of +1, a perfect antipathetic a coefficient of −1, and a random relationship a value of zero (Garrett & Nichol 1969).

To facilitate comparison between two particular elements using correlation coefficients, the following grouping was used; very close correlation (coefficients between 1.0 and 0.9), close correlation (coefficients between 0.9 and 0.7), moderate correlation (coefficients between 0.7 and 0.4) and little or no correlation (coefficients below 0.4). It must be emphasized that this classification gives only a rough relationship of the elements (cf. Qvarfort 1977).

Symbols were employed to represent the particular classes in the correlation matrices as shown in Tables 12−20. Details of the correlation values may be lacking but the correlation of any pair of elements can be recognized very simply.

To express the relationships of multivariate data with discrete geochemical features, R-mode Orthogonal Varimax Rotation factor analysis was computed, using the Hewlett Packard statistic programme. The number of factors extracted from 11 element variables was arbitrarily limited to 6. These 6 factors account for more than 84 % of the total variation in the correlation data of all sampling media.

The factor analysis solution matrices of all sampling media are treated similarly as the correlation matrices. The factor loadings were grouped as; strong loading (>0.8), moderate loading (0.6−0.8), weak loading (0.4−0.6), and non-significant loading (<0.4). Each group was coded in grades, by solid circles of varying diameter as portrayed in Tables 21−29.

Factor scores obtained from factor analysis virtually relate to the element content in the samples, therefore plotting of factor scores of a particular element dominating factor on the map may reveal the anomalous areas relating to that element. Since tungsten deposits are the targets in this investigation, only factor scores of the factor that contains the highest loading values of W (called tungsten ore mineral factor) in each sampling medium is taken into account.

The factor scores of 0, 1 and 2 are arbitrarily chosen as the boundaries for dividing the data into four groups. The positive or negative signs of factor scores are relevant to the signs of the element loadings. Each group of the stream sediment and slope base soil samples was coded distinctly on the maps by different sized solid circles shown in Figs. 26−31, whereas each group of the detailed soil samples was depicted by a distinctive linear pattern in Figs. 32−33.

To demonstrate the numbers of samples accounted for in each constituent group of data in all sampling media, their proportions are presented as cumulative percentiles, starting from the largest number of factor scores, regardless of the signs of the numbers.

Discussion of results

Basic statistics

The mean value of the W content of top and basal stream sediment samples are 31 and 46 ppm, respectively (Table 5), the mean content of the basal stream sediment samples being 32 % greater than that of the top stream sediment samples. The range (maximum−minimum) of W content in the basal stream sediment is 3-fold greater than in the top stream sediment samples. From these facts, it can be inferred that the natural accumulation of the stream sediment is greater in the basal coarse layer. A similar phenomenon occurs regarding Cu. The mean and range values of the other elements are

Table 5. Statistical parameters of element contents, in ppm, of 148 top and basal stream sediment samples.

Element	x̄	x̄+s	x̄−s	maximum	minimum
Top stream sediment samples:					
W	31	127	8	2038	0
Cu	59	101	34	213	18
Zn	109	152	78	537	46
As	20	45	9	166	2
Mo	35	50	25	306	11
Sn	6	20	2	298	0
Ni	76	106	55	253	40
Fe	24355	33174	17881	44619	6008
Ca	4815	10527	2202	35885	459
Ti	7401	9202	5952	10703	3196
K	35481	45279	27804	54531	14924
Basal stream sediment samples:					
W	46	187	11	5931	0
Cu	100	216	46	1098	16
Zn	106	138	81	260	44
As	21	49	9	169	2
Mo	35	49	25	63	8
Sn	9	30	3	778	0
Ni	63	87	46	174	34
Fe	24266	34522	17057	48094	5693
Ca	4443	10590	1864	95275	312
Ti	8061	9408	6907	11766	3830
K	35892	44648	28854	52734	15162

Table 6. Statistical parameters of element contents, in ppm, of 79 A1, A2, B and C horizon slope base soil samples.

Element	x̄	x̄+s	x̄−s	maximum	minimum
A1 horizon:					
W	15	44	5	329	0
Cu	39	67	22	274	15
Zn	105	127	87	266	72
As	29	63	13	265	5
Mo	26	37	18	49	11
Sn	4	9	2	27	0
Ni	60	77	46	159	41
Fe	24099	33589	17290	57718	10458
Ca	7711	15621	3806	53768	1718
Ti	8857	10857	7226	20646	5794
K	30606	41889	22361	52878	9748
A2 horizon:					
W	15	40	6	417	0
Cu	40	74	22	176	11
Zn	101	124	83	244	68
As	34	73	16	297	5
Mo	25	35	18	52	7
Sn	4	10	2	33	0
Ni	63	81	48	190	37
Fe	27990	38557	20188	71626	11189
Ca	2089	4330	1008	29386	584
Ti	9598	11628	7923	22636	6253
K	31879	44740	22714	54144	6662
B horizon:					
W	15	42	5	595	0
Cu	46	88	24	251	13
Zn	104	125	86	213	67
As	38	83	18	372	10
Mo	24	37	16	46	3
Sn	4	10	1	52	0
Ni	67	87	52	194	42
Fe	31434	44340	22284	68832	12855
Ca	1318	2470	703	23162	527
Ti	9546	11695	7791	22466	6166
K	31239	45698	21355	53586	4424
C horizon:					
W	14	45	4	708	0
Cu	49	97	24	350	13
Zn	106	129	87	210	64
As	37	85	16	363	6
Mo	27	38	19	74	9
Sn	4	10	2	56	0
Ni	69	90	53	178	43
Fe	31974	46817	21837	64363	11788
Ca	1321	2705	645	25050	536
Ti	9262	11389	7532	22368	4942
K	30960	44968	21316	56614	6145

more or less the same in both types of stream sediment samples.

The mean values of W content in A1, A2, B and C horizon slope base soil samples are equal to each other (Table 6). The range (maximum−minimum) increases from A1 to C horizons respectively. Conversely, the mean and range of Ca content decreases from A1 to C horizons, whereas those of the other elements do not show any significant difference. Considering that the range of W content in C horizon is 100 % greater than in A1 horizon, this shows the effects of weathering and erosion which gradually become less as one descends in the soil profile. Thus one can expect to obtain the best contrast (i.e. the greatest range) of the W content in C horizon soil samples, and this can help to recognize simply the anomaly related to mineralization. The decrease in Ca content as one descends to B horizon shows the accumulation of Ca in A1 and A2 horizons due to evaporation and capillary action (cf. page 58).

The mean and range values of all the elements, except Fe and Ca in A1 and B horizon detailed soil samples are more or less the same (Table 7). The higher mean value of Fe content in B horizon shows the accumulation of Fe ion at the groundwater level due to leaching from the upper horizons. On the other hand, the Ca ion has accumulated through evaporation and capillary action in the A1 horizon.

Not surprisingly, extraordinary high average contents of W, Zn, As, Sn and Ca are found in tailing material (Table 8). This is because the minerals constituted of these elements (cf. page 58) were trapped in the dam when they were discarded from the mine.

The effects of natural panning at the inner side of

Table 7. Statistical parameters of element contents, in ppm, of 415 A1 and B horizon detailed soil samples.

Element	x̄	x̄+s	x̄−s	maximum	minimum
A1 horizon:					
W	33	70	15	319	4
Cu	43	66	28	198	12
Zn	86	115	64	250	43
As	28	54	14	215	2
Mo	34	47	24	214	5
Sn	7	18	3	45	0
Ni	45	52	38	76	31
Fe	16696	22279	12511	34197	6958
Ca	7418	14388	3825	86372	727
Ti	8397	9640	7313	12965	5116
K	38450	49625	29792	59101	14187
B horizon:					
W	31	82	12	391	0
Cu	43	70	26	161	5
Zn	87	112	67	297	46
As	40	80	20	457	8
Mo	28	39	20	121	7
Sn	8	21	3	44	0
Ni	56	65	48	107	37
Fe	23999	33636	17124	67529	8195
Ca	994	1971	502	8613	104
Ti	8453	10320	6923	16950	3219
K	40476	53420	30669	66523	2266

Table 8. Statistical parameters of element contents, in ppm, of 108 tailing samples.

Element	x̄	x̄+s	x̄−s	maximum	minimum
W	6226	9303	3149	15148	100
Cu	44	55	33	83	21
Zn	197	235	159	264	99
As	485	680	290	953	40
Mo	24	32	20	37	6
Sn	358	567	149	1373	12
Ni	39	49	29	65	18
Fe	23244	26902	19588	35236	14155
Ca	24178	35466	12890	60316	2920
Ti	6585	7480	2690	8757	4631
K	37278	40725	33821	46889	29791

meander bends and behind the obstructing boulders can be seen by the average W content in stream sediment samples which is more than twice that of slope base soil samples, taken from the same sampling sites (Tables 5 and 6).

The average W content in the detailed soil samples is twice that of the slope base soil samples (Tables 6 and 7). This can arise by the sampling of detailed soil from the smaller area of 1 km^2 in the vicinity of the exposed quartz veins which were possibly associated with tungsten mineralizations, whereas samples of the slope base soil were taken from the larger area of some 6 km^2, which is underlain chiefly by barren rocks.

Advanced statistics

Probability graphs. – The great advantage of the cumulative probability graphs is that the mixture of several geochemical populations can be partitioned into individual populations and considered separately.

In all sampling media, the first two populations are assigned as anomalous populations, since they have higher tendencies to relate with the possible existing mineralizations. The remaining populations are assigned as background populations derived from the barren rocks.

In stream sediment samples (Table 9), the mean W content of the 1st anomalous population of the

Table 9. Estimated statistical parameters of partitioned populations and their threshold values of W contents in top and basal stream sediment samples.

Population	Threshold in ppm	Values in ppm W x̄	x̄+s	x̄−s	Proportion %	No. of samples
Top stream sediment samples:						
A: 1st anomalous		851	1349	537	8	12
	371					
A+B: 2nd anomalous (combination of two extremities of A and B)						
	290					
B: 1st background (granite)		184	248	136	9	13
	109					
C: 2nd background (contact zone)		42	61	29	28	41
	27					
D: 3rd background (schist−slate)		14	19	10	52	77
	5					
E: 4th background (schist−slate)		3	5	2	3	5
	0					
Total					100	148
Basal stream sediment samples:						
A: 1st anomalous		1250	2704	578	7	10
	635					
A+B: 2nd anomalous (combination of two extremities of A and B)						
	204					
B: 1st background (granite)		199	326	121	18	27
	105					
C: 2nd background (contact zone)		53	77	36	23	34
	35					
D: 3rd background (schist−slate)		20	30	14	49	73
	6					
E: 4th background (schist−slate)		3	4	2	3	4
	0					
Total					100	148

Table 10. Estimated statistical parameters of partitioned populations and their threshold values of W contents in slope base soil samples.

Population	Threshold in ppm	Values in ppm W $\bar{x}$	$\bar{x}+s$	$\bar{x}-s$	Proportion %	No. of samples
A1 horizon slope base soil samples:						
A: 1st anomalous		228	324	161	2.52	2
	136					
B: 2nd anomalous (mineralized zone)		57	77	43	5.36	4
	40					
C: 1st background (mineralized zone)		27	35	22	39.15	31
	19					
D: 2nd background (barren rocks)		10	16	7	44.53	35
	3					
E: 3rd background (barren rocks)		1.9	2.3	1.6	8.44	7
	0					
Total					100.00	79
A2 horizon slope base soil samples:						
A: 1st anomalous		417	–	–	1.26	1
	189					
B: 2nd anomalous (mineralized zone)		105	–	–	1.22	1
	68					
C: 1st background (mineralized zone)		43	49	38	11.73	9
	34					
D: 2nd background (barren rocks)		16	24	10	78.12	62
	4					
E: 3rd background (barren rocks)		2	2.3	1.7	7.67	6
	0					
Total					100.00	79
B horizon slope base soil samples:						
A: 1st anomalous		595	–	–	1.26	1
	256					
B: 2nd anomalous (mineralized zone)		118	–	–	1.26	1
	88					
C: 1st background (mineralized zone)		30	41	21	44.21	35
	18					
D: 2nd background (barren rocks)		10	15	6	40.20	32
	4					
E: 3rd background (barren rocks)		3	4	2	13.07	10
	0					
Total					100.00	79
C horizon slope base soil samples:						
A: 1st anomalous		708	–	–	1.24	1
	241					
B: 2nd anomalous (mineralized zone)		97	112	84	2.48	2
	75					
C: 1st background (mineralized zone)		24	41	14	62.98	50
	11					
D: 2nd background (barren rocks)		7	11	5	22.30	17
	3					
E: 3rd background (barren rocks)		1.6	1.9	1.3	11.00	9
	0					
Total					100.00	79

Table 11. Estimated statistical parameters of partitioned populations and their threshold values of W contents in detailed soil samples.

Population	Threshold in ppm	Values in ppm W $\bar{x}$	$\bar{x}+s$	$\bar{x}-s$	Proportion %	No. of samples
A1 horizon detailed soil samples:						
A: 1st anomalous		202	252	161	3.20	13
	159					
B: 2nd anomalous (mineralized zone)		69	98	49	26.66	111
	48					
C: 1st background (granite)		30	42	21	46.62	193
	8					
D: 2nd background (schist)		14	18	11	21.33	89
	8					
E: 3rd background (schist)		8	6	5	2.19	9
	0					
Total					100.00	415
B horizon detailed soil samples:						
A: 1st anomalous		283	316	254	1.73	7
	218					
B: 2nd anomalous (mineralized zone)		99	143	68	20.89	87
	67					
C: 1st background (granite)		37	56	24	41.34	171
	21					
D: 2nd background (schist)		14	22	9	34.63	144
	3					
E: 3rd background (schist)		1.5	1.7	1.3	1.41	6
	0					
Total					100.00	415

basal stream sediment samples is 32 % greater than that of the top stream sediment samples whereas the means of all the background populations are more or less the same. This supports the inference mentioned above that the natural accumulation of stream sediment is greater in the basal coarse layer. In this case, only anomalous populations are considered.

In slope base soil samples (Table 10), the mean W content of the 1st anomalous populations of A2, B and C horizon increase by 2, 3 and 3.5 times respectively more than that of the A1 horizon. For the 2nd anomalous populations, the mean W content of the A1 horizon is half the mean of the underlying horizons. The mean values of the first two background populations of the A2 horizon are about 30 % higher than that of A1, B and C horizons.

The gradual decreasing of weathering and erosion effects, as one descends in the soil profile can be confirmed by increasing of W content from A1 to C horizons in anomalous populations. However, tungsten as a member of insoluble minerals can persist very well as residual product in A2 horizon (cf. page 58). This can be clearly seen by higher means of W content in background populations (Table 10).

The means of W contents in both the 1st and 2nd anomalous populations of the B horizon detailed soil samples are 30 % higher than those of the A1 horizon (Table 11). The means of W contents of the corresponding background populations of the A1 and B horizon are however more or less identical. The effects of weathering and erosion as discussed above are once again enhanced.

In anomalous areas, the averages of W contents in stream sediments are generally higher than those of the slope base soil samples since the mineral grains are naturally accumulated in the stream patterns (Tables 9 and 10).

Comparing the mean values of anomalous populations of the slope base soil and the detailed soil samples (Tables 10 and 11), it was shown that the potential mineralization in the vicinity of the slope base soil sampling area is possibly richer than that of the detailed soil samples.

Correlation. – Top stream sediment samples. – Close to moderate correlations of W–Sn–As–Ca,

Table 12. Correlation coefficients of elements in 148 top stream sediment samples.

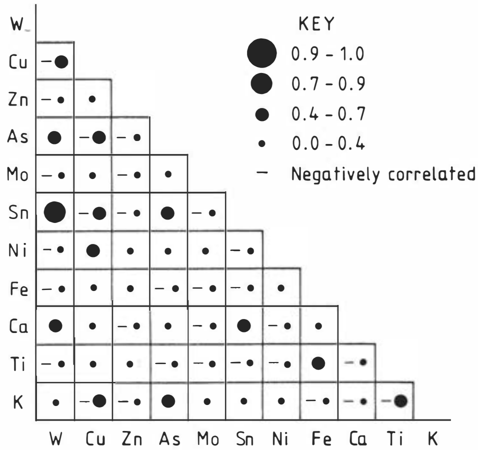
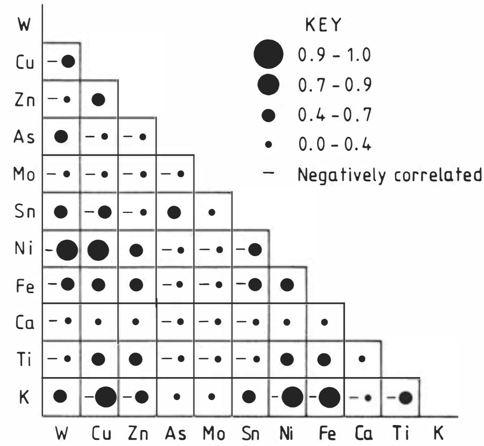


Table 14. Correlation coefficients of elements in 79 A1 horizon slope base soil samples.



moderate correlations of Cu–Ni and Fe–Ti are evident in Table 12. The elements in the first group vary, to some extent, antipathetically with those of the other two groups.

Basal stream sediment samples. – Close to moderate correlations of W–Sn–As–Ca, moderate correlations of Cu–Mo and Zn–Ni–Fe are apparent in Table 13. The elements in the first group vary antipathetically with the other two groups.

The close correlation between W and Sn is remarkably evident in both top and basal stream sediment samples. The element associations can be roughly estimated as W–Sn–As–Ca association of tungsten ore minerals.

A1 horizon slope base soil samples. – Moderate correlations of W–Sn–As–K and close to moderate correlations of Cu–Zn–Ni–Fe–Ti are found in Table 14. The elements in the first group vary antipathetically with those of the latter group.

A2 horizon slope base soil samples. – Moderate to little correlations of W–Sn–As–K and close to moderate correlations of Cu–Zn–Ni–Fe are evident in Table 15. These two groups of elements vary antipathetically with one another.

B horizon slope base soil samples. – Moderate to little correlations of W–Sn–As and close to moderate correlations of Cu–Zn–Ni–Fe–Ti–Ca can be found in Table 16. They vary antipathetically with one another.

C horizon slope base soil samples. – Moderate to

Table 13. Correlation coefficients of elements in 148 basal stream sediment samples.

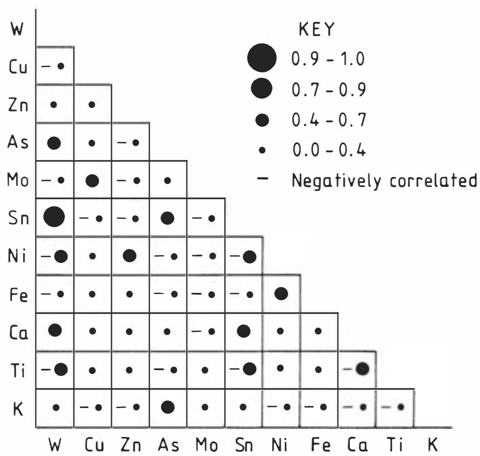


Table 15. Correlation coefficients of elements in 79 A2 horizon slope base soil samples.

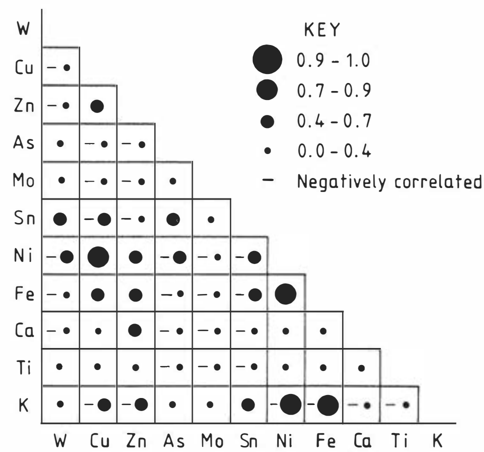
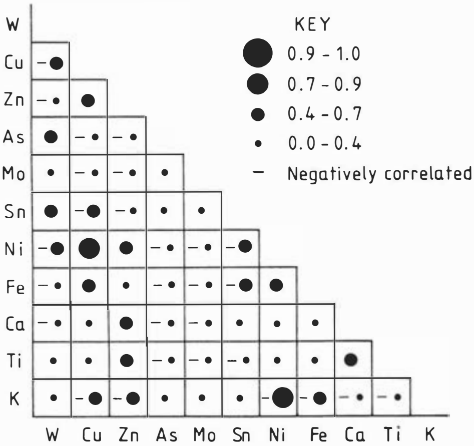


Table 16. Correlation coefficients of elements in 79 B horizon slope base soil samples.



little correlations of W–Sn–As and close to moderate correlations of Cu–Zn–Ni–Fe–Ca can be observed in Table 17. The elements in these two groups vary antipathetically with one another.

It is evident that the number of close to moderate correlation coefficients of elements are found mostly in the A1 horizon slope base soil and decline successively in the A2, B and C horizons. However, the correlations of elements in the B and C horizons are quite similar to each other. Two element associations can be accounted roughly as the W–Sn–As–K association of tungsten ore minerals and the Cu–Zn–Ni–Fe–Ti association of sulphide ore minerals.

A1 horizon detailed soil samples. – Only moderate to little correlations of W–Sn–As–Zn–K–Ni can be observed in Table 18, but Cu and Fe vary antipathetically with them.

Table 17. Correlation coefficients of elements in 79 C horizon slope base soil samples.

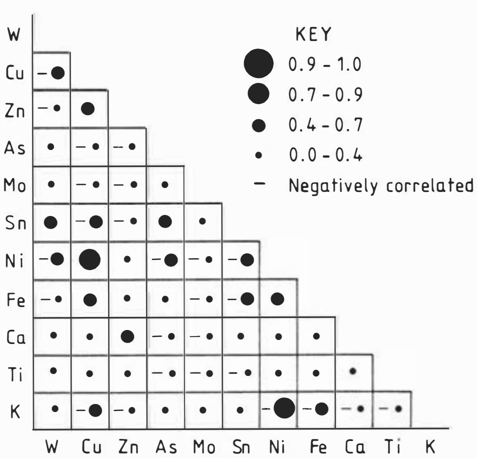
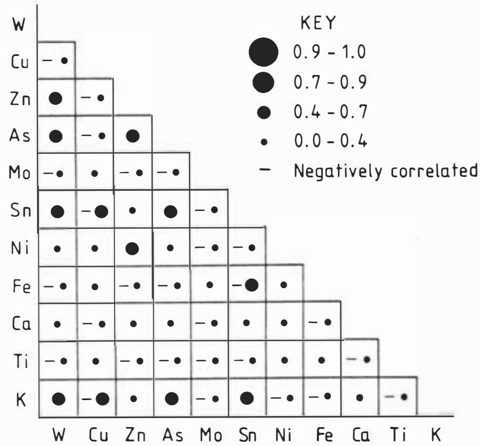


Table 18. Correlation coefficients of elements in 415 A1 horizon detailed soil samples.



B horizon detailed soil samples. – Moderate correlations of W–Sn–As–K and moderate correlation of Cu–Fe are observed in Table 19. These two groups of elements vary antipathetically with one another.

Two general element associations of W–Sn–As–K and Cu–Fe in both A1 and B horizon detailed soil samples can be observed, and they are more or less identical to those of the slope base soil samples.

Tailing material samples. – An extraordinary number of close correlation coefficients is presented

Table 19. Correlation coefficients of elements in 415 B horizon detailed soil samples.

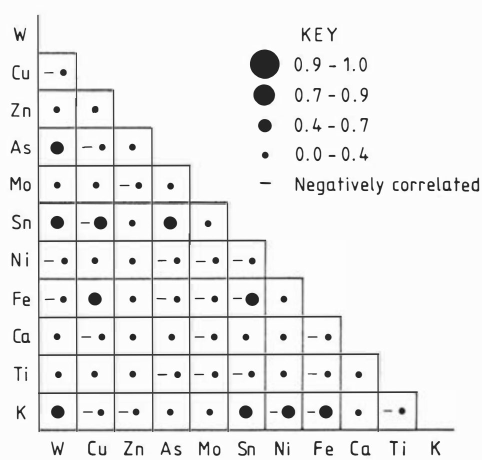


Table 20. Correlation coefficients of elements in 108 tailing material samples.

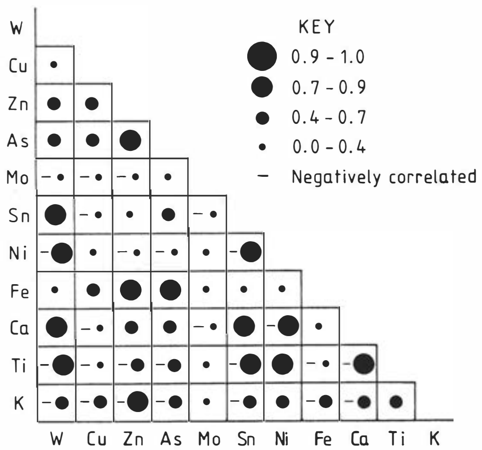
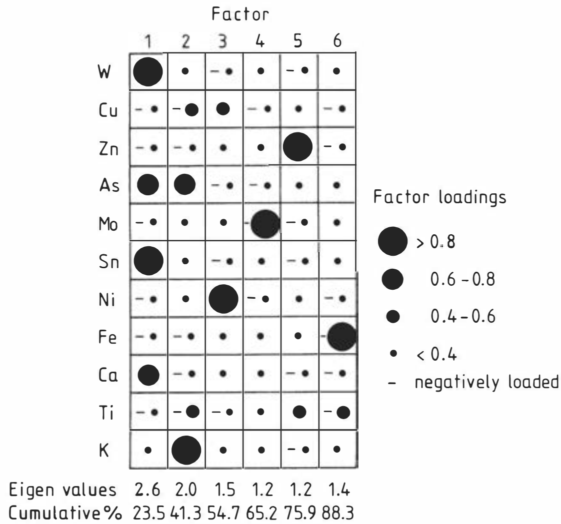


Table 21. Orthogonal varimax rotated factor solution of 148 top stream sediment samples.



in Table 20. This shows marked repetitions of element distributions in the tailing dam.

The W, Sn, As, Cu, Zn, Ca and Fe vary antipathetically with Ni, Ti and K. This demonstrates that the minerals constituted of the elements of the first group deposited simultaneously at one particular place, i.e. perhaps at once when the stream reached the water level in the tailing dam and lost its velocity which caused the deposition of transported sediments. The minerals constituted of the elements in the second group, on the other hand, may be carried further and deposited lately closer to the dam wall.

Factor analysis. – Top stream sediment samples. – Factor 1 accounts for 23.5 % of total variance and reveals the positive strong loadings of W and Sn and positive moderate loadings of As and Ca (Table 21). This element association represents the tungsten ore mineral association. Ca in this factor may occur as a constitutent element in calcium carbonate. The Ca in scheelite ($CaWO_4$) would have been already removed when scheelite was weathered and later eroded down to stream channel (cf. page 52). Factor 2 represents 17.8 % of the total variance; it is characterized by positive strong loading of K and positive moderate loading of As. Strong positive loading of Ni, strong negative loading of Mo, strong positive loading of Zn and strong negative loading of Fe are found in Factors 3, 4, 5 and 6 respectively.

Basal stream sediment samples. – Factor 1 represents 23.6 % of total variance, and is dominated by positive strong to weak loadings of W, Sn, As and Ca (Table 22). Factor 2 accounts for 13.3 % of the total variance and is characterized by a negative strong loading of Zn and a negative moderate loading of Ni. Strong positive loadings of Cu and Mo characterize Factor 3, which accounts for 14.6 % of the total variance. Positive strong loadings of K and Ti are found in Factors 4 and 5 respectively. Negative moderate and negative strong loadings of Ca and Fe are found in Factors 5 and 6 respectively.

The W–Sn–As element association which dominates in Factor 1 of both top and basal stream sediment samples represents the tungsten ore

Table 22. Orthogonal varimax rotated factor solution of 148 basal stream sediment samples.

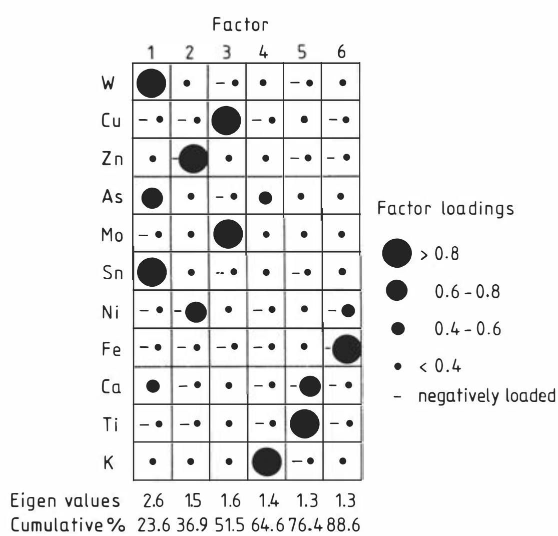


Table 23. Orthogonal varimax rotated factor solution of 79 A1 horizon slope base soil samples.

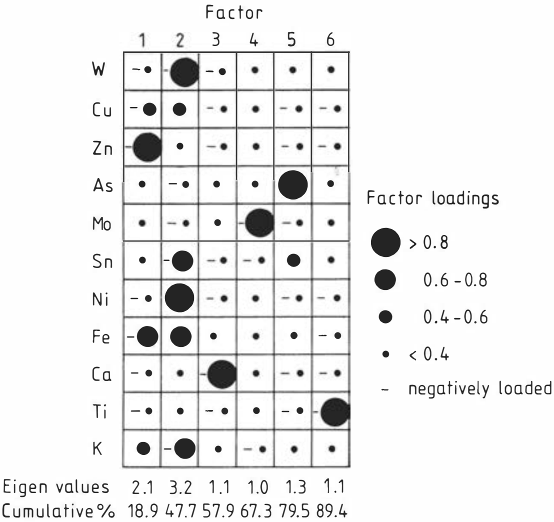
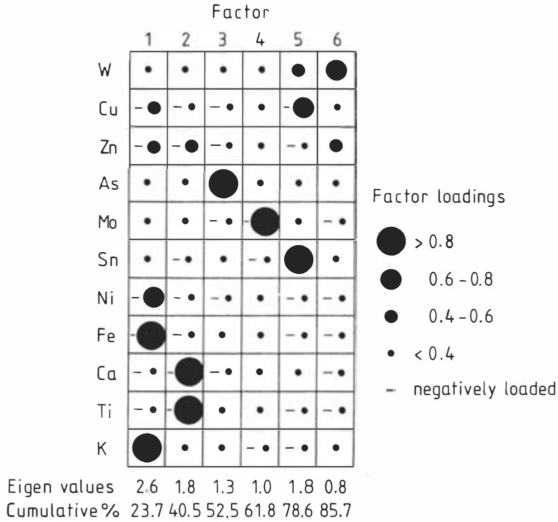


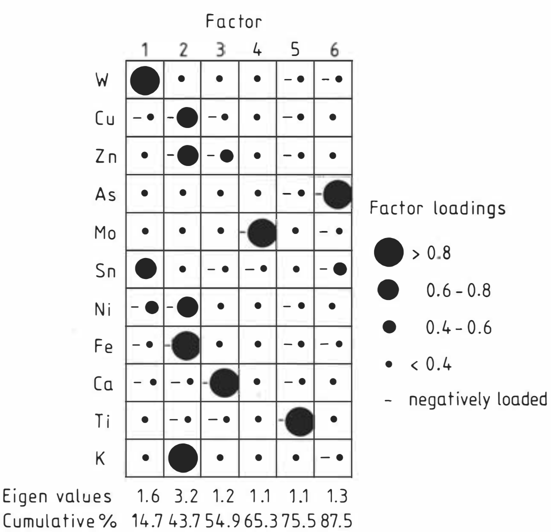
Table 25. Orthogonal varimax rotated factor solution of 79 B horizon slope base soil samples.



mineral factor. The displacements of elements in corresponding factors of top and basal stream sediment samples may be affected by distinct indigenous weathering environments in each particular layer.

A1 horizon slope base soil samples. – Negative strong loading of Zn and negative moderate loading of Fe dominate Factor 1 in Table 23, which accounts for 18.9 % of total variance. This may be the characteristic of weathering products of sulphide minerals (i.e. sphalerite, pyrrhotite and pyrite) in this investigated area. These minerals were also recognized by Baum et al. (1972) and Jivathanond (1981) in the mining area. Negative strong loading of W and negative moderate loadings of Sn and K are found in Factor 2 which accounts for 28.8 % of the total variance. This factor is assumed to be the tungsten ore mineral factor. However, positive strong loading of Ni and positive moderate loading of Fe are also presented in this factor. Factors 3, 4, 5 and 6 are loaded independently by Ca, Mo, As and Ti respectively.

Table 24. Orthogonal varimax rotated factor solution of 79 A2 horizon slope base soil samples.



A2 horizon slope base soil samples. – Factor 1 in Table 24 accounts for 14.7 % of total variance and is dominated by positive strong loading of W and moderate loading of Sn. Therefore this factor is assumed to be the tungsten ore mineral factor. Factor 2 which accounts for 29.0 % is dominated by negative strong loading of Fe and negative moderate loadings of Cu, Zn and Ni, and strong positive loading of K. This element association is the characteristic of weathering products. Factors 3, 4, 5 and 6 are loaded almost independently by Ca, Mo, Ti and As respectively.

B horizon slope base soil samples. – Factor 1 which reveals 23.7 % of total variance is characterized by negative strong loading of Fe, negative moderate loading of Ni and negative weak loadings of Cu and Zn, and positive strong loading of K (Table 25). This is the characteristic of weathering products of minerals. Factor 2 which accounts for 16.8 % of the total variance is negatively loaded by Ca and Ti. Factors 3 and 4 are As and Mo factors respectively. Factor 5 which accounts for 16.8 % of the total variance is characterized by positive strong and positive weak loadings of Sn and W respectively. Negative moderate loading of Cu is also found in this factor. The tungsten ore mineral factor is recognized in Factor 6 which accounts for 7.1 % of the total variance. This factor is characterized by positive moderate and positive weak loadings of W and Zn respectively.

C horizon slope base soil samples. – Factor 1 in Table 26 accounts for 25.4 % of total variance and is dominated by positive strong and positive moderate loadings of Sn and W, and negative moderate loadings of Cu and Ni respectively. This factor can be interpreted as the tungsten ore mineral factor. Factor 2 is characterized by negative strong and negative moderate loadings of Zn and Ca. Factor 3 is negatively strongly loaded by K and positively moderately loaded by Ni. Factors 4 and 5 are dominated independently by Mo and Ti respectively. Factor 6 represents the As–Fe association of weathering products of sulphide minerals.

Distinct from the tungsten mineral factors of the stream sediment samples, the tungsten ore mineral factors of the slope base soil samples are generally characterized by loadings of only W and Sn, except C horizon slope base soil samples in which As is also associated. This shows the effects of weathering processes that affect distinctly the mobilization of elements in different soil horizons, in which the least effects are always found in C horizon. However Cu, Zn, Ni and Fe seem to associate very well with each other in all horizons. The association of these elements is perhaps the weathering products of the sulphide mineral association.

Since it was known that C horizon has the least effects of weathering processes, compared to the overlying horizons, the primary mineral association of the ore deposit can be traced by considering the element association of C horizon in which the W–Sn–As association is present. Thus the primary tungsten mineral association is perhaps a scheelite–cassiterite–arsenopyrite association. Nevertheless, the absence of Ca from this association can be caused by the extreme weathering of C horizon in the area. Hence, the possible existing mineralization in the investigated area tends to be that of the hydrothermal or porphyry-type deposits (cf. page 52).

A1 horizon detailed soil samples. – Factor 1 in Table 27 represents 27.2 % of total variance and is dominated by positive strong loadings of As, Sn and K, and positive moderate loading of W. This factor represents the tungsten ore mineral association. Factor 2 is dominated by negative strong and negative moderate loadings of Zn and Ni respectively. Factors 3, 4, 5 and 6 are loaded almost exclusively by Ti, Mo, Fe and Ca respectively.

B horizon detailed soil samples. – In Table 28, Factor 1 accounts for 21.2 % of total variance. Positive strong to moderate loadings of W, As and Sn represent the association of tungsten ore minerals in this factor. Factor 2 is loaded exclusively by Zn. Factor 3 is characterized by negative strong to weak loadings of Ca and Fe, and positive moderate loading of Cu. Factors 4 and 5 are loaded almost inde-

Table 26. Orthogonal varimax rotated factor solution of 79 C horizon slope base soil samples.

	Factor 1	2	3	4	5	6
W	0.6 - 0.8	- < 0.4	- < 0.4	- < 0.4	< 0.4	< 0.4
Cu	- 0.6 - 0.8	- < 0.4	0.4 - 0.6	< 0.4	< 0.4	< 0.4
Zn	- < 0.4	- > 0.8	< 0.4	< 0.4	< 0.4	< 0.4
As	0.4 - 0.6	< 0.4	- < 0.4	- < 0.4	< 0.4	0.6 - 0.8
Mo	< 0.4	< 0.4	- < 0.4	- > 0.8	- < 0.4	- < 0.4
Sn	> 0.8	< 0.4	- < 0.4	- < 0.4	- < 0.4	- < 0.4
Ni	- 0.6 - 0.8	- < 0.4	0.6 - 0.8	< 0.4	< 0.4	- < 0.4
Fe	- < 0.4	- < 0.4	0.4 - 0.6	< 0.4	- < 0.4	0.6 - 0.8
Ca	< 0.4	- 0.6 - 0.8	< 0.4	- < 0.4	< 0.4	- 0.4 - 0.6
Ti	< 0.4	- < 0.4	< 0.4	< 0.4	> 0.8	- < 0.4
K	< 0.4	< 0.4	- > 0.8	- < 0.4	- < 0.4	- < 0.4
Eigen values	2.8	1.6	1.8	1.0	1.1	1.2
Cumulative%	25.4	39.9	56.1	65.5	75.4	85.9

Factor loadings: > 0.8; 0.6 - 0.8; 0.4 - 0.6; < 0.4; - negatively loaded

Table 27. Orthogonal varimax rotated factor solution of 415 A1 horizon detailed soil samples.

	Factor 1	2	3	4	5	6
W	0.6 - 0.8	- 0.4 - 0.6	< 0.4	- < 0.4	< 0.4	< 0.4
Cu	- 0.4 - 0.6	- < 0.4	0.4 - 0.6	- 0.4 - 0.6	- < 0.4	< 0.4
Zn	< 0.4	- > 0.8	< 0.4	< 0.4	< 0.4	< 0.4
As	> 0.8	- < 0.4	< 0.4	- < 0.4	- < 0.4	< 0.4
Mo	- < 0.4	< 0.4	- < 0.4	- > 0.8	- < 0.4	- < 0.4
Sn	> 0.8	- < 0.4	- < 0.4	< 0.4	< 0.4	< 0.4
Ni	- < 0.4	- 0.6 - 0.8	< 0.4	< 0.4	- 0.4 - 0.6	- < 0.4
Fe	- < 0.4	- < 0.4	< 0.4	- < 0.4	- > 0.8	- < 0.4
Ca	< 0.4	- < 0.4	- < 0.4	< 0.4	< 0.4	> 0.8
Ti	- < 0.4	- < 0.4	> 0.8	< 0.4	- < 0.4	- < 0.4
K	> 0.8	< 0.4	- < 0.4	< 0.4	< 0.4	< 0.4
Eigen values	3.0	1.6	1.1	1.2	1.3	1.1
Cumulative%	27.2	41.3	51.6	62.5	74.7	84.1

Factor loadings: > 0.8; 0.6 - 0.8; 0.4 - 0.6; < 0.4; - negatively loaded

Table 28. Orthogonal varimax rotated factor solution of 415 B horizon detailed soil samples.

	Factor 1	2	3	4	5	6
W	> 0.8	- < 0.4	- < 0.4	- < 0.4	- < 0.4	< 0.4
Cu	- < 0.4	- < 0.4	0.6 - 0.8	- < 0.4	- < 0.4	- < 0.4
Zn	- < 0.4	- > 0.8	- < 0.4	- < 0.4	< 0.4	- < 0.4
As	> 0.8	- < 0.4	< 0.4	< 0.4	< 0.4	< 0.4
Mo	< 0.4	< 0.4	< 0.4	< 0.4	- > 0.8	- < 0.4
Sn	0.6 - 0.8	< 0.4	- < 0.4	< 0.4	- < 0.4	< 0.4
Ni	- < 0.4	- < 0.4	- < 0.4	- < 0.4	- < 0.4	- 0.6 - 0.8
Fe	- < 0.4	- < 0.4	- 0.4 - 0.6	- 0.4 - 0.6	< 0.4	- 0.4 - 0.6
Ca	< 0.4	- < 0.4	- > 0.8	- < 0.4	< 0.4	- < 0.4
Ti	- < 0.4	- < 0.4	< 0.4	- > 0.8	< 0.4	- < 0.4
K	< 0.4	- < 0.4	- < 0.4	< 0.4	- < 0.4	> 0.8
Eigen values	2.3	1.3	1.7	1.2	1.0	1.7
Cumulative%	21.2	32.7	48.5	59.6	69.0	84.7

Factor loadings: ● > 0.8; ● 0.6 - 0.8; ● 0.4 - 0.6; • < 0.4; - negatively loaded

pendently by Ti and Mo respectively. Factor 6 is characterized by positive strong loading of K, negative moderate loading of Ni and negative weak loading of Fe.

The tungsten ore mineral factors of the detailed soil samples are characterized generally by the loadings of W, Sn and As; however, in the A1 horizon samples, K is also present in this factor. This can be caused by distinct weathering effects in these two horizons. These weathering effects can also be seen by the different distributions of other elements. The tungsten ore mineral association may be a scheelite–cassiterite–arsenopyrite association which may be associated with quartz veins in this area.

It is possible that W which is detected in stream sediment slope base soil and detailed soil samples does not exist as primary scheelite ore but rather in the form of products of its alteration, namely anthoinite, meymacite and/or tungstite (cf. page 52); otherwise Ca would have associated with the elements in the tungsten ore mineral factors.

Table 29. Orthogonal varimax rotated factor solution of 108 tailing material samples.

	Factor 1	2	3	4	5	6
W	> 0.8	< 0.4	- < 0.4	- < 0.4	- < 0.4	< 0.4
Cu	- < 0.4	0.4 - 0.6	- < 0.4	> 0.8	- < 0.4	< 0.4
Zn	< 0.4	0.6 - 0.8	- < 0.4	< 0.4	- < 0.4	< 0.4
As	< 0.4	> 0.8	< 0.4	< 0.4	- < 0.4	< 0.4
Mo	- < 0.4	< 0.4	> 0.8	- < 0.4	< 0.4	- < 0.4
Sn	> 0.8	< 0.4	< 0.4	< 0.4	< 0.4	< 0.4
Ni	- > 0.8	- < 0.4	< 0.4	< 0.4	< 0.4	- < 0.4
Fe	- < 0.4	> 0.8	< 0.4	< 0.4	- < 0.4	- < 0.4
Ca	> 0.8	< 0.4	- < 0.4	- < 0.4	- < 0.4	< 0.4
Ti	- 0.6 - 0.8	- < 0.4	< 0.4	- < 0.4	< 0.4	- 0.6 - 0.8
K	- 0.4 - 0.6	- 0.4 - 0.6	< 0.4	- < 0.4	0.6 - 0.8	- < 0.4
Eigen values	4.3	2.9	1.0	1.0	0.7	0.5
Cumulative%	39.4	65.5	74.9	83.6	89.6	94.2

Factor loadings: ● > 0.8; ● 0.6 - 0.8; ● 0.4 - 0.6; • < 0.4; - negatively loaded

Tailing material samples. – Factor 1 in Table 29 accounts for 39.4 % of total variance, and is distinctly dominated by strong positive loadings of W, Sn and Ca. Even the deposition of these elements is not a wholly natural occurrence. Their association in this factor may be derived mostly from skarn scheelite ore mineral association and scheelite has not yet been altered to secondary tungsten minerals. Negative loadings of Ni, Ti and K are also found in Factor 1 and may indicate the composition of minerals of granite bedrock. Factor 2 represents 26.0 % of the total variance, and is characterized by strong to moderate positive loadings of As, Fe and Zn. This factor can be the representative of hydrothermal sulphide minerals. Independently, strong to moderate loadings of Mo, Cu, K and Ti occur in Factors 3, 4, 5 and 6 respectively.

A deduction can be made by comparing the characteristics of factor distributions in stream sediment, slope base soil, detailed soil and tailing material samples. Even though the tungsten ore mineral associations of the potential mineralizations of both areas of slope base soil and detailed soil samples were assumed to be scheelite–cassiterite–arsenopyrite, the Ca was, however, absent from this association. This is because the minerals were sufficiently weathered and Ca had been removed.

The tungsten ore mineral association of the tailing material is assumed to be a scheelite–cassiterite association. Ca is present in this association. This can be explained by assuming that scheelite minerals which were dug by men and later discarded from the mining area have been exposed to weathering processes in a relatively short time before being deposited in the dam. Therefore scheelite was not altered to secondary tungsten minerals from which Ca would be removed.

Although the element associations obtained by the factor analysis are due to secondary minerals, the primary mineral associations can still be traced from the characteristics of the secondary associations. Thus the potential mineralizations in the slope base soil sampling areas can be assumed to be of hydrothermal or porphyry-type. The mineralization in the detailed soil sampling area is hydrothermal and associated with quartz veins. The ore deposit in the mining area was reported to be a skarn bearing hydrothermal and porphyry-type deposit (Baum et al. 1972 and Jivathanond 1981).

Aerial distributions of univariate data. – Top stream sediment samples. – A possible, existing mineralized zone in the triangular area bounded by the streams I, K and M in Fig. 18 was recognized by the solid circles of the 1st and 2nd anomalous populations along streams M, I and K. Weathered mineralized soil in this zone was eroded down to streams M and K, causing anomalies in these streams.

Values of the 1st anomalous population above the 371 ppm threshold (see Table 9) were dispersed at an approximate distance of 800 m from sampling point 141, along streams M and I, and at an equal distance from sampling point 105, along streams K and I. A value, belonging to the 2nd anomalous population at sampling point 112 may indicate an interruption of the dispersion pattern because of stream I joining stream M above the sampling point 137, where barren stream sediments were added to the total mixture. This causes dropping of the W content in sampling point 112 to below the 371 ppm threshold. Additional tungsten from a possible minor mineralization on the southern slope of sampling point 112 combined with the sorting of sediments are perhaps the reasons for the recovery of the anomaly at sampling point 136. The same action can be seen at sampling points 99 and 126 below the junction of streams K and I.

The values in the 1st background population (see Table 9) are interpreted as those correlated with the mineralizations associated with granite intrusion. The values of the 2nd background population are limited around the contact zones of the granite with schist and gneiss bedrock. The 3rd and 4th background populations are located distinctly to the extension of schist, slate and gneiss bedrock.

Basal stream sediment samples. – Dispersing distances of the values of the 1st anomalous population (see Table 10) are 500 m from sampling point 141, along stream M, and 600 m from sampling point 105, along stream K (Fig. 19). The effect of combination with barren stream sediments below the junction of streams M and I cause a drop in the concentration of sampling point 137. The values of the 2nd anomalous population extended 1000 m along stream I from its junction with stream M, and at least 350 m below the junction of streams K and I. It is clearly seen that the dispersion of the 1st anomalous population is definitely limited by the combination of sediments from the joining streams.

The 1st anomalous value at sampling point 25 in stream B shows a successive increase of the concentrations from sampling point 27. Similar action, but on a smaller scale, occurs at sampling points 28, 29 and 30 of stream C.

The anomaly of stream M has abrupt contact with the 3rd background population at sampling point 142. This can be explained by the large supply of tungsten at sampling point 141, compared with a relatively smaller supply at sampling point 27. After a distance of 250 m along stream B, sorting can reach its optimum effect at sampling point 25.

The values of the 1st background population are delineated distinctly within the area of granite intrusion. The values of the 2nd background population are limited to the contact zones of the granite. The 3rd and 4th background populations are limited to the extension of schist, slate and gneiss bedrock.

The 1st anomalous values of the top stream sediment samples are dispersed in the greater distances along the streams than those of the basal stream sediment samples. However, the dispersion of the 2nd anomalous population of the basal stream sediment samples is greater than that of the top stream sediment samples. Altogether, the dispersion of anomalous populations is greater in the basal stream sediment samples. Thus, in the regional stream sediment survey, it would be more profitable if the basal stream sediment samples are employed so that the chance of missing the anomaly is smaller than that of the top stream sediment samples.

A1 horizon slope base soil samples. – A single value of the 1st anomalous population above the 136 ppm threshold (see Table 10) was detected on the western slope of sampling point 141 (Fig. 20). Two values of the 2nd anomalous population are located on the southern slope of sampling points 108 and 112. Together with the 1st anomalous value at sampling point 141, they can form a triangular area of potential mineralization which corresponds perfectly with that of the stream sediment samples. The other three values of the 2nd anomalous population occur sporadically at sampling points 104, 144 and 145. A remarkable value of the 1st anomalous population appears on the northern slope of sampling point 27 and may indicate a potential minor mineralization, situated on the slope above this sampling point.

The values of the 1st background population are limited within the granite intrusion area and around its contact zones, which have a high potentiality of mineral occurrences. The locations of values in the 2nd and 3rd populations are governed chiefly by schist, slate and gneiss bedrock.

A2 horizon slope base soil samples. – A single value from each of the 1st and 2nd anomalous populations occurs at sampling points 141 and 108

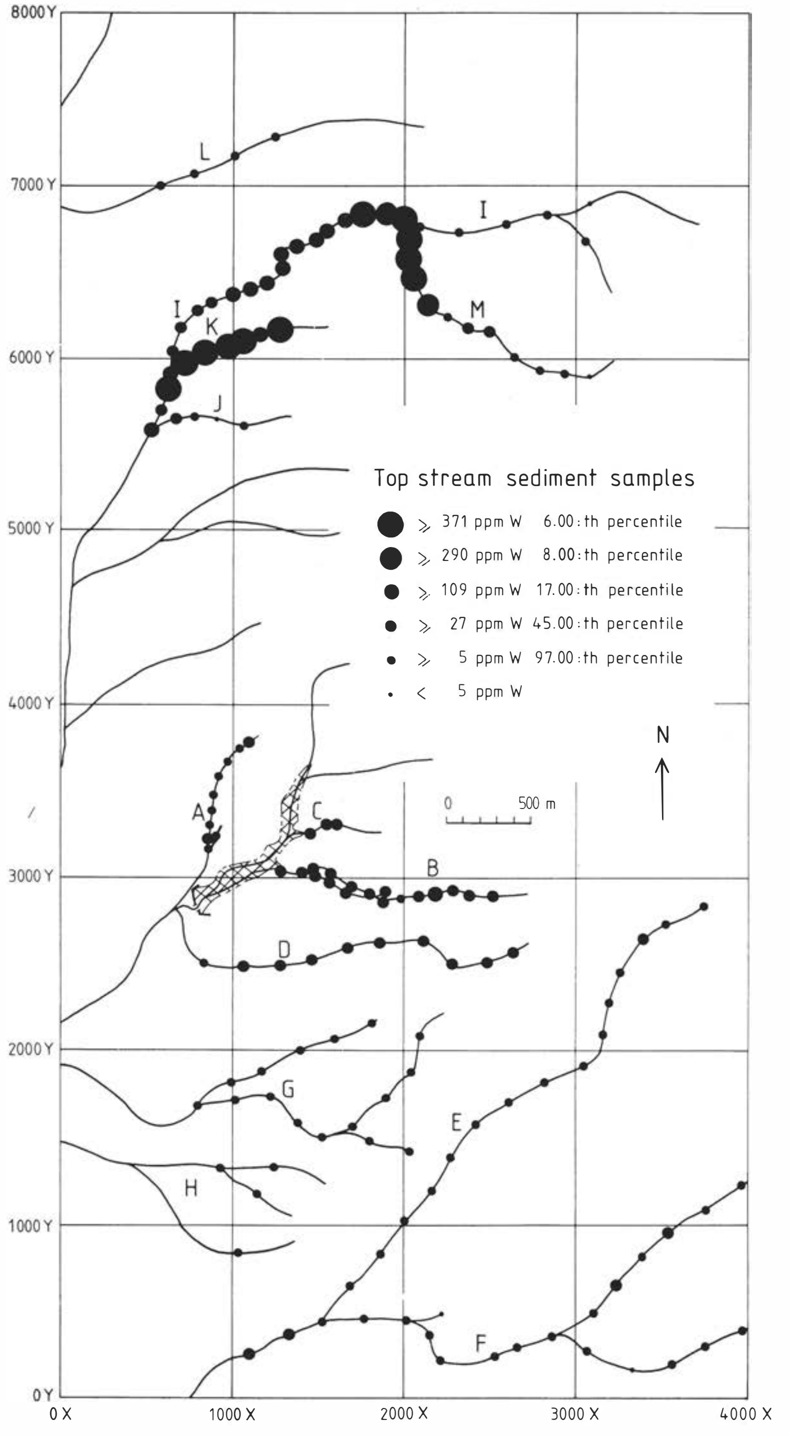


Fig. 18. Distribution of W contents in 148 top stream sediment samples.

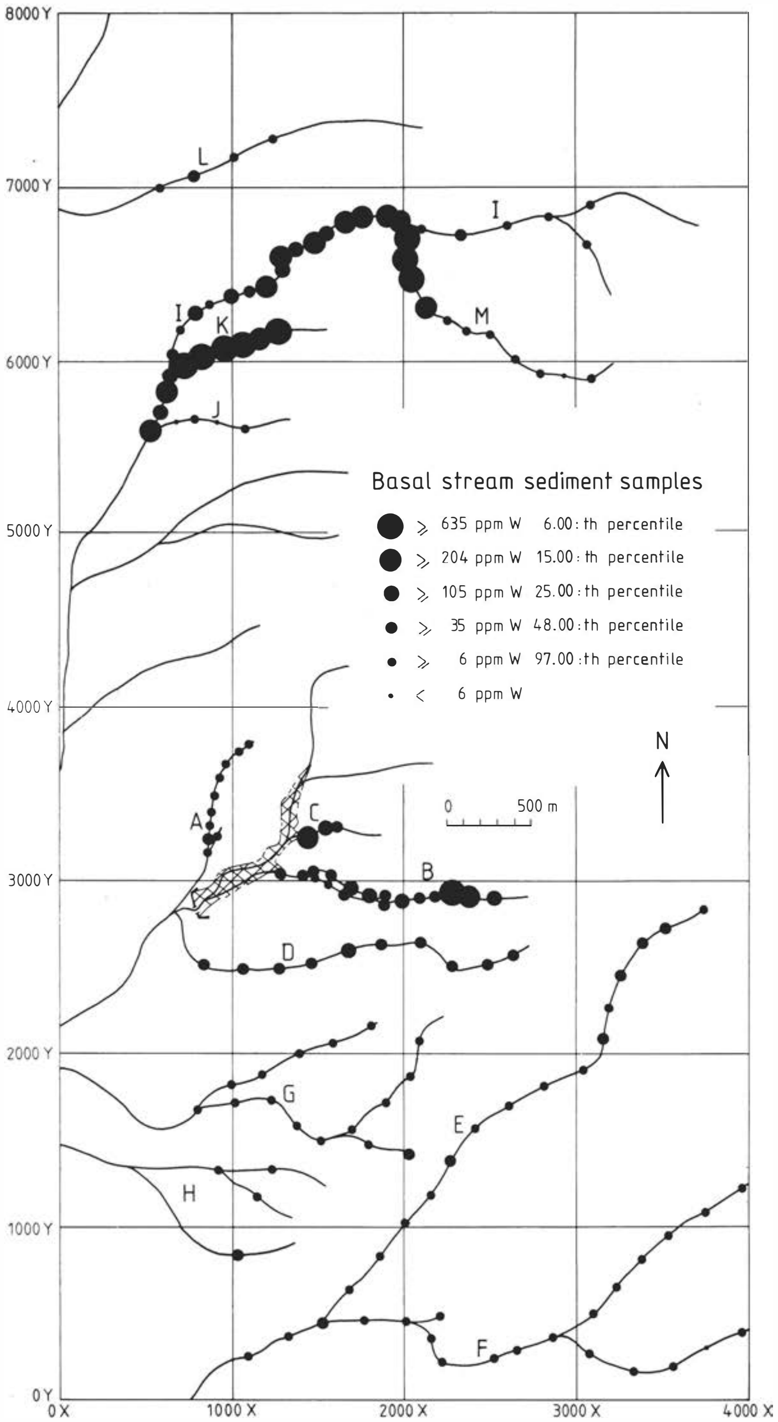


Fig. 19. Distribution of W contents in 148 basal stream sediment samples.

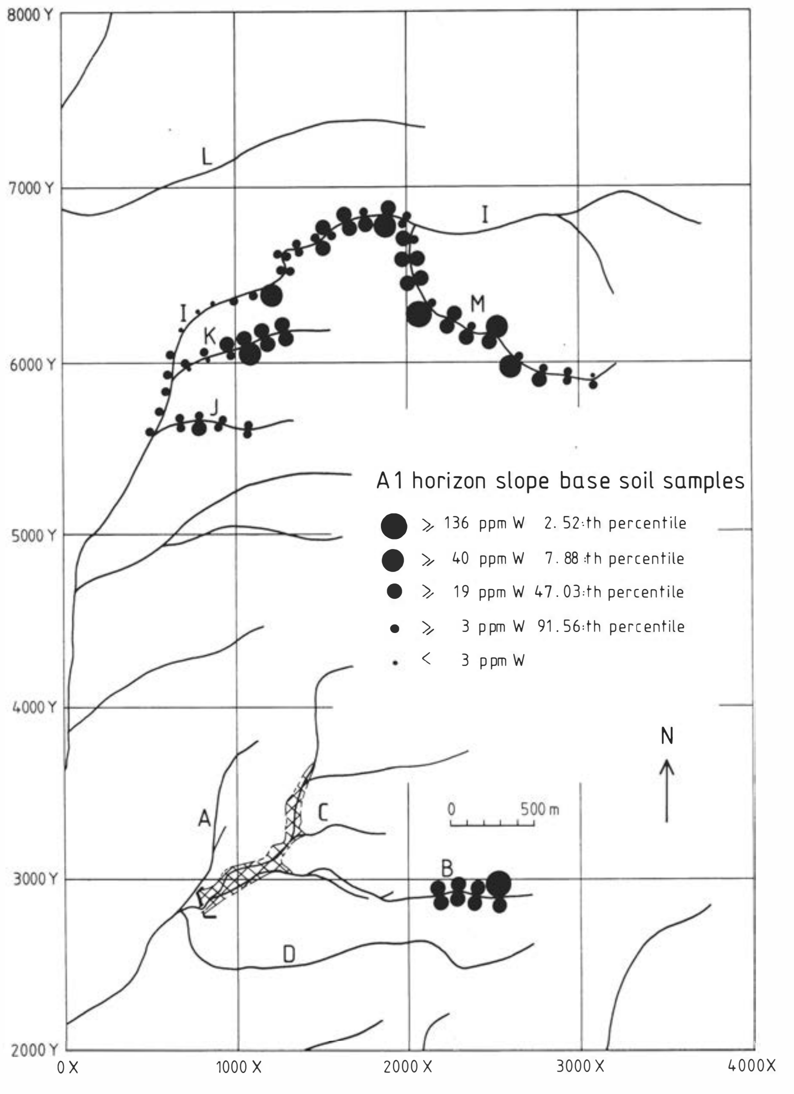


Fig. 20. Distribution of W contents in 79 A1 horizon slope base soil samples.

(Fig. 21). Values of the 1st background population are located either within the granite intrusion area or in its contact zones. Values of the 2nd and 3rd background populations are distributed extensively over the whole sampling area.

B horizon slope base soil samples. – The distributions of the 1st and 2nd anomalous populations of B horizon (Fig. 22) coincide with those of the A2 horizon. Values of the 1st background population are limited to the granite intrusion area and its contact zones. The 2nd background values are spread over the whole area and the 3rd background values are situated in areas underlain by schist, slate and gneiss.

C horizon slope base soil samples. – The distributions of anomalous values of the 1st and 2nd populations of the C horizon are located within the triangular area of the potential mineralization at sampling points 141, 108 and 112 respectively (Fig. 23). The most pronounced distribution of the 1st background population is shown and it apparently indicates possible mineralized zones in the areas underlain by the granite intrusion and its contact zones. The 2nd and 3rd background populations are

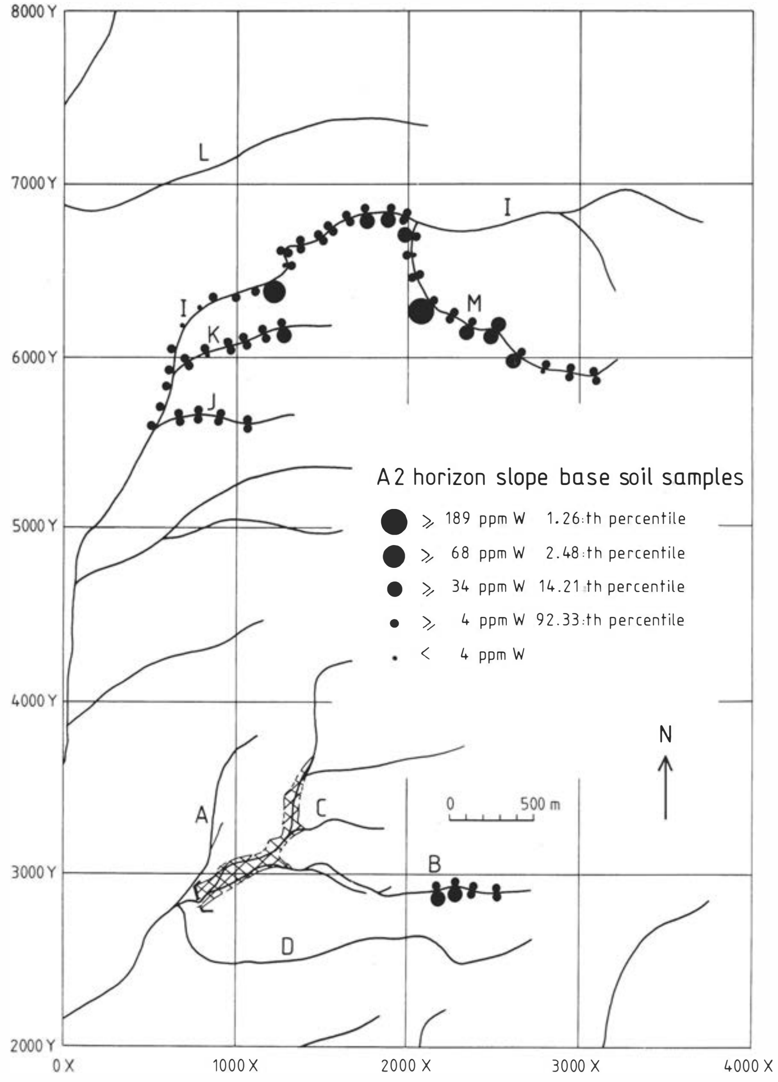


Fig. 21. Distribution of W contents in 79 A2 horizon slope base soil samples.

located mostly within the areas underlain by the barren gneiss, schist and slate bedrock.

The possible occurrence of the mineralized zone in the triangular area bounded by streams I, K and M is enhanced by all horizons of the slope base soil samples. However, the W contents at sampling point 112 of the A2 and B horizon dropped down to the 2nd anomalous populations. The potentiality of the occurrence of the minor mineralization around stream B which was discovered by the basal stream sediment samples was supported merely by the value of the 1st anomalous population of the A1 horizon on the northern slope of sampling point 27. In addition, some other areas of the 2nd anomalous population that could not be detected by the A2, B and C horizon samples, could be detected by the A1 horizon samples.

Since C horizon has the least effects of weathering and erosion, it can be expected to approach the initial element distributions in bedrock by studying element distributions in this horizon. Therefore, if there is any mineralization in the bedrock, the anomalous element distribution in C horizon will always occur. Thus far, it makes the results obtained from C horizon samples to be fairly reliable.

The results obtained from A1, B and C horizon

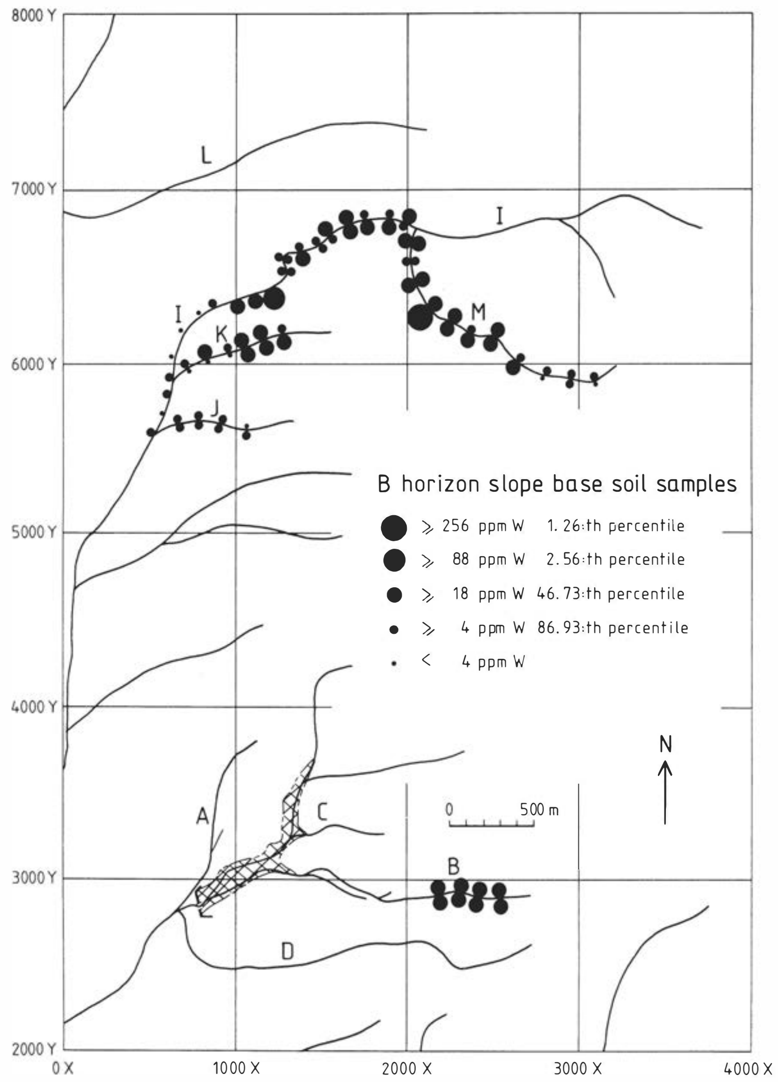


Fig. 22. Distribution of W contents in 79 B horizon slope base soil samples.

slope base soil samples are significantly similar. Together they indicate the potential mineralizations in connection with granite intrusion in the investigated area. Considering the more simple and rapid sampling method for the A1 horizon samples, it will be more advantageous to use this horizon samples for slope base soil survey.

A1 horizon detailed soil samples. – The distributions of the values of the 1st anomalous population (see Table 11) can be divided into two topographical areas. The first is correlated with a potential mineralized zone associated with outcrops and possible suboutcrops of the quartz veins at sampling points 360, 384, 410 and 435 (Fig. 24). The second is situated on the terraces, beside the major stream flowing from the mining area, at sampling points 73, 326, 353, 431, 432, 459, 512 and 564. This latter anomalous group does not pinpoint any mineral deposits but rather reflects the occurrence of the mineralization upstream.

The extents of the potential mineralized zone and stream terraces can be estimated roughly within the area governed by the 2nd anomalous population. Most of values from the 1st background population are distributed within the area of the granite intrusion and along the major stream flowing from the

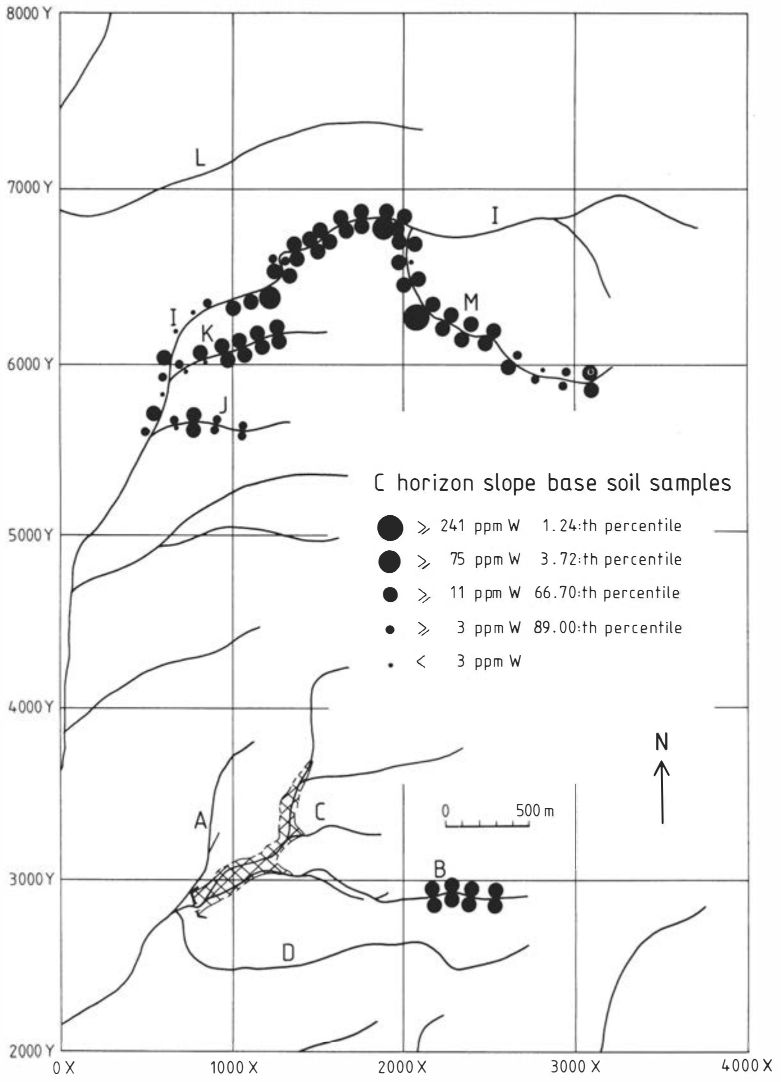


Fig. 23. Distribution of W contents in 79 C horizon slope base soil samples.

mine. The 2nd and 3rd populations are located in the area underlain by schist bedrock.

B horizon detailed soil samples. – In areas related to quartz veins, the distributions of the 1st anomalous population (Fig. 25) coincide perfectly with those of the A1 horizon (Fig. 24). However, an additional anomalous value is revealed at the sampling point 289 near the stream channel. This could be the effect of soil creep that transfers W in the A1 horizon from its origin, down to the stream channel. Compared with the A1 horizon samples, fewer of the 1st anomalous values in B horizon samples occur on terraces.

To a lesser extent than those of A1 horizon, the 2nd anomalous values are limited to the potential mineralized area and the terraces.

The extents of the 1st and 2nd background populations coincide to some extent, with those of the A1 horizon. The 3rd background values definitely indicate barren schist bedrock.

The areas of the 1st anomalous populations, related to the outcrops of quartz veins, of A1 and B horizon samples coincide very well with each other. More regular and greater dispersion of the 2nd anomalous population, however, is found in the samples of the A1 horizon. This can be the effects

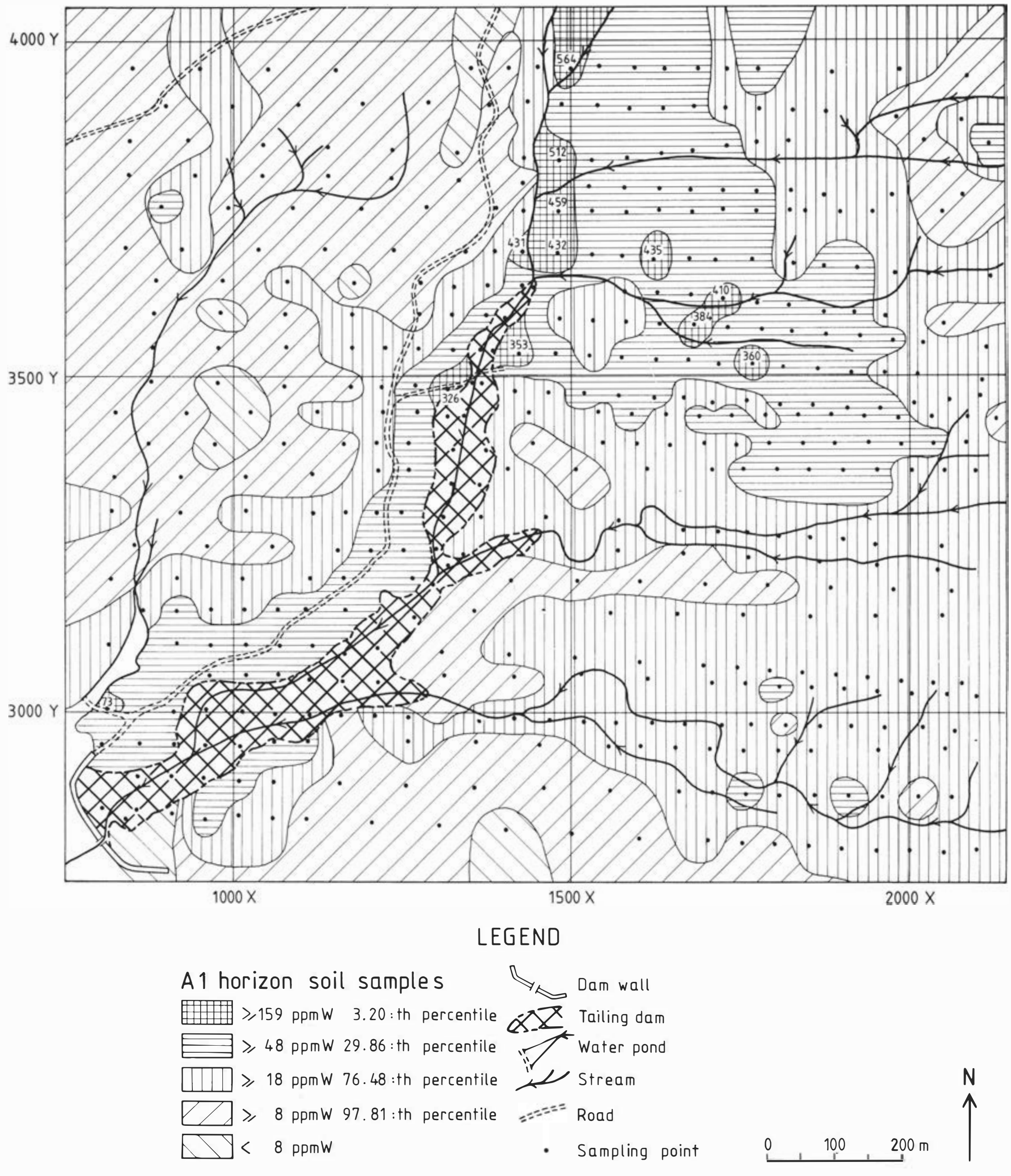


Fig. 24. Distribution of W contents in 415 A1 horizon detailed soil samples.

of reworking of elements in A1 horizon by weathering and erosion processes, by which the elements are dispersed laterally along the surface.

As the same result can be obtained by both A1 and B horizon detailed soil samples, it will be more profitable to use A1 horizon samples for detailed soil survey, owing to the greater simplicity and rapidity of taking A1 horizon samples.

Considering the two types of soil samples in this investigation, i.e. slope base soil and detailed soil

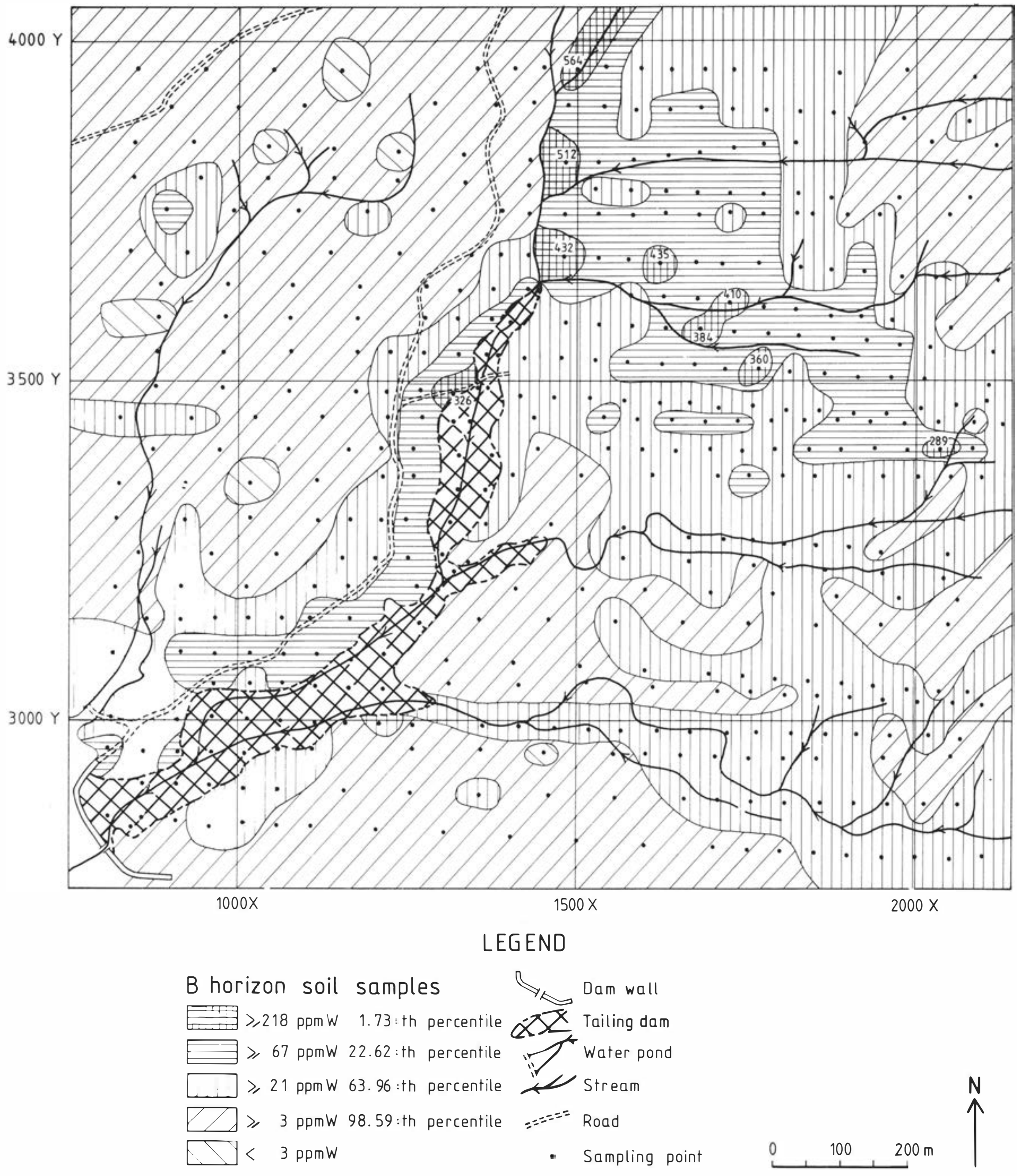


Fig. 25. Distribution of W contents in 415 B horizon detailed soil samples.

samples, the A1 horizon samples are preferable to the samples from the underlying horizons. Thus far, the A1 horizon samples prove to be the most profitable for geochemical soil survey, especially in tropical terrain.

Aerial distributions of multivariate data. – Top stream sediment samples. – The potential mineralized zone in the triangular area bounded by the streams I, K and M was recognized by the solid circles of the 1st group (factor scores >2) and the

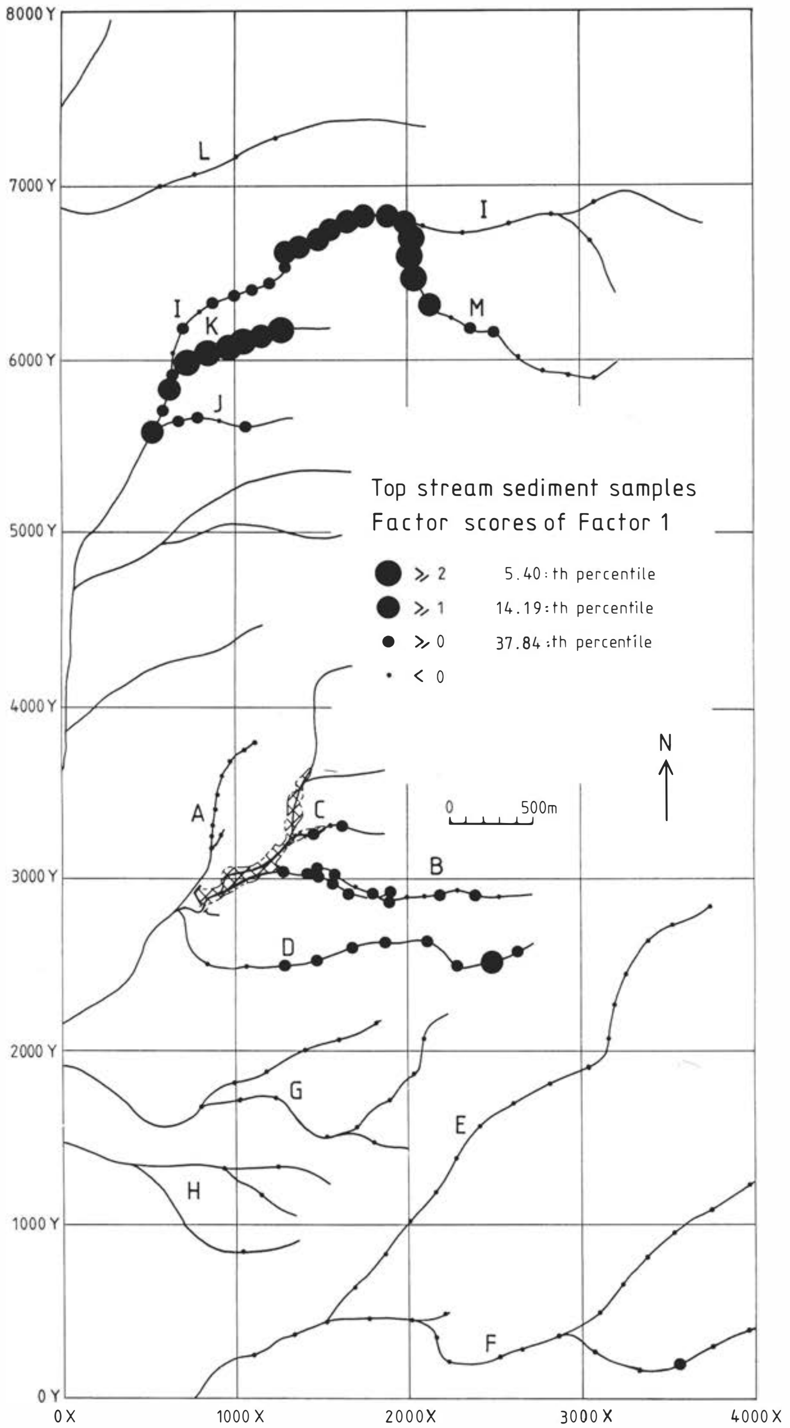


Fig. 26. Distribution of factor scores in Factor 1 of 148 top stream sediment samples.

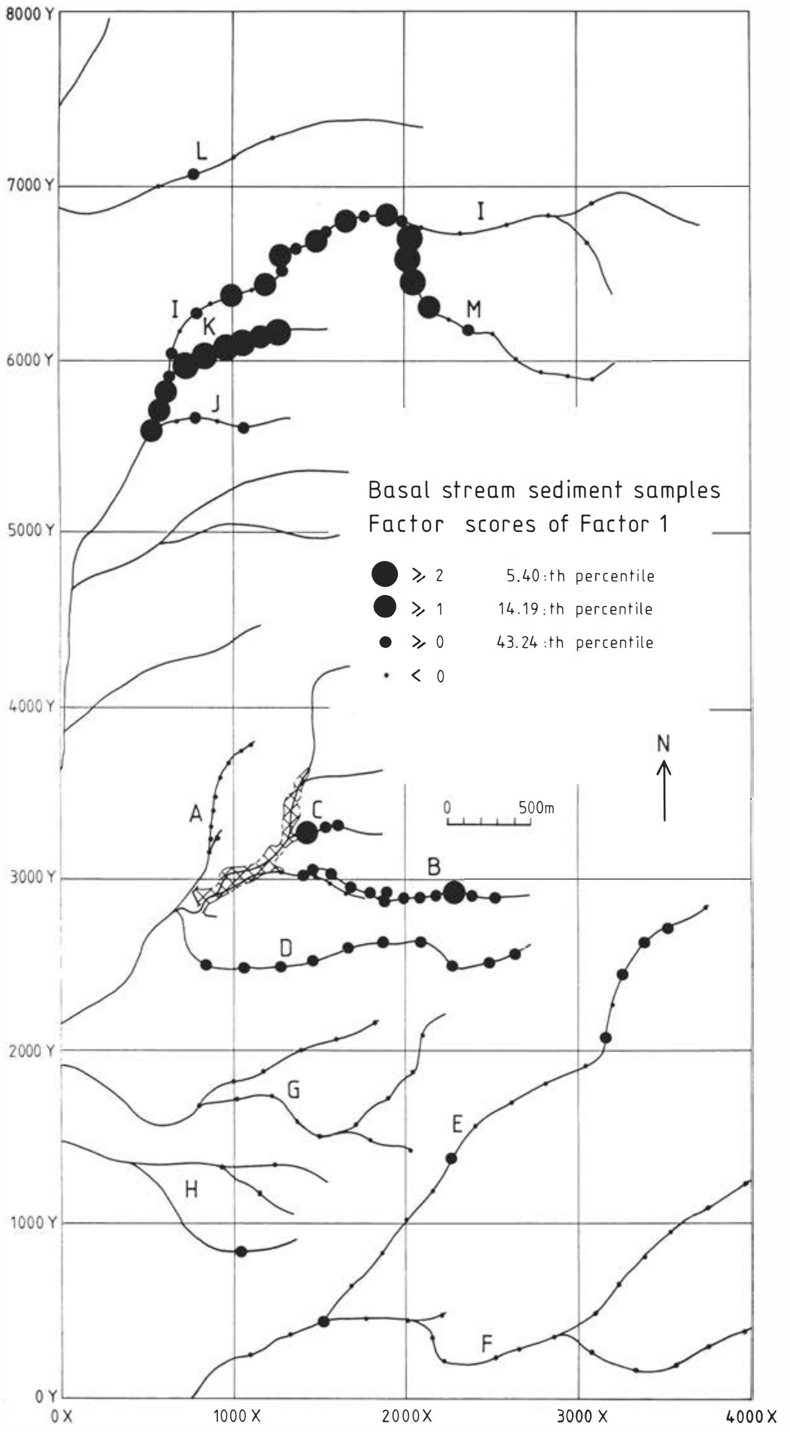


Fig. 27. Distribution of factor scores in Factor 1 of 148 basal stream sediment samples.

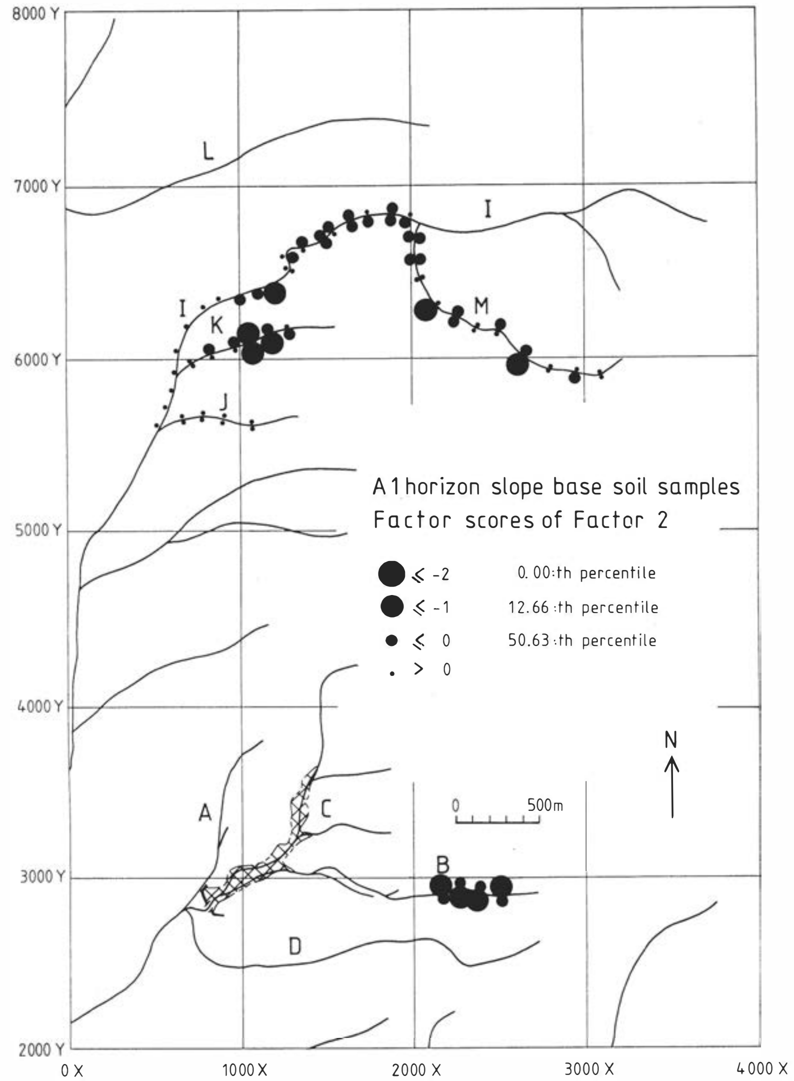


Fig. 28. Distribution of factor scores in Factor 2 of 79 A1 horizon slope base soil samples.

2nd group (factor scores 1−2) in Fig. 26. Dispersions of the values above the threshold of factor scores 2 in streams M and K were limited to the junction with stream I, to which the barren stream sediment was added to augment the mixture of the total stream sediment. The dispersions of the values of the 2nd group extended 700 m from the junction of streams M and I, and 350 m from the junction of streams K and I. A single insignificant value of this group occurs also at the sampling point 39 of stream D. The values of the 3rd group (factor scores 0−1) were generally located within the area underlain by barren granite bedrock or its contact zone. The values of the 4th group (factor scores <0) were distributed in the areas underlain by the schist, slate and gneiss bedrock.

Basal stream sediment samples. − The dispersions of the values of the 1st group in basal stream sediment samples (Fig. 27) were identical with those of the top stream sediment samples (Fig. 26). The values of the 2nd group were sporadically dispersed 1200 m from the junction of streams M and I, but were more regularly dispersed 350 m from the junction of streams K and I. They were also found at the sampling point 25 of stream B and at the sampling point 28 of stream C. The distributions

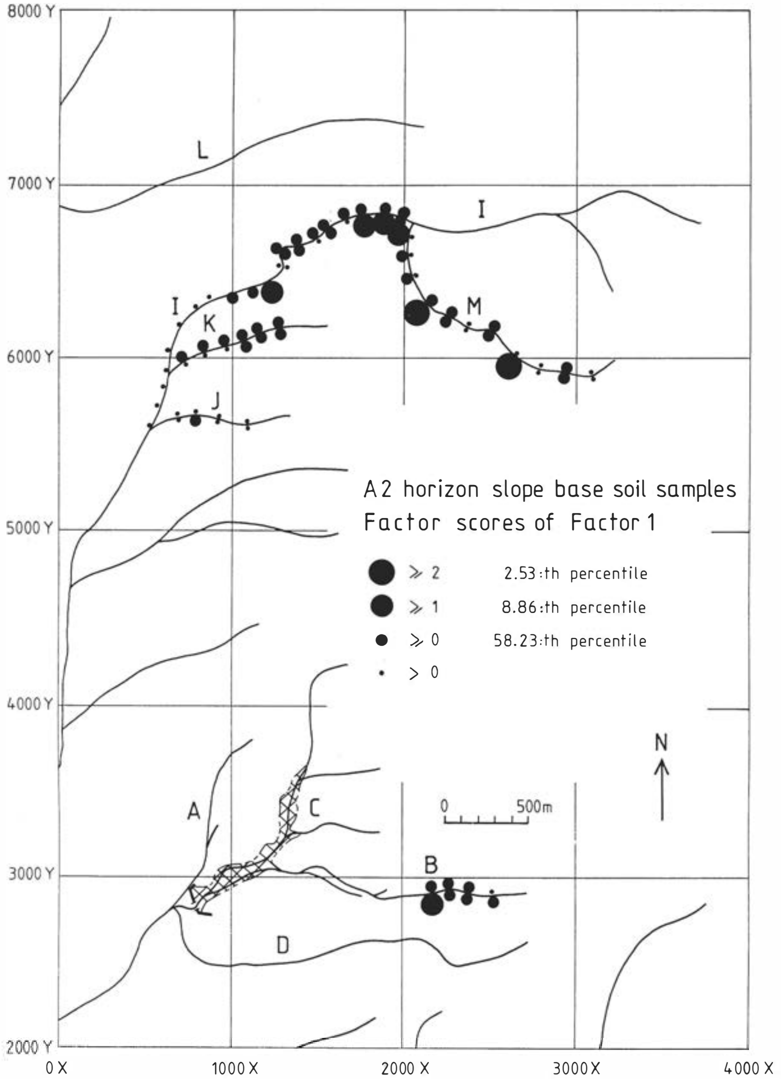


Fig. 29. Distribution of factor scores in Factor 1 of 79 A2 horizon slope base soil samples.

of the values of the 3rd group were generally limited to the area of granite intrusion and its contact zone. The values of the 4th group were situated in the area underlain by the schist, slate and gneiss bedrock.

The dispersions of the values of the 1st group of the top and basal stream sediment samples are identical. The dispersions of the values of the 2nd group of the basal stream sediment samples, even though more irregular, are of greater extent than those of the top stream sediment samples. Moreover, the values of the 2nd group at the sampling point 25 of stream B and at the sampling point 28 of stream C are missing in the top stream sediment samples. Hence, this proves that better results can be achieved by employing the basal stream sediment samples for regional stream sediment survey.

Comparing two different statistical methods, i.e. the univariate and multivariate methods, the dispersions of the values of the 1st and 2nd anomalous populations, obtained from probability graphs correspond very well with the 1st and 2nd groups, obtained from factor analysis. Thus, either method may be employed successfully for the interpretation of any chemically analytical data. Moreover, both statistical methods have proved that, for stream

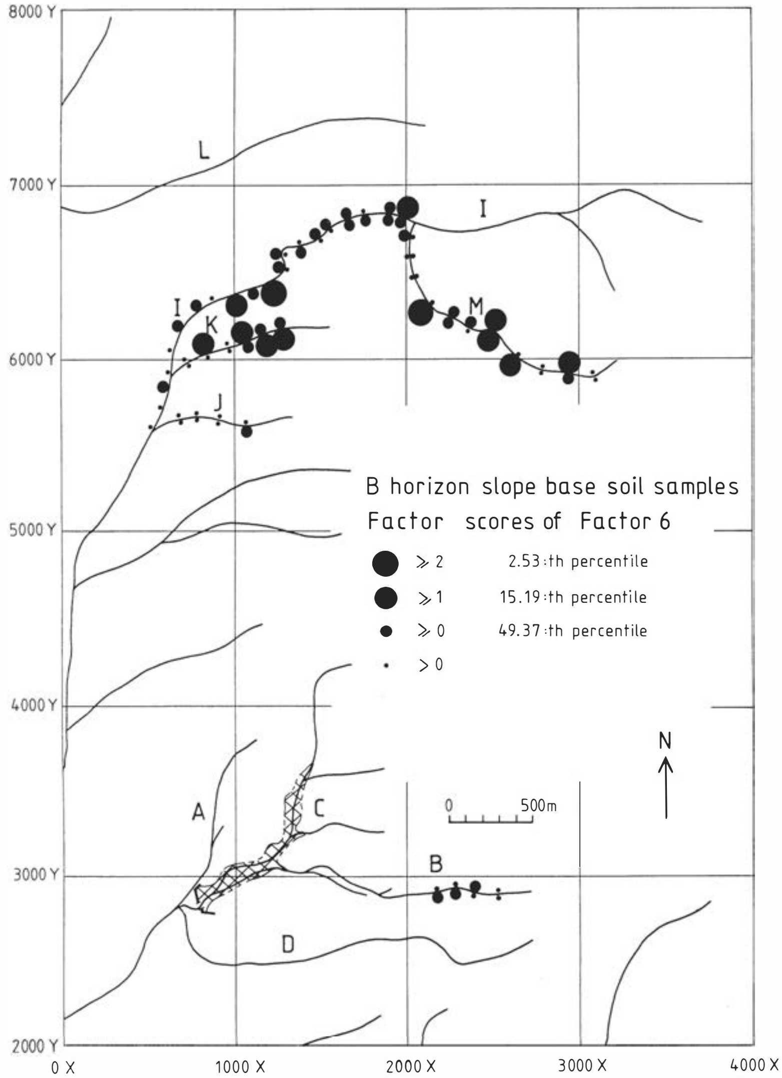


Fig. 30. Distribution of factor scores in Factor 6 of 79 B horizon slope base soil samples.

sediment survey, using the basal stream sediment is more profitable than using the top stream sediment samples.

A1 horizon slope base soil samples. – Unexpectedly, there is no value of the 1st group (factor score <−2) distributed in the investigated area (Fig. 28). The potential mineralization in the triangle bounded by streams I, K and M is indicated by the values of the 2nd group (factor scores −1 to −2) at the sampling points 104, 129, 108 and 141. The potential minor mineralization around stream B is revealed also by the values of this group at the sampling points 24–27. The single value of the 2nd group at the sampling point 145 of stream M may indicate another minor mineralization. The values of the 3rd group (factor scores −1 to 0) are limited to the extension of the granite intrusion and its contact zones. The values of the 4th group (factor scores >0) are dispersed wholly over the northern part of the area.

A2 horizon slope base soil samples. – The potential mineralization is evidently recognized by the values of the 1st group (factor scores >2) at sampling point 141 and of the 2nd group (factor score 1–2) at sampling points 108, 136, 112 and 138 (Fig. 29). Values of the 1st group, located at the sam-

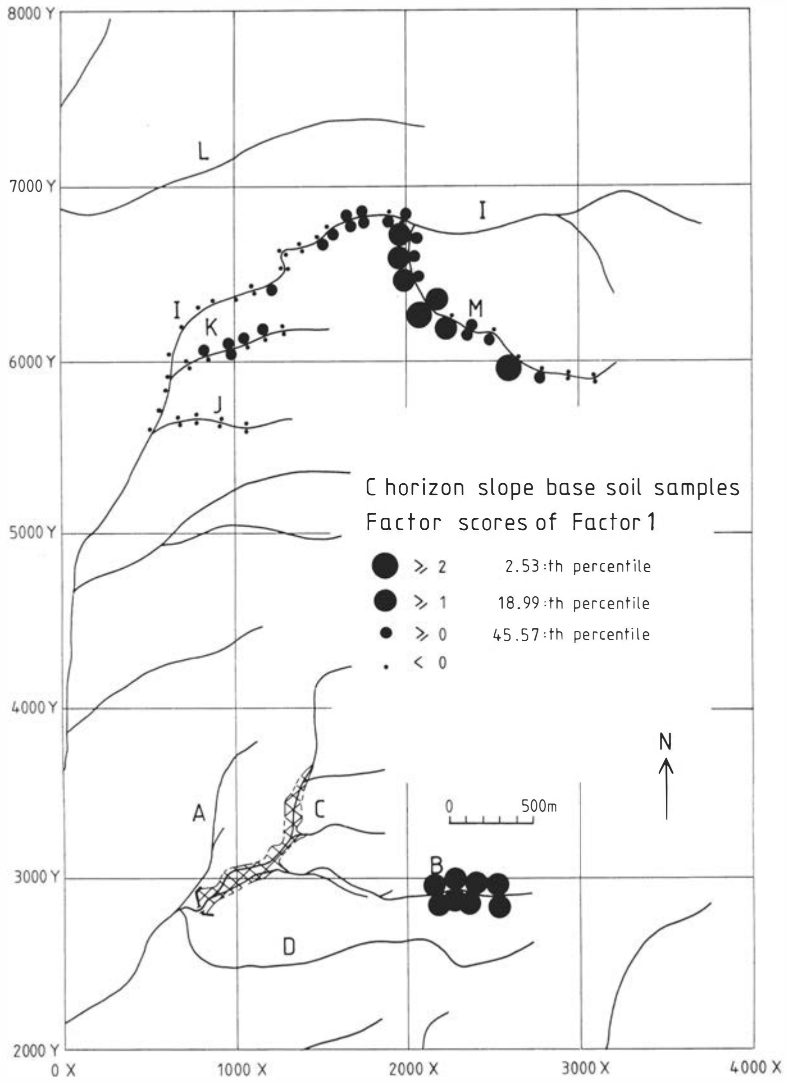


Fig. 31. Distribution of factor scores in Factor 1 of 79 C horizon slope base soil samples.

pling point 145 and of the 2nd group, located at the sampling point 24 may indicate the possible minor mineralizations. The values of the 3rd group (factor scores 0–1) are limited to the extension of the granite intrusion and its contact zones. The values of the 4th group (factor scores <0) are spread over the whole area.

B horizon slope base soil samples. – The potential mineralization is indicated distinctly by the values of the 1st group (factor scores >2) at sampling points 108 and 141, and values of the 2nd group (factor scores 1–2) at sampling points 103, 104, 129, 105, 107 and 137 (Fig. 30). The potential minor mineralization around sampling point 145 may be located by the values of the 2nd group at sampling points 144, 145 and 147. The values of the 3rd group (factor scores 0–1) are limited to the extension of the granite intrusion and its contact zones. The values of the 4th group (factor scores <0) are dispersed over the whole area.

C horizon slope base soil samples. – Apparently, the potential mineralization bounded by streams I, K and M, is indicated merely by a value of the 1st group at sampling point 141 and values of the 2nd group at sampling points 138 to 142 (Fig. 31). The potential minor mineralization around sampling

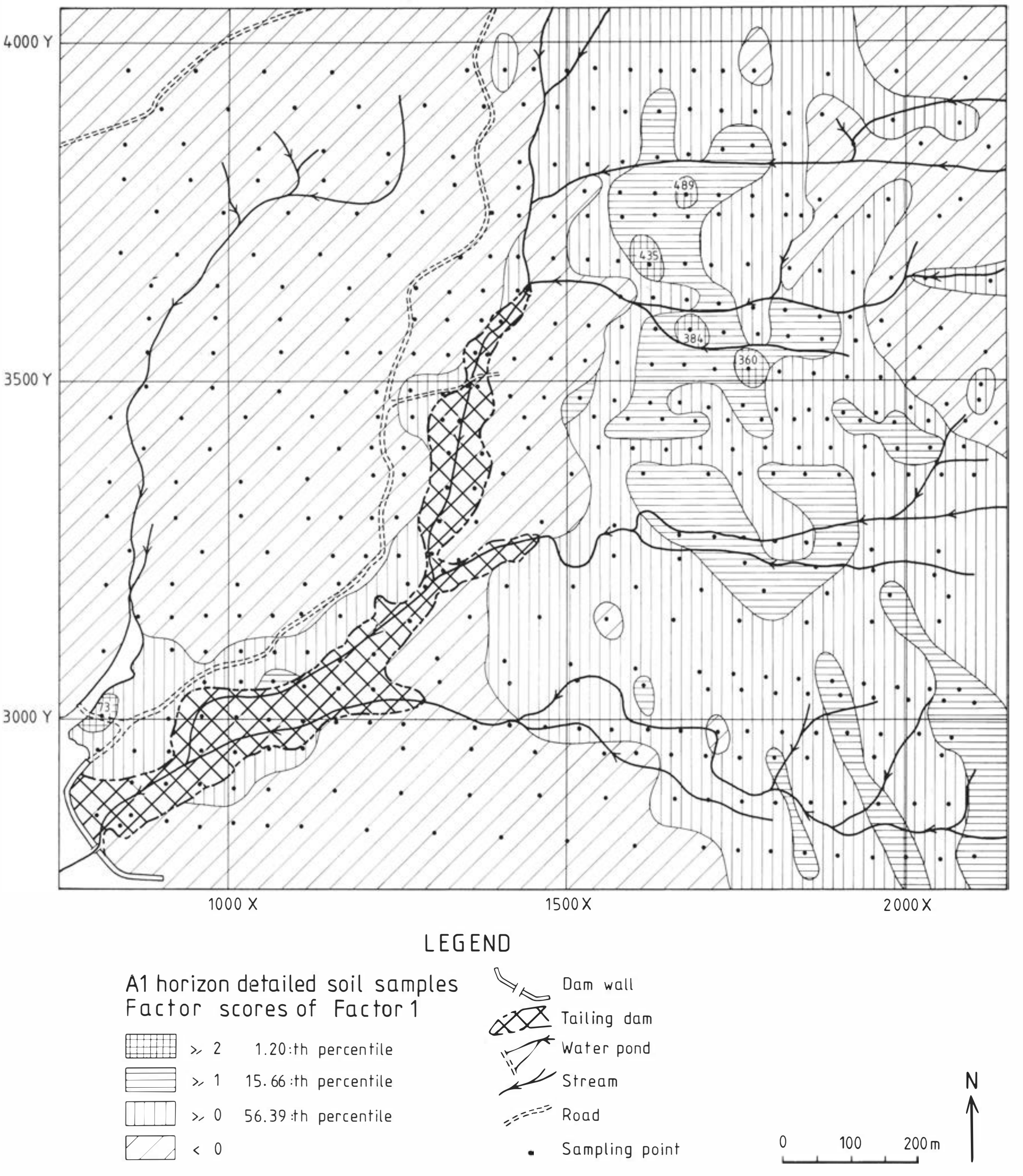


Fig. 32. Distribution of factor scores in Factor 1 of 415 A1 horizon detailed soil samples.

point 145 is recognized by a value of the 1st group. Another potential minor mineralization around stream B is clearly indicated by values of the 2nd group, at sampling points 24 to 27. Very few values of the 3rd group are distributed in the granite intrusion area and its contact zones. The values of the 4th group are spread over most of the northern part of the area.

The potential mineralized zone in the triangular area, bounded by the streams I, K and M is, more

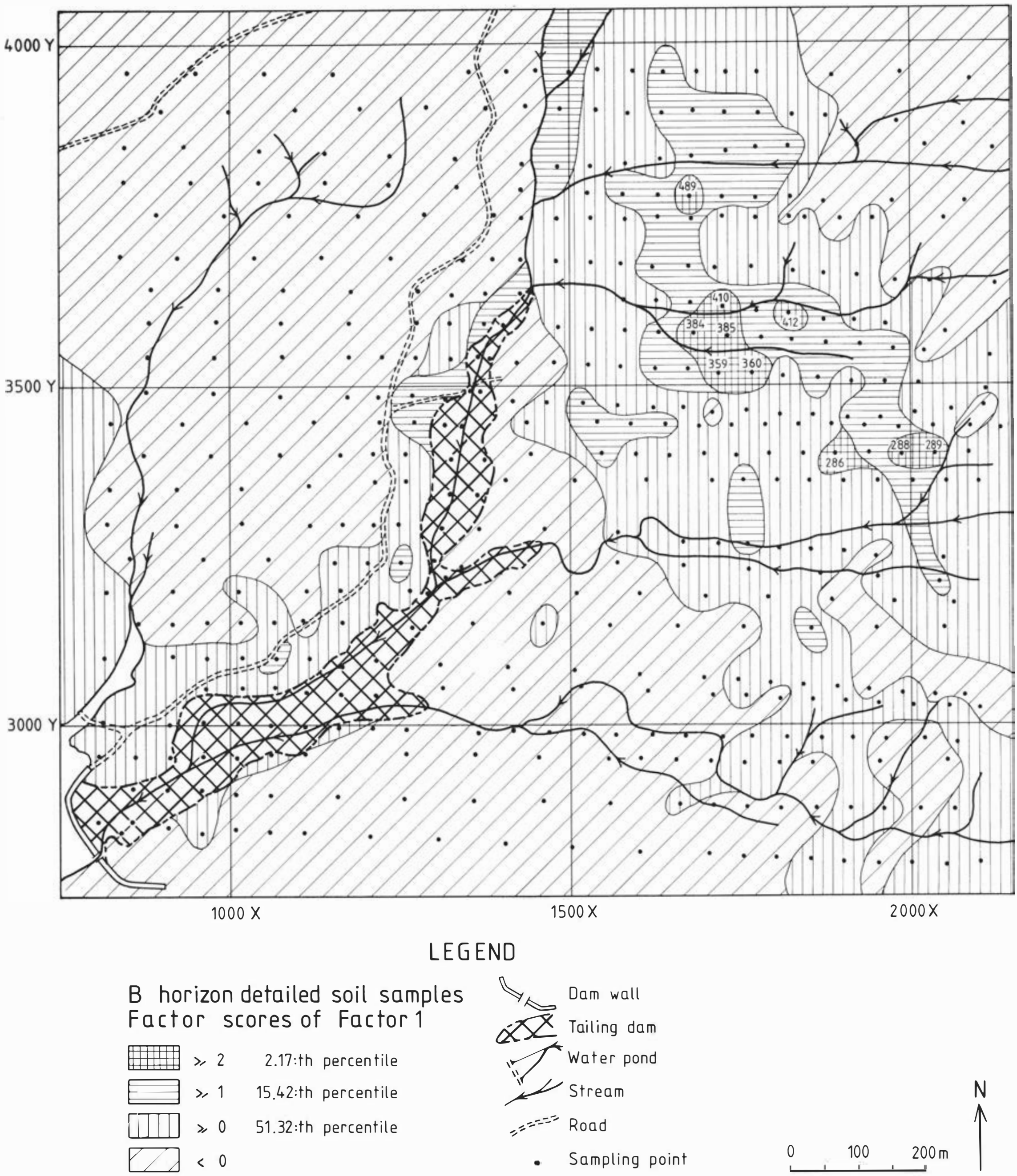


Fig. 33. Distribution of factor scores in Factor 1 of 415 B horizon detailed soil samples.

or less, indicated correspondingly in the samples of A1, A2, B and C horizons. One of the minor potential mineralizations around sampling point 145 was coincidentally discovered by samples of all four horizons. Another potential minor mineralization around stream B is recognized best by the samples of C horizon and fairly well by the samples of A1 horizon, but poorly by the samples of A2 and B horizons.

Comparing the two different statistical methods, i.e. the univariate and multivariate methods for the treatment of slope base soil samples data, the more regular distributions of the data are achieved by the univariate method, though the results obtained by both methods are fairly similar. This can be caused by the fact that only the W content is taken into account in the univariate method, while total 11 element contents are taken into account in the multivariate method.

Note that the possible minor mineralization around sampling point 145 of stream M is indicated very well by all soil horizons if the data are treated by the multivariate method but it is indicated apparently only by A1 horizon if the data are treated by the univariate method.

A1 horizon detailed soil samples – The distributions of values of the 1st group (factor scores >2) are limited rather well to the extension of outcrops and suboutcrops of quartz veins at sampling points 360, 384, 435 and 489 (Fig. 32). Another value of this group, located at sampling point 73 may be affected by the elements transported by the stream from the mining area. The distributions of the values of the 2nd group (factor scores 1–2) clearly indicate the north–south trends of the quartz veins in the area investigated. The distributions of the 3rd group (factor scores 0–1) are delineated within the extension of the granite intrusion and the terraces on both sides of the major stream, flowing from the mine. The extent of schist bedrock is indicated by the distributions of values of the 4th group (factor scores < 0).

B horizon detailed soil samples. – The more extensive and greater distributions of the values of the 1st group are found in the area underlain by quartz veins in Fig. 33. The extension of quartz veins and some terraces beside the major stream is possibly indicated by the areas governed by the values of the 2nd group. The distributions of values of the 3rd group are located in the areas underlain by the granite bedrock and on the terraces. The extent of schist bedrock is delineated by the distribution of values of the 4th group.

The indications of the potential mineralizations, relating to the quartz veins, of the A1 and B horizon samples correspond fairly well with one another. However, some more values of the 1st group are found in the B horizon samples. The boundary between granite and schist bedrock can be approximated by the contact between the areas of the 3rd and the 4th group of both A1 and B horizon samples.

Comparing two different statistical methods for treating the detailed soil samples data, the distributions of the 1st and 2nd group of the multivariate data seem to be limited exclusively within the extension of the quartz veins and have greater extents than those of the 1st and 2nd anomalous populations of the univariate data. Further, some values of the 1st and 2nd anomalous populations of the univariate data are located on the terraces beside the major stream. This shows the effects of natural transportation and deposition of minerals along the stream patterns. These values might be the indication for searching placer deposit of the minerals.

It was found that the statistical results obtained by the univariate and multivariate methods are more or less identical in all corresponding media, even though only W content is taken into account for the univariate method and a total of 11 element contents are taken into account for the multivariate method. Therefore, the choice of the statistical method seems to be less important than the choice of sampling media to be employed in geochemical prospecting.

Eventually conclusions can be drawn here that for stream sediment survey, it will be more profitable if the basal stream sediment samples are employed so that the chance of missing any anomaly is smaller than by the use of top stream sediment samples. For soil survey, even though the statistical results obtained from all horizons are more or less identical, it will be more advantageous to use A1 horizon samples, owing to the greater simplicity and rapidity of sampling.

Evaluation of the ore reserve in the tailing dam

An effort has been made to evaluate the possible ore reserve in the tailing dam with the expectation that the ineffective method of manual ore concentration used previously, may have left an economic amount of ore deposited in the dam. The average weights and W contents in different grain sizes of 10 samples, 6 from site 12 and 4 from site 17, were

Table 30. Average weight percentages and tungsten contents in different grain-size fractions of 10 tailing material samples, 6 from sampling site 12, and 4 from sampling site 17, and expected contents of each fraction in total mass of material in the tailing dam.

Fraction mm	Average Weight (%)	Average W content (%)	Expected W content (%)
< 0.075	13.53	0.6000	0.7076
0.075 – 0.175	10.53	0.2983	0.2992
0.175 – 1.0	51.52	0.1608	0.1713
1.0 – 2.0	14.08	0.3436	0.3686
> 2.0	10.34	0.2196	0.2417
Total	100.00	0.3066	0.3457

Table 31. Calculated proportions, in per cent and possible tons of total available tungsten, in the tailing dam.

Fraction mm	Proportions of total tungsten %	tons
< 0.075	32.73	409
0.075 – 0.175	10.77	134
0.175 – 1.0	30.19	377
1.0 – 2.0	17.75	222
> 2.0	8.55	107
Total	99.99	1249

calculated and listed in Table 30. The locations of the sampling sites can be seen in Fig. 5.

The relations of W contents in the <0.075 mm fraction and coarser fractions, including original samples, were calculated by drawing regression lines through plotted points in scattergrams. Thus the W contents of the <0.075 mm fraction, determined by XRF were used to calibrate the expected contents in 0.075–0.175 mm, 0.175–1.0 mm, 1.0–2.0 mm, >2.0 mm fractions, and original samples. The expected contents in each fraction from a total of 91 samples of tailing materials were averaged and listed in column 4 of Table 30.

The expected concentration of 3457 ppm W (0.35 % W) in total tailing samples was achieved. However, the concentration in the <0.075 mm fraction is at least twice as high as in the other fractions. Based on the weight percentages in each fraction, the proportions of available W contents in different fractions can be obtained as shown in column 2 of Table 31.

Based on information from the drill holes, the amount of wet tailing material in the tailing dam was calculated to be approximately 360000 tons. Hence, at the optimum, 1300 tons of W (corresponding to 1600 tons WO_3) can be available in this dam. Of this total, W in the <0.075 mm fraction comprises one third of the total. The possible proportions of the total available tungsten in each fraction are listed in column 3 of Table 31.

Conclusions

Once the tungsten minerals are supplied to the total mixture of the stream sediments in the drainage patterns the mechanisms of the stream flow will sort the sediments so that minerals maintain their concentrations sufficiently high to be detected at distances far from their sources. The sorting effects were found to be better in the basal coarse layer than in the upper sandy layer. Therefore, the dispersions of the anomalies revealed by the basal stream sediment samples are greater than those revealed by the top stream sediment samples. In addition, a potential minor mineralization was detected fairly well by the basal stream sediment samples but failed to be detected by the top stream sediment samples.

In regional stream sediment survey, a great area is always subjected to investigation. The appropriate sampling density must be chosen so that none of the anomalies derived from any economic mineralizations fails to be detected. Thus the basal stream sediment samples would be preferable to the top stream sediment samples.

The potential mineralizations indicated by the stream sediment samples may occur on either side of the slopes above the stream channels. Hence soil samples on the base of slopes can be of great advantage to delineate the approximate extension of the mineralizations, as an intermediate step before the detailed survey. In this investigation, soil samples of A1, A2, B and C horizons on the base of slopes were studied. Expectedly, the most satisfactory results were obtained from the C horizon samples. However, the results from the overlying horizons were more or less identical to those from C horizon. Because of the greater rapidity and simplicity of the sampling methods for the A1 horizon samples, these would be preferable to samples from other horizons for follow-up survey to proceed to the regional stream survey.

For detailed survey, several types of sampled materials are employed. Soil samples are quite widely used, due to simplicity of taking and reliability of results. In this study, samples of A1 and B horizons were investigated. The potential mineralizations, related to quartz veins and mineral accumulations on the terraces were very well located by both A1 and B horizon samples. If this is so, the greater rapidity and simplicity of the sampling methods for A1 horizon samples would have made the A1 horizon samples preferable to the B horizon samples for the detailed soil survey.

Thus far, the A1 horizon is demonstrated to be the most advantageous for soil survey both in the intermediate step for the proceeding stream sediment survey and in the final step for detailed survey before physical surveys, eg. pitting, trenching and diamond drilling.

The chemical analysis by X-ray fluorescence spectrometry was also investigated. It was demonstrated that from the same piece of scheelite ore, the finer the ore was milled, the higher the estimated concentration was detected. It was found that in soil samples of A1 horizon, the highest estimated W content was obtained from the <0.03 mm fraction.

The role of statistical analysis in geochemical exploration is to distinguish the data related to mineralizations from the data related to barren rocks. Both single element (univariate) and multielement (multivariate) data can be used for this purpose. In this context, the results obtained from both univariate (probability graphs) and multivariate (factor analysis) methods coincide very well with each other. However, slight differences were found in the results of the detailed soil samples. Namely, by the univariate method, the distributions of the elements on the terraces above the major stream were placed in the 1st anomalous population and is referred to as the first priority of interest. Nevertheless, by the multivariate method, they were placed in the 2nd group of factor scores and are referred to as the 2nd priority of interest. In other words, the multivariate method gives 1st priority to the area in the vicinity of the quartz veins as the only area related to the potential mineralizations.

Unfortunately, the existence of potential mineralizations in the investigated areas was not confirmed by diamond drilling as was planned because the ownership of the company was changed shortly after finishing the sampling project.

The tailing dam, when built, was designed to protect the tailing materials from extension over the rice fields in the local villages. Because of improper methods of ore concentrations, a large amount of scheelite ore was discarded from the mining area and later accumulated in the tailing dam. The relatively low concentration of the scheelite ore in the dam and the low efficiency of the concentration methods at that time made the ore deposit in the dam to be of less economic value.

With time, methods for the concentration of ore were developed, the 0.35 % W content of the tailing material is accepted as being high enough to be profitable if the material were fed into a modern concentration plant. A concentration plant, of a capacity of 100000 tons/year is now under construction. It was hoped that the material from the dam would be sufficient to supply the plant for three years. This is one example of a tailing dam that can turn out to be of economic value again.

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