A STUDY OF A LATE DEVONONIAN-CARBONIFEROUS, PORPHYRITIC MICROGRANITE-HOSTED, HYDROTHERMAL BRECCIA PIPE IN THE MOUNT PLEASANT CALDERA COMPLEX, NEW BRUNSWICK, CANADA

Submitted by

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ABSTRACT

The South Oromocto Lake (SOL) breccia zone is located approximately 5.3km NE of Mount Pleasant in the Mount Pleasant caldera complex, south-western New Brunswick, Canada. Late stage hydrothermal activity during cooling of the McDougall Brook Porphyritic Microgranite (PMG) has resulted in the hydrothermal brecciation of the surrounding PMG, and formation of a breccia pipe. The SOL breccia body, due to its dyke-like shape, 350-450m long and 10-15m wide in outcrop, is presumed to have formed along a fracture in the PMG. Preceding the period of most intense brecciation, there was injection of a small chloritic aplite dyke and several other small aplitic breccia dykes. There appears to have been at least two main periods of brecciation which resulted in precipitation of numerous veins of various compositions.

Hydrothermal activity has also resulted in, sometimes intense, alteration of the host PMG and formation of chloritized, sericitized, silicified, and hematized alteration zones. Although there is no economic concentrations of Sn, W, Cu, Zn, Mo, Ag, or Au, this study reveals higher concentrations of the above elements in the surrounding alteration zones than in the actual brecciated zone.

A chemical survey of secondary chlorite has distinguished at least three different populations, possibly reflecting hydrothermal fluid composition changes. An overall depletion of iron and magnesium in the bulk composition of the PMG unit with increasing intensity of alteration, and a dramatic increase in modal percentage of chlorite, has been found. This problem was not resolved, however, it is proposed that abundant disseminated carbonate in the relatively fresh PMG, which is leached out during alteration, is dolomitic in composition and has been the source of iron and magnesium in the secondary chlorite.

Clearly more work is needed to answer all the questions and resolve all of the problems of the SOL breccia zone.

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Chapter 1. Introduction

1.1 General Statement

Volcanic activity in volcano-plutonic arc settings very commonly leads to late-stage hydrothermal activity resulting in formation of hydrothermal breccia pipes. A number of pipes in volcano-plutonic arcs contain breccias with associated ores, however, a great number of apparently similar breccias lack even sub-economic concentrations of mineralization (Gates, 1959; Morris and Kopf, 1967; Bussell and McCourt, 1977). A similar situation prevails in the Mount Pleasant caldera complex, part of the Piskahegan Group in New Brunswick, Canada. Mineralized breccia pipes are found at Mount Pleasant in both the Fire Tower and North zones, but an unmineralized breccia pipe, the one presented in this study, also exists, located approximately 5.3 km NE of Mount Pleasant.

1.2 Geography/Location

The Mount Pleasant caldera complex is located in Charlotte County, New Brunswick approximately 60 km south of Fredericton and 35 km north of St. George. It occupies a large part of the area between lat 45°24' and 45°36' and long 66°33' and 66°53' (see figure 1). The exact locations of the caldera margins are not known but McCutcheon (1983) proposed minimum dimensions of 34 X 13 km. Access to the caldera is by all-weather roads and

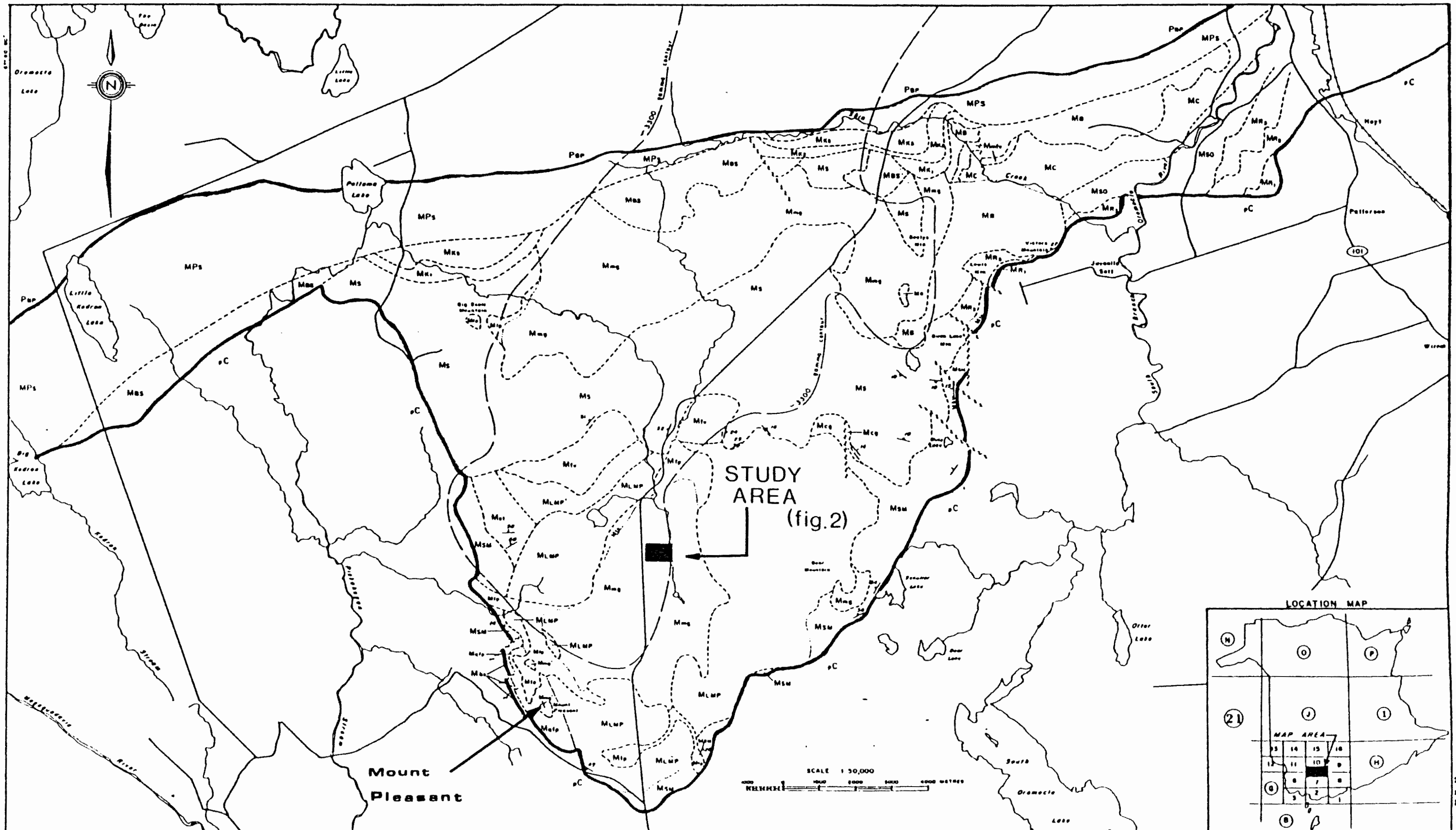


Figure 1 Geology of the Mount Pleasant Caldera

logging roads. The South Oromocto Lake (SOL) claim group and the SOL Breccia Zone are located approximately 5.3 km NE of Mount Pleasant at lat 45°28' and long 66°47' and can be reached from the main road between Blissville and Mount Pleasant (see figure 2). The area has been heavily glaciated, has low relief, and is covered with a mixed deciduous and coniferous forest. The breccia zone was first uncovered during logging road construction (Rankin,1980), and the best exposures are on the north side of the road.

1.3 Previous and current work

Tin was first discovered in the area in 1937 on Kedron Brook, approximately 9 km west of Mount Pleasant (Wright, 1940). Regional geochemical surveys for base metals resulted in the first claim being staked in 1954.

Since this time, the Mount Pleasant deposits have been extensively explored and have had many owners.In 1983, a joint venture between Sullivan Mining Group and Mount Pleasant Mines Ltd. brought the deposit into production. However, production ceased in July, 1985 (Kooiman et al.,1986).

The deposits and surrounding complex have been the target of much scientific research (Hosking, 1963; Ruitenberg, 1963; Petruk, 1964; Ruitenberg, 1967; Van de Poll, 1967;Dagger, 1972; Gemmel, 1975; Parrish, 1977; McCutcheon, 1982 and 1983; Kooiman et al., 1986; and many others). Work is currently being done by McCutcheon (in prep.) in an attempt to resolve some of the

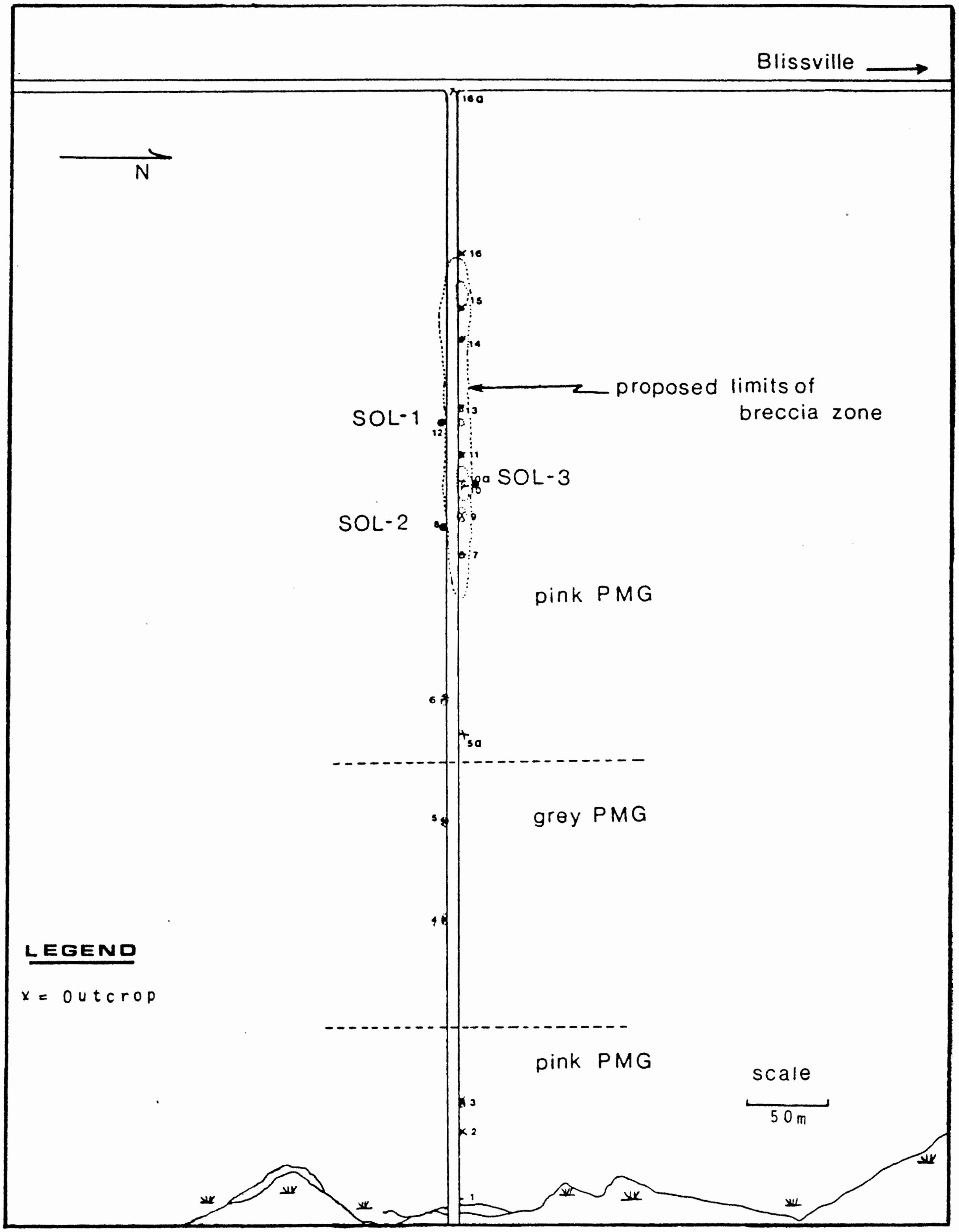


FIGURE 2 Breccia Zone Location Map

stratigraphic problems in the Shin Creek-Mount Pleasant area. The economic potential of this area necessitates the resolution of these problems to aid in future exploration (McCutcheon, 1982).

In December,1979, a newly bulldozed road roughly 4 miles NW of Deer Lake revealed float of intrusive breccia. The area was staked, and in May 1980 trenching uncovered a breccia pipe similar to the mineralized ones at Mount Pleasant (Rankin, 1980). In late October-early November,1982, Billiton Exploration Canada Limited commissioned Logan Drilling of Musquodoboit, Nova Scotia to drill into the SOL breccia zone. Three holes were completed totalling 533 metres of penetration. All cores are BQ diameter (about 3.7cm across) and the core is now stored at the core library at the Sussex branch of New Brunswick Department of Natural Resources, Geological Surveys Branch. Mineralized portions of the core were assayed for Mo, Sn, W, Cu, Zn, and Ag, but results were not encouraging. This core has been the main sample source for this project.

1.4 This Thesis

1.4.1 Thesis objectives and limitations

The fundamental purpose of this thesis is to provide a general study of the South Oromocto Lake breccia body. More specific objectives of the study are: 1) to determine a possible genetic history of the body, 2) to determine any possible relationships between alteration and mineralization and 3) to determine possible genetic similarities and differences with the Mount Pleasant ore bodies in order to understand the absence of economic mineralization in the SOL breccia body.

Time limitations on this thesis unfortunately did not allow detailed scientific investigation into all possible aspects of the study. One major limitation is the lack of a detailed fluid inclusion study, another is the lack of an extensive geochemical survey of each core. It is hoped that the data presented here will aid any future studies that may be undertaken.

1.4.2 Field Work

Field work for this project was conducted in early August, 1985 under the supervision of S.R. McCutcheon. One day was spent on a field survey of the various lithologic units and a brief visit to the Mount Pleasant Mine. Representative samples of the different lithologic units were also collected. A second day was spent in mapping and sampling the SOL breccia zone. A total of 25 field samples were taken. The field studies were supplemented with detailed logging of the three drill holes (SOL-1,-2, and -3) that penetrated the breccia body. Fifty-five samples were taken from the drill core. The drill core was again examined in December, 1986 to confirm the earlier observations and interpretations.

1.4.3 Sampling and Analytical Methods

Field samples are of a random grab-sample nature. Core sampling was done primarily to obtain representative unaltered samples of the various lithologies and of the various alteration zones. In addition, some samples were collected from unusual zones that required further study.

Thirty-one thin sections were prepared, twenty-eight polished and three normal. These were used to determine mineralogical and textural variations throughout the core and in the various alteration zones in and surrounding the breccia zone. Microprobe analyses were performed on many of the thin sections in order to aid in identification of secondary minerals and to relate chemical and mineralogical variations. Ten powdered samples, representing the various units and variations in degree of hydrothermal alteration, were analysed at Saint Mary's University for major and trace elements. X-ray diffraction (XRD) analyses were performed on clay fractions from 15 samples of intensely altered core.

1.4.4 Organization of this thesis

This thesis is organized into seven chapters. Chapter one introduces the thesis, briefly describes previous work on the surrounding area and explains the methods of data acquisition. The second chapter describes the regional geology of the Mount Pleasant caldera complex and the specific lithologic units in the study area. Whole-rock geochemistry and metal distribution and how they are affected by alteration are presented in chapter three. Chapter four deals with mineralogy and mineral chemistry. Chapter five presents data on alteration and the genetic history of the breccia pipe. XRD results on clay fractions analysed are presented here also. The data are summarized and interpreted in chapter six. The final chapter, chapter seven, presents conclusions of this study and recommendations for future work. Detailed core logs of the SOL cores are presented in appendix A. Appendix B presents petrographic descriptions of representative and interesting samples. Microprobe analyses of representative samples are compiled in appendix C. X-ray diffraction patterns of various phases are presented in appendix D. Finally, X-ray fluorescence analyses are presented in appendix E.

Chapter 2 - Geology and Petrology

2.1 Regional Geology

Many workers have contributed to an understanding of the regional geology of the Mount Pleasant complex (Ruitenburg, 1967; van de Poll, 1967; Gemmell, 1975; McCutcheon, 1982, 1983, in prep.). The caldera is bounded on the east and west by turbiditic graywacke and slate of the Silurian Waweig and Digdeguash Formations and by calcareous sandstone, slate and phyllite of the Upper Silurian-Lower Devonian Flume Ridge Formation. On the southern boundary is the Devono-Carboniferous St. George batholith. Complex contact relationships exist between the late Devono-Carboniferous rocks within the caldera and the older sedimentary and granitic rocks outside (Kooiman et al., 1986) (see figure 1).

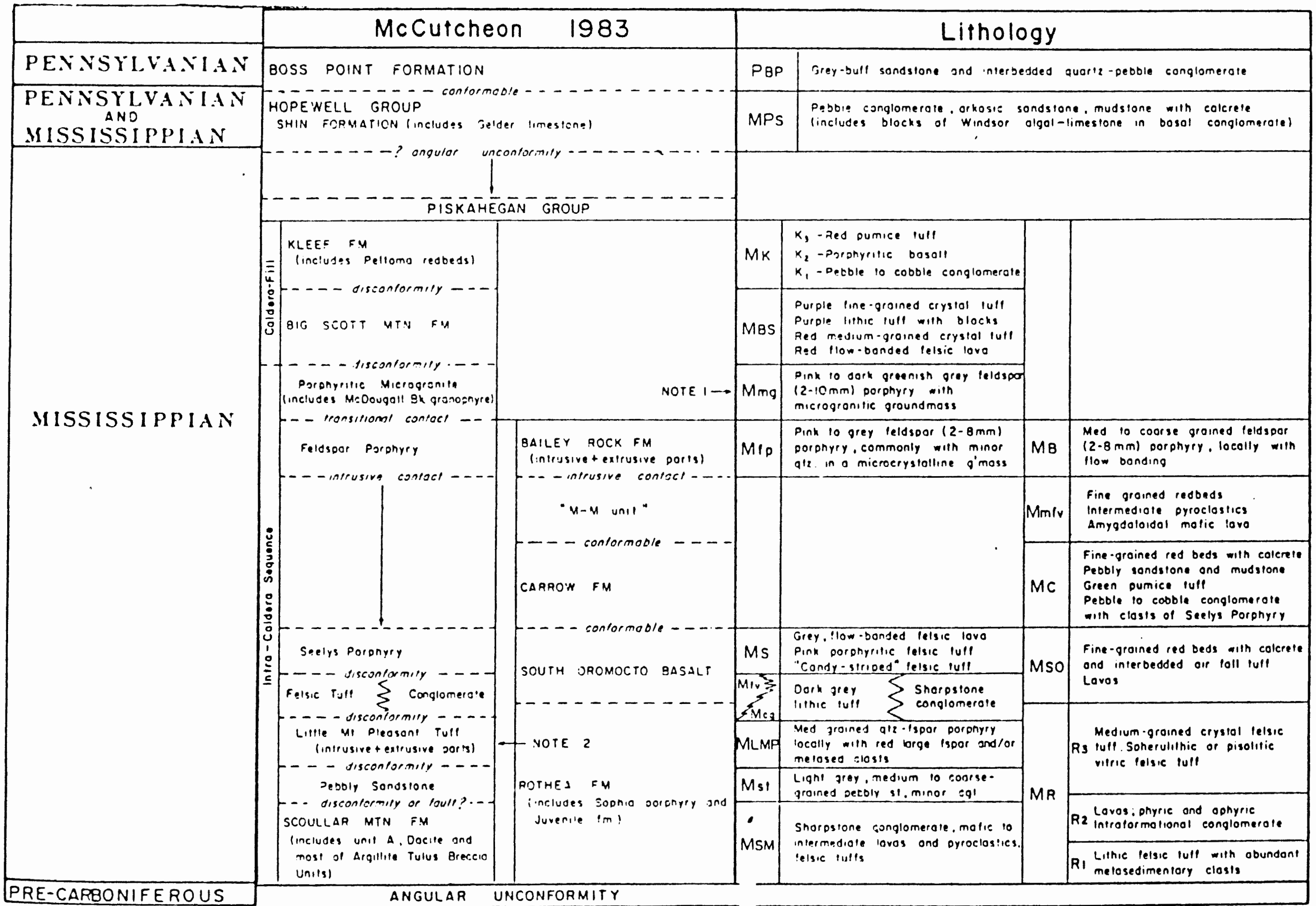
2.1.1 Mount Pleasant Caldera Complex

The Mount Pleasant caldera complex is of late Devono-Carboniferous age and comprises part of the Piskahegan Group. The stratigraphy has been described by van de Poll (1967), Gemmell (1975), and McCutcheon (1982, 1983, in prep.). The rocks consist of minor basalts and at least two major ash-flow tuffs which are overlain by interbedded red sandstone and conglomerate. Occurrences of argillite breccia on the eastern and western caldera margins probably represent talus accumulations along fault scarps related to caldera collapse. Although Mount Pleasant is one of the few vent areas known, the ash-flow tuffs of the Piskahegan Group may have been extruded from numerous vents within the caldera. Ruitenberg and McCutcheon (1980) and McCutcheon (1983) suggest that the hypabyssal intrusions at Mount Pleasant are possibly correlative with one or more formations in the Piskahegan Group.

Devono-Carboniferous volcanic activity in the Mount Pleasant area was associated with the emplacement of Devonian to Mississippian granitic rocks following termination of intense polyphase deformation of the Acadian orogeny (Ruitenberg et al., 1977). Ruitenberg and McCutcheon (1982) suggest that this igneous activity was associated with an episode of compressive deformation that interrupted a period of predominantly extensional tectonism. They also postulate that earlier formed wrench faults were reactivated during this period and that these controlled the emplacement of the Mississippian granitic stocks northwest of the St. George batholith and subvolcanic intrusions within the Mount Pleasant Caldera. A more complete picture of the stratigraphy of the caldera complex is presented in figure 3.

Late stage hydrothermal activity at Mount Pleasant and surrounding areas within the caldera resulted in the formation of several breccia bodies. Dagger (1972) and Parrish and Tully (1978) recognize two distinct mineralized breccia bodies, about 1 km apart, the North zone and the Fire Tower zone. Most certainly, numerous other breccia zones exist in the caldera

Stratigraphic Correlation Chart
Mount Pleasant Caldera



(from McCutcheon, 1983)

NOTE 1 Unit Mmg' at Mount Pleasant is a phase of Unit Mmg

NOTE 2 Unit Mstp at Mount Pleasant is the intrusive equivalent of Unit MLMP and Unit Mst is a sedimentary breccia related to the forceful emplacement of Mstp

FIGURE 3.

complex, however, the only other one known to the author is the SOL breccia zone, the subject of this study.

Seemingly, with each new study, different names have been assigned to the various rock units of the caldera complex. Those of McCutcheon (1983) are adopted in this thesis.

2.2 Local Geology and Petrology

2.2.1 General Statement

The South Oromocto Lake breccia zone is hosted in the McDougall Brook Porphyritic microgranite (PMG) and possibly the Little Mount Pleasant tuff (LMPT) of the caldera complex. The Porphyritic microgranite intrudes the LMPT and thus the crosscutting relationship seen between the LMPT and the SOL breccia may be most easily explained if the LMPT occurred as large xenoliths in the PMG unit. The closest outcrop of LMPT is approximately 1 km east of the breccia pipe.

Diamond drilling in 1982 produced three drill holes, SOL-1: 150.66m, SOL-2: 150.72m, and SOL-3: 232.01m. All holes were collared in PMG, passed through the brecciated zone and back into unbrecciated porphyritic microgranite. Two of the holes, SOL-2 and -3 pass through 13.90m and 2.20m of LMPT, respectively. In both cases the LMPT was encountered before the drill entered the zone of intense brecciation and is variably altered.

Enclaves of coarser grained granite are randomly dispersed in the core but only in the PMG unit.

2.2.2 Little Mount Pleasant Tuff

The Little Mount Pleasant Tuff is one of the main units in the intra-caldera sequence. McCutcheon (1985) describes it as an unwelded, high-silica, crystal tuff containing phenocrysts of feldspar and quartz. Characteristically, it has scattered red (pumice?) fragments containing phenocrysts that are significantly larger than those in the matrix, as well as some metasedimentary clasts.

An average modal composition is quartz (15-30%), plagioclase (5-10%), K-feldspar (15-30%), chlorite (1-2%), muscovite (1-2%), oxides (1-2%), accessory apatite and zircon (<1%), all set in a cryptocrystalline groundmass (40-70%). Quartz most commonly occurs as fragments 1-3mm in size commonly with glassy inclusions. The plagioclase is of albitic composition, and occurs as subhedral grains up to 2mm in length. Alteration has almost completely obliterated the twinning. Highly altered potassium feldspar (sanidine) occurs in subhedral grains up to 1.5mm across. Chlorite occurs in subhedral grains up to 1.5mm and also as tiny fibro-radial blobs. It was probably formed by alteration of biotite. Muscovite and iron oxides are also present both as anhedral-subhedral grains less than 1.0mm in length. The groundmass is cryptocrystalline except for subgranophyric lenticular patches (after pumice) and frequent metasedimentary clasts which have been partially assimilated.

2.2.3 McDougall Brook Porphyritic Microgranite Unit

The McDougall Brook Porphyritic Microgranite is another main unit in the intra-caldera sequence. Commonly associated with the PMG is a marginal or border phase composed of quartz-feldspar porphyry (McCutcheon, 1985). The PMG intrudes the rest of the intra-caldera sequence and typically has a lower topographic relief than the rocks it intrudes. McCutcheon (1985) interprets the porphyritic microgranite as the final fill in the high level magma chamber that fed the intra-caldera sequence.

Petrographically, the PMG is quite simple. Phenocrysts of euhedral feldspar (plagioclase > K-feldspar) form 30-50%. These crystals are up to 8.0mm across, with some zoning apparent. Anti-perthitic texture is common, and the feldspars are partially to completely altered to sericite $\pm$ kaolinite $\pm$ carbonate. Subhedral-euhedral quartz phenocrysts comprise up to 5% and range up to 3mm across. These commonly contain small inclusions of unknown opaques. Quartz increases in abundance with proximity to the intrusive contact. Chlorite comprises 1-5% of most specimens and commonly occurs as fibro-radial spheres, <1mm across. It is believed to be an alteration product of biotite. It is almost always pleochroic, from dark green to light yellow. Also present in most specimens are apatite needles (up to 1mm in length, <1%), zircon (up to 0.3mm, <1%), carbonate (up to 2mm, <1%), pyrite (<1mm, up to 2%), and epidote (<1mm, <1%). The groundmass comprises 30 - 60% and is composed of feldspar, quartz (frequently interstitial) and minor chlorite. It has an equigranular texture and ranges in size from 0.1mm-0.5mm (see photo 2).

2.2.4 Aplite Breccia Dyke

The aplite breccia is believed to be distinct from the SOL breccia zone. This breccia occurs in several small dyke-like bodies that crosscut the PMG unit. It occurs peripherally to the intensely brecciated zone in SOL-1 at a depth of 52.25m, at 126.80m, and 145.60m, in SOL-2 at a depth of 133.70m, and 139.60m, and in SOL-3 at a depth of 117.50m. The breccias are variable in appearance but are generally light green to dark green (almost black) with varying amounts of PMG incorporated as xenolithic fragments (see photo 1). The aplite breccia has a matrix of cryptocrystalline to very fine grained quartz, feldspar?, chlorite, pyrite, sericite, zircon, clays and rock flour, probably derived from the PMG unit. The clasts in the aplite breccia are less altered than the surrounding granite. Clasts vary in abundance from 1-50% and their abundance decreases away from the contact with the country rock. Chlorite and other green clays vary from 10-80% depending upon the degree of alteration. Also present are feldspar (0-5%) zircon (<1%), and pyrite (<2%). Sericite is quite abundant (50-60%) in some samples.The matrix varies from very quartz rich (70%), to very sericite-rich (80%), to very chlorite/green clay-rich (80%).

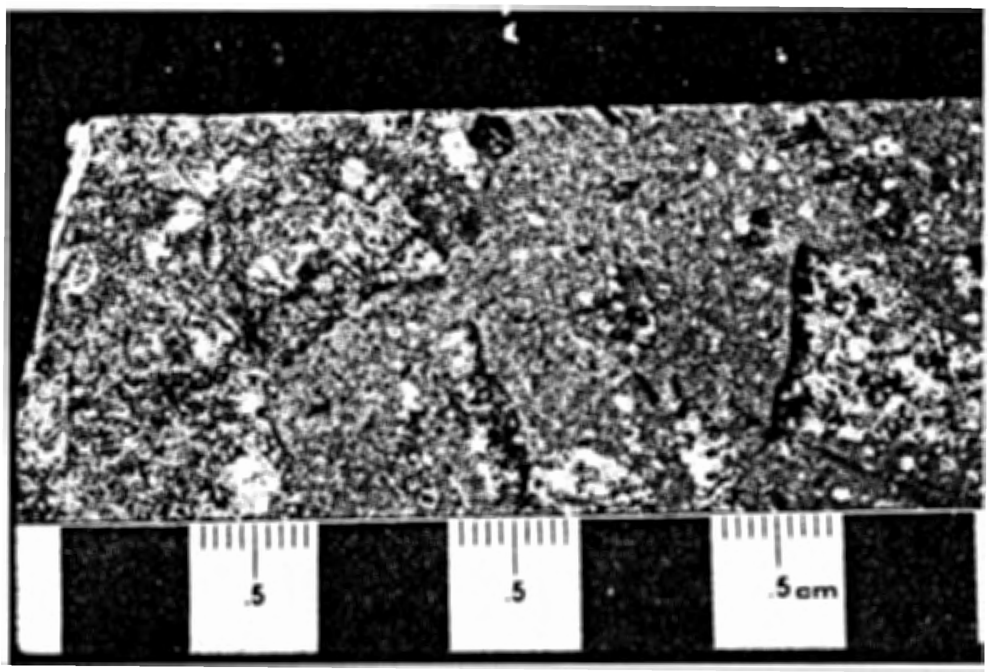


Photo 1. Aplite Breccia Dyke.

2.2.5 Aplite Dyke

This chloritized aplite dyke is also believed to be distinct from the SOL breccia zone. It crosscuts the PMG at a depth of 126.80m in SOL-1, and this is the only location where it is seen. The dyke is 60 cm across in the core, and has produced an alteration halo of 50-100 cm on either side. The bottom contact of the aplite dyke is cut by the aplite breccia dyke, resulting in a 1 cm wide hematite alteration halo in the aplite dyke, due to this later intrusion.

The aplite dyke is medium to dark green in color and is composed of quartz (35%, 0.5mm), potassium feldspar (30%, 0.3mm), plagioclase (15%, 0.25mm), chlorite (15%, 0.6mm), pyrite (5%, 0.1mm), apatite (1-3%, 0.5mm long), and zircon (<1%, 0.05mm). The aplite dyke has a fine-grained granitic texture.

2.2.6 Granite Enclaves

Scattered through the drill core are zones of coarse grained granitic rock which occur as enclaves in the PMG unit. There are no reaction or resorption rims around the xenoliths and they display the same visual alteration characteristics as the surrounding PMG. The coarse grained texture of these enclaves distinguishes them from the host rock. They range in size from 10-50cm, but most are 10-20cm (see photo 2).

The enclaves consist of granite composed of quartz(35%, 4.0mm), plagioclase(20%, 4.0mm), K-feldspar(40%, 3.0mm), chlorite (after biotite)(4%, 1.0mm), apatite(1%, 0.2mm), ± pyrite, ± Fe-

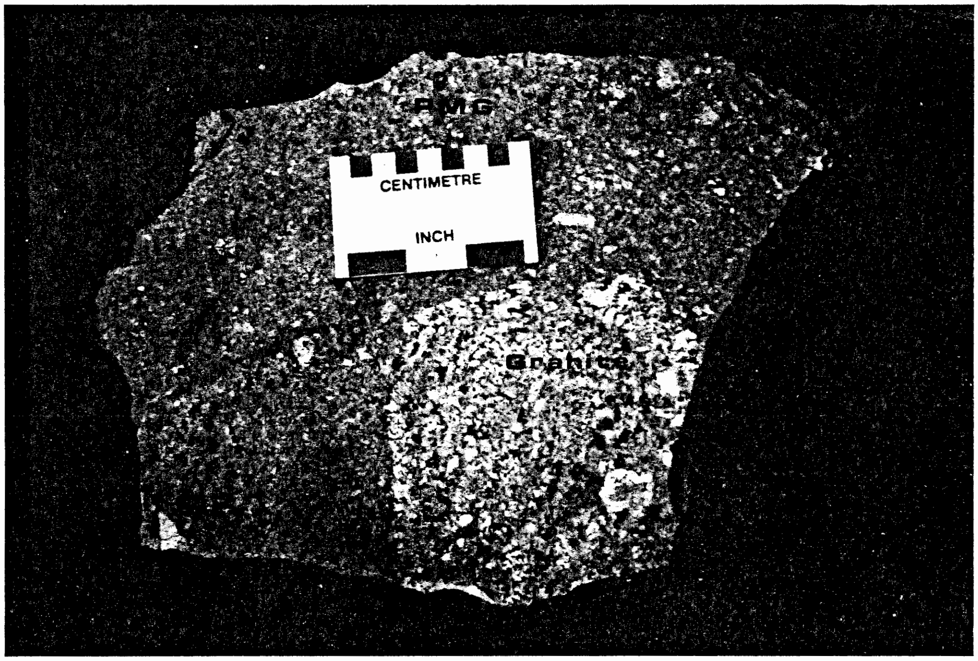


Photo 2. Granite enclave and surrounding PMG.

oxide. Quartz and K-feldspar occur as perthitic intergrowths, commonly with a quartz core surrounded by a myrmekitic rim. The feldspars are completely altered to sericite and/or other clays.

Although the source of these granite enclaves is unknown, it is suspected that they are fragments of the St. George Batholith.

2.2.7 Other Enclaves

Another type of enclave in the PMG unit consists almost entirely of carbonate, chlorite and quartz.

In the one thin section examined the mineralogy was found to be quite complex, consisting mostly of quartz phenocrysts (60%, 0.5mm), chlorite (30%, 1.8mm), carbonate (10%, 2.0mm), minor amounts (<1% each) of fluorite, muscovite/sericite, K-feldspar, zircon, apatite, and traces of opaque mineral. At the outer edge of the xenolith is a red alteration/resorption zone of myrmekite (quartz/ K-feldspar), chlorite, and minor opaques. A few quartz phenocrysts still remain but the feldspars are completely altered.

2.2.8 Veining and Brecciation

Late-stage hydrothermal activity has resulted in many stages and periods of veining and brecciation of the host McDougall Brook Porphyritic Microgranite. Economic mineralization is known to be associated with this sort of igneous activity.

2.2.8.a Early Fracturing

One of the earliest evidences of fracturing and veining is the existence of K-feldspar-rich dark red bands which randomly crosscut the PMG. Most are inclined 70-90° to the core axis. The cores of these bands commonly contain inclusion-rich carbonate (calcite), chlorite, and minor quartz. In the red band there is a noticeable depletion of quartz (10%) and plagioclase (<1%) with the quartz occurring mostly in odd myrmekitic intergrowths. The myrmekitic intergrowths in the red bands are not "wormy" in appearance but instead are straight and parallel to each other with the feldspar being completely altered to a red-brown clay mineral. It is suspected that these bands represent early fractures/veins which were later altered and modified. The significance of this occasional, odd myrmekitic texture is unknown. Porphyritic microgranite immediately surrounding the red band also shows a myrmekitic texture, however, these intergrowths display the normal "wormy-intergrowth" appearance.

2.2.8.b The Main Period of Veining and Brecciation

The SOL breccia body is a dyke-shaped body, 350-450m long and 10-15m wide in outcrop. From diamond drilling data it is

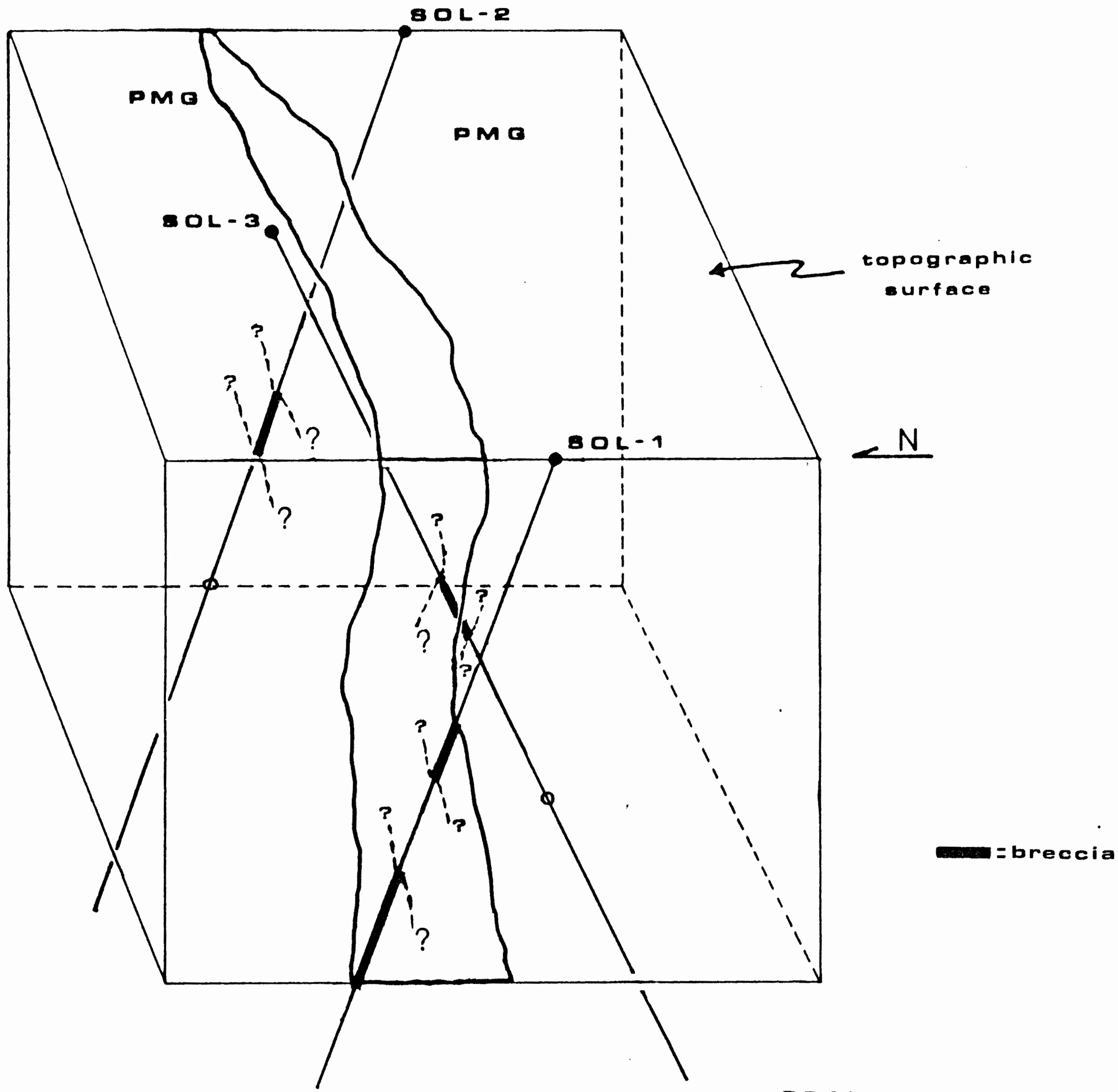


FIGURE 4 Sub-surface Diagram

apparent that the body dips 70-90° to the south (figure 4). The body is presumed to have formed along a fracture or fracture intersection, or possibly a small fault.

Injection of a chloritic aplite dyke which is seen in SOL-1 at 126.80m depth preceded the period of most intense brecciation and veining. Following this was the injection of a set of slightly different chloritic aplite dykes which brecciated the surrounding microgranite and transported PMG clasts along with it. The crosscutting relationship between these two dykes is seen in SOL-1 at 126.80m depth.

Veining and vein constituents of the breccia zone are very complex. There appear to have been two major episodes of brecciation, probably explosive in nature, followed by several less dramatic episodes of brecciation and fluid fracturing. The net result of this, as well as the many additional phases of fluid injection, is an extremely complex and somewhat indefinite genetic history for the breccia body. Veins vary in composition from calcitic to chloritic, fluoritic, hematitic, or silicic. At least eight silicic varieties are present, with variation depending on inclusion type and proportion (see photo 3). Minor sulphide mineralization, in vein form, is associated with one of the episodes of chlorite veining.

As a result of the limiting nature of the drill core, and the lack of dramatic lithological contrasts, it is difficult to tell whether the net direction of transport of the clasts in the breccia was up or down. It is also quite possible there was only very minor net transport so that the clasts have remained

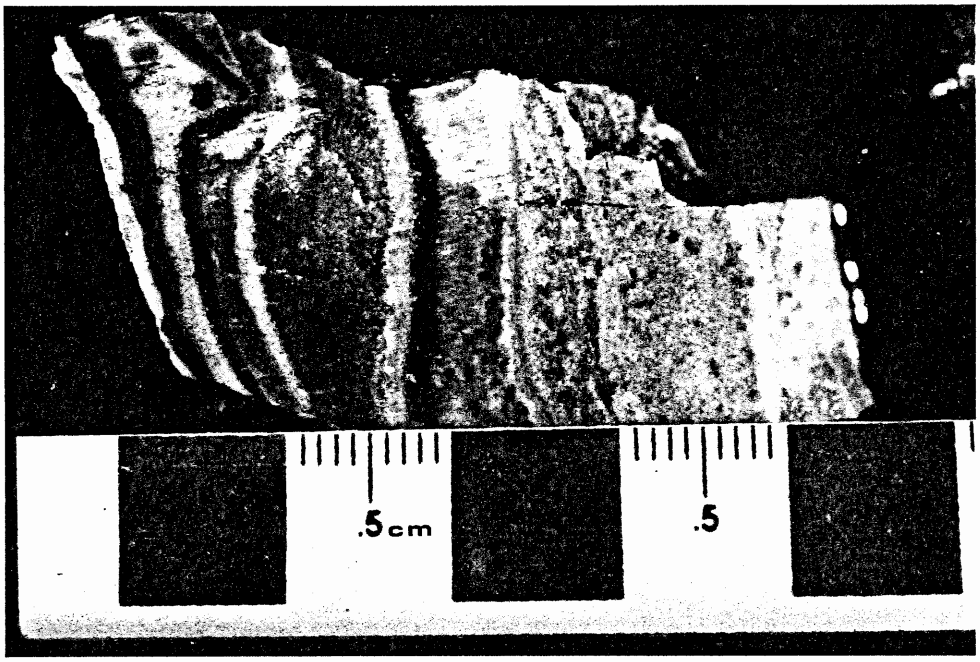


Photo 3. Vein fragment illustrating various stages of fluid injection.

approximately in situ. Although some rounding is seen in the clasts this could easily have resulted from in place rotation and corrosion. Clasts are matrix (vein material) supported and range in size from >1.0m to a few millimeters. Rock flour is also present.

Some clasts resemble pebbles (eg. in SOL-3 below the brecciated zone) but these may merely be zones of intense sericitization, chloritization, and/or hemitization.

Chapter 3 - Whole-rock Geochemistry and Metal Distribution

3.1 General Statement

Both major and trace element analyses were done on ten powdered samples from the three drill holes in the SOL breccia zone. Ten major oxides (SiO_2, Al_2O_3, Fe_2O_3, MgO, CaO, Na_2O, K_2O, TiO_2, MnO, and P_2O_5) and loss on ignition (LOI) values were determined from a fused samples. Trace elements which were analyzed for include Ba, Rb, Sr, Y, Zr, Nb, Th, Pb, Ga, Zn, Cu, Ni, TiO , V, and Cr. The ten samples consist of four PMG samples, three granite samples, two LMPT samples and one sample of aplitic dyke rock. This study of major and trace element data compares changes in concentrations with changes in alteration as a result of hydrothermal activity.

Essentially unaltered PMG is illustrated by the geochemical analysis of sample 85-SD-79, unaltered LMPT by sample 85-SD-71, and unaltered granite enclave material by sample 85-SD-66. Sample 85-SD-67 stands on its own, illustrating the aplite dyke unit as distinct from the other lithological units. Compositional deviations from those values are interpreted as reflecting hydrothermal alteration of the rock. As a result of the small number of analyses the results are only a preliminary indication of the complex changes in bulk chemistry which have occurred in the various lithological units.

3.2 Changes in chemistry with increasing alteration

For the purpose of sample selection the degree of alteration was defined by a combination of intensity of chloritization and general deviation of appearance (color, texture, and coherentness) from the essentially unaltered host rock found outside the hydrothermally affected zone. This initial definition is supported by the data presented.

Titanium is the only immobile element common to both major and minor element analyses thus most elements have been plotted versus titanium to illustrate variation with alteration.

3.2.1 Major Elements

3.2.1.a Porphyritic Microgranite

The PMG unit reveals many expected as well as some interesting and somewhat unexpected chemical alterations. Figure 5 shows a rather significant increase (6-7%) in SiO_2 content with increasing alteration. This probably reflects a combination of leaching of other elements from the unit and thus a relative increase in silica content and an absolute increase in silica resulting from precipitation of quartz.

Figure 6 clearly shows a decrease in Al_2O_3 with alteration. Because aluminum is relatively immobile during alteration and weathering, the decrease seen in the PMG is probably relative, reflecting an increase in SiO_2 rather than a large decrease in Al_2O_3.

Magnesium shows a general decrease with alteration (see figure 7) in the PMG unit. Magnesium, being very mobile, has been leached out of this unit. One of the more intensely altered sample(85-SD-49), shows an increase in Mg relative to the unaltered sample. The reason for this is unknown.

Iron, also being very mobile, shows a decrease in percentage with alteration (see figure 8). This is quite surprising considering the dramatic increase in chlorite in the intensely altered PMG. The reason for this apparent leaching effect is not clear.

Calcium content in the PMG (see figure 9) drops drastically in the two most altered samples. This is not surprising as calcium is very easily remobilized during hydrothermal alteration. The most altered sample (85-SD-45) has a slightly higher CaO content than the less altered sample 85-SD-49, however, minute calcite veinlets are quite common in the highly altered sections and sample 85-SD-45 may have been contaminated by these veinlets.

Sodium has also been leached out of the unaltered PMG as shown in figure 10. The complete breakdown of plagioclase in the most intensely altered zones reflects this depletion.

As illustrated in figure 11, manganese, although somewhat less dramatically, is also depleted in the PMG.

There are no clear cut trends in P_2O_5 and K_2O with alteration (figures 12 and 13). There is however, less potassium in the two more altered samples than in the two less altered samples.

Loss on ignition values for the PMG generally decrease with increasing alteration except for sample 85-SD-45 (see figure 14) This is apparently reversed from what would normally be expected, it can be explained most easily by examining how the change in L.O.I. relates to the CaO content (see figure 15). There is a definite increase in L.O.I. with increased CaO content, reflecting an abundance of carbonate.

3.2.1.b Little Mount Pleasant Tuff

The LMPT shows relatively minor changes in composition due to alteration compared to the PMG. However, in general, the two LMPT samples show expected alteration effects.

Figure 5 shows that there has been a small decrease in SiO_2 content in the LMPT with alteration. No obvious reason is known for this decrease.

There is a minor increase in Al_2O_3 content (figure 6), which might reflect the increase in alumino-silicate minerals (i.e. chlorite), or simply a relative depletion of other elements in the tuff.

MgO and FeO increase with alteration. (see figures 7 and 8, respectively). The large increase of chlorite in the tuff is likely responsible for this.

Calcium increases with alteration (figure 9). Considering the mobile nature of calcium, this increase probably is due to the presence of calcite veinlets in the altered sample.

Sodium decreases with alteration (figure 10), this is represented mineralogically by disappearance of plagioclase grains in the intensely altered LMPT.

Manganese and potassium both increase in the more altered LMPT sample (figures 11 and 13, respectively) whereas phosphorous does not change (figure 12).

Loss on ignition is greatest in the altered LMPT sample (figure 14), reflecting the inferred higher concentration of volatiles (ie. calcite).

3.2.1.c Granite enclaves

The granite enclaves have undergone similar chemical changes, during hydrothermal alteration as the LMPT unit.

Generally, there is a decrease in SiO_2 with increasing alteration (figure 5), and an increase in Al_2O_3 (figure 6). Iron and magnesium (figures 8 and 7, respectively) both increase with degree of alteration, and increasing percentage of chlorite. Calcium in the granite enclaves decreases from sample 85-SD-66 to sample 85-SD-48 but drastically increases in sample 85-SD-39, the most altered one (see figure 9). This is probably once again due to the presence of minute calcite veinlets in the highly altered sample. Sodium is very depleted in the two altered granite samples compared to the relatively unaltered one, as is apparent in figure 10. Manganese clearly increases with degree of alteration (figure 11), whereas the behaviour of P_2O_5 and K_2O is not as clear but they both tend to decrease in the more altered samples (figures 12 and 13). There is a very clear and large increase in L.O.I. from the least altered sample to the most altered sample (see figure 14).

3.2.2 Trace Elements

Geochemical distinction among the various lithologic units is seen best in the plot of Zr vs TiO_2 (figure 16). Alteration has apparently not affected concentrations of these two incompatible and immobile elements. Graphs have been plotted of the various trace elements versus TiO_2. Interesting and significant changes of the various trace element concentrations in the different lithologies are discussed below.

3.2.2.a Porphyritic Microgranite

In the PMG unit, with increasing alteration, there are enrichments in Rb (figure 17), Th (figure 18), Ni (figure 19), and Ga (figure 20), and depletion of Ba (figure 21), Sr (figure 22), Zn (figure 23), and V (figure 24). There is no apparent change in concentration of Y (figure 25), Zr (figure 16), Nb (figure 26), Pb (figure 27), and Cr (figure 28).

3.2.2.b Little Mount Pleasant Tuff

In the LMPT unit, with increasing alteration, there are enrichments in Rb (figure 17), Th (figure 18), Ga (figure 20), Zn (figure 23), Ni (figure 19), and Y (figure 25), and depletion of Ba (figure 21), Sr (figure 22), and V (figure 24). There is no apparent change in concentration of Zr (figure 16), Nb (figure 26), Pb (figure 27), and Cr (figure 28).

3.2.2.c Granite enclaves

In the granite enclaves with increasing alteration, there are enrichments in Rb (figure 17), Th (figure 18), Ga (figure 20), Zn (figure 23), and Y (figure 25), and depletion of Ba (figure 21), Sr (figure 22), and V (figure 24). There is no apparent change in concentration of Zr (figure 16), Nb (figure 26), Pb (figure 27), Ni (figure 19), and Cr (figure 28).

3.2.2.d Summary

Trace element variations are very similar in all surveyed lithologies. This suggests that hydrothermal solutions responsible for alteration were enriched in Rb, Th, Ga, Zn, Ni, and Y, and depleted in Ba, Sr, and V.

SYMBOLS

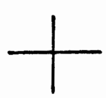
$\circ_1 - \circ_2$ = **Little Mount Pleasant tuff**

$\square_1 - \square_4$ = **Porphyritic Microgranite**

$\triangle$ = **Aplite dyke**

$\diamond_1 - \diamond_3$ = **Granite enclave**

Note: Numbers denote a relative increase in alteration within that lithology (ie. 1 being essentially unaltered, 2 being more altered than 1).

 **Error range**

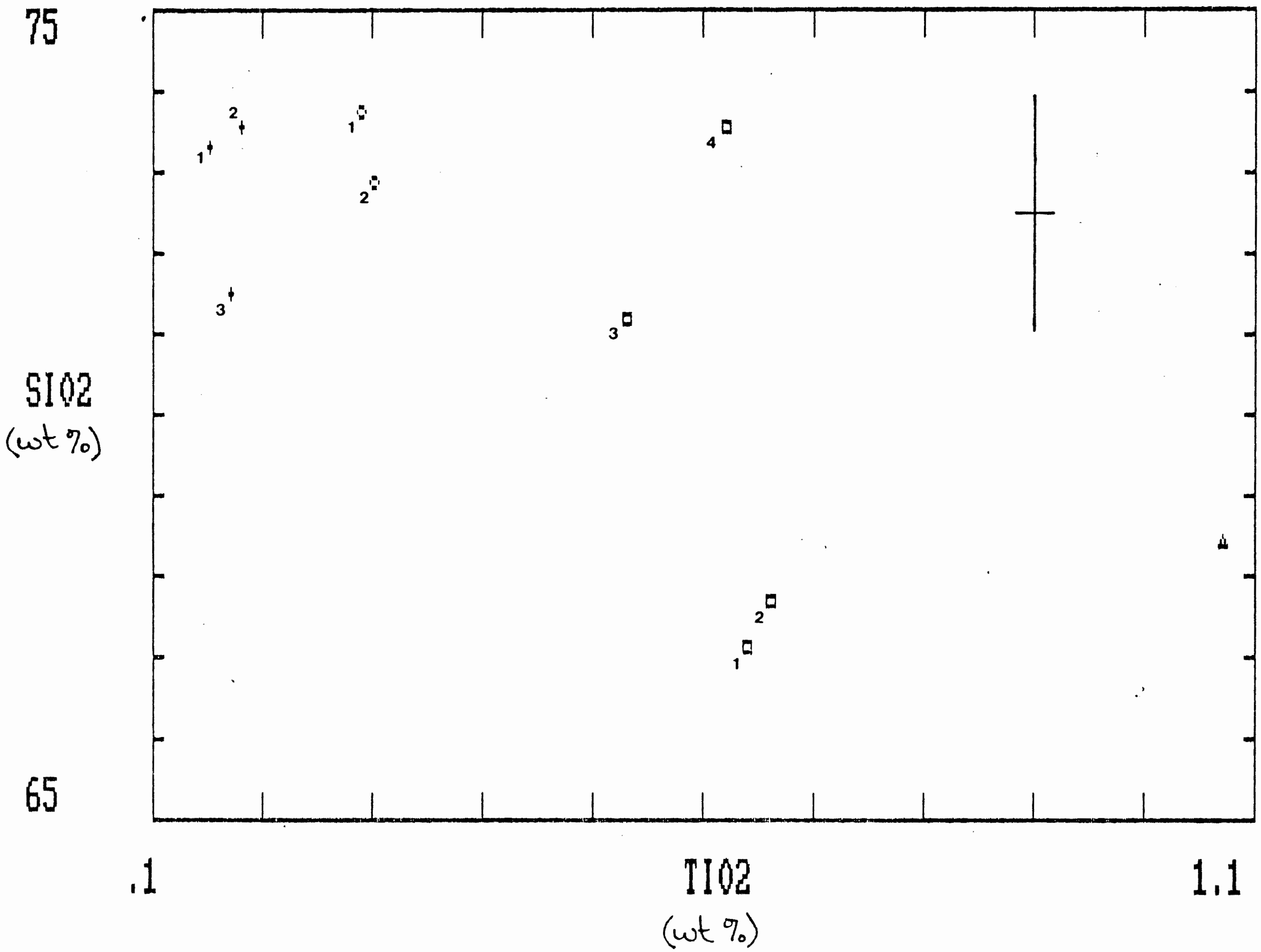


Figure 5

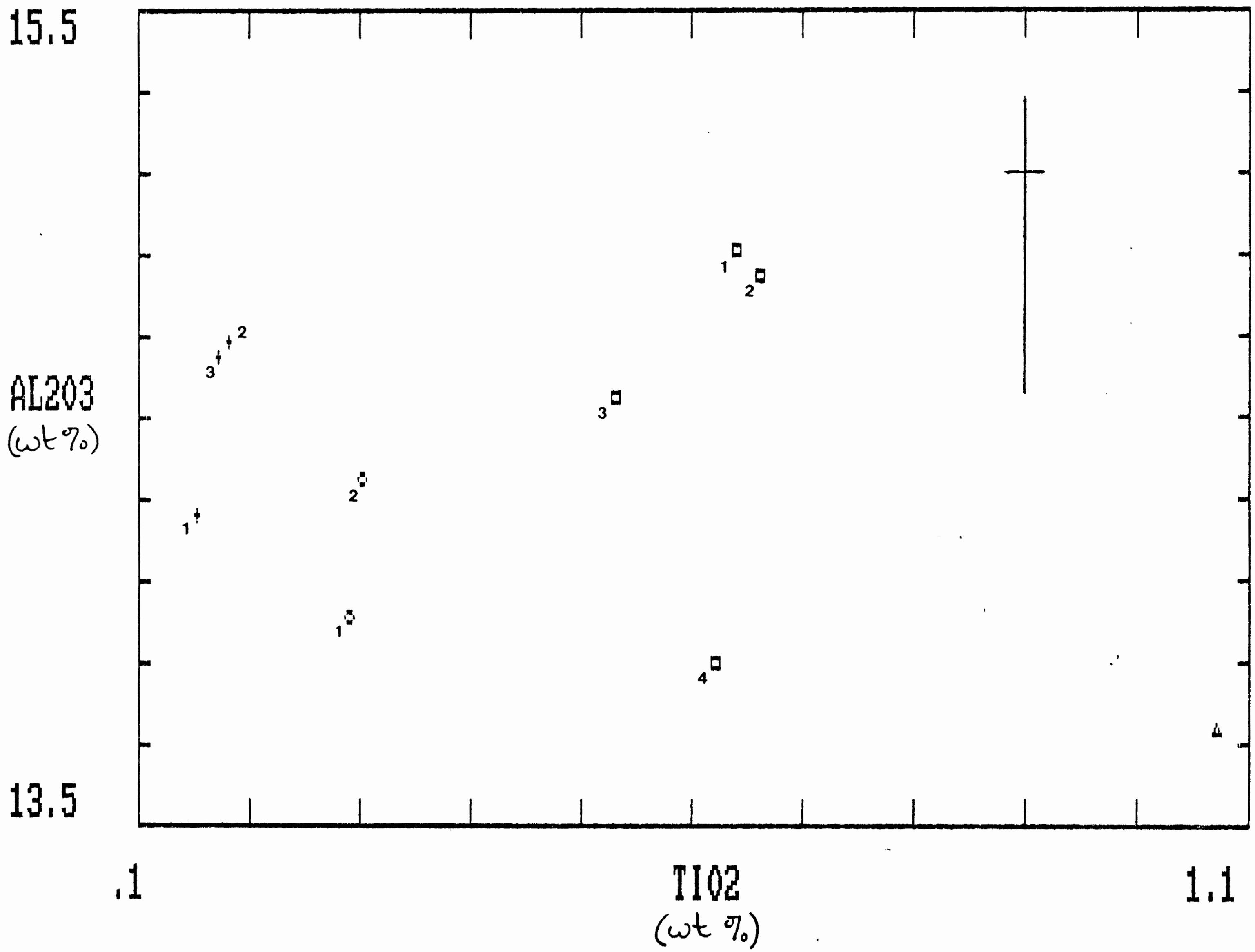


Figure 6

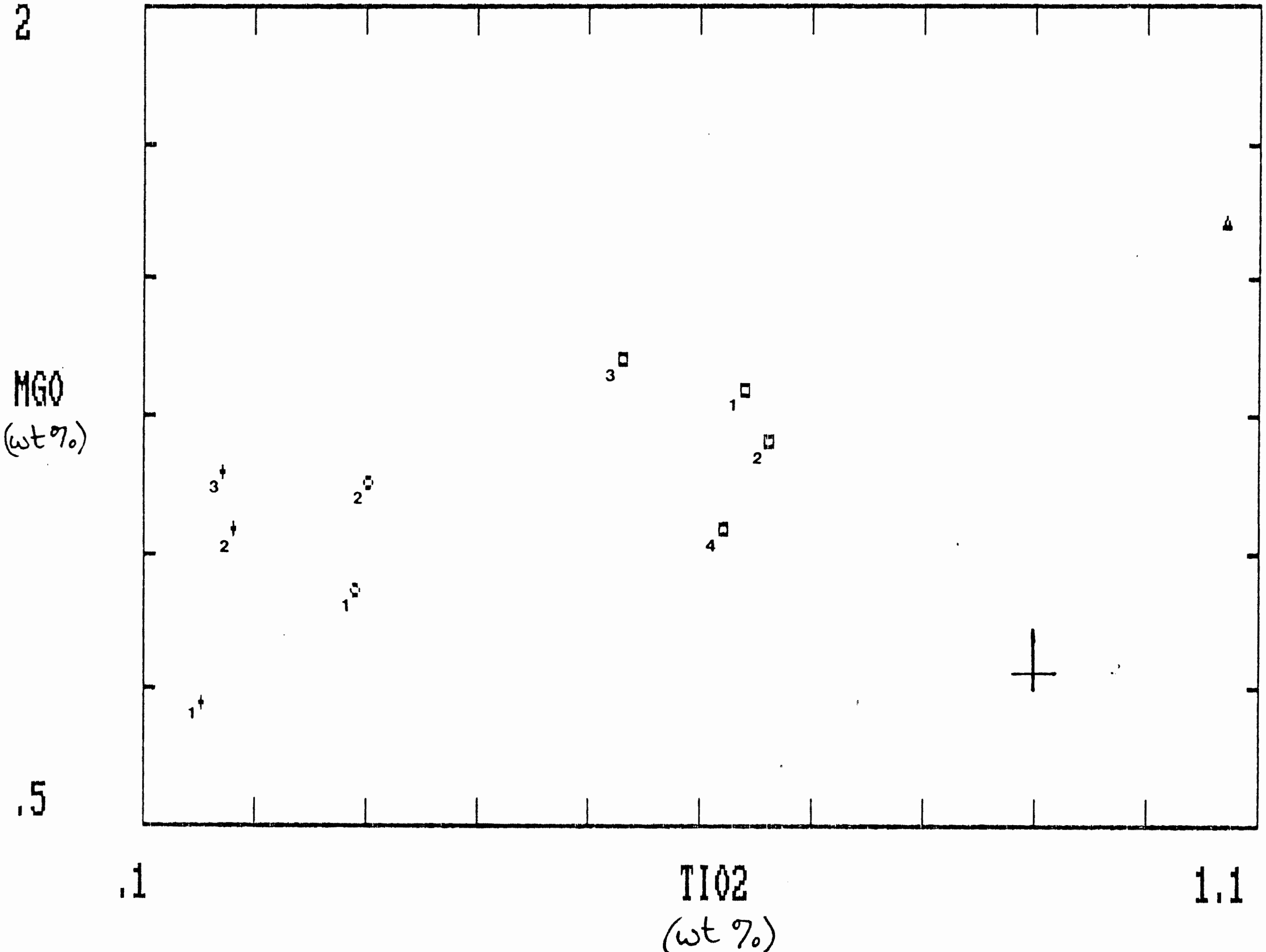


Figure 7

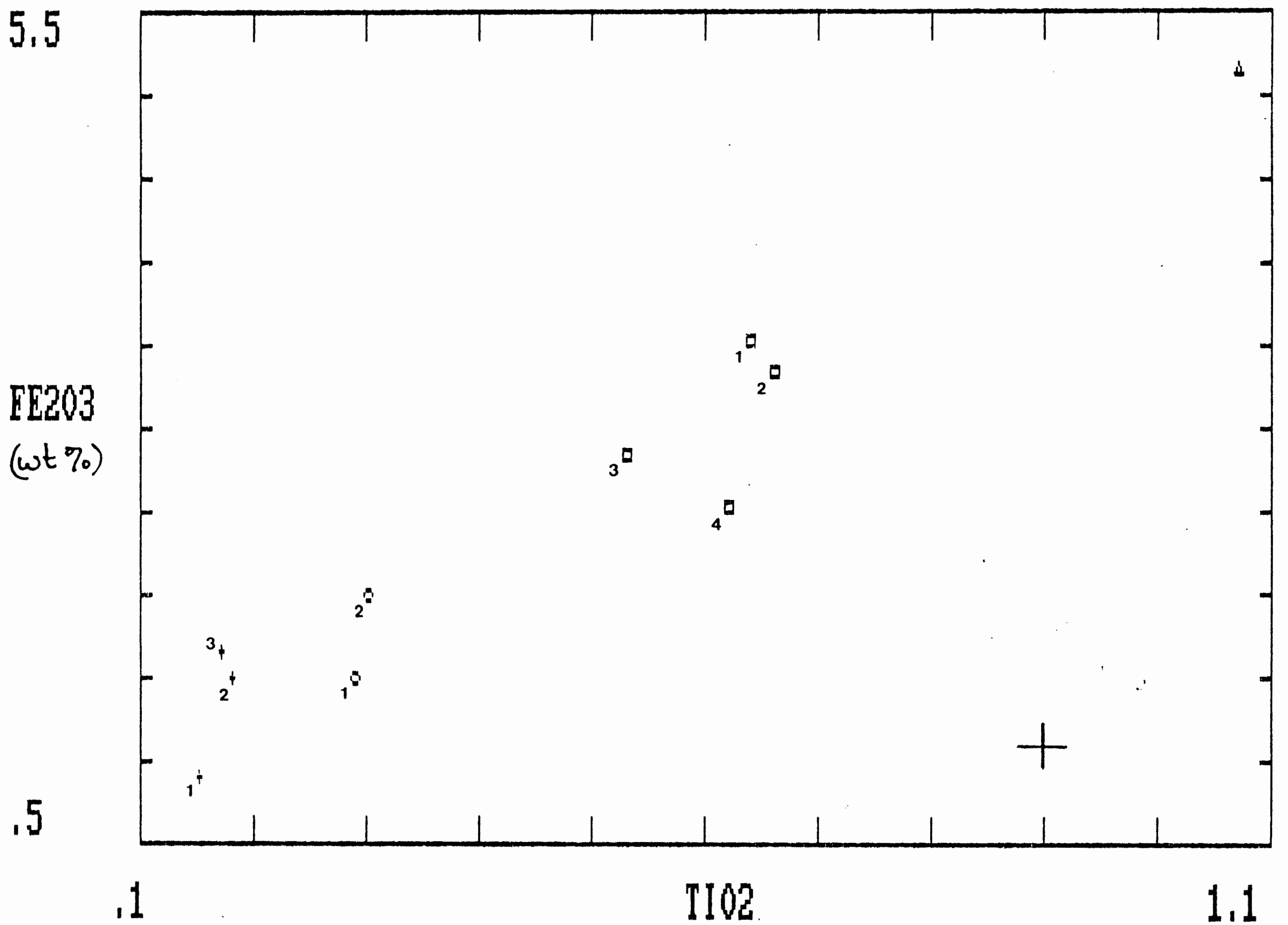
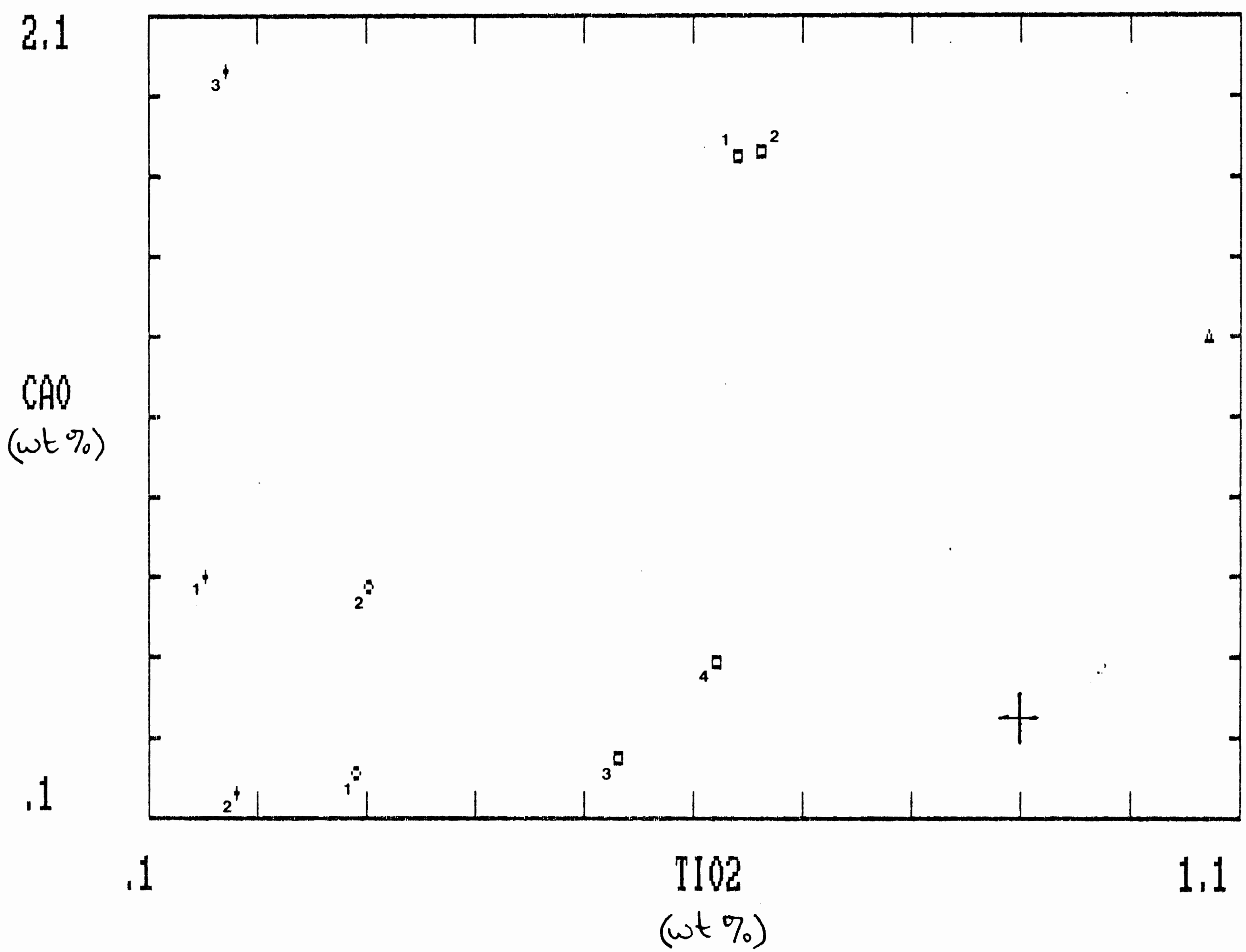


Figure 8



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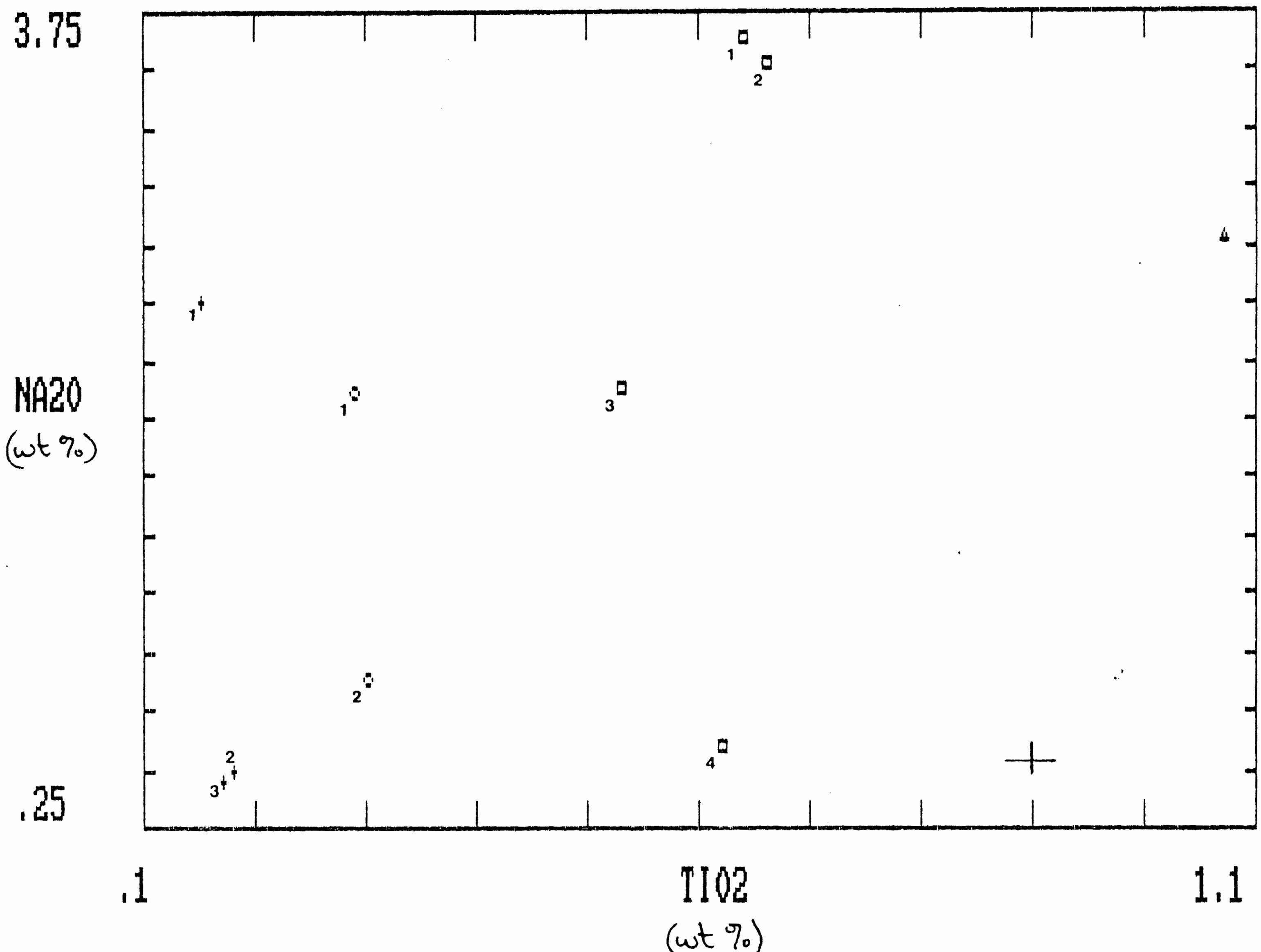
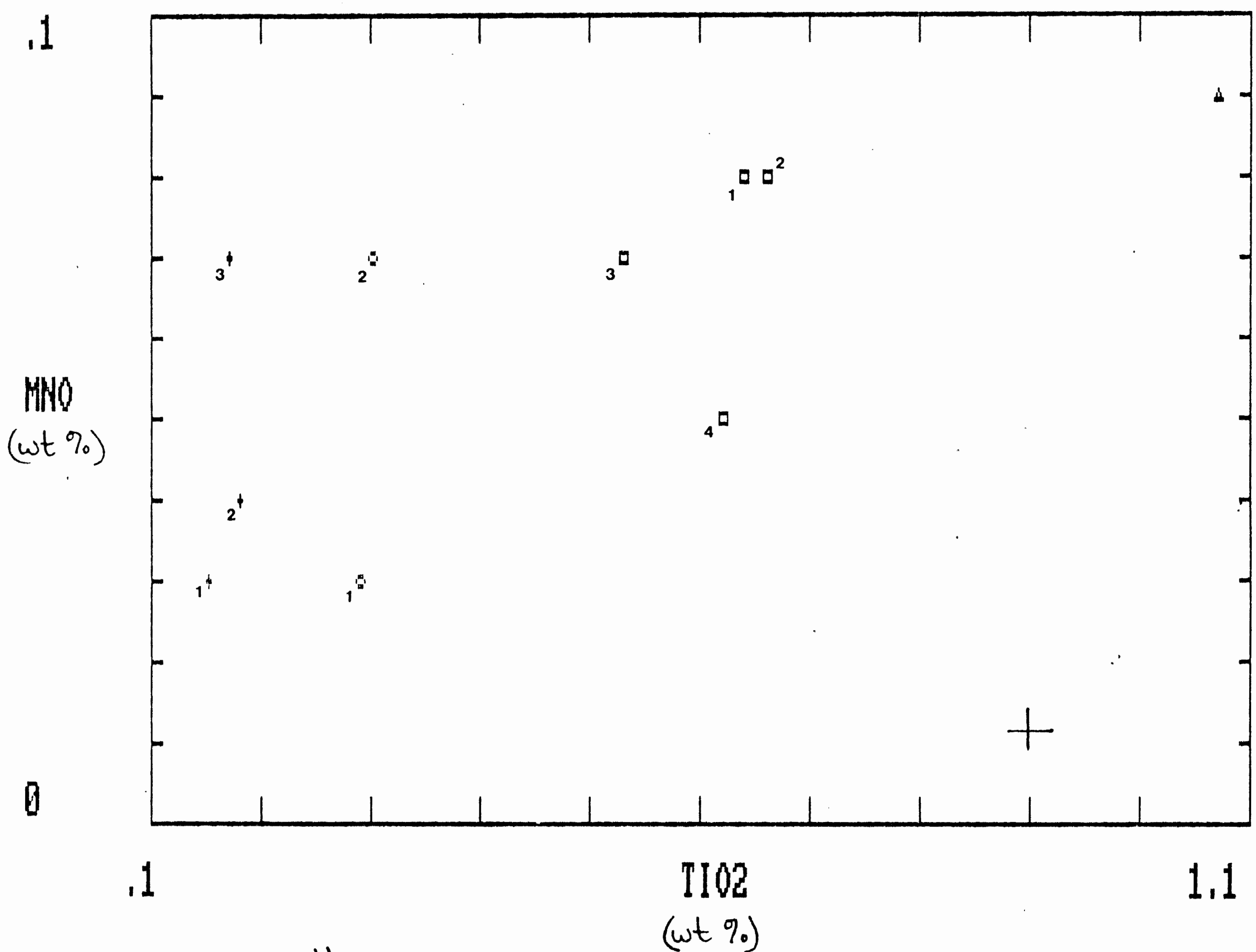


Figure 10



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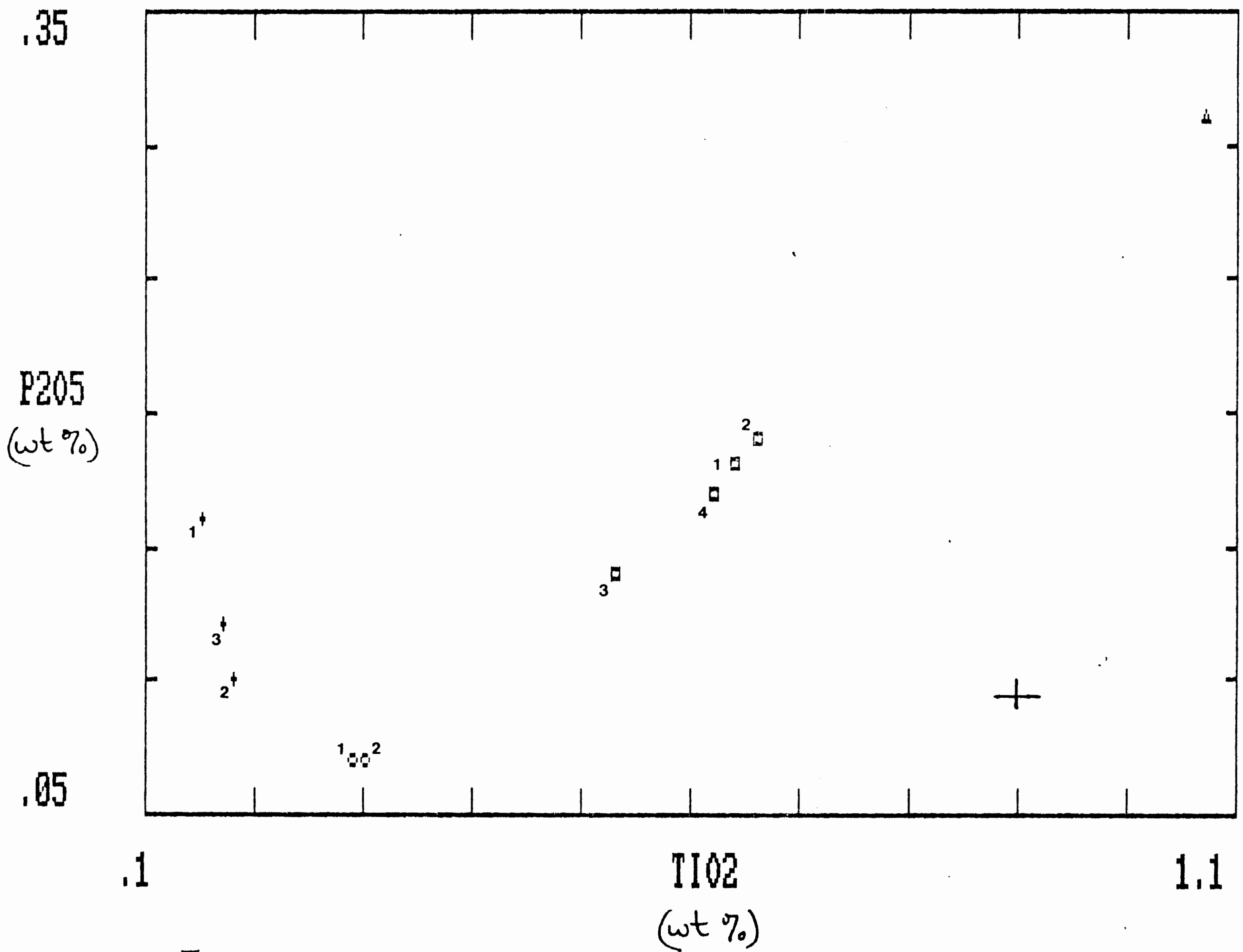

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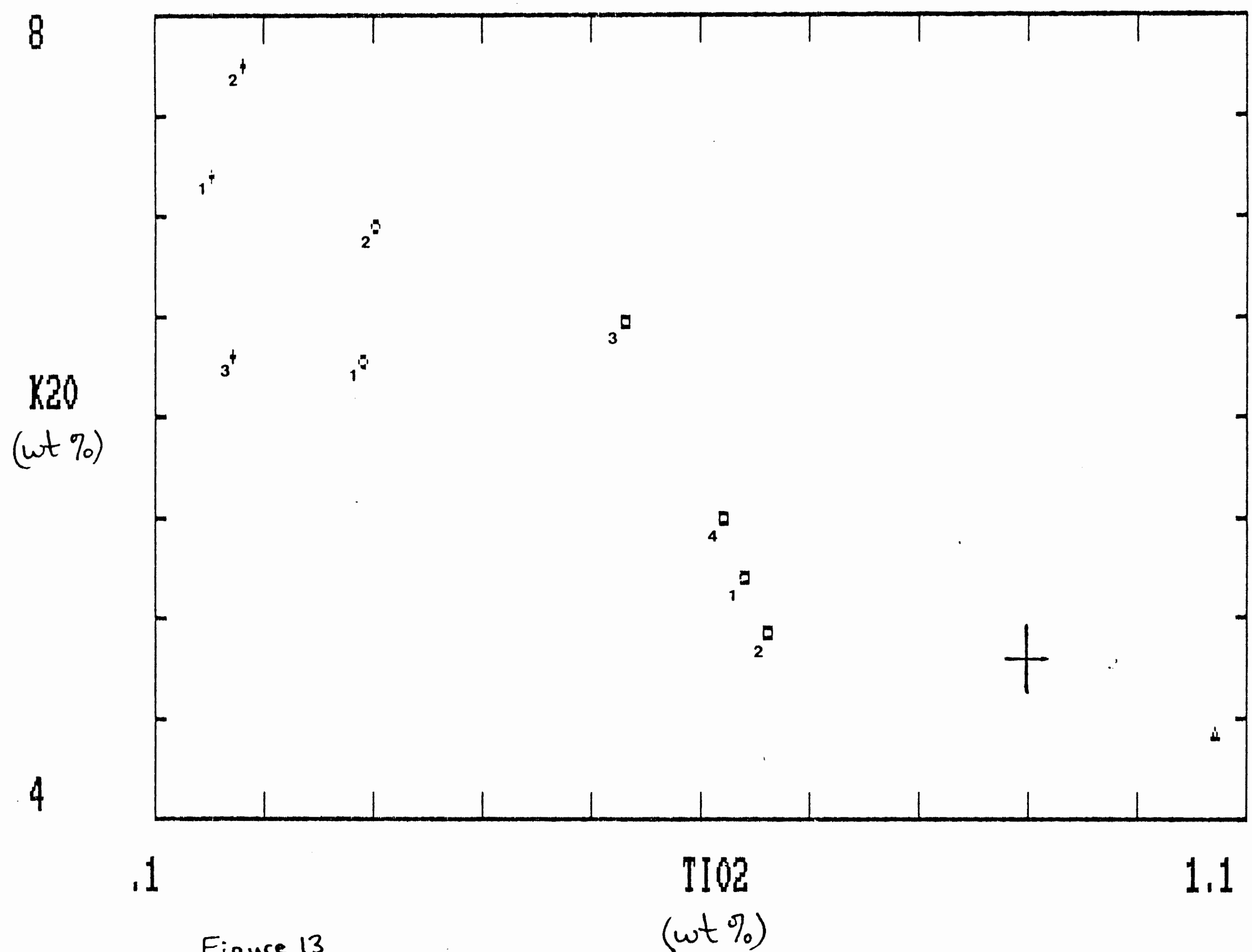

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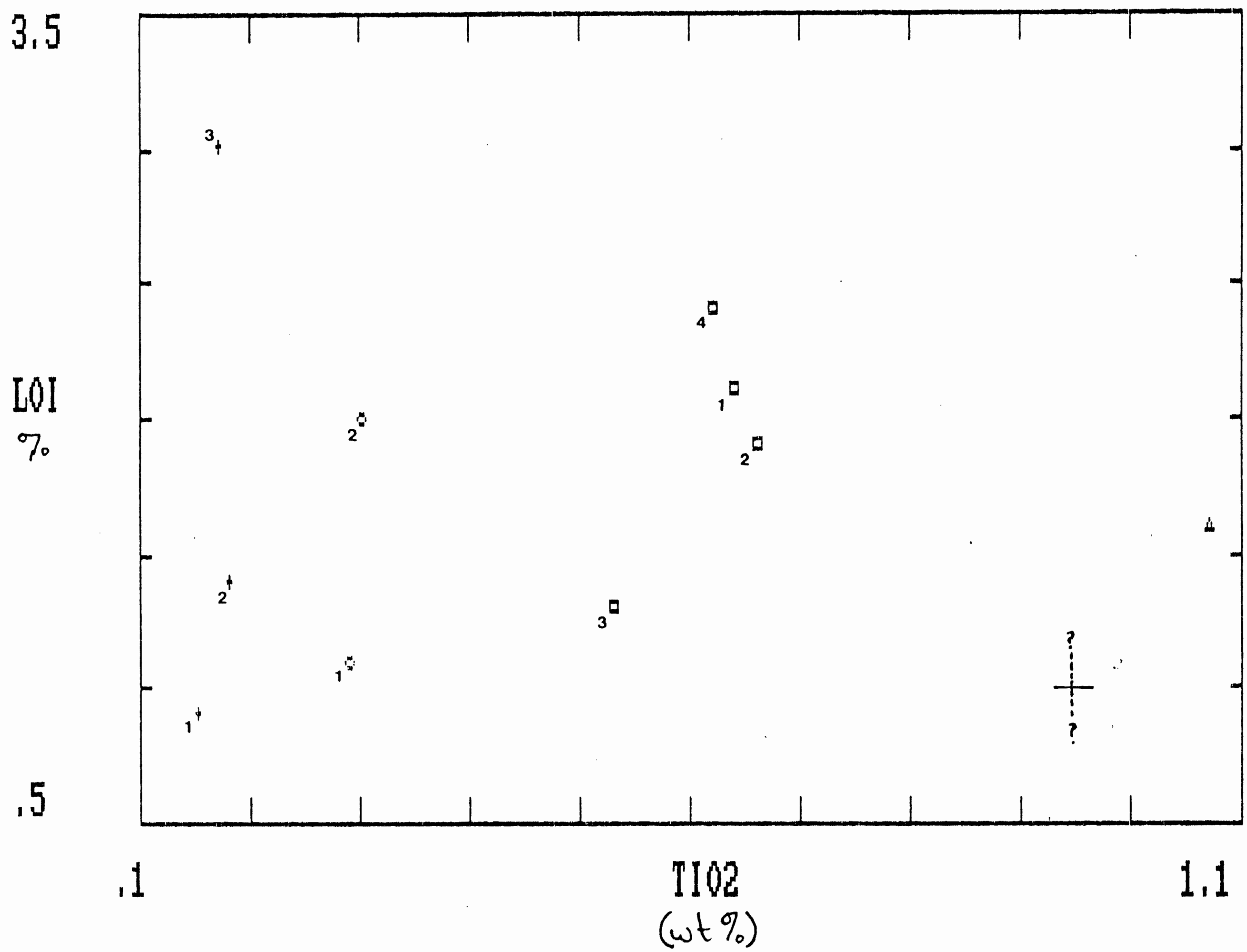


Figure 14

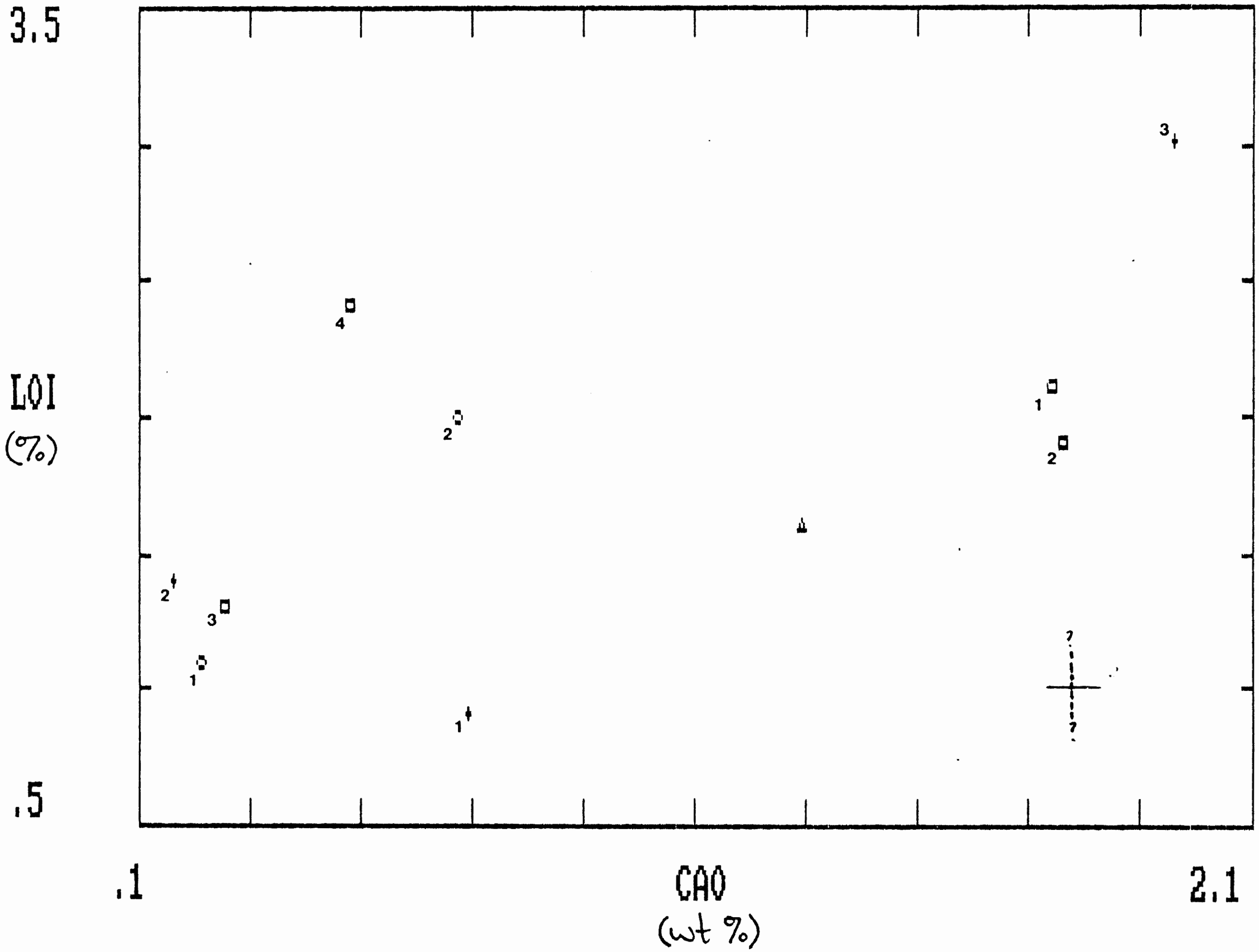


Figure 15

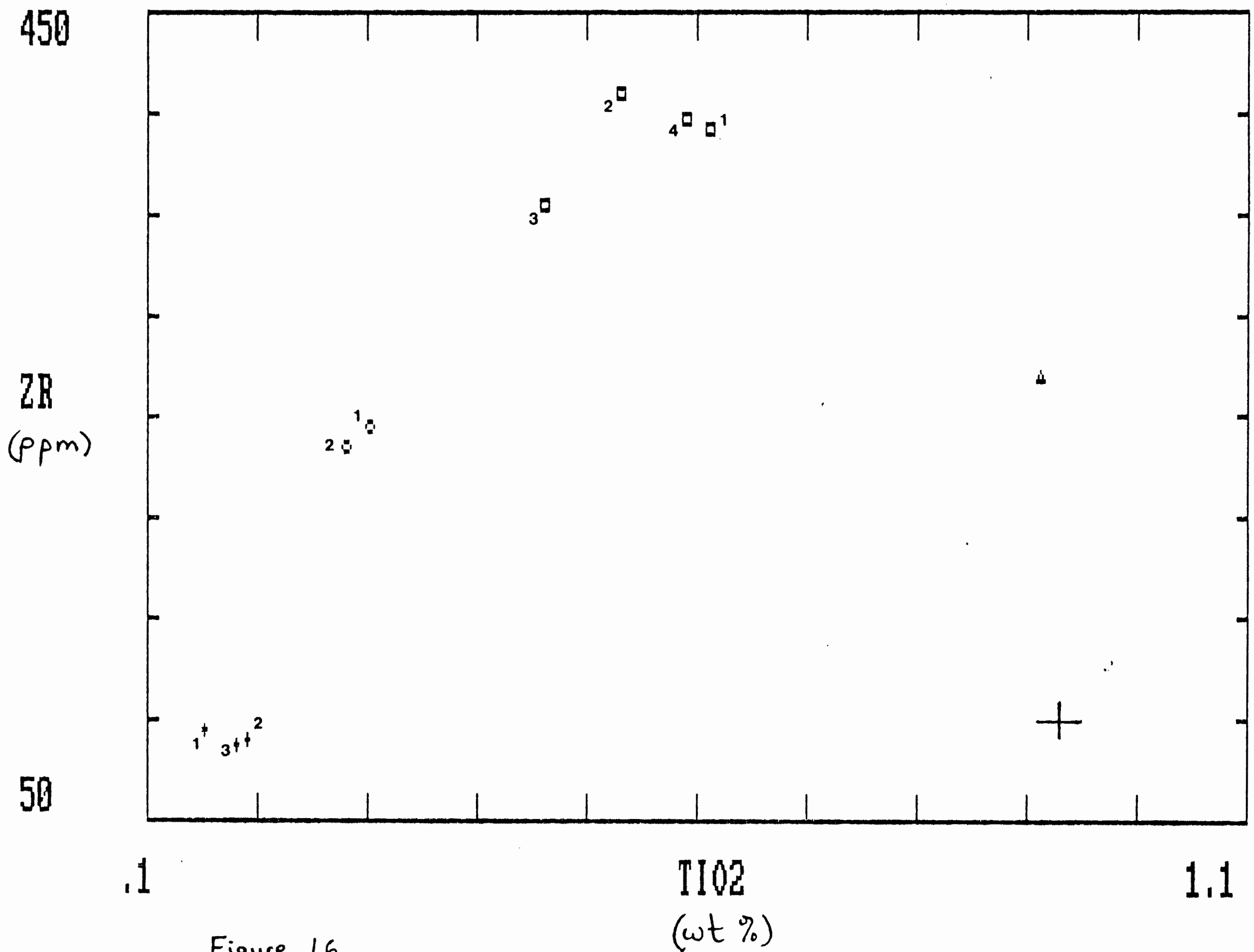


Figure 16

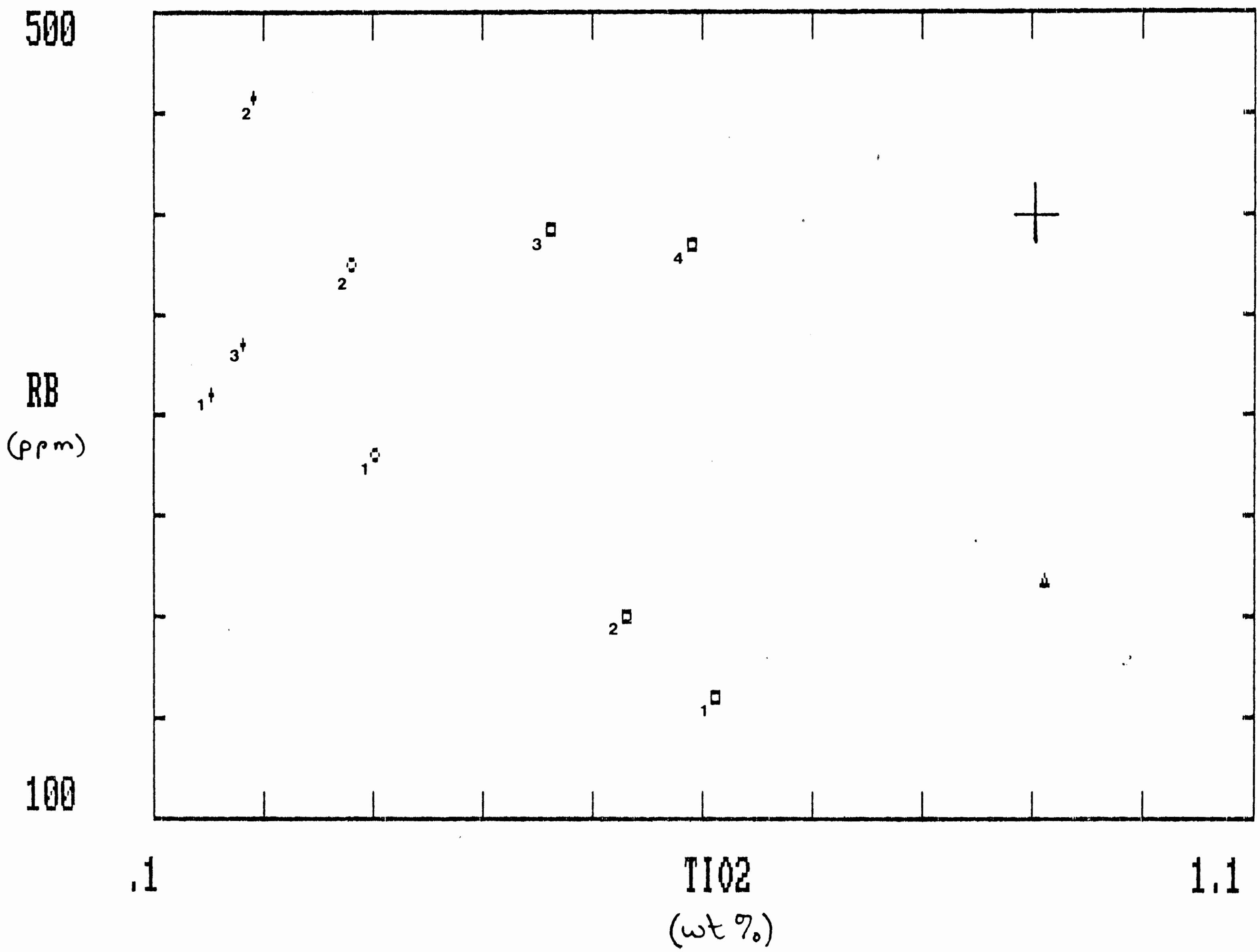
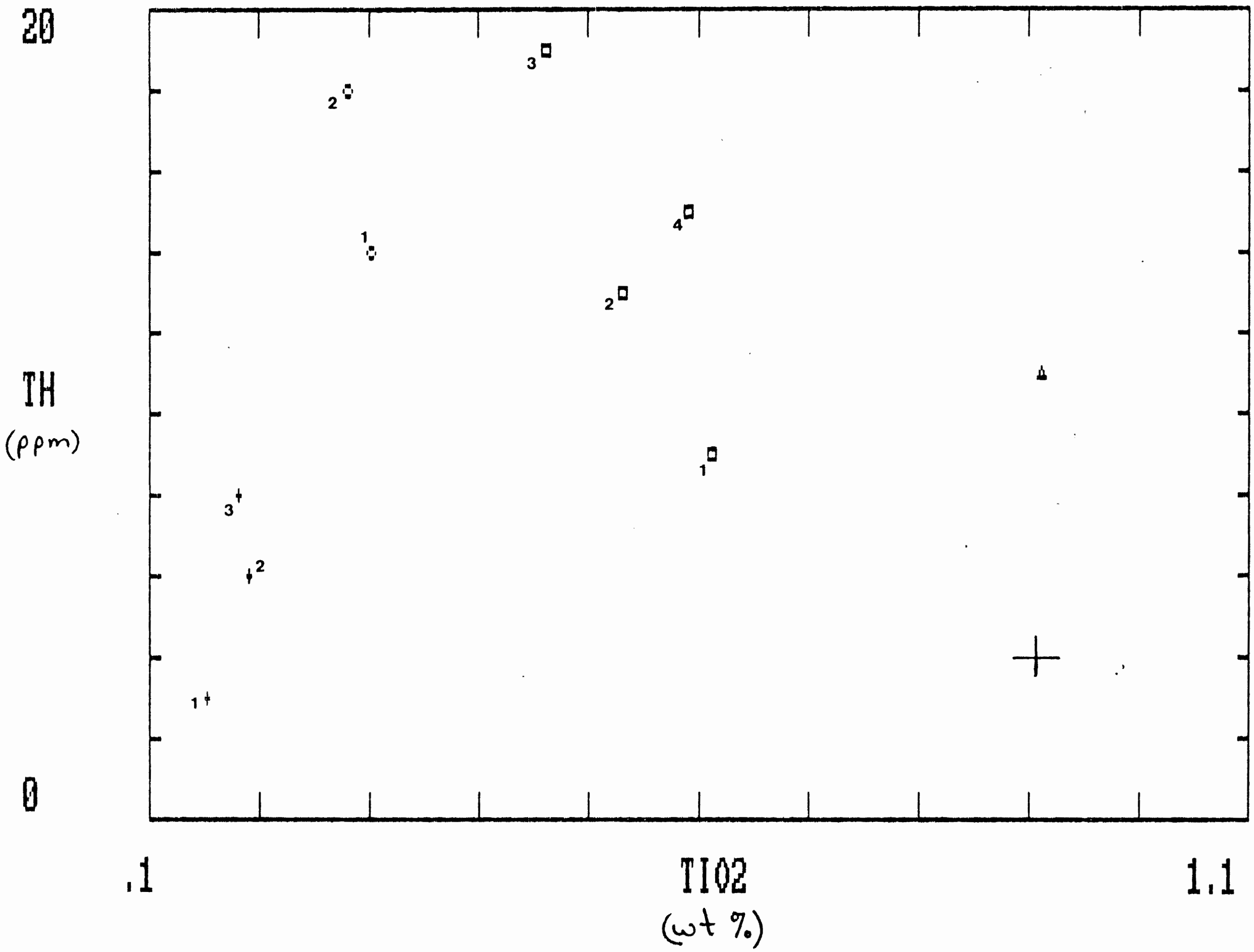


Figure 17



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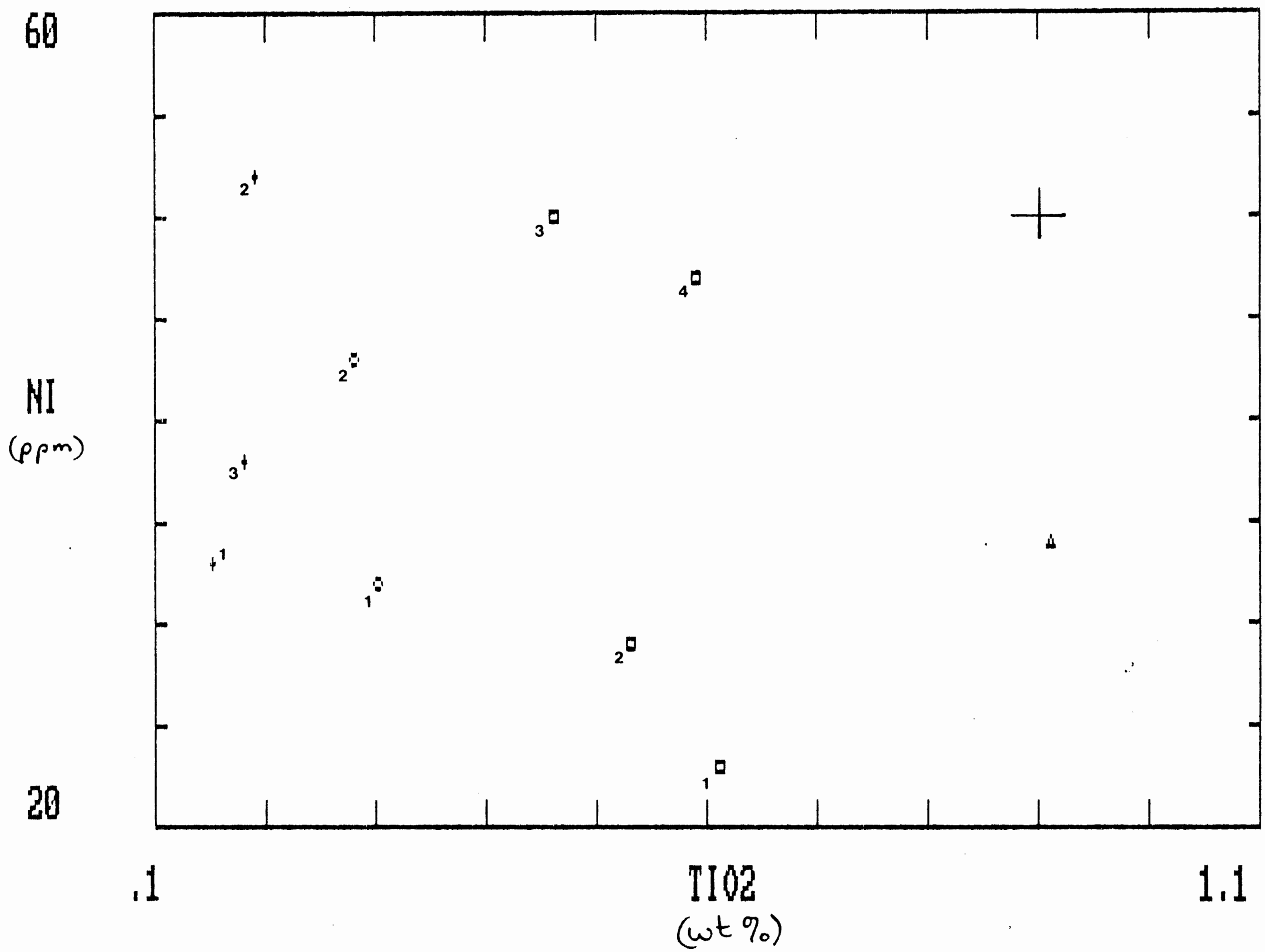
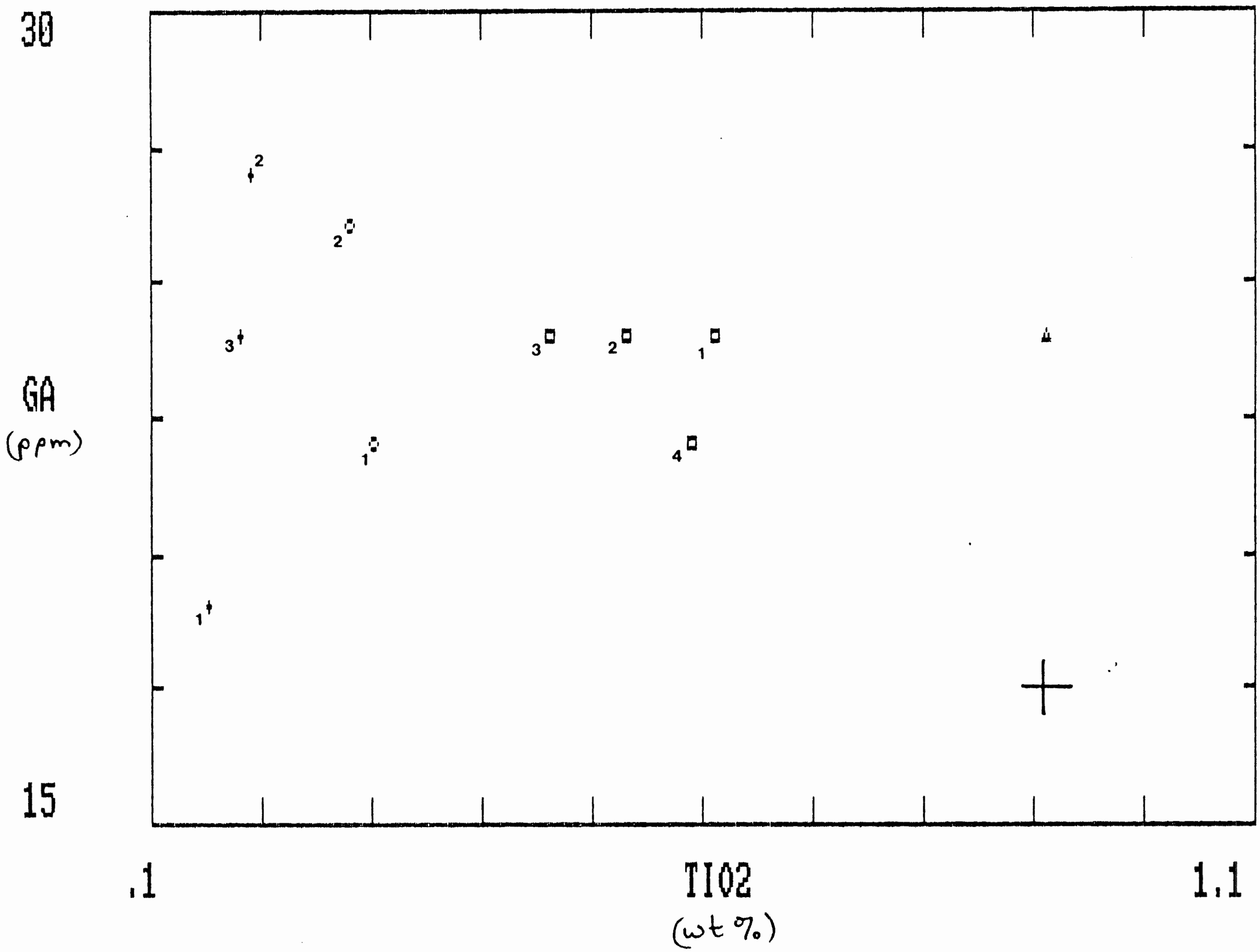


Figure 19



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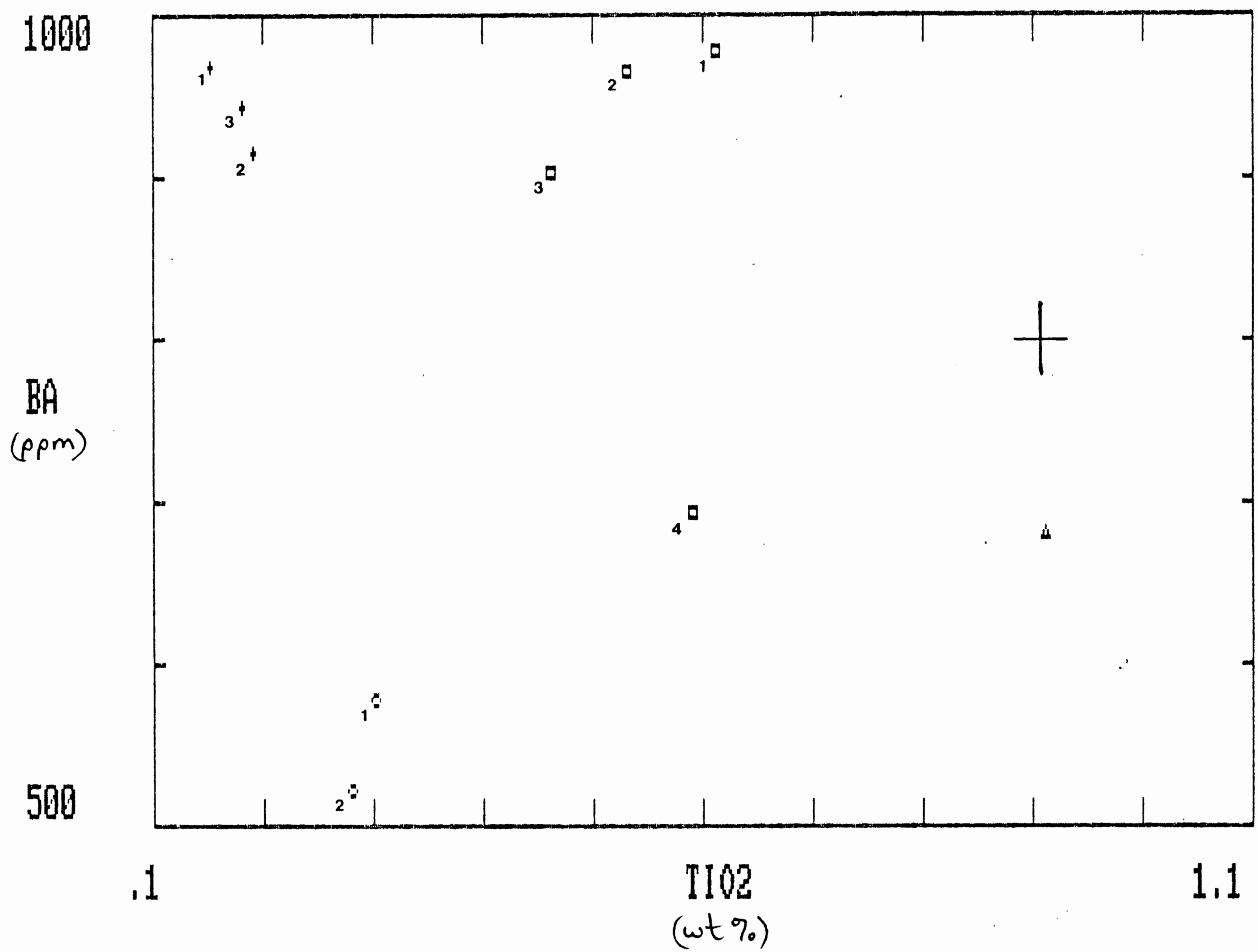

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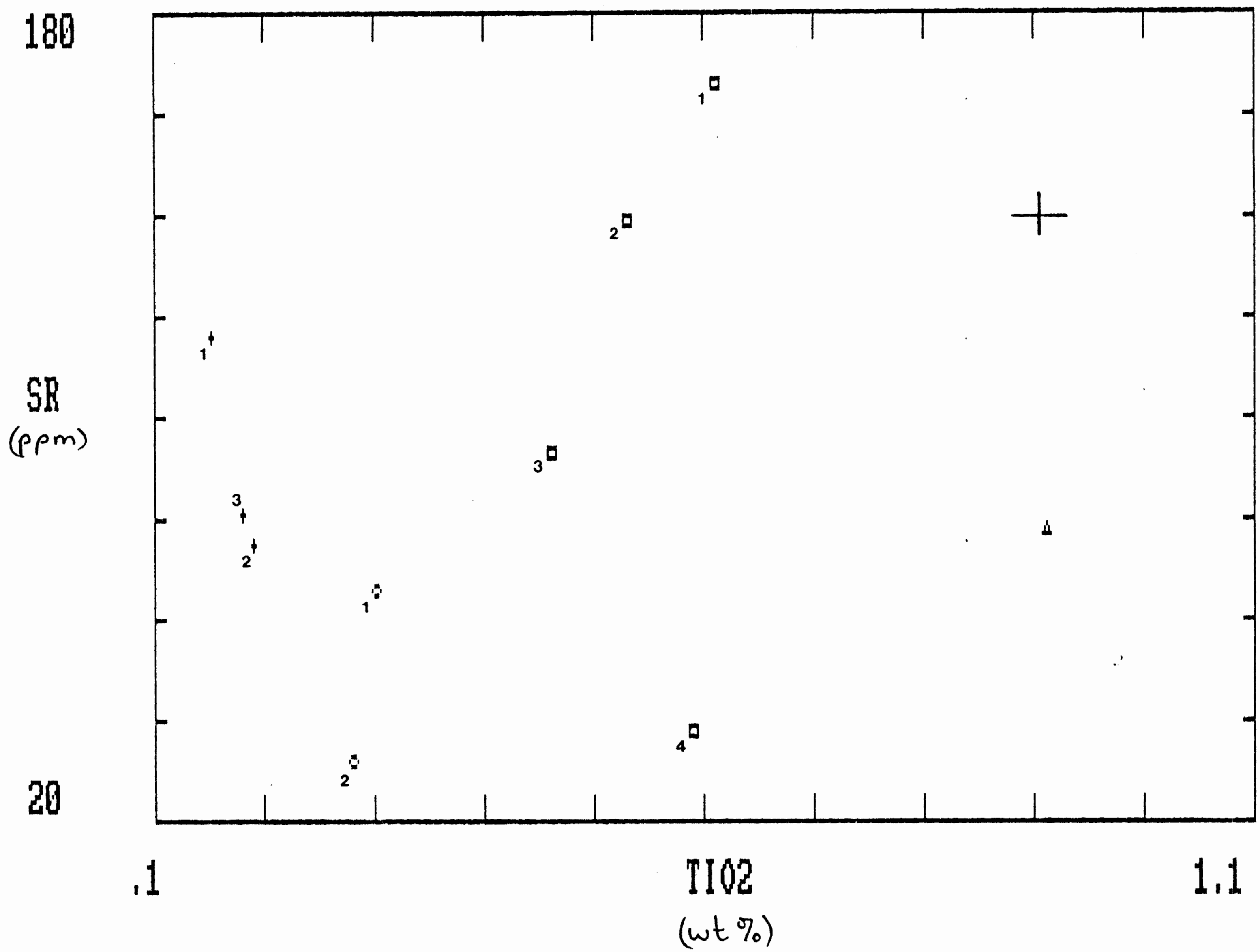

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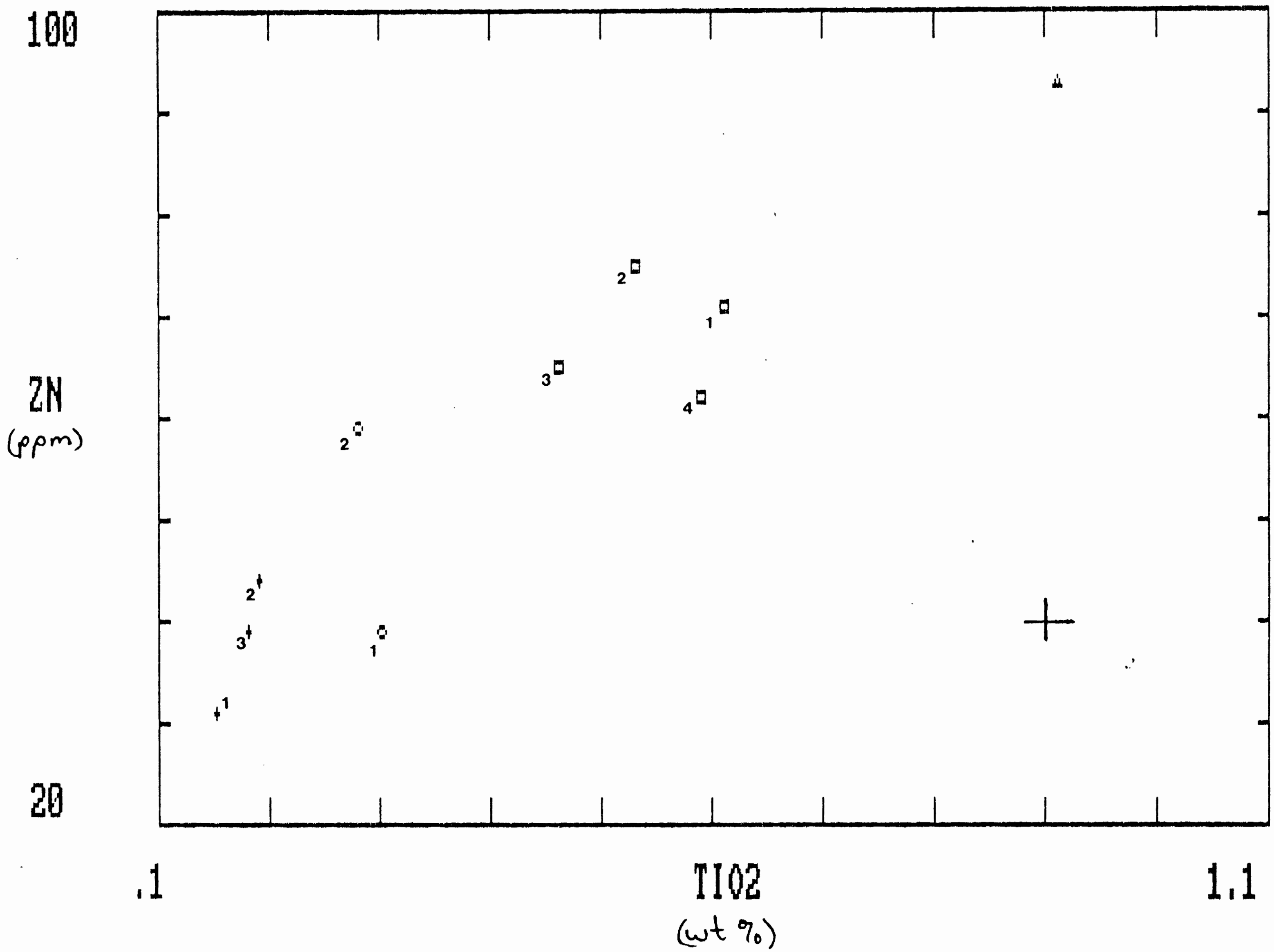

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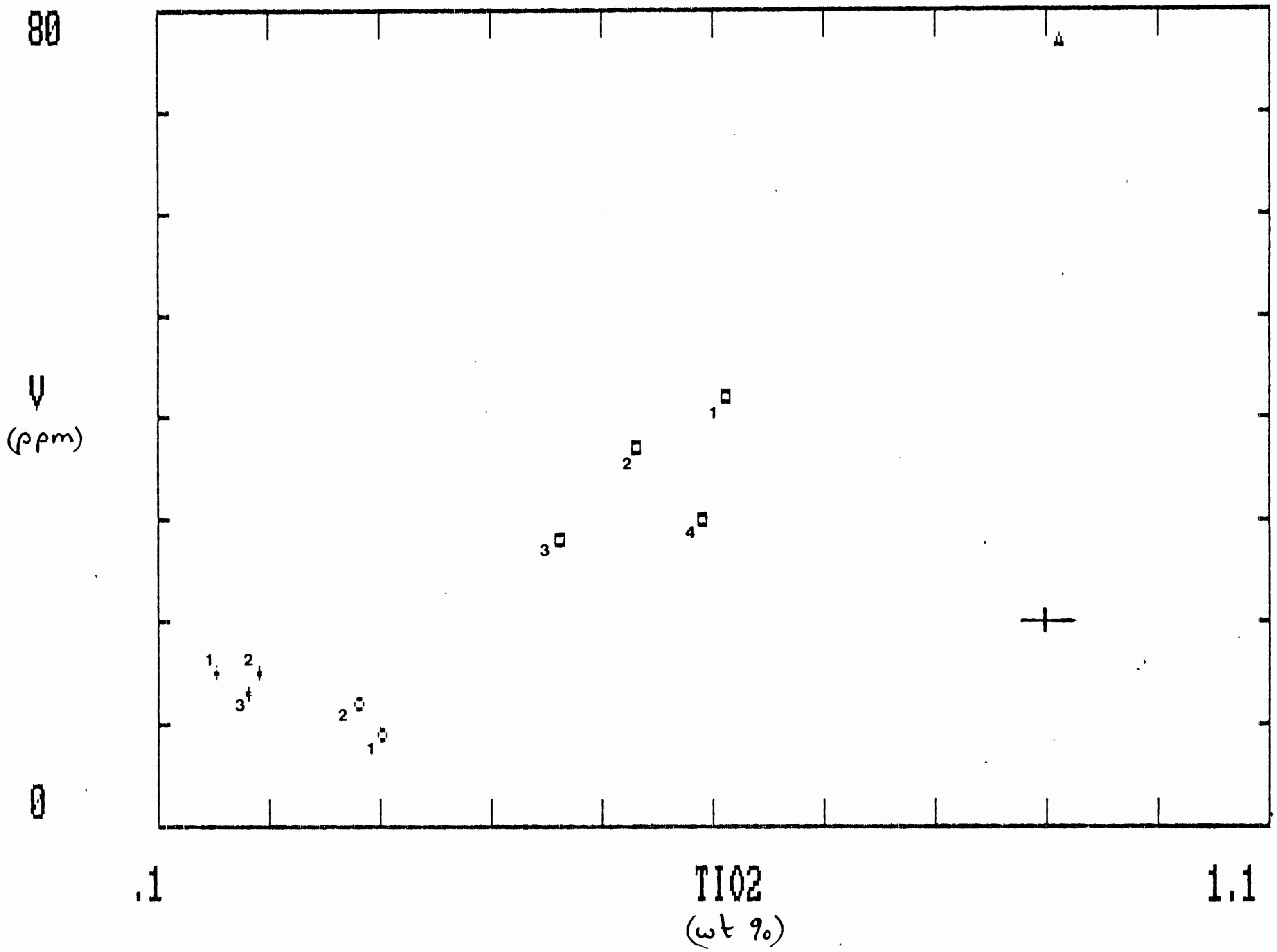

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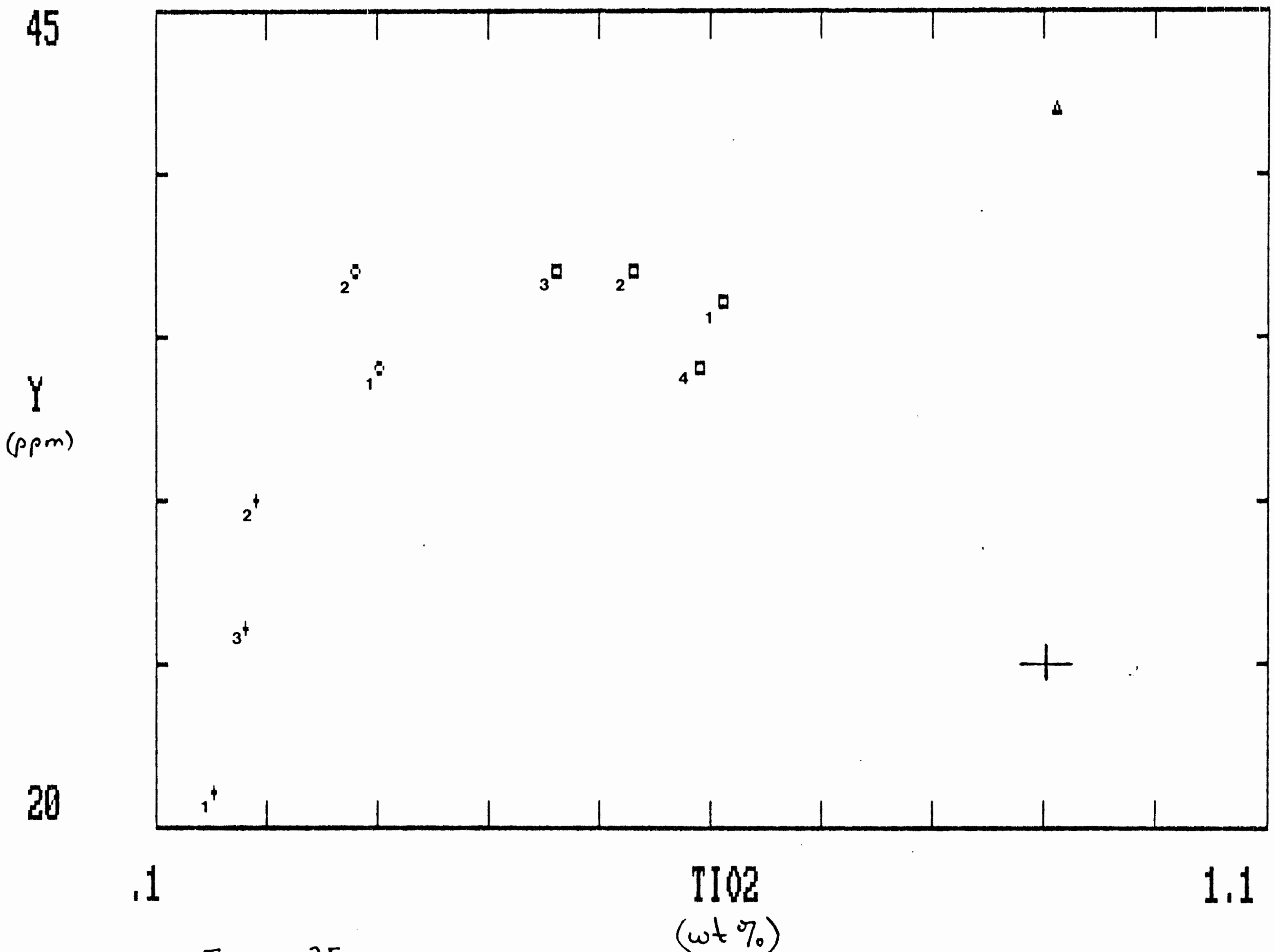

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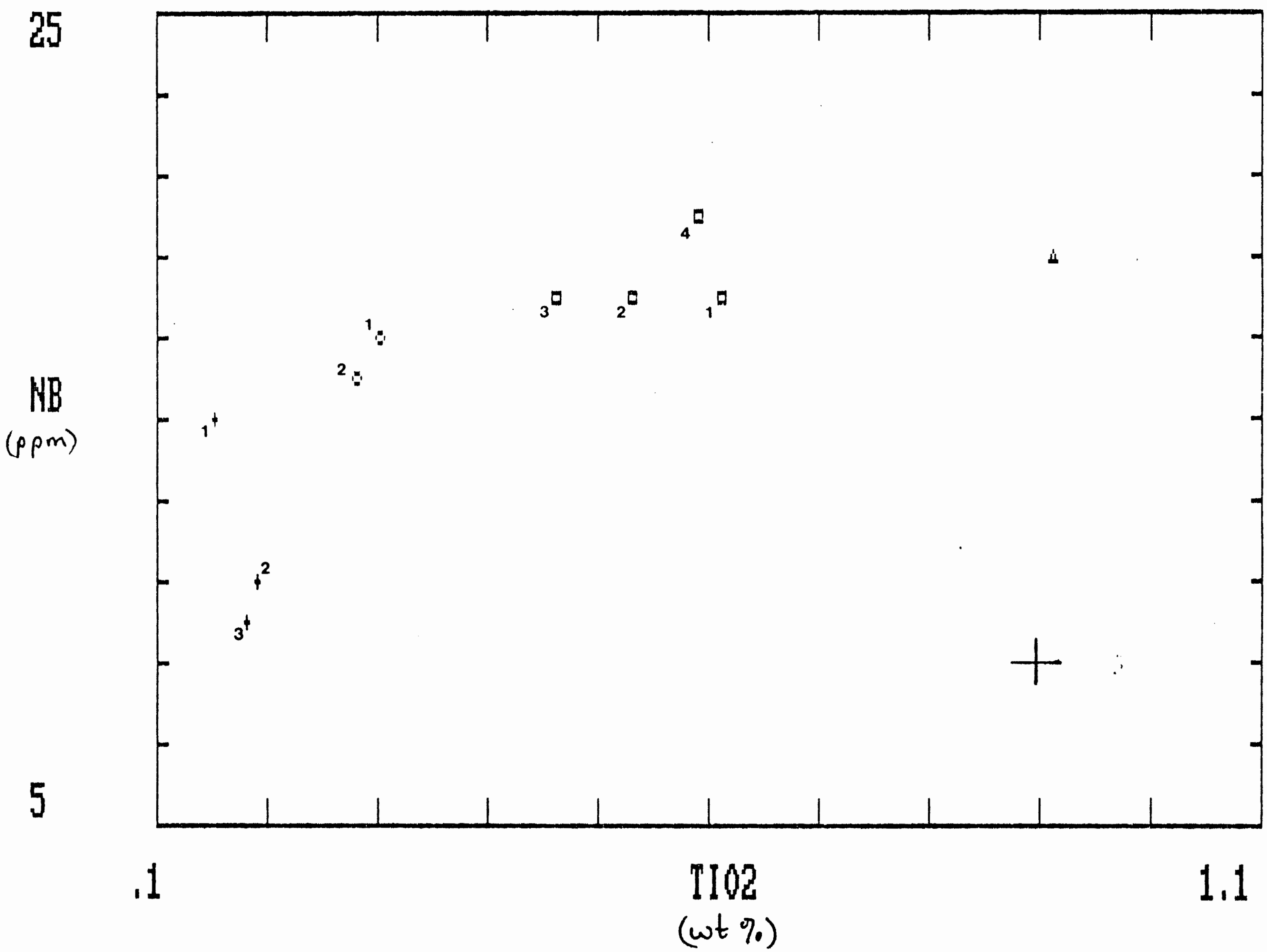

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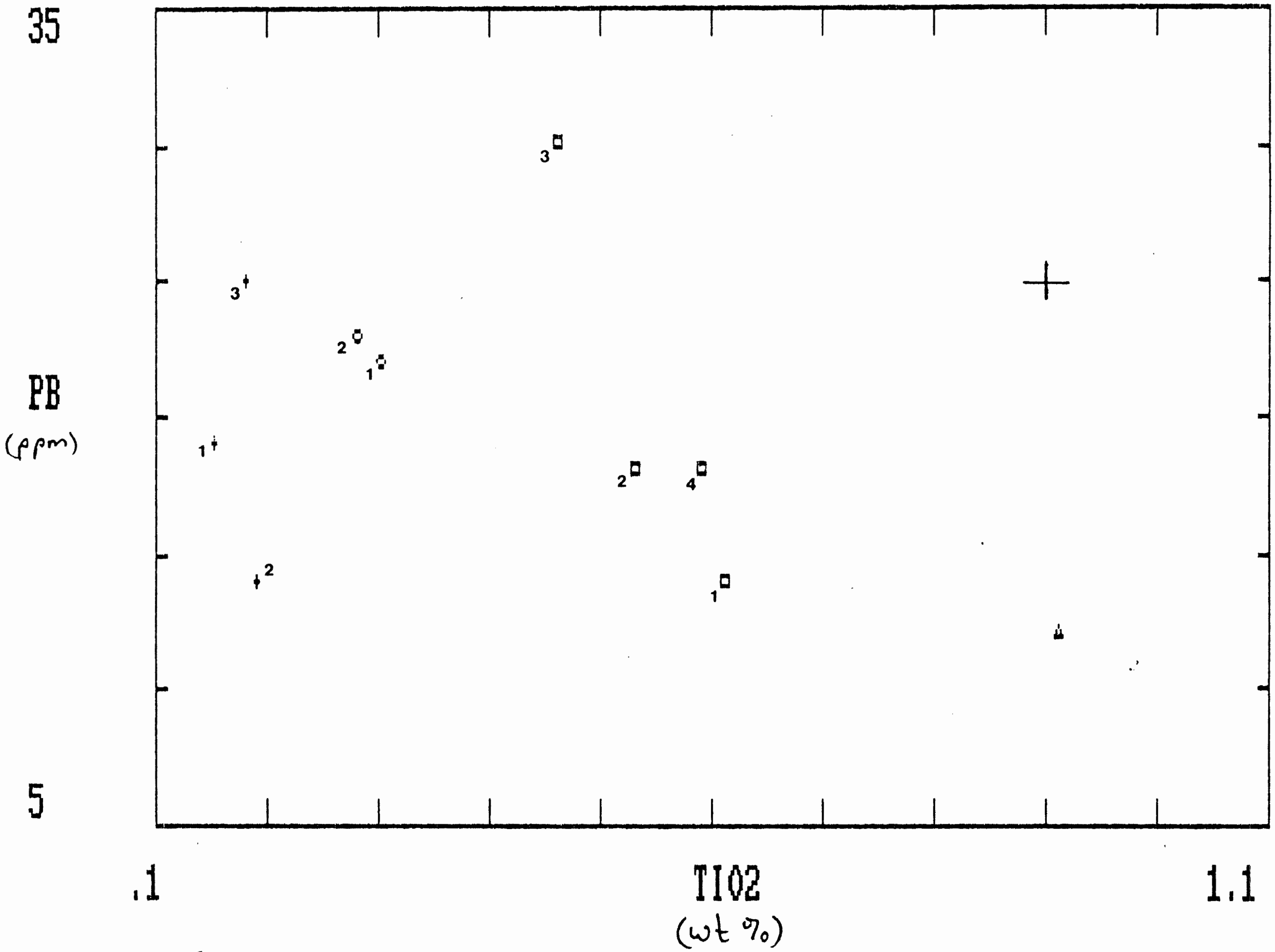


Figure 27

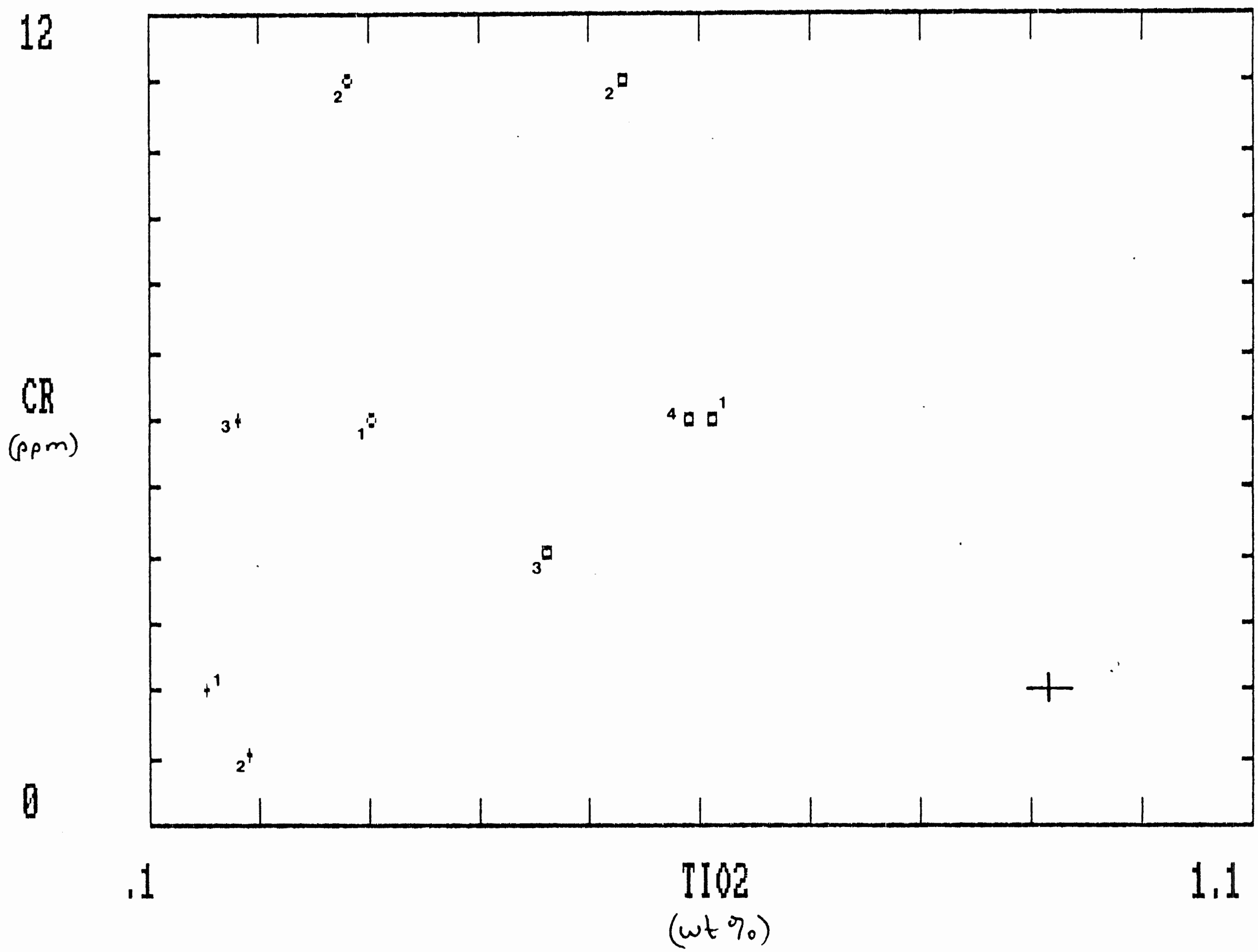


Figure 28

3.3 Aplite dyke unit

Because there is only one sample of the aplite dyke chemical variations resulting from alteration could not be determined. However, the one analysis available shows that the aplite is distinct from the other lithologies. When compared with the other lithologies the aplite dyke is 1) enriched in TiO_2, MgO, Fe_2O_3, MnO, P_2O_5, Y, V, Zn, and Nb, 2) depleted in SiO_2, Al_2O_3, K_2O, Rb, Pb, and Cr.

3.4 Metals Distribution

3.4.1 General Statement

As part of the drilling investigation, Billiton Exploration assayed the economically interesting sections of the cores for Sn, W, Cu, Zn, Mo, and Ag. Fourteen samples were assayed from SOL-1, sixteen from SOL-2, and twenty-two from SOL-3. Lengths of approximately 3m each were assayed.

Additional chemical analyses were done for the purpose of this thesis. Ten powdered samples sent to Saint Mary's University for XRF analysis provide a small amount of additional data on metal distribution.

3.4.2 Assay Results

The results of the Billiton assays and the XRF analyses are presented below. See figures 29, 30 and 31. There are clearly no great concentrations of economically interesting elements. The highest metal concentrations are found in the alteration zones around the breccia, more specifically in the highly chloritized and sericitized zones. However, because each sample covers a length of about 3m, and is not restricted by lithological, textural, or alteration changes and variations, conclusions concerning the exact cause or significance of the concentration values can not be precisely assessed. Time was not available to conduct a quantitative statistical analysis of metal concentrations and associations.

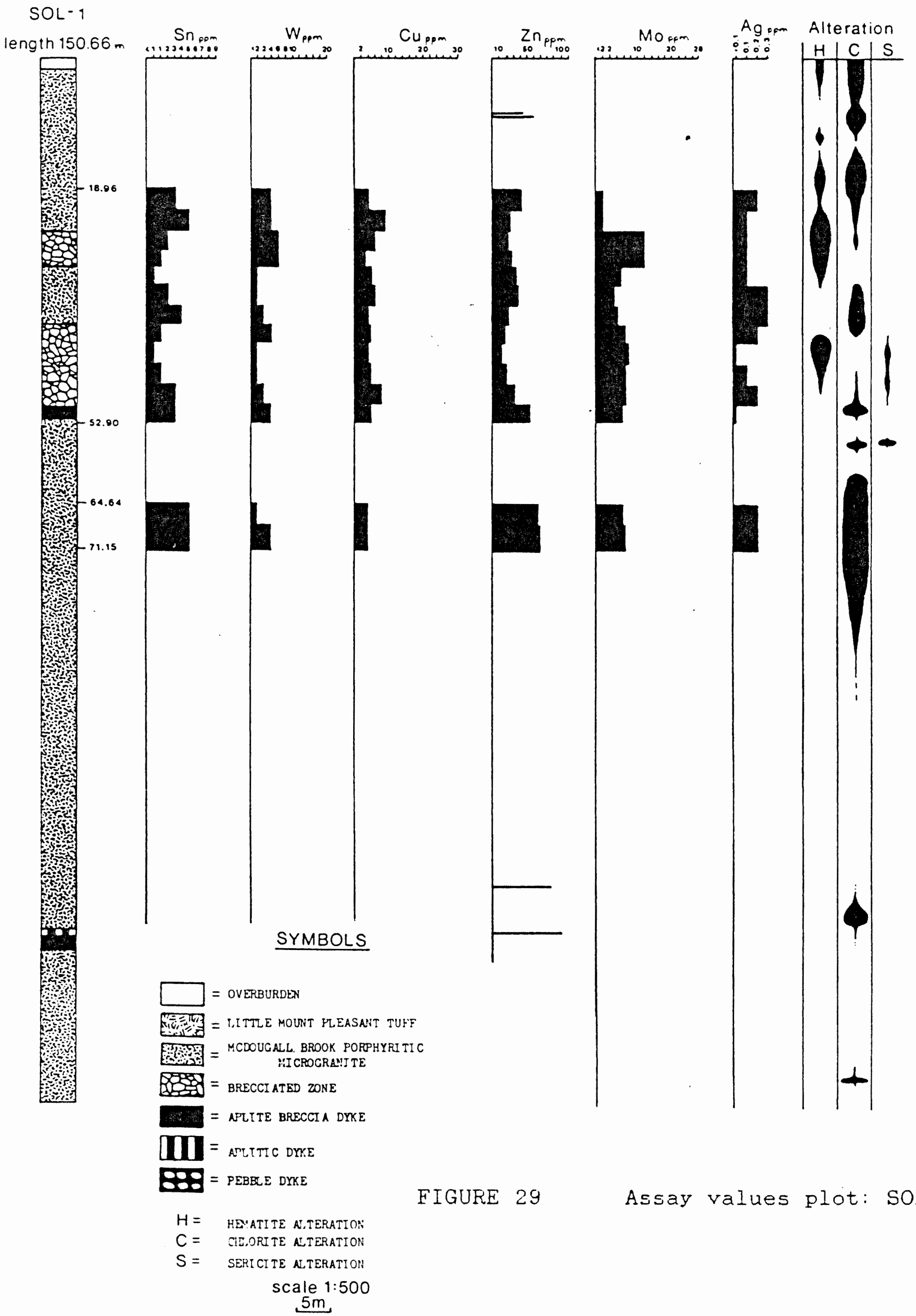


FIGURE 29 Assay values plot: SOL-1

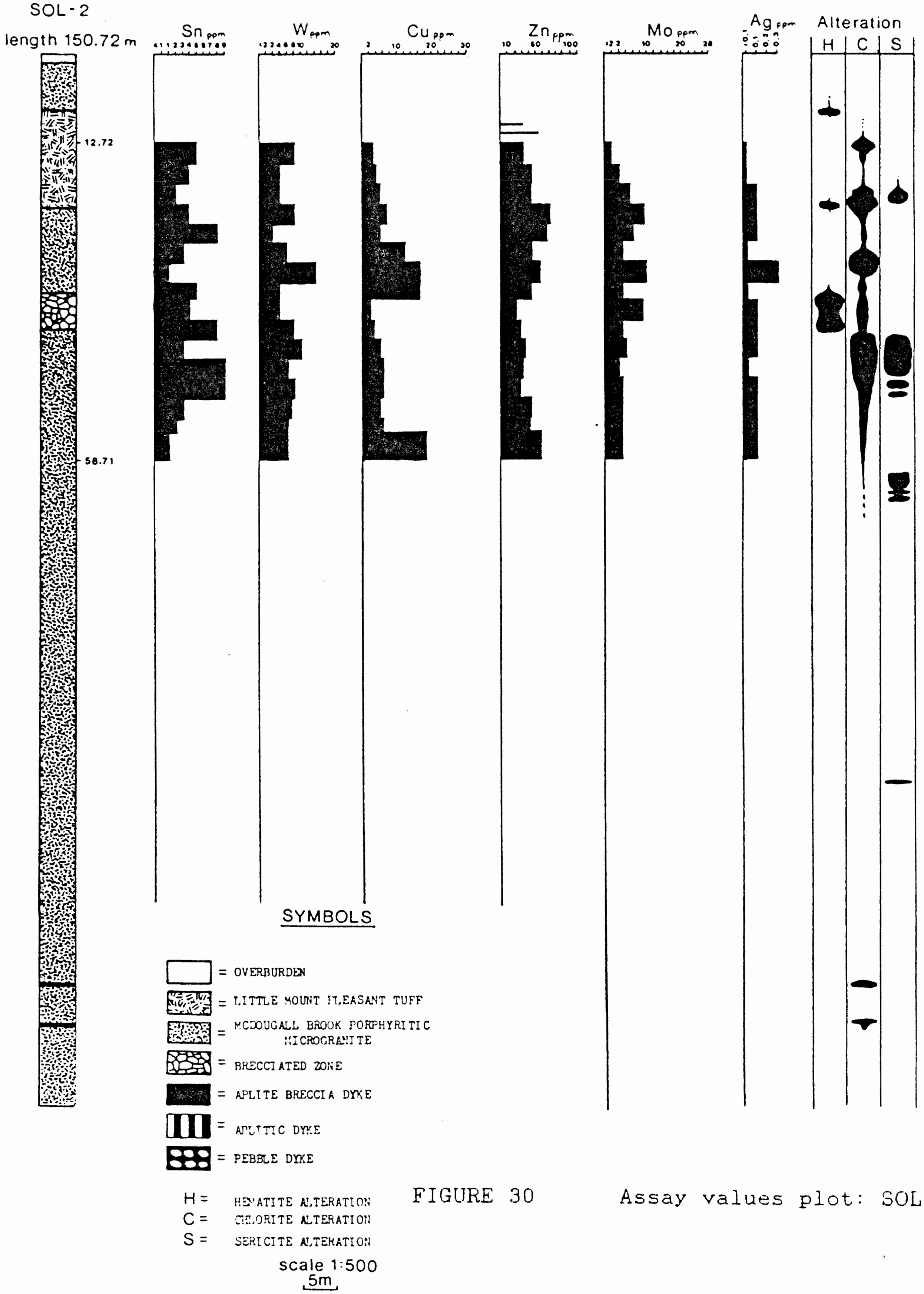


FIGURE 30 Assay values plot: SOL-2

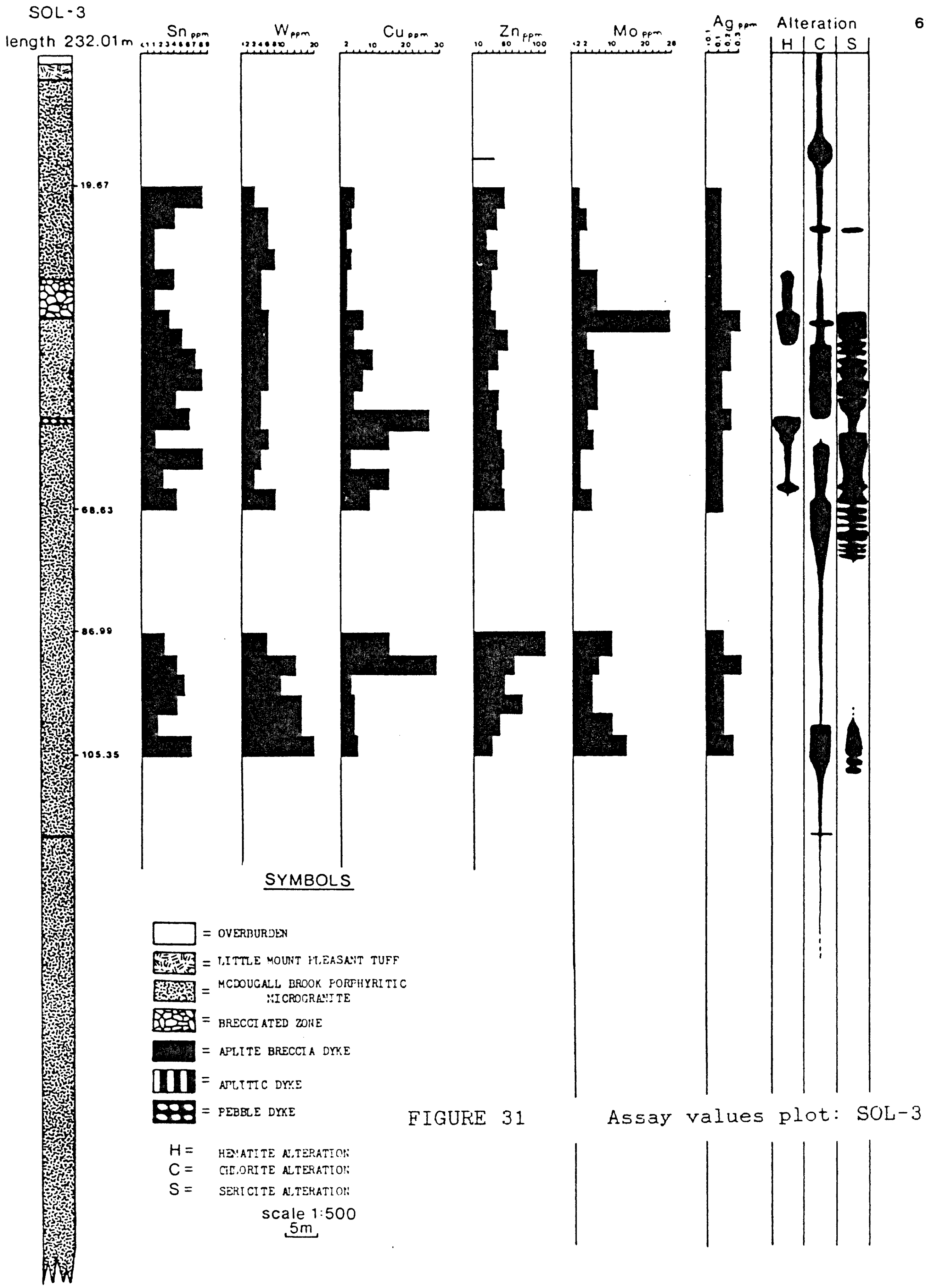


FIGURE 31 Assay values plot: SOL-3

Chapter 4 - Mineralogy and Mineral Chemistry

4.1 General Statement

Most mineral phases were identified optically , however, some mineral compositions were determined by microprobe analysis at Dalhousie University, Halifax, Nova Scotia. Some samples were analyzed simply because they were optically unidentifiable phases. Others, such as chlorite were analyzed to determine their compositional ranges. It was anticipated that these data would permit some general conclusions to be reached concerning the chemistry of the hydrothermal fluids.

4.2 Minerals

4.2.1 Potassium Feldspar

Potassium feldspar is present in the PMG, LMPT, granite enclaves, aplite breccia dyke, and aplite dyke lithologies. The feldspars in all units have been slightly to extensively altered to sericite, chlorite ± small amounts of kaolinite. Of all the units, the aplite dyke contains the freshest K-feldspar, which is orthoclase (Or_{98}) in composition. Orthoclase compositions are also indicated for K-feldspars in the other units (Appendix C). The K-feldspar is commonly found occurring in myrmekite and as large phenocrysts (8.0mm) in the PMG and LMPT units.

4.2.2 Plagioclase

Plagioclase is found in the same lithological units as potassium feldspar. It is also partly altered to sericite and chlorite. Relatively fresh plagioclase feldspars are present in the aplite dyke. Microprobe analyses of these reveal an albitic composition (An <1) (Appendix C). One plagioclase analysis obtained from a PMG clast in the aplite breccia dyke is also albite (An 2). Other analysed plagioclase grains gave low totals and thus their exact compositions are not known.

4.2.3 Quartz

Quartz is found in all rock units but it most commonly occurs in veins associated with the period of intense brecciation. It ranges in size from submicroscopic to 8.0mm across and in shape from anhedral to euhedral with perfect terminations at one end. Color varies from red (hematite inclusion-rich) to clear to milky to green (chlorite inclusion-rich). Growth rings, defined by increases in inclusion concentration, are seen on some of the larger grains.

4.2.4 Chlorite

Chlorite occurs throughout the PMG unit in low concentrations. It most commonly is an alteration product of biotite, however, its highest concentration is in the propylitic alteration halo surrounding the SOL breccia pipe.

Numerous chlorites were analysed in an attempt to distinguish chemically different populations possibly related to hydrothermal fluid evolution. Twenty-three analyses, in total, have been plotted on binary diagrams. Plots include FEO vs MGO (figure 32), FEO vs AL2O3 (figure 33), and FEO vs MNO (figure 34). A ternary diagram of MgO-FeO-Al_2O_3 has also been plotted (figure 35). It appears there are at least two and possibly three or more different populations of chlorite present in the samples studied. Analyses 1-3 show similar compositions (i.e. low Mg, low Fe, low Mn, and high Al, relative to the other chlorite analyses). Analysis 5 shows very little displacement from plot to plot, relative to the other data points, and is somewhat isolated on the plots. Analysis 4, although it has a similar Fe and Mn content, is quite distinct from analysis 5, and seems to fit better with the other analyses which tend to cluster fairly closely. Analyses 4, 6, and 7, are somewhat distinct from the high iron content group. They are all from the same lithology (aplite breccia), and might be grouped together. This may simply reflect a difference in whole rock chemistry as opposed to a distinct generation of chlorite.

The size of the data set does not permit a detailed comparison of chlorite composition with lithology, nor does it permit exact conclusions to be drawn concerning evolution of hydrothermal fluid compositions. However, in the PMG unit some general changes in chlorite chemistry reflect changes in fluid

SYMBOLS

□ = Porphyritic Microgranite.

▲ = Aplite dyke or Aplite Breccia dyke

♦ = Granite enclave

8 = Analysis number

\+ Error range

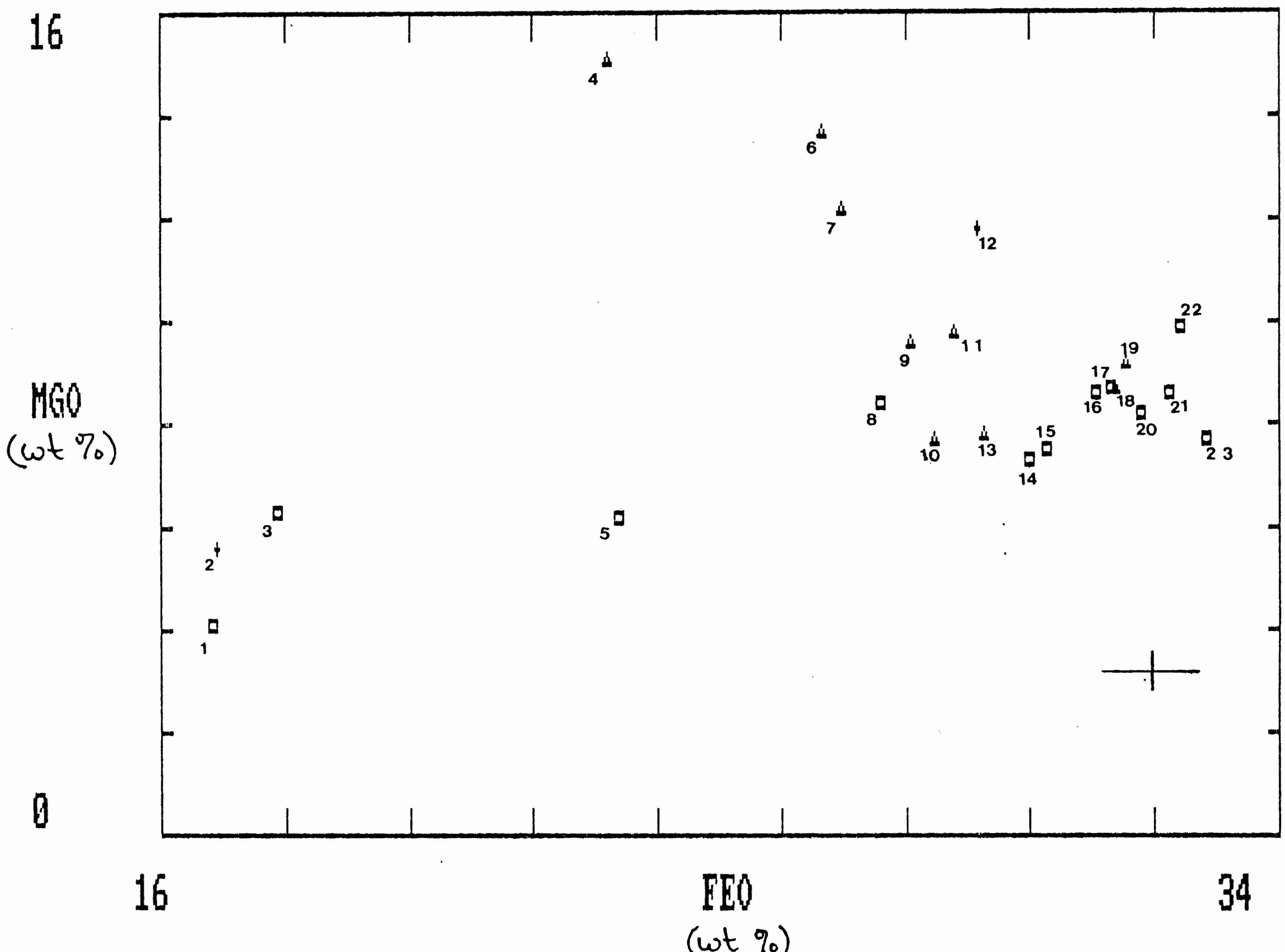
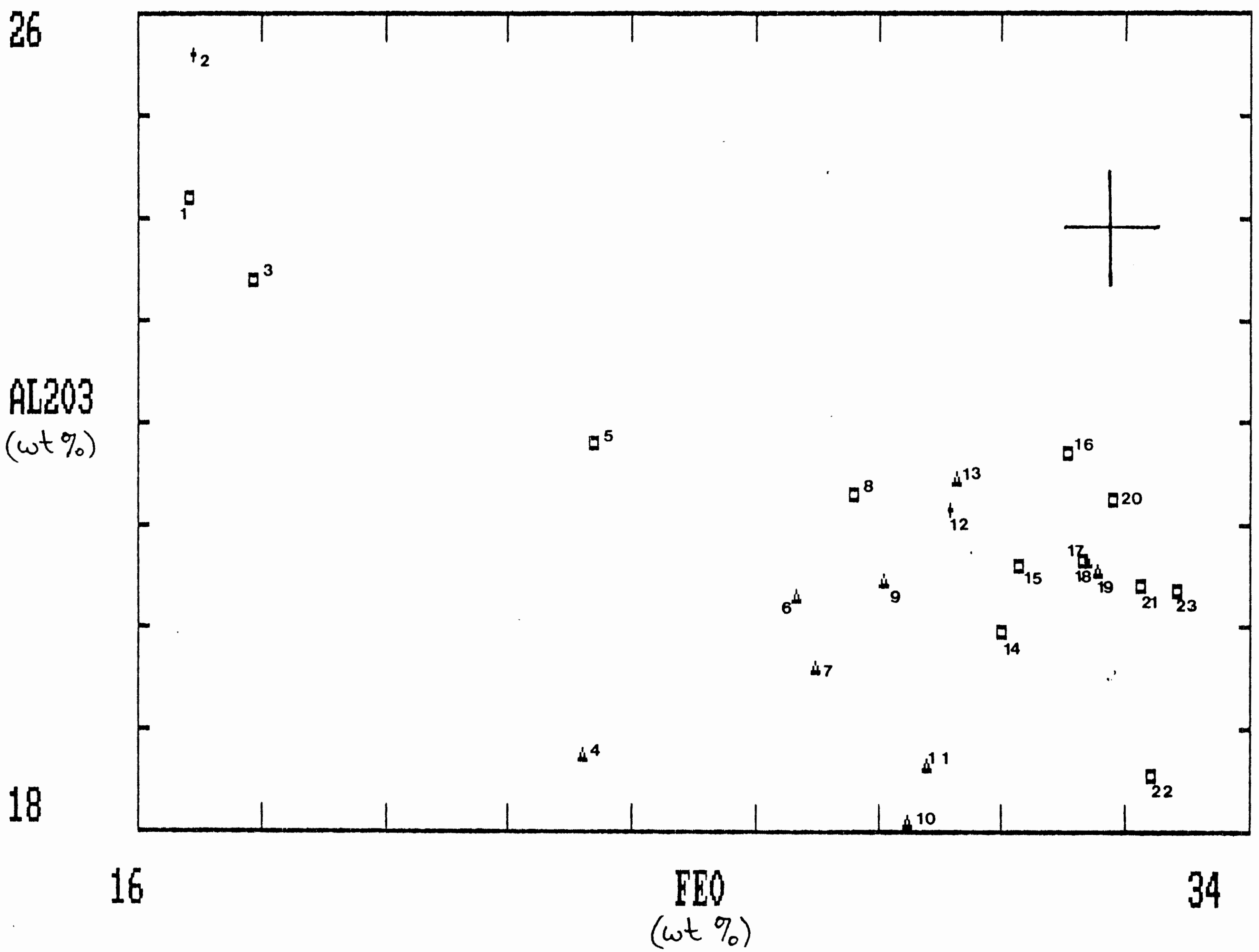

16
MGO
(wt %)
0
16
FEO
(wt %)
34
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23

Figure 32


26
18
AL2O3
(wt %)
16
34
FEO
(wt %)
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
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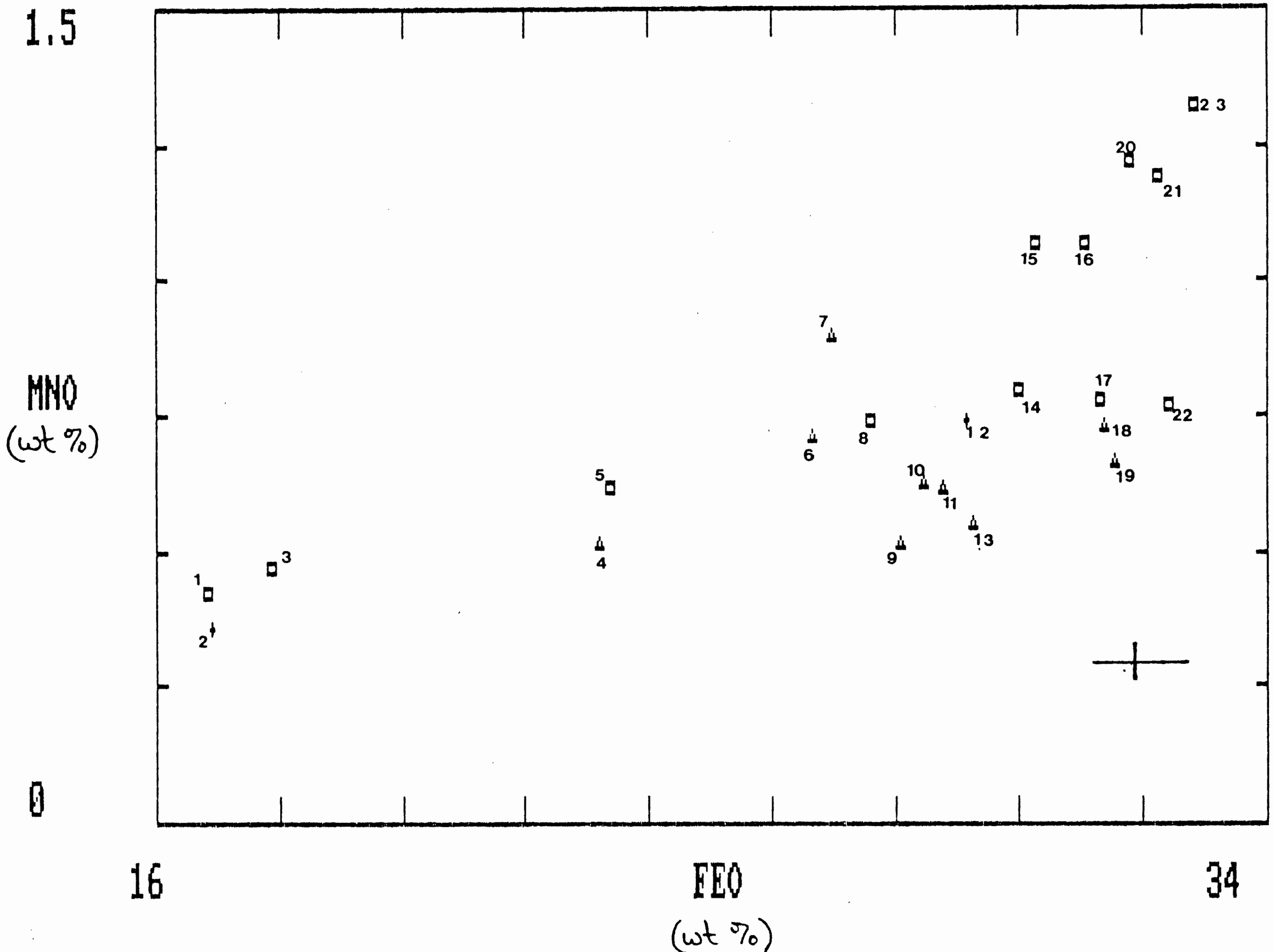
21
22
23

Figure 33


1.5
MNO
(wt %)
0
16
FEO
(wt %)
34
1
2
3
4
5
6
7
8
9
10
11
1 2
13
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15
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17
18
19
20
21
22
2 3

Figure 34

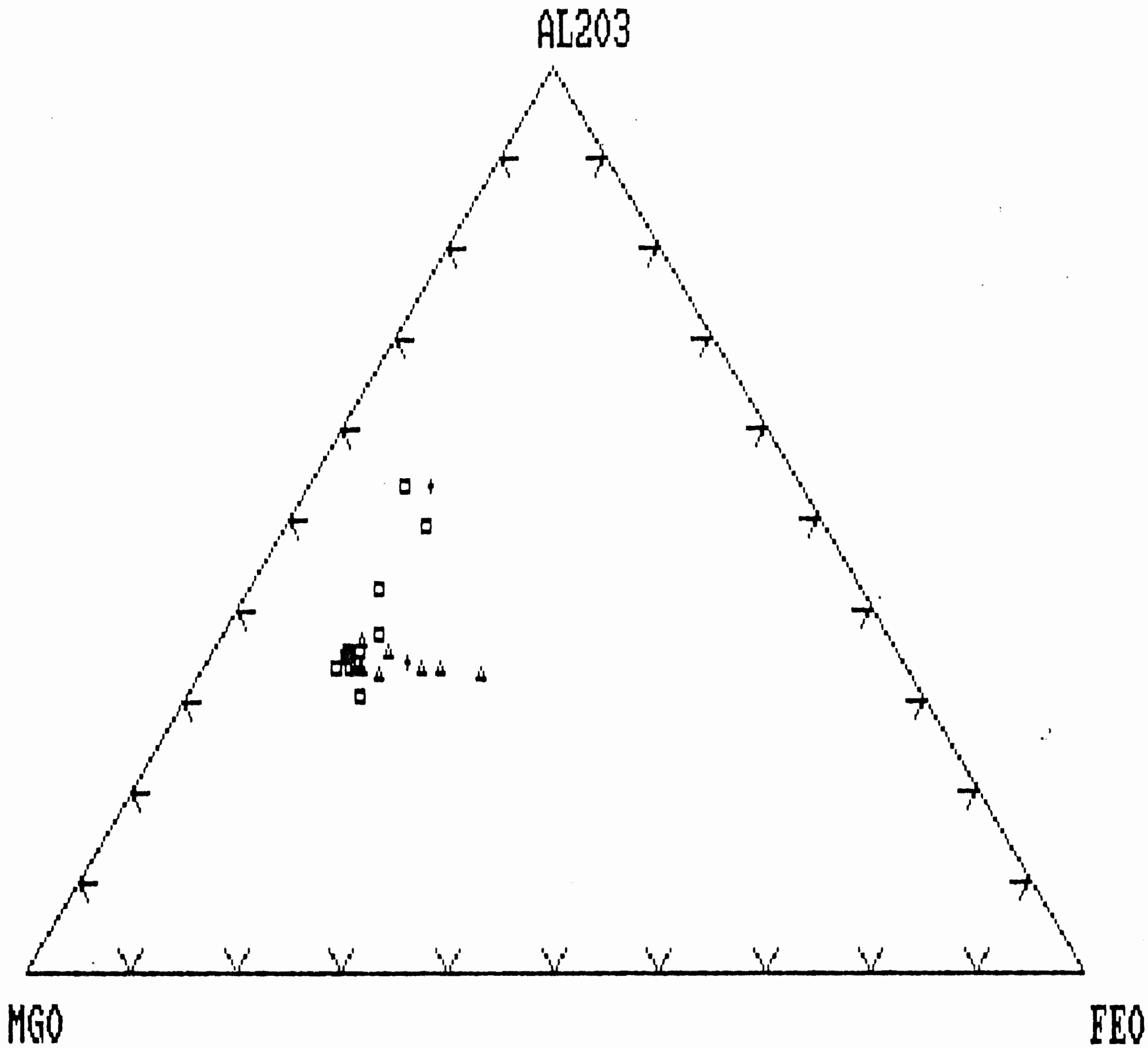

Figure 35

composition. Figure 33 shows a decrease in Al_2O_3 with increasing FeO. Figures 34 and 32 show respective increases in MnO and MgO with increasing FeO.

4.2.5 Sericite

Sericite replaces feldspar widely in the breccia zone. Three zones of intense sericitization are the result of alteration during the latest stages of hydrothermal activity.

4.2.6 Fluorite

Fluorite occurs in veins throughout the brecciated zone and in the PMG and LMPT directly associated with the brecciated zone. These veins formed relatively late in the veining sequence and usually they follow along the paths of weakness created by previous veins. The fluorite of the SOL breccia zone occurs in three different colors, in order of decreasing abundance, purple, clear/ white, and green.

4.2.7 Manganite

Manganese oxide (manganite) is associated with late stage carbonate veining. It occurs as minute blebs and laths in the calcite crystals sometimes so highly concentrated that there is no longer any white color visible. It is possibly an alteration product of rhodochrosite or rhodonite.

4.2.8 Hematite

In the SOL breccia zone, hematite occurs as an alteration product of iron-rich phases, and in distinct veins which have formed during at least two and most probably three different periods of hematite-rich fluid injection.

Oxidation and alteration of iron-rich mineral phases, such as pyrite and chlorite, has produced zones of brown iron oxide staining.

Red hematite veins crosscut the drill core over the entire length except in the deepest part of SOL-3. Veining is most concentrated in the brecciated zone, rapidly becoming less concentrated through the alteration halo and into the relatively unaltered PMG. Color variations and crosscutting relationships have allowed identification of the different periods of hematite injection.

4.2.9 Carbonate

Vein carbonate form in SOL-1 was determined to be calcite from microprobe analysis. The carbonate in carbonate-rich enclaves in the PMG was also analysed on the electron microprobe and determined to be calcite. Carbonate found randomly dispersed in the PMG unit was not analysed but it is proposed that it is dolomitic in composition. If this assumption is true, this would provide a source for iron and magnesium to form the chlorite found in the chloritized zones and possibly explain the depletion of Fe and Mg in the bulk PMG composition as alteration intensifies.

4.2.10 Pyrite

Pyrite occurrence correlates, and is directly associated with the presence of chlorite. Areas which have been the most intensely chloritized contain the highest concentration of pyrite. Pyrite is also found rimmed or partially rimmed by chlorite, with the chlorite appearing to pseudomorph the pyrite as it replaces it. In the hematized areas of the core, the pyrite has been completely oxidized. Scattered pyrite grains are found finely dispersed in the pink, relatively unaltered PMG, but here once again the grains are usually very close to or in contact with chlorite.

Pyrite grains are euhedral, relatively small (up to 2.0mm), and most commonly disseminated. However, clusters of pyrite crystals are not uncommon within chlorite veins.

4.2.11 Accessory minerals

Apatite and zircon occur as accessory minerals in the PMG, LMPT, granite enclaves, aplite breccia dyke, and aplite dyke units. They constitute less than one percent of all units except the aplite dyke of which they make up 1-3%. Zircons are generally less than 0.1mm across and apatite grains ranges from 0.1mm to 4.0mm.

4.2.12 Clays

Detailed description and analysis of clay minerals found in the SOL breccia zone is dealt with in section 5.1.3.

4.3 Discussion

Considering the presence of the secondary iron-rich mineral phases present (chlorite and pyrite), and the extensive hematite veining which is seen in the SOL breccia, it is probably quite safe to conclude that the fluids which brecciated the PMG were very iron rich or have caused remobilization of the iron found in the mineral phases of the PMG, possibly the proposed dolomitic carbonate.

Chapter 5 - Alteration and Genetic Relationships and Associations

5.1 Alteration

5.1.1 General Statement

Alteration seen in the SOL breccia zone is clearly of a hydrothermal metasomatic nature. This has led to breakdown of many minerals, particularly feldspars, and the formation of many clay-rich zones. Physical characteristics of the rock such as colour, texture, and strength have been modified as a result of alteration. Mineralogical changes have also occurred as a result of introduction and removal of elements enriched or depleted in the hydrothermal fluids. As is demonstrated by the changes in mineralogy of the host rocks, there has been an obvious change in the bulk chemistry of the system. Physical changes, mineralogical changes, and some general statements about chemical changes are discussed in the first section of this chapter.

5.1.2 Physical changes

Physical changes in the host PMG resulting from the intense hydrothermal activity are immediately apparent from examination of the drill core.

The most noticeable physical change is intense brecciation and veining of the PMG, however, color variations are also important. There is a large halo of greenish propylitic alteration surrounding the breccia body, generally most intense near the area which is actually fractured, and decreasing in intensity away from this zone. Disseminated pyrite is found throughout the zone of propylitic alteration, becoming more concentrated in the intensely altered regions. Many, but not all, veins crosscutting the drill core have minor zones of propylitic alteration associated with them. Unfortunately, available data do not present conclusive evidence indicating which specific phase(s) of fluid injection have caused this phenomenon.

Iron in pyrite and chlorite in the different lithologies appears to have been oxidized during one or more phases of silica injection. The intensely brecciated zone and other zones surrounding some silica veins have been almost entirely hematized. The hematization is quite local in effect as seen by abrupt changes in colour, from red-brown hematized regions to green chloritized regions through the brecciated zone. Alteration haloes around veins are also very localized, their size depending upon the thickness of the vein.

5.1.3 Mineralogical changes

The mineralogy of the PMG has not changed dramatically. Associated with the propylitic alteration is an increase in modal percent of chlorite (<1% up to 30%) and pyrite (<1% up to 7%) in the host rock and subsequent oxidation of these iron-rich phases has resulted from further alteration. The formation of clay minerals seems to represent the strongest change in mineralogy.

Fifteen clay samples were analysed by XRD, eleven from an intensely altered zone in SOL-3 (40.10m to 66.80m), two from SOL-1 (26.25m and 55.10m) and two from SOL-2 (33.50m and 106.00m). Selections were made primarily on color variations. Analyses revealed very similar clay mineralogies in all samples.

With the exception of palygorskite, this mineralogy is what would be expected from alteration of the PMG (refer to table 1). All samples contain abundant illite/ muscovite, 13 contain albite, 10 contain chlorite, 2 contain hematite, 5 contain orthoclase, 3 contain kaolinite, 6 contain goethite, 3 contain calcite, and 1 possibly contains palygorskite. Samples 56 and 62 are from SOL-1, samples 75 and 77 are from SOL-2, and samples 26 through 37 are from SOL-3.

5.1.4 Chemical Changes

Detailed descriptions of the chemical changes resulting from hydrothermal alteration have been presented in chapter 3.

5.2 Genetic Relationships and Associations

The following is a summary of genetic relationships and associations seen in the three drill holes. The following were determined from macroscopic and microscopic crosscutting relationships. They are arranged in relative order of occurrence and will be used in a later chapter to create a possible genetic history for the SOL breccia body.

sample	quartz	illite/ muscovite	albite	chlorite	hematite	orthoclase	kaolinite	goethite	calcite	palygorskite
85-SD-26	X	X								
85-SD-27	X	X	X	X						
85-SD-28	X	X	X	X						
85-SD-29	X	X	X	X	X					
85-SD-30	X	X	X	X						
85-SD-31	X	X	X	X			X			
85-SD-32	X	X	X			X	X			
85-SD-33	X	X	X	X				X	X	
85-SD-34	X	X	X	X			X	X		
85-SD-36	X	X	X					X		
85-SD-37	X	X	X	X		X		X	X	
85-SD-56	X	X	X			X		X		
85-SD-62	X	X	X	X	X	X				
85-SD-75	X	X	X			X				
85-SD-77	X	X		X				X	X	X

TABLE 1. XRD Analyses for SOL Breccia Zone

-formation of granitic rock found as enclaves/ xenoliths in the PMG; formation of the rock now found as carbonate-rich xenoliths in the PMG.

-extrusion/ eruption of LMPT

-intrusion of PMG into LMPT and other units

-cooling of PMG

-formation of red bands with carbonate centres

-formation of aplite dyke (there is only evidence to suggest that this unit was formed before the aplite breccia dyke, how long after is undeterminable from the core).

-formation of aplite breccia dyke

-major brecciation begins (silicification).

-precipitation of milky white quartz crystals; formation of hematite alteration haloes around some veins and over the majority of the brecciated zone.

-fine grained chlorite precipitation followed by coarse grained chlorite precipitation, with associated pyrite.

-precipitation of clear quartz crystals.

-first phase of hematite veining.

-green silica injection (has clasts of milky quartz and hematite vein fragments (first phase)) (see photo 4 and 5).

-clear silica precipitation; this is the point at which the majority of the fluid injection occurred, brecciation and re-brecciation is quite extensive and dominant (see photo 6); the second and most extensive phase of hematite veining occurs during this period.

-fluorite veining (purple, clear, green) occurs.

-hematite veining (third phase)

-carbonate veining

-formation of clay zones found in the drill core.

-alteration of feldspars in PMG on a regional scale (sericitization).

-erosion

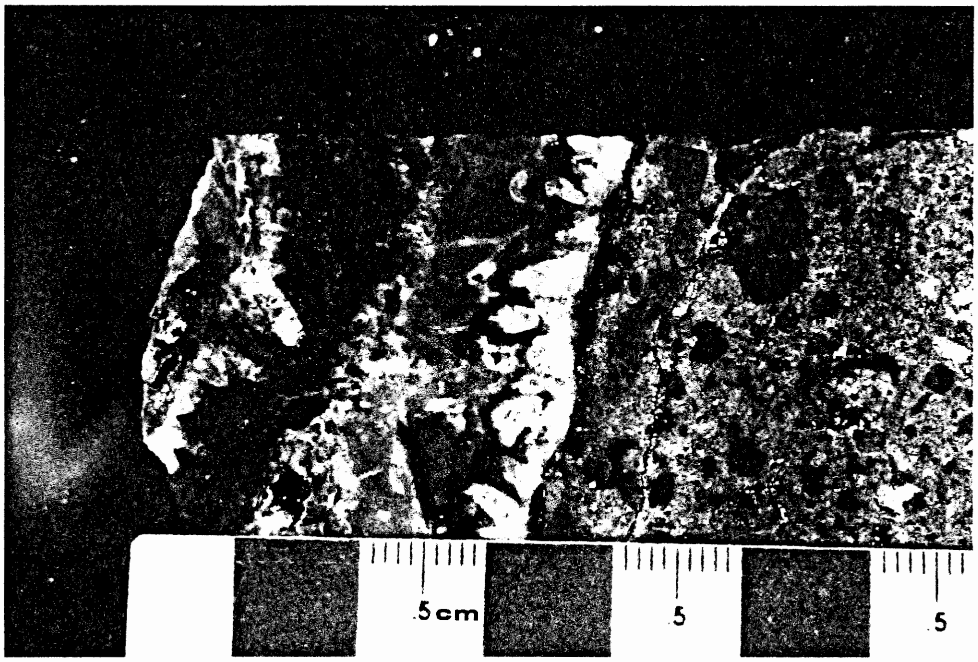

Photo 4. Complex veining history seen in sample 85-SD-47A.

Photo 5. Surface sample illustrating at least two different stages of brecciation.

Photo 6. Minor stages of brecciation are visible, most have preceded the fluorite veining.

CHAPTER 6 - GENERAL DISCUSSION

6.1 Proposed genetic history

Combining observed genetic relationships and relative timing of events with general ideas and concepts presented in the literature on hydrothermal brecciation in volcano-plutonic arcs, a possible genetic history for the SOL breccia zone is proposed.

Formation of the granite enclaves in their source area, the St. George batholith, during the mid to late Devonian is the earliest event which has occurred and/or can be determined from the diamond drill core. Carbonate-rich xenoliths also found in the PMG must have been formed before or roughly at the same time as the granite enclaves. The primary mineralogy of the carbonate-rich enclaves is believed to have been different from the present mineralogy which is probably almost entirely secondary in nature.

Although many other events have occurred within the caldera complex, the next event recorded in the drill core is the extrusion/eruption of the LMPT. This, as well as other units, in the area were later intruded by the PMG unit in the early Mississippian. It is believed that at some point during the cooling history of the PMG, early fractures, and possibly veins, formed which were altered and became the red K-feldspar-rich bands with carbonate-rich centres seen scattered over the length of core. This occurred sometime before the commencement of silica veining, possibly while the PMG still had some heat left in it to enable it to alter the original veins. As cooling of the PMG magma continued, an overpressuring of volatile-rich fluids developed in the final melt of the PMG. It is not certain, but evidence would seem to suggest that the formation of the halo of propylitic alteration in the surrounding PMG and LMPT occurred prior to the subsequent injection of the aplite dyke unit and formation of aplite breccia dyke. This is suggested by the presence of unchloritized clasts of PMG in the aplite breccia dyke, a section of which is located within a zone of intense chloritization, This suggests that either the aplite breccia was emplaced subsequent to chloritization or the aplitic matrix has effectively sealed off the clasts from the subsequent alteration. The former seems to be the most reasonable explanation.

Following the above events the major episode of brecciation, silicification, and veining began. The relative timing sequence of the crosscutting network of veins and different episodes of brecciation was examined and the following sequence of events is proposed.

The first distinct event was precipitation of milky white quartz crystals, seen in sample 85-SD-47A. It appears this event was responsible for the formation of localized hematite alteration haloes around some veins and over the majority of the brecciated zone. Following this there was precipitation of fine-grained chlorite followed by precipitation of coarse-grained chlorite. Pyrite is found enclosed in many chlorite veins and thus appears to be directly associated with precipitation of chlorite and chloritization of the surrounding host rock. Following this another fluid was injected which resulted in the precipitation of clear quartz crystals seen in sample 85-SD-47A. Immediately following was the first phase of hematite veining. The first period of brecciation resulted in injection and precipitation of green silica containing angular clasts of milky quartz, first-phase hematite vein material and PMG fragments.

Veining resulting in precipitation of a white and clear silica mix occurs at this stage where the majority of the fluid injection occurred. A second stage of major brecciation and subsequent minor, localized re-brecciation, and hematite veining is quite extensive at this stage.

Numerous fluorite veins crosscut the second phase of hematite veins. Purple, clear, and green fluorite is present, in order of decreasing abundance. A third phase of hematite veins crosscuts the fluorite veins; the fluorite veins are in turn cut by carbonate veins with associated manganite.

The latest stage fluids resulted in low temperature alteration and the formation of intensely altered sericite-rich clay zones.

Sometime following cessation of hydrothermal alteration in the SOL breccia zone there was an episode of regional clay alteration (sericitization) of feldspars in the PMG. This was followed by erosion of the region to its present day level. It is not known how much of the system has been eroded away but estimates for the Mount Pleasant breccia pipes suggest at least 450m (Parrish and Tully, 1978).

6.2 Physical Conditions

Although no supporting quantitative data were collected in this study, it is quite apparent, when the mineralogy, petrology, chemistry, and physical appearance of the brecciated zone are examined, that P-T conditions during the formation of the breccia pipe were very similar to those of an epithermal system. Having no genetic connotations, this would imply temperatures between roughly 50 and 300 C, and pressures ranging from 0 to 1 kb. Waning of temperature in the system and in brecciating fluids is seen in the progressive change of vein mineralogy through time.

6.3 Formation Mechanism

Fluid pressure in excess of lithostatic load plus rock tensile strength must exist for hydraulic fracturing to occur (Nelson and Giles, 1985). Brecciation is attributed to violent release of magmatic-hydrothermal fluids from cooling stocks. Fluid liberation during second boiling, followed by decompression of the released fluids (Burnham, 1979, 1985), is also effective in explaining the brecciation. Norman and Sawkins (1985) explain the unmineralized East breccia zone in the Tribag breccia pipes as forming by a process analogous to that described by Burnham (1979) for porphyry copper systems. This same process, based on somewhat limited data, is proposed for the SOL breccia zone. Fracturing resulted from volatile over-pressuring generated by exsolution of hydrous vapour from a cooling water-saturated magma. Such explosive-like fracturing events would generate a wide range of fragment sizes, such as seen in the SOL breccia pipe, would rotate the fragments, rounding them somewhat, and would mix them on a local scale . Possible surface venting would result in rapid decreases in pressure and initiate rapid precipitation of minerals from fluids, which would seal the hydrothermal-magmatic system. This would result in increasing pressure again, and thus, the multiple episodes of brecciation and mineralization seen in the SOL breccia could occur.

The SOL breccia is clast supported. This fact further supports the mechanism of formation outlined above. Limited open-space filling occurs in breccias formed by this mechanism (Burnham, 1979) as opposed to those formed by collapse into open space (Norton and Cathles, 1973).

6.4 Economic Potential

As was the conclusion of Billiton Exploration Ltd. in 1982, there is no real economic potential for the SOL breccia zone. Assay values determined in 1982, additional metal values on whole-rock powders determined by XRF analysis for this thesis, and an Au assay (McCutcheon, pers. comm.), have shown no economic concentrations of Sn, W, Cu, Zn, Mo, Ag, Pb, Ni, Cr, or Au.

When compared with the mineralized breccia pipes of the North and Fire Tower zones at Mt. Pleasant, there seem to be distinct differences in the mechanism of formation and evolution of the two. Norman and Sawkins (1985) describe how differences in hydrothermal processes can affect whether a breccia body will become economically mineralized or not. Conditions described for unmineralized breccias seem to best fit the observed properties and characteristics of the SOL breccia zone.

Sillitoe (1985) states that less than 50 percent of breccias in any given cluster of pipes will be ore-bearing. Although the SOL breccia is the only known pipe in the area and likely is the only one that exists, the possibility of other potentially mineralized breccia pipes in the immediately surrounding area should not be entirely dismissed. However, the chance of finding such economic mineralization is very low at best.

Instead of being homogeneously mineralized, many breccias contain only restricted volumes of ore-grade material; ore may be restricted to portions of the interior of the pipe (Sillitoe, 1985). In the Fire Tower and North zones economic minerals are Mo, W, and Sn, with Sn being found in greisens, and Mo and W minerals most concentrated in the highly brecciated part of the zones. Results from the SOL breccia show higher values in the alteration zone around the highly brecciated zone than within it. This may imply that mineralization exists in the SOL breccia zone but has simply not yet been recognized.

6.5 Possibility of Other Breccia Pipes in the Area?

Considering the manner in which the SOL breccia zone was found, (while bulldozing a logging road) it does not seem unreasonable that there are many other breccia pipes within the caldera complex. A review of the literature on hydrothermal breccia pipes, indicates that occurrences of two or more pipes within a caldera complex is quite common (Sillitoe, 1985; Atkinson et al., 1982; Wright, 1983; Norman and Sawkins, 1985). It would not seem that the Mount Pleasant caldera complex should be any different.

6.6 Pebble Dykes?

In hydraulic fracturing at depths of 2 to 5 km, energy is usually dissipated within fractures and by stockwork brecciation. However, portions of the overpressured fluid may flash and drive towards the surface along cracks, perhaps resulting in features such as pebble dykes (Nelson and Giles, 1985). It is quite possible that a similar event occurred in the SOL breccia zone and resulted in the formation of the proposed pebble dyke seen in SOL-3 at 54.80m.

6.7 Comparison of SOL breccia to the Mount Pleasant breccia

Definite similarities exist between the SOL breccia and the Mount Pleasant breccia. A brief summary of the W-Mo orebody in the Fire Tower breccia at Mount Pleasant has been extracted from Kooiman et al. (1986) and is presented below.

The orebodies consist of mineralized fractures, quartz veinlets, and disseminations in the breccia matrix. Basic mineralogy includes wolframite, molybdenite, fluorite, arsenopyrite, bismuth, and bismuthinite. Surrounding the orebodies are haloes of greisen-type alteration consisting of quartz + topaz + sericite + fluorite which grades outwards into an assemblage of quartz + biotite + chlorite + topaz, and into propylitic alteration, mainly chlorite and sericite. Crosscutting fracture and veinlet relationships reveal that mineralization occurred in multiple stages.

The formation of the porphyry deposits appears to be related to the development of high pressures associated with crystallization of underlying magma and subsequent fracturing and breccia formation. The Mount Pleasant deposits also occur in tin-bearing polymetallic veins and replacement bodies related to a different episode of igneous intrusion. These did not cause extensive fracturing and brecciation.

The basic similarities between the Mount Pleasant breccia bodies and the SOL breccia body are quite apparent. Both have generally the same proposed mechanism of formation, overpressuring of fluids during cooling of an intrusive igneous body; both have undergone multiple stages of brecciation; and both have undergone some form of propylitic alteration.

However, it is the contrasts between the two areas which is most important. The biggest and most obvious difference is the lack of mineralization in the SOL breccia zone. The scale of the bodies is also quite different, with the SOL breccia being on a considerably smaller scale. This scale difference is also reflected in the type of maximum alteration seen in and surrounding each breccia body. Also, a much shorter lifetime is suspected for the SOL breccia body than was the case for the Mount Pleasant breccia.

The lack of economic mineralization in the SOL breccia zone is likely due to a combination of the above differences and possibly others.

CHAPTER 7 - CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

1) The granite enclaves, as shown through mineralogical, petrological, and chemical data, are clearly xenolithic in nature. Their most probable source of origin is the St. George batholith located to the south of the SOL breccia zone and the caldera complex.

2) The aplite dyke represents a distinct lithology, based on chemical and petrological data and observations. The aplite breccia dyke is suspected to also be distinct from the other lithologies.

3) An overall decrease in iron and magnesium in the PMG unit with increasing alteration (chloritization and sericitization) suggests an Fe- and Mg- enriched material which disappears with alteration. The relatively fresh rock contains abundant disseminated carbonate which is leached out during alteration. If this carbonate were dolomitic in composition it could have been the source of the iron and magnesium. Unfortunately, this carbonate was not analysed with the microprobe and thus this hypothesis can not be confirmed.

4) Analyses of 23 chlorite grains have distinguished at least three and possibly four distinct populations of secondary

chlorite, based on FeO-MgO-Al_2O_3-MnO ratios, in the SOL breccia zone, possibly reflecting changes in fluid composition of the hydrothermal system over time.

5) The actual brecciated zone is dyke-like in shape on surface and has probably followed some previous structural weakness, such as a joint or fracture, following explosive fracturing of the wall rock which occurred as a result of fluid overpressuring and volatile release during final cooling stages of the PMG magma body.

6) Brecciation occurred under low P-T conditions with fractures possibly propagating to the palaeosurface, allowing rapid drops in system pressure resulting in rapid mineral precipitation and second boiling (Burnham, 1985) of the fluids in the system. This has resulted in the multiple fracturing and fluid injection stages seen in the brecciated zone.

7) Several styles of alteration are represented in the SOL breccia zone. These include, propylitic (chloritic) alteration, silicification, sericitization, hemitization and there is clear zoning of the various alteration styles with relation to the highly brecciated zone.

8) Although the SOL breccia zone appears similar to the Mount Pleasant breccia, there are differences in mineralogy, alteration, size, and probably lifespan of the hydrothermal

system, which have undoubtably contributed to the lack of mineralization in the SOL breccia zone.

7.2 Recommendations

1) A study of fluid inclusions in the various generations of vein minerals would aid in determining more detailed information concerning fluid evolution and precipitation temperatures. An oxygen isotope study would also provide useful information on sources of water in the system.

2) Since hydrothermal breccia pipes generally occur in clusters (Sillitoe, 1985),and less than 50 percent of breccias in any given cluster are ore bearing (Sillitoe, 1985), the possibility of economic mineralization in the area surrounding the SOL breccia zone exists. Geophysical surveying in the PMG surrounding the breccia zone might detect the high concentration of disseminated pyrite in chloritized alteration zones surrounding other breccia pipes and reveal their existence.

3) Chemical composition of the carbonate found disseminated in the PMG should be determined to either substantiate or disprove the suggestion that it is dolomitic in composition.

4) It would appear that no further work is required concerning the economic potential of the breccia pipe examined in this study.

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APPENDIX A

SYMBOLS

= OVERBURDEN

= LITTLE MOUNT PLEASANT TUFF

= MCDOUGALL BROOK PORPHYRITIC MICROGRANITE

= BRECCIATED ZONE

= APLITE BRECCIA DYKE

= APLITIC DYKE

= PEBBLE DYKE

= HEMATITE ALTERATION

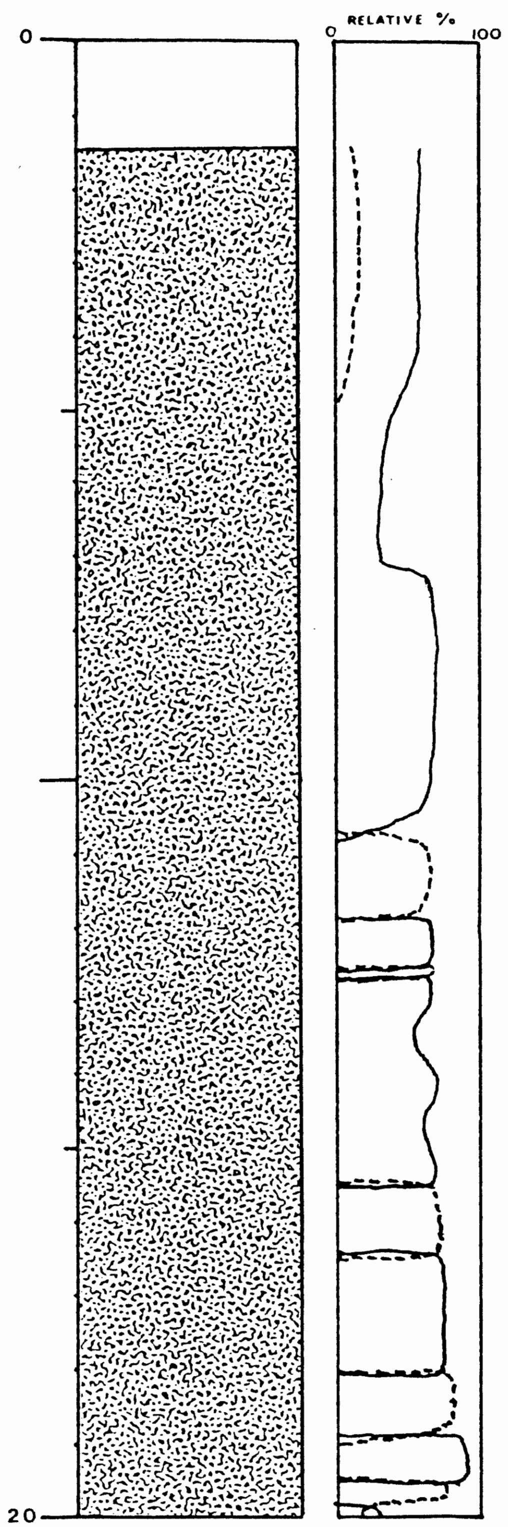
= CHLORITE ALTERATION

= SERICITE ALTERATION

scale 1:100

1m

SOL-1



DESCRIPTION

SOL-1

0-1.5m
Overburden

1.5m - 25.40m
Porphyritic Microgranite

1.5 - 7.15m
Green brown color; chlorite-rich down to 5.25m; chlorite alteration less pervasive from 5.25 - 7.15m.

7.15 - 10.90m
Green color; chlorite-rich.

10.90 - 11.85m
Brown color; hematite alteration, oxidation of pyrite, no chlorite left; contact on either side is quite sharp; no chlorite veining in this section; slight green tinge to some large feldspar grains.

11.85 - 12.50
Green color; chlorite-rich

12.50 - 12.55
Brown color; hematite alteration (around fracture).

12.55 - 15.40
Green color; chlorite-rich; several areas of silica veining around which percent chlorite decreases.

15.40 - 15.85
Brown color; hematite alteration; with silica veining, hematite veining; no chlorite veining.

15.85 - 16.20
Green color, chlorite-rich.

16.20-16.45
Brown color; hematite alteration.

16.20 - 16.30
Granite enclave

16.45 - 18.05
Green color; chlorite-rich.

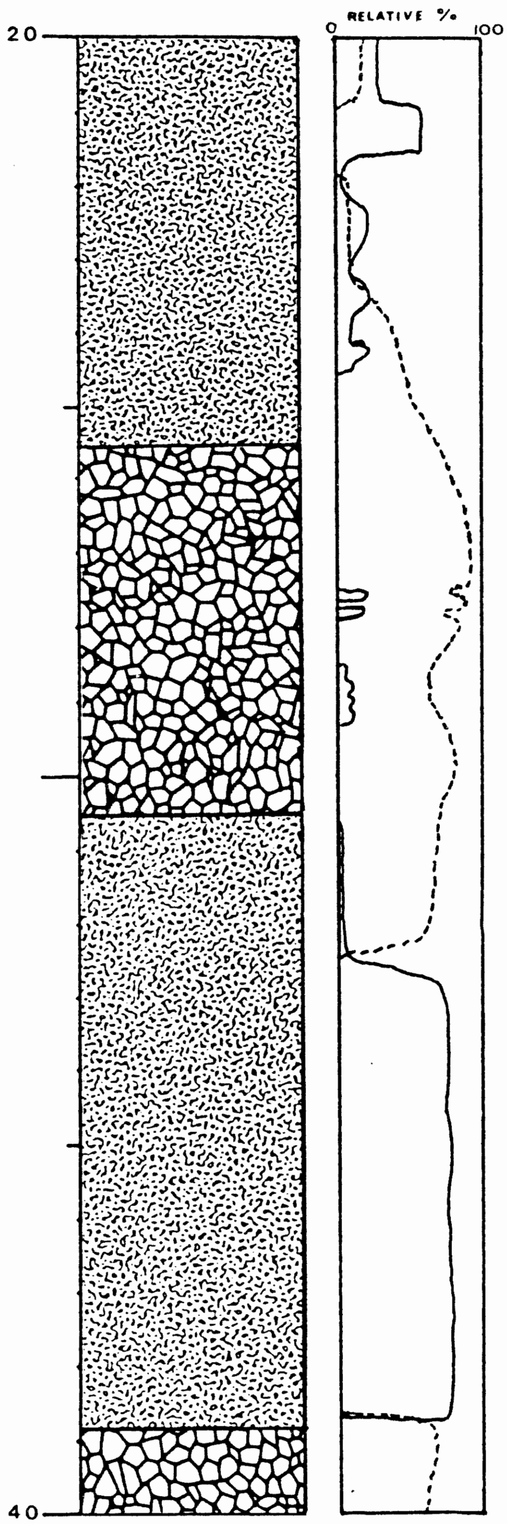
18.05 - 18.90
Brown color; hematite alteration; sharp contact at top, gradational at bottom; white quartz and hematite veins.

18.90 - 19.50
Green color; dark-green chlorite-rich.

19.50 - 19.80
Brown color; hematite veins, white quartz veins with hematite vein borders.

19.80 - 20.80
Brownish green-gray to brownish-red (rusty) colored.

ALTERATION



DESCRIPTION

20.80 - 21.55
Green color

20.80 - 21.05
Dark green chlorites, very few pink feldspars compared to rocks above.

21.05 - 21.55
Highly brecciated; abundant white quartz and hematite veining; no pink feldspars left.

21.00 - 52.75
Chlorite disappears for the most part.

21.55 - 24.65
Mostly light rusty color except for the occasional small greenish patch; scattered hematite veinlets with fewer white quartz veins, in some cases quartz veins are alone, in others, still, quartz borders hematite veins (at 22.20m); no visible pink feldspars.

24.65 - 25.40
Blackened due to MnO; small amounts of blackening on either side of this section; hematite and quartz veining common; some localized blackening at periphery of quartz veins.

24.40 - 30.35
Brecciated zone. Clasts are quite angular

25.40 - 26.95
Beyond MnO blackening, rock becomes very rich in hematite-rich silica with associated small patches and veinlets of white quartz. Quartz phenocrysts are found in the brecciated pieces of microgranite. Green chlorite color returns towards 26.95m.

26.95 - 27.70
White quartz-rich breccia with very few fragments of green silica; some flourite veining; scattered MnO blackening becoming more abundant towards 27.95m.

27.70 - 28.05
Brown hematite color; greenish at either end; abundant hematite veining with a lesser amount of white quartz veining. First appearance of flourite veins.

28.05 - 28.40
Silica-rich breccia, appears the same as 26.95- 27.70m except lower boundary becomes quite flourite-rich.

28.40 - 29.30
Breccia with green PMG clasts, milky quartz cement towards the top with flourite veining; about half way between 28.40 and 29.30 are white quartz, flourite and chlorite veins, white quartz crosscuts flourite and flourite crosscuts milky quartz.

28.90
Carbonate crosscuts flourite vein; most commonly carbonate is found to the side of other veins, travelling along the same plane of weakness.

CONTINUED

29.30 - 29.72

Very high silica (matrix) to clast ratio; PMG clasts are very altered; abundant flourite veining.

29.72 - 29.90

Coarse grained calcite vein containing some quartz, clasts of PMG, and flourite; calcite is mostly white but some grains are light pink.

29.90 - 30.35

Highly brecciated with abundant veining of flourite and hematite.

This translates into a more solid looking altered microgranite at 30.35m; some locallized MnO blackening.

30.35 - 38.85

Porphyritic Microgranite

Very altered (chloritized)

30.35 - 32.60

Brownish color with only a hint of green; very little veining down to 32.00m. Highly banded vein at 32.25.

32.60 - 38.85

Greenish color; quartz phenocrysts still present.

32.75 - 33.60

A few veins present

33.60 - 34.00

Abundant white silica veins some having hematite vein borders.

34.00 - 34.80

Abundant green silica veins (1-3cm in size)

34.25 - 38.35

Scattered hematite, quartz flourite, and very few chlorite veins.

38.35 - 38.85

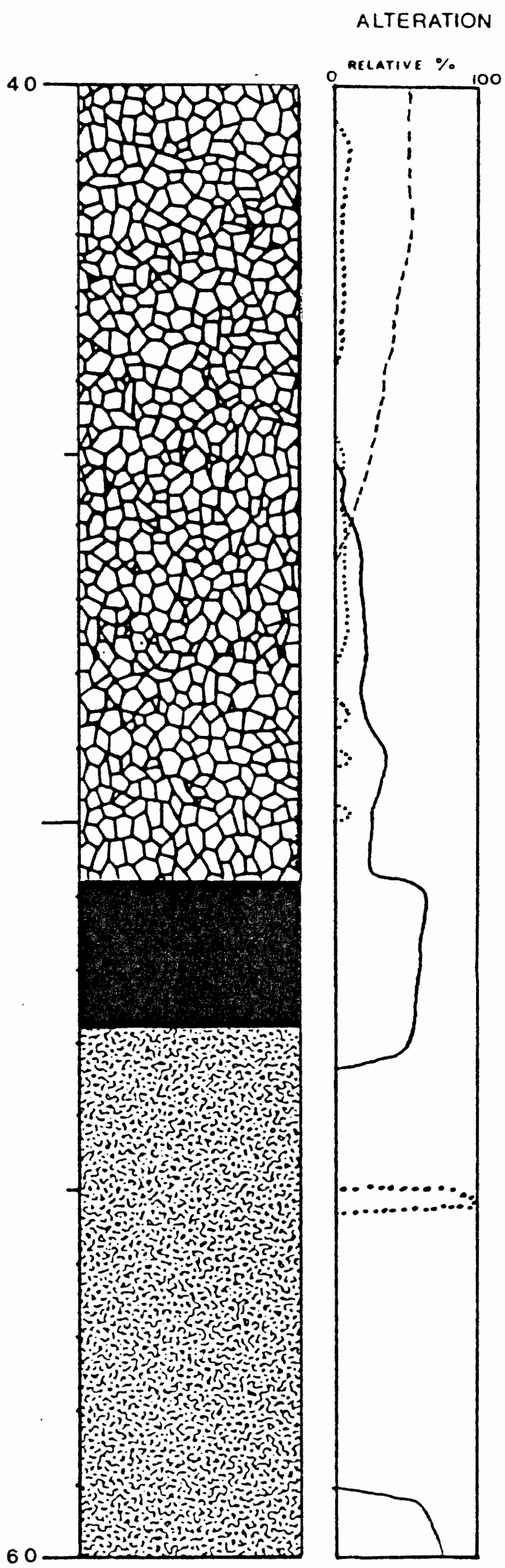
Minor brecciation; hematite and silica veining.

38.85 - 50.75

Brecciated zone

38.85 - 45.80

Very brecciated; matrix material consists of abundant milky quartz and reddish silica. Flourite veins are also common; pure hematite veining seems confined to clasts.



DESCRIPTION

41.00 - 41.15

Vein of MnO and calcite mixture.

41.91 m

Vein of MnO and calcite crosscuts silica

43.05; 43.25; 43.55 - 43.70; 44.50

Same as 21.91

45.80 - 50.75

Predominant color is green, due to very abundant green silica and chloritized PMG, however, small patches of rusty brown color do exist. Scattered areas of white quartz, clear quartz, flourite and hematite veining exist; small veinlets of hematite occur throughout. Several areas of MnO blackening exist.

49.30

Clast of brown microgranite cut by veins of green silica.

49.85 - 50.75

Very rich in green silica; many of the PMG clasts appear almost completely resorbed by the silica.

50.75 - 52.75

Aplite Breccia

Green fine grained rock containing clasts of relatively unaltered PMG contact on the bottom is not distinctly visible due to the broken nature of the core but it is presumed to be sharp; there is a sharp contact at the top with a chill margin on the breccia zone side.

50.75 - 51.75

Dark green color with clasts of pink PMG. At 51.30 there is a small section (5cm) with hematite and flourite veining; white quartz veinlets are scattered throughout this section.

51.75 - 52.60

Light green aplite with fractures defined by dark green chlorite veinlets. PMG clasts are still present and are cut by flourite veins but not by chlorite. Flourite veins cut the light green aplite also.

52.60 - 52.75

Looks essentially the same as the section from 51.75 - 52.60 except this is lighter green.

52.75 - 126.20

Porphyritic Microgranite

Chlorite reappears; disseminated pyrite present in more intensely chloritized regions.

52.75 - 53.00

Green color; chlorite-rich.

53.00 - 53.20

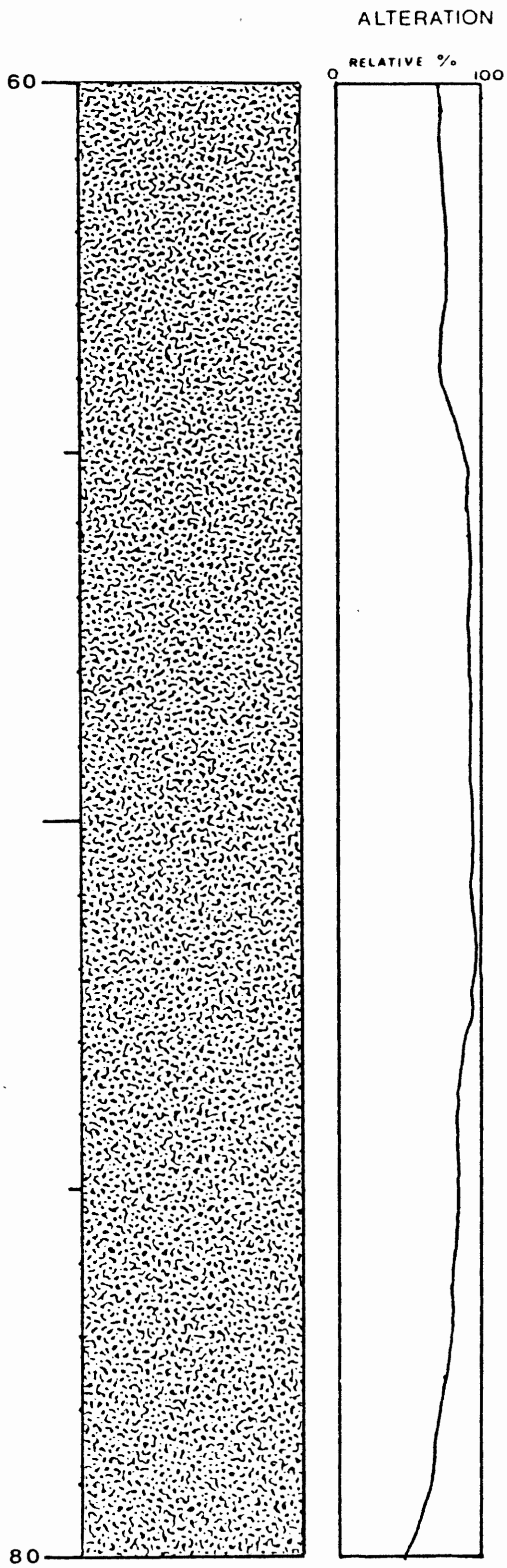
Transition zone to pink PMG

53.20 - 59.00

Pink color; essentially unaltered except for last 2m which has slight green tinge.

55.00 - 55.15

Intense clay alteration; brown color



DESCRIPTION

59.00 - 79.50

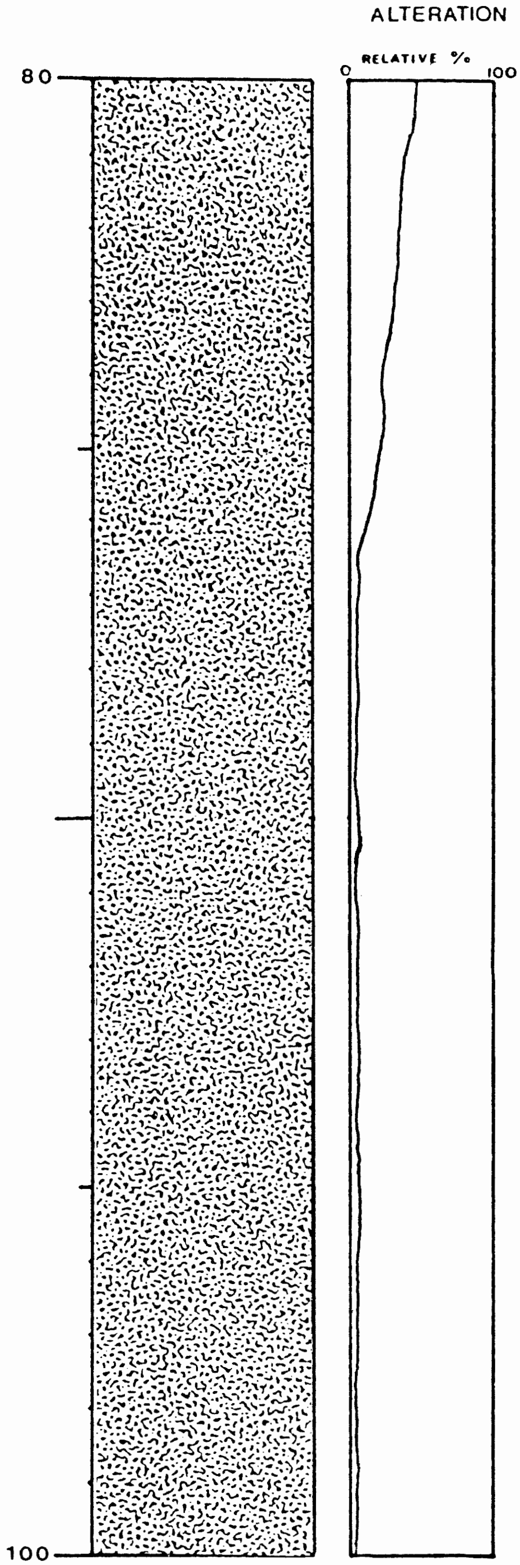
Green color; scattered with carbonate, flourite, quartz and chlorite veins; flourite crosscuts chlorite veins; chlorite contains abundant disseminated pyrite mineralization.

70.55

Quartz is cut by chlorite which is cut by hematite, this is cut by quartz which is cut by flourite

79.50 - 86.50

Chlorite content decreases until at 79.50. There is a strong pink color to the PMG. Chlorite content continues to decrease until it is essentially absent at 86.50.



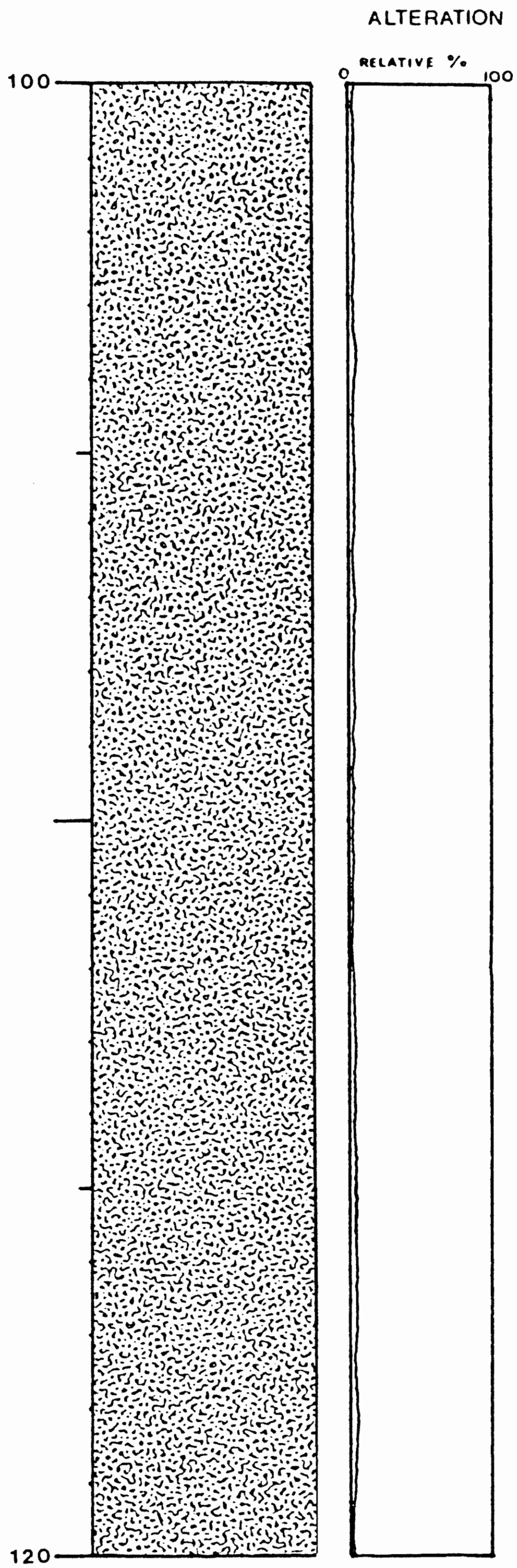
DESCRIPTION

86.50 - 122.72

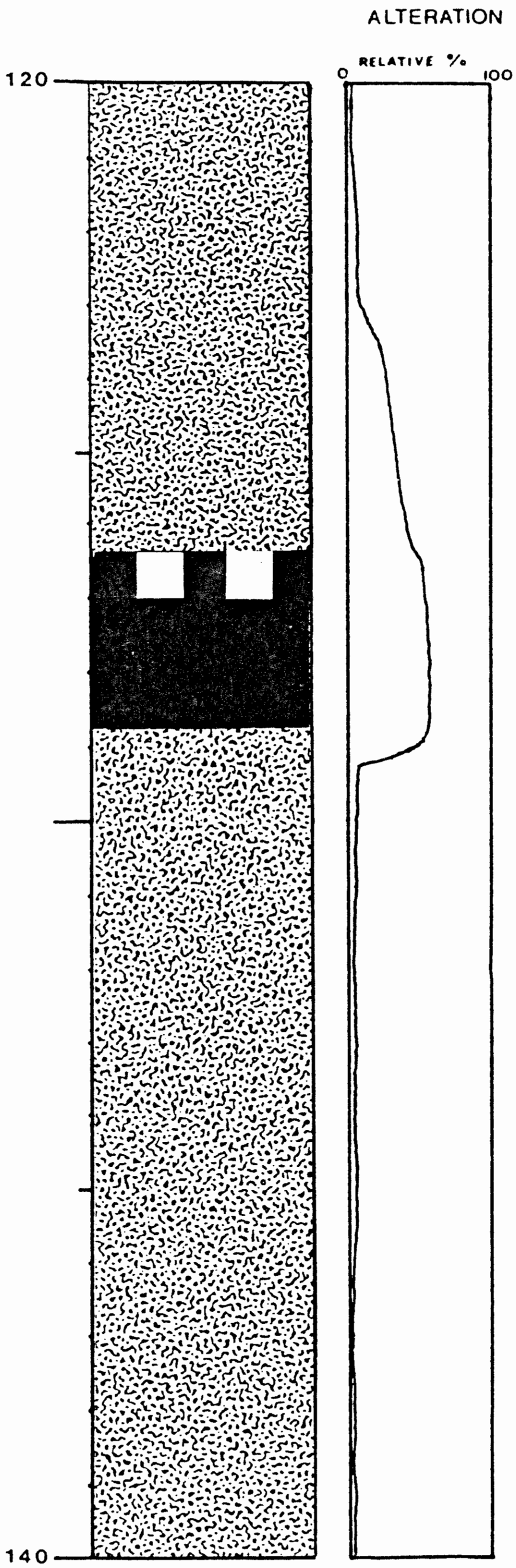
Dark pink color; essentially unaltered.

96.03

Carbonate-rich red band; these are randomly scattered throughout the microgranite but are only visible in the unaltered PMG, presumably they have been erased by alteration in the other areas.



DESCRIPTION



DESCRIPTION

122.72 - 126.20
Slightly chloritized alteration zone around dyke located below. Rock is a light pink color.

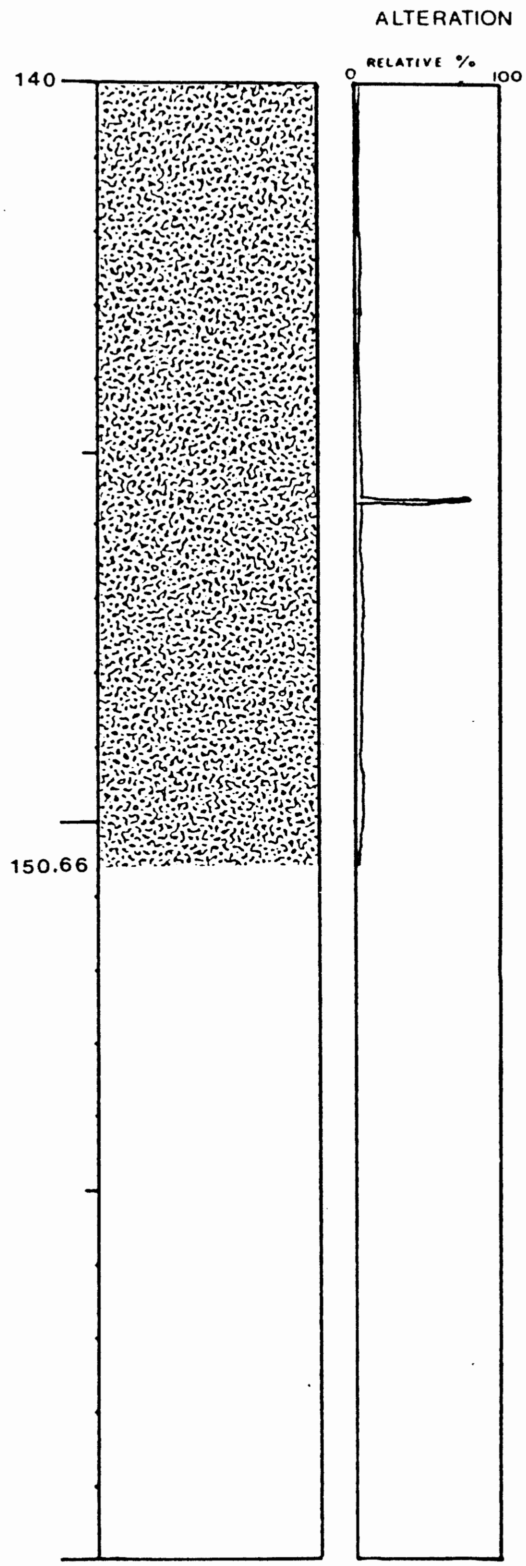
124.20
Granite enclave

126.20 - 126.80
Chloritized aplitic dyke; 1cm wide hematite alteration zone on lower contact.

126.80 - 128.80
Aplite breccia dyke
Fractured by very fine grained chlorite-rich material; contains clasts of PMG which are essentially unaltered; there is also a 1 cm wide carbonate vein associated with this rock; chill margin at upper contact with aplitic dyke.

128.80 - 129.05
Slightly altered PMG (chloritized)

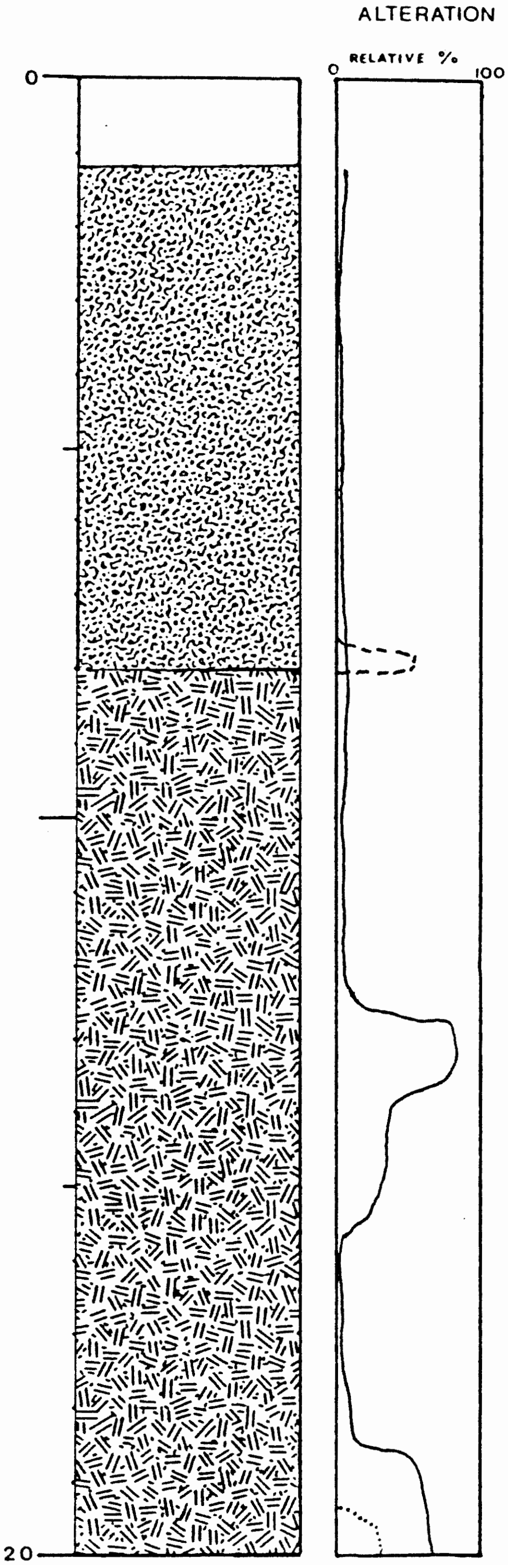
129.05 - 148.65
Dark pink PMG; essentially unaltered



DESCRIPTION

145.60
Small offshoot of aplite breccia dyke.

SOL-2



DESCRIPTION

SOL-2

0 - 1.16
Overburden

1.16 - 8.00
Porphyritic Microgranite
Pink colored; PMG contains blue quartz phenocrysts; white quartz veins present; PMG acquires a light brown tinge near the contact with the LMPT.

7.05 - 7.13m
Granite enclave

Lower contact of PMG with LMPT is not clear due to broken nature of the core.

8.00 - 22.15
Little Mount Pleasant Tuff

8.00 - 12.60
Pink color; essentially unaltered until 12.45 then chloritization begins at a sharp boundary. Metasedimentary clasts present scattered throughout. The LMPT doesn't seem to alter as readily as the PMG.

12.60 - 13.50
Green color; intense chloritization of LMPT; crosscut by chlorite veins containing pyrite. There is disseminated pyrite throughout this section. K-feldspars are completely obliterated; pseudomorphs of plagioclase are present.

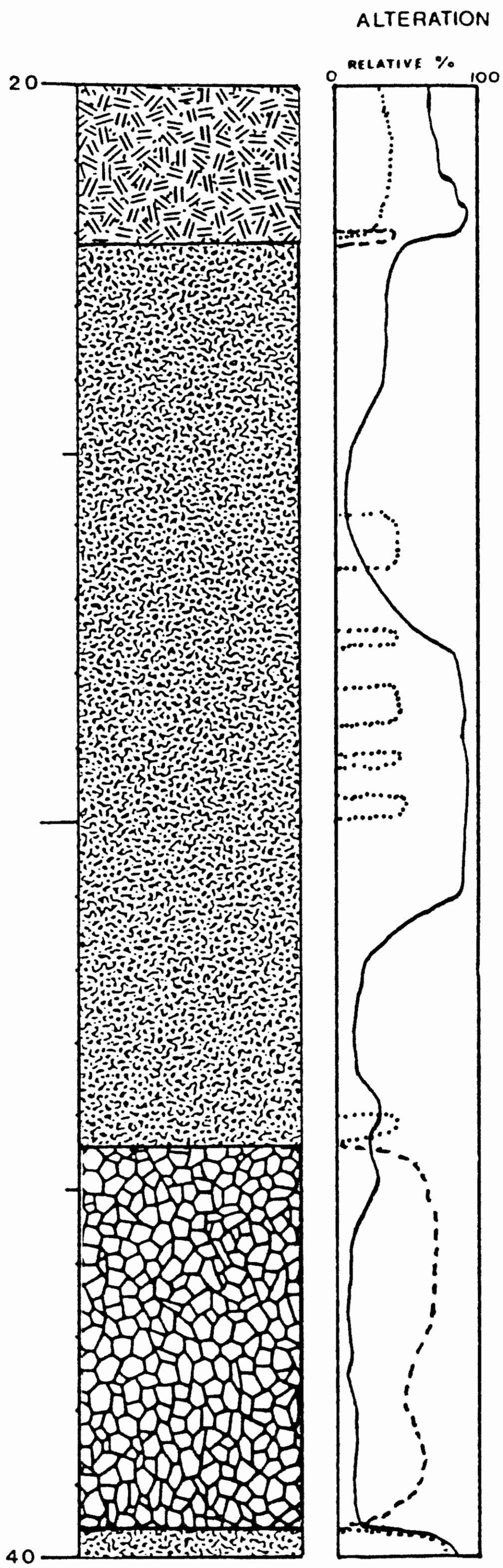
13.50 - 13.80
Breccia vein containing flourite, white quartz and hematite veins.

13.80 - 15.80
Green color; only minor alterations, abundant chlorite veining, few milky quartz veins.

15.80 - 19.30
Color changes from green to pink and back to green.

19.30 - 19.80
Gradual decrease in amount of K-feldspar down to almost nothing.

19.80 - 21.40
Same as 12.60 - 13.50 except chlorite viens are more abundant.



DESCRIPTION

21.40 - 21.60

Essentially the same as 13.80 - 15.80 except this is slightly more altered and has less K-feldspar.

21.60 - 21.80

Extremely altered; chloritized, sericitized.

21.80 - 22.15

Same as 21.40 - 21.60 except that the last 10 cm has a light rusty brown color similar to the top contact between the PMG and the LMPT.

22.15 - 34.50

Porphyritic Microgranite

22.15 - 24.00

Green colored; slight alteration

22.60 - 22.70

Granite enclave

23.60 - 23.80

Granite enclave

24.00 - 27.30

Color changes from green to pink to green gradually.

25.70 - 26.60

Moderate clay alteration

27.30 - 30.00

Green colored; veins of chlorite and white quartz. Intense chloritization is enhanced by sericitization in localized areas; original texture is completely obliterated in these places.

30.00 - 31.00

Slightly sericitized; green color

31.00 - 31.30

Green color; moderate alteration.

31.30 - 33.25

Light green/pinkish colored.

33.25 - 34.20

Highly sericitized zone; crosscut by earlier chlorite and calcite viens; greenish yellow color.

34.20 - 34.50

Slightly sericitized.

34.50 - 39.70

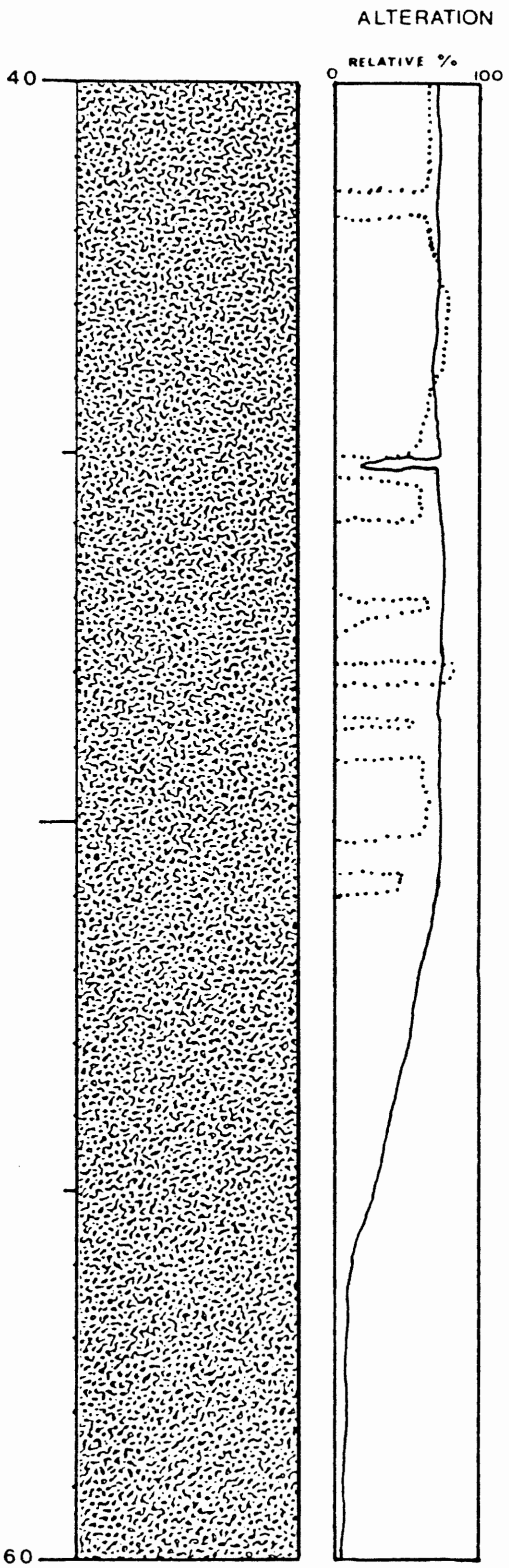
Brecciated zone.

34.50 - 36.00

Green color; PMG highly silicified with green silica; minor hematite, white quartz, and chlorite veining.

36.00 - 39.70

Dominantly green silica which has been brecciated by white silica, fourite and hematite viens; clasts are fairly angular.



DESCRIPTION

39.70 - 133.70

Porphyritic Microgranite

Locally fractured PMG with small regions at various stages of alteration; disseminated pyrite exists down to about 53.00m and is locally concentrated in chlorite veins; randomly dispersed throughout the unaltered PMG are small (<1cm) areas of carbonate, they are usually associated with chlorite.

39.70 - 41.35

Highly sericitized and chloritized; original texture of PMG is almost completely destroyed.

41.35 - 41.75

Green colored; chlorite alteration.

41.75 - 45.10

Highly sericitized and chloritized; locally high concentration of green silica veins; chlorite and white quartz veins also present; hematite veins present in last 30cm.

45.10 - 45.25

Granite enclave; pink color.

45.25 - 51.00

Zone of locallized sericitization of highly chloritized PMG; chlorite, quartz, and calcite veins scattered throughout; hematite veins present in first 1.5m.

51.00 - 56.00

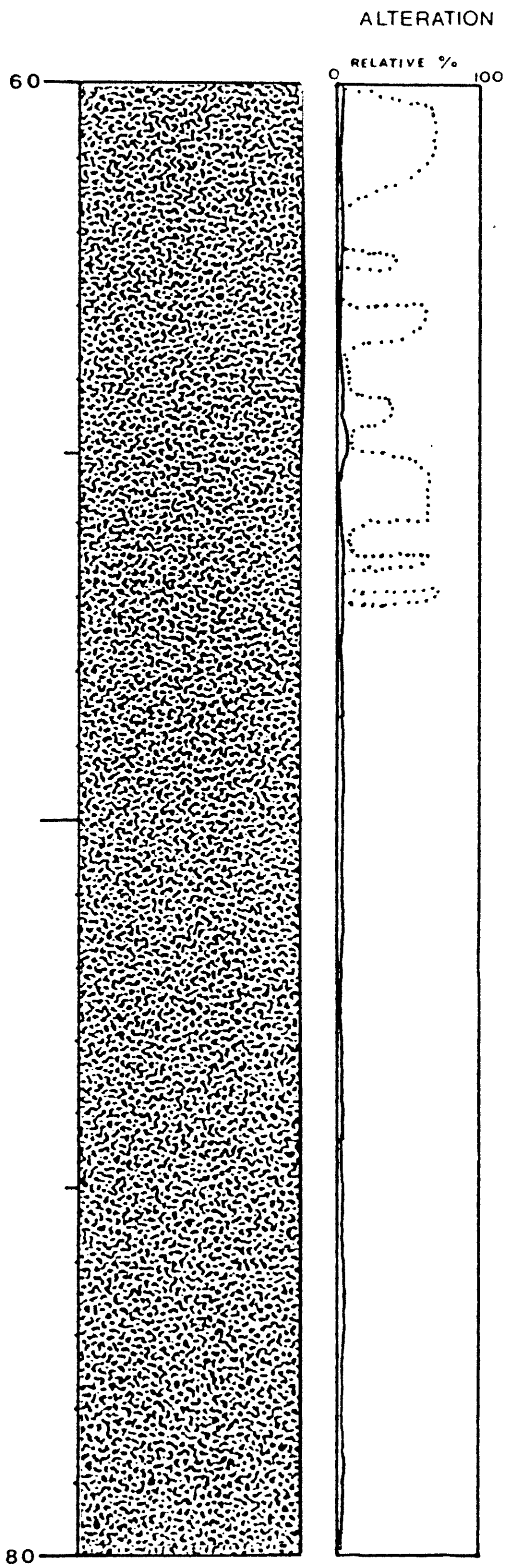
Color changes from green back to the unaltered pink color. Three bands of green silic a exist in the first 1.75m which contain hematite veins. Hematite veins persist down about 2m more; chlorite, quartz and calcite viens are also present.

56.00 - 60.00

Pink color; scattered calcite and milky quartz veins.

59.25 - 59.50

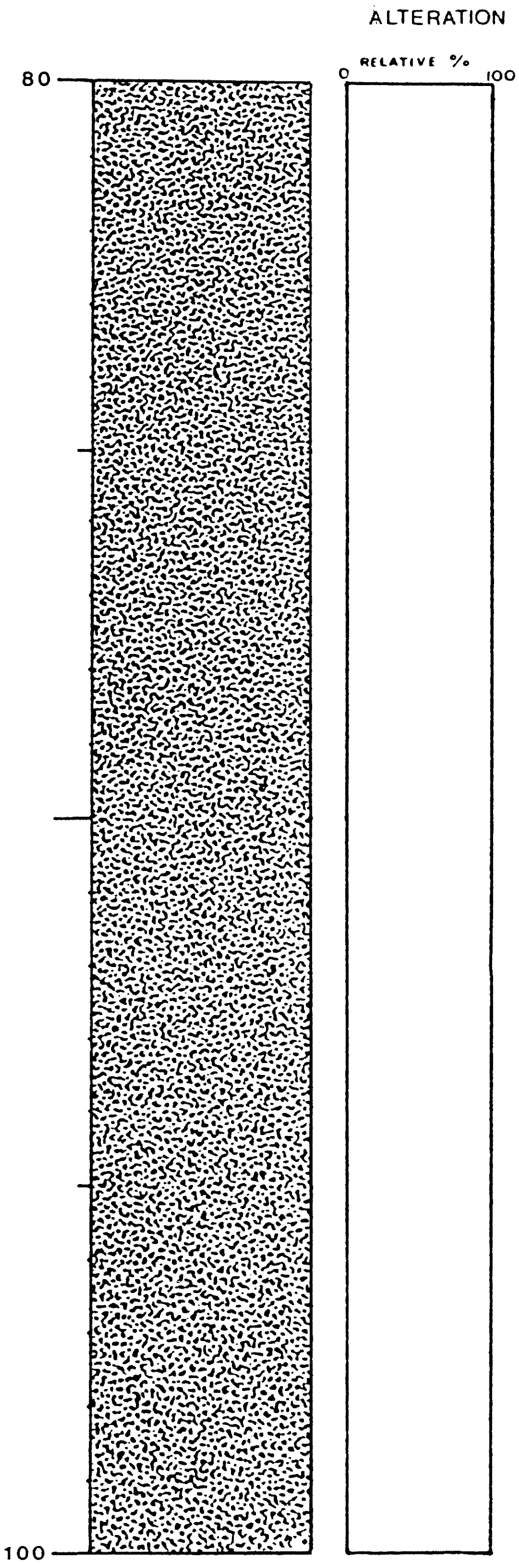
Large quartz and hematite vein with alteration zone around it.



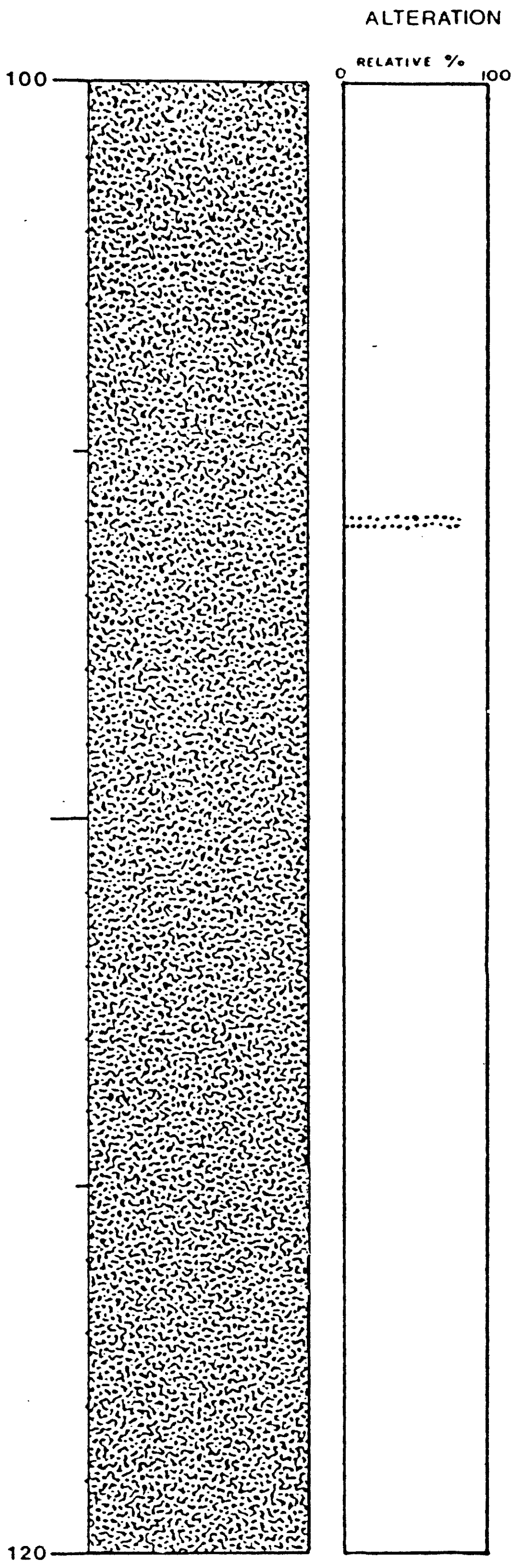
DESCRIPTION

60.00 - 67.00
Locallized to extensive sericitization of PMG; very crumbly; some calcite veins.

67.00 - 150.72
Red/pink colored PMG with scattered chlorite, white quartz and flourite veins; calcite crosscuts chlorite.



DESCRIPTION



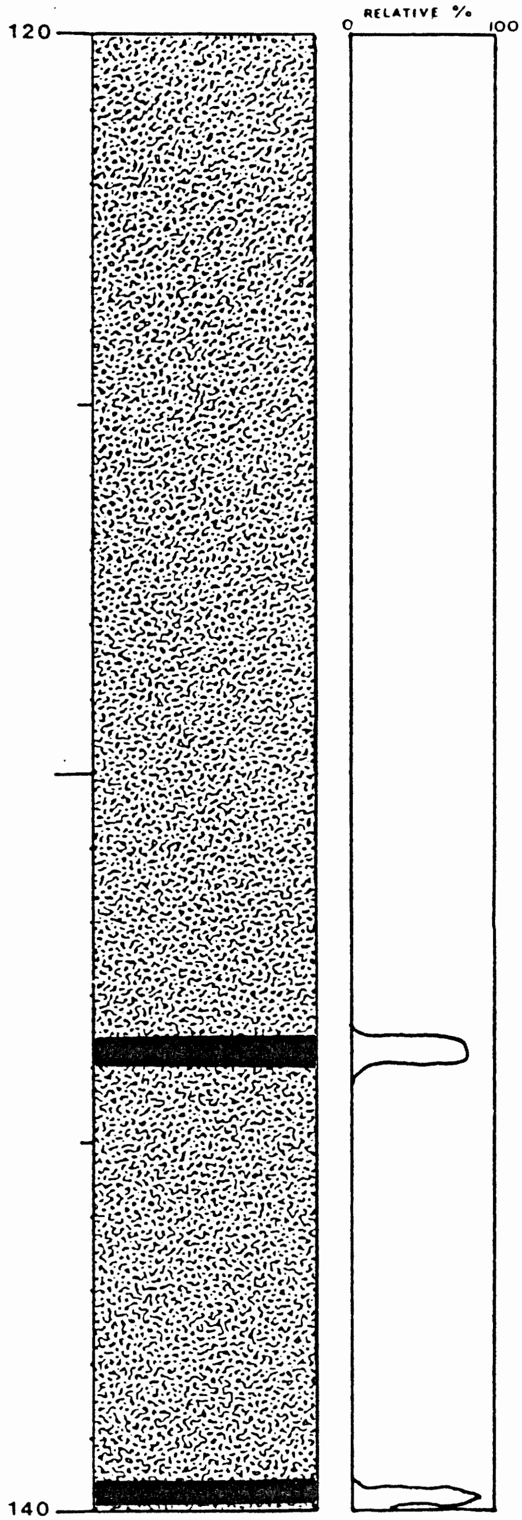
DESCRIPTION

106.00m
Sericitized fracture

106.20 - 106.50
Calcite, chlorite and flourite vein with hematite veining in and around it.

107.00
Same as 106.20 - 106.50 except smaller.

ALTERATION



DESCRIPTION

133.70 - 134.00
Dark green chlorite-rich aplite breccia; contain calcite and hematite veins.

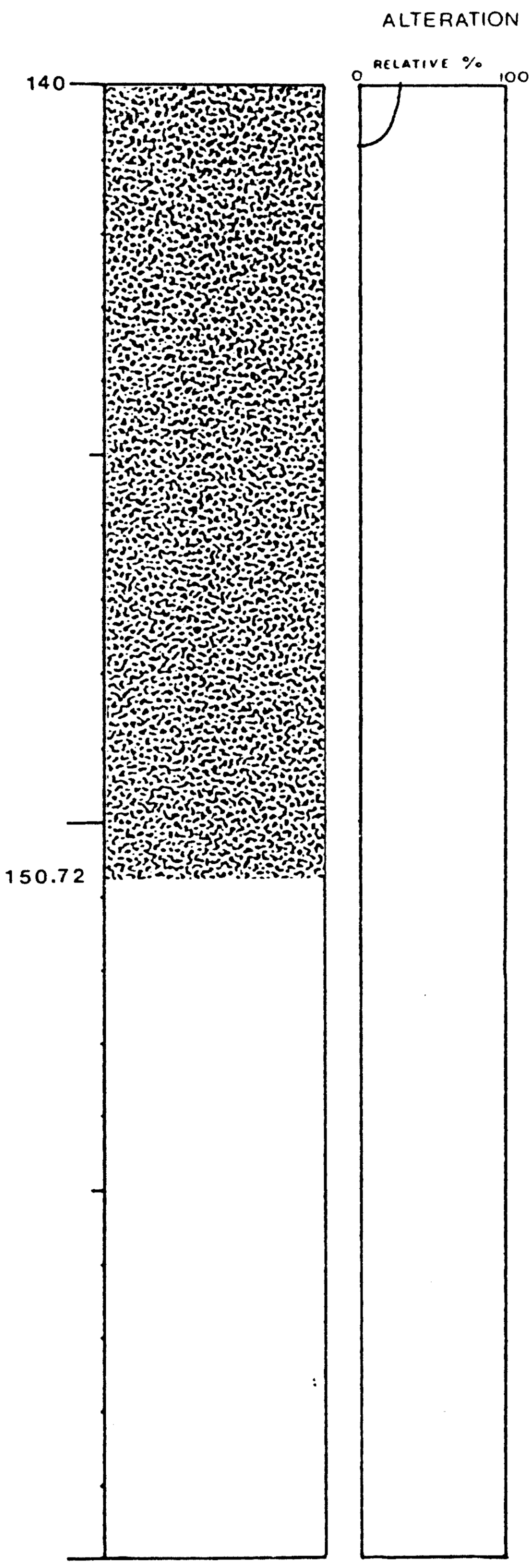
134.00 - 138.65
Pink color; essentially unaltered.

136.87
Three 1cm calcite veins.

138.65 - 139.60
Light pink color; altered by the dyke below.

139.60 - 139.85
Small chloritized aplite dyke; has chill margins of fine grained chlorite; contains angular clasts of pink PMG (2-5cm).

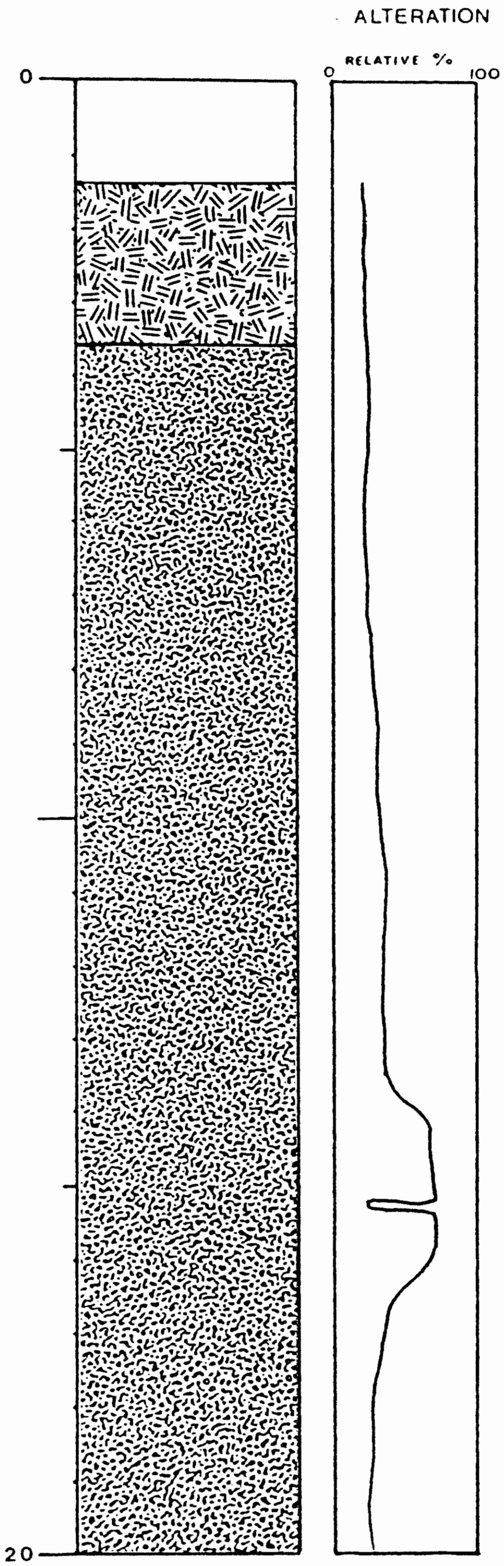
139.85 - 140.71
Light pink color; altered due to the dyke above.



DESCRIPTION

140.71 - 150.72
Pink PMG; essentially unaltered.

SOL-3



DESCRIPTION

SOL-3

0 - 1.31
Overburden

1.31 - 3.50
Little Mount Pleasant Tuff: slight chlorite alteration; contains hematite, quartz, flourite, and chlorite veins.

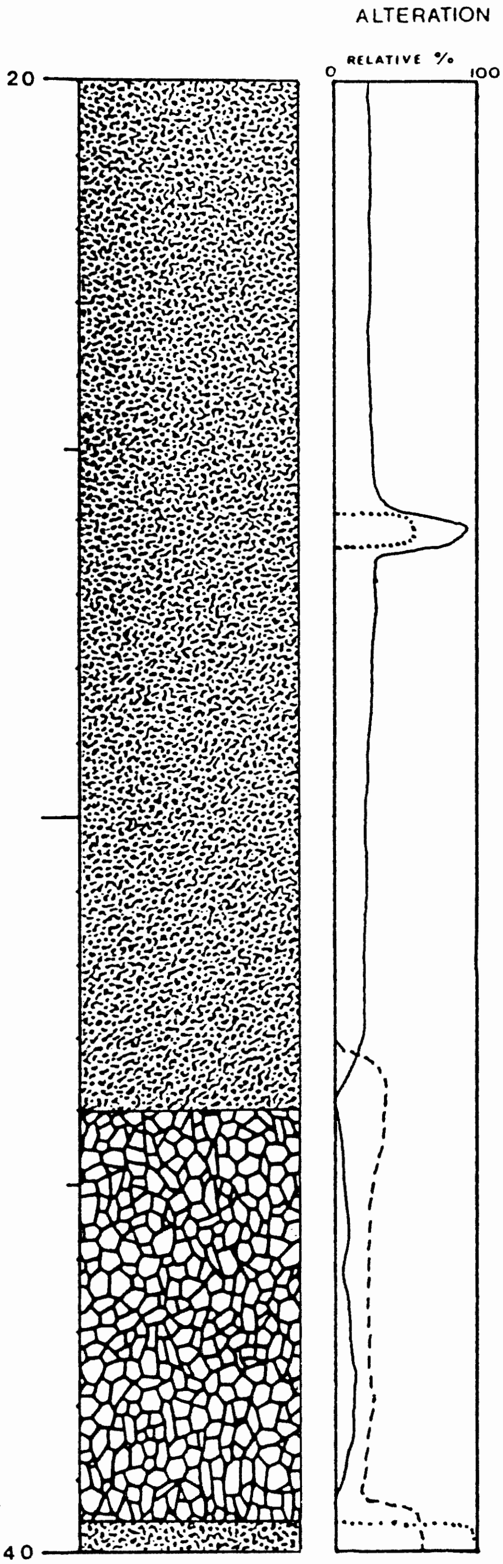
3.50 - 26.40
Porphyritic Microgranite: Greenish pink color; cut by scattered veins of quartz, flourite, hematite and chlorite.

10.30 - 10.80
Granite enclave.

14.00 - 15.80
Green color; chlorite alteration.

15.15 - 15.25
Granite enclave; pink color.

17.50
Purple flourite vein with green flourite in the center.



DESCRIPTION

24.05 - 24.30
Granite enclave.

25.80 - 26.40
Partially sericitized; highly chloritized; crosscut by numerous hematite veinlets.

26.40 - 34.00
Slightly brecciated progressing to highly brecciated PMG; first 2.5m is composed mostly of green silica then hematite and flourite veins become abundant; last meter has a mottled greenish gray and yellowish brown color; few quartz veins.

34.00 - 39.63
Brecciated zone.

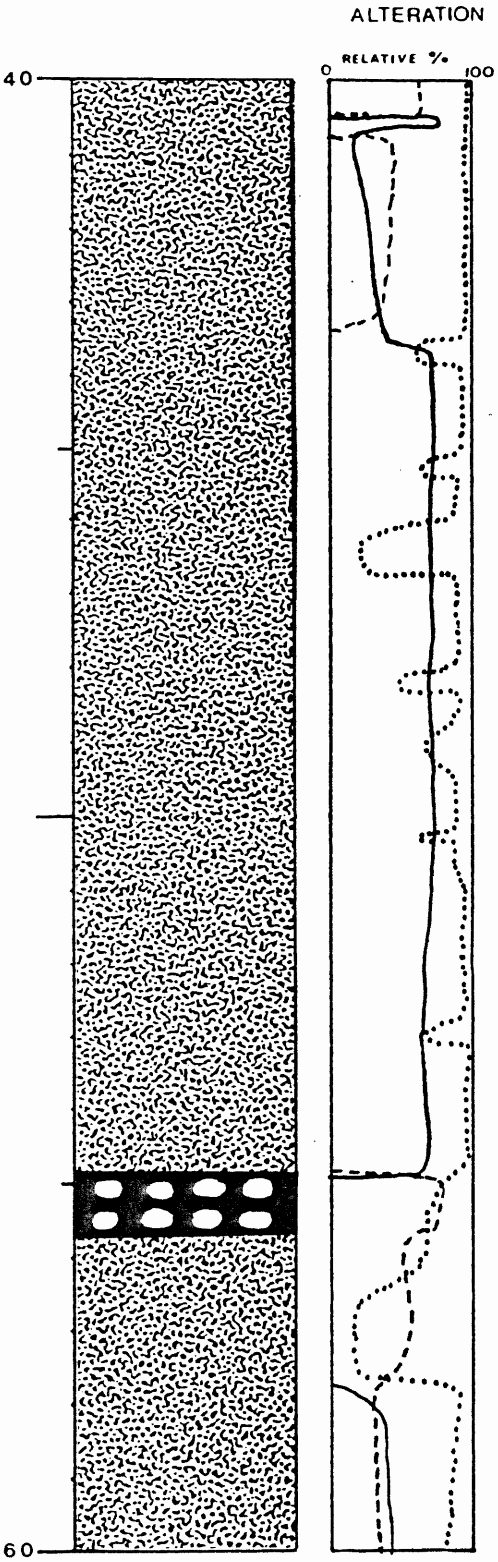
34.00 - 35.70
Highly silicified breccia; white quartz, flourite and minor hematite veins; silica fill.

35.70 - 36.90
Slightly sericitized PMG with abundant quartz and chlorite veins.

36.90 - 39.63
Silica-rich breccia; silica-fill; abundant clasts; becomes brown from hematite alteration in last 15cm.

39.63 - 54.80
Porphyritic Microgranite
This section has been extremely sericitized

39.63 - 40.40
Light brown color.



DESCRIPTION

40.40 - 41.55
Green color

41.55 - 43.30
Brownish green color; becomes more altered towards bottom.

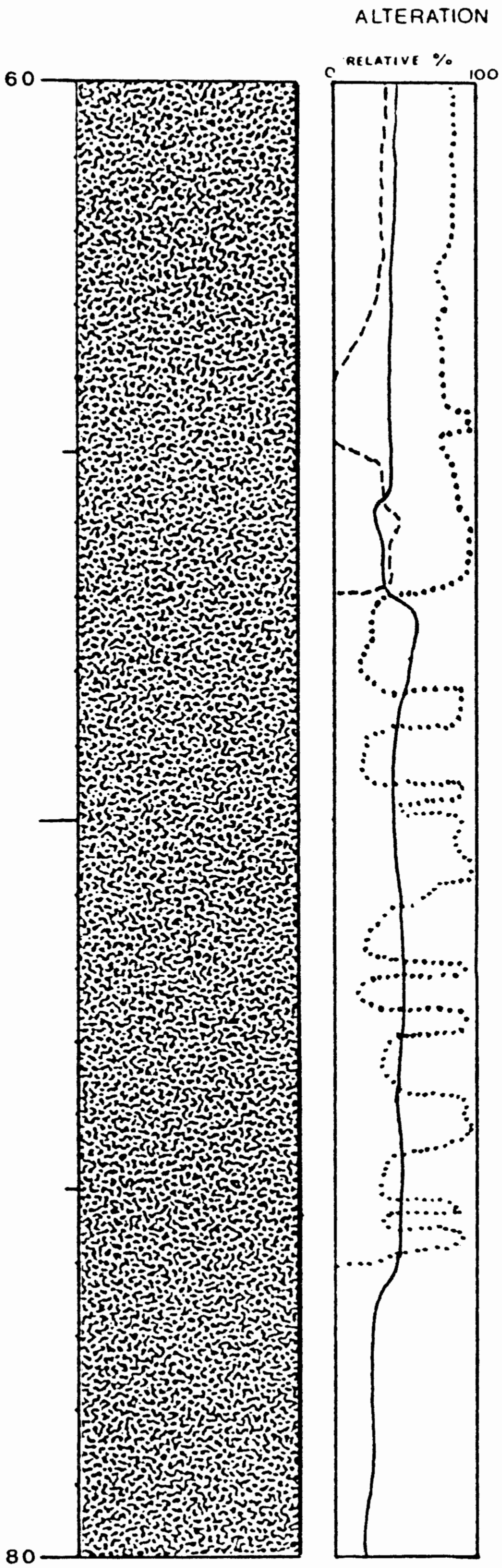
43.30 - 54.80
Predominantly green colored; localized areas are less sericitized then the majority; minor hematite veining; minor chlorite veining with associated pyrite. Coherent fragments of 1mm to 3cm in size are present.

54.80 - 55.70
Pebble Dyke
Deep red-brown hematite color offset by greenish brown rounded fragments of PMG; matrix is mixture of clay and quartz fragments; fairly cohesive compared to surrounding clay zones.

55.70 - 117.50
Porphyritic Microgranite

55.70 - 57.70
Dominantly brown-red color; mottled in places with greenish colored clasts; fairly silicified; some chlorite veins.

57.70 - 64.60
Green-brown color; locally highly sericitized and silicified; cut by quartz, chlorite and hematite veins; locally highly silicified by green silica; color becomes totally green near bottom.



DESCRIPTION

62.50
Quartz phenocryst are no longer present.

64.60 - 64.90
Green color; highly sericitized; completely clay.

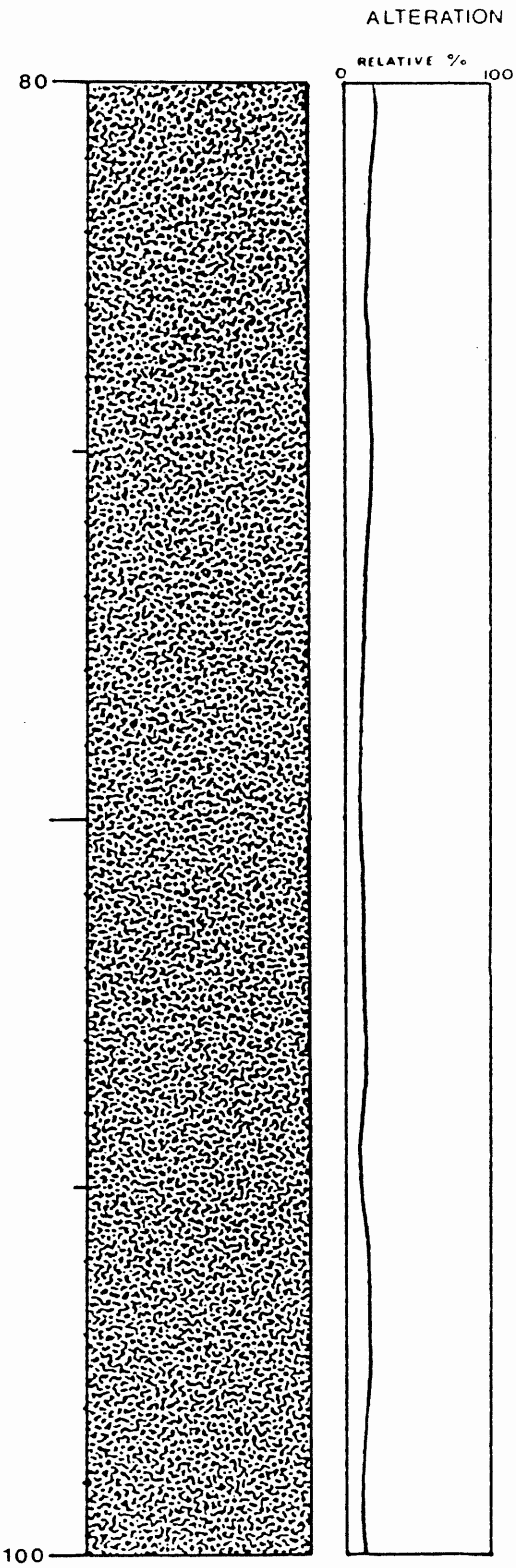
64.90 - 65.90
Same as 57.00 - 64.60 except color changes to light brown near 65.90.

65.90 - 66.90
Color changes from greenish yellow to greenish brown; highly sericitized.

66.90 - 75.75
Fairly cohesive PMG but highly fractured with minor to intense sericitization.

75.75 - 76.00
Green color; sericitized with crosscutting carbonate veins.

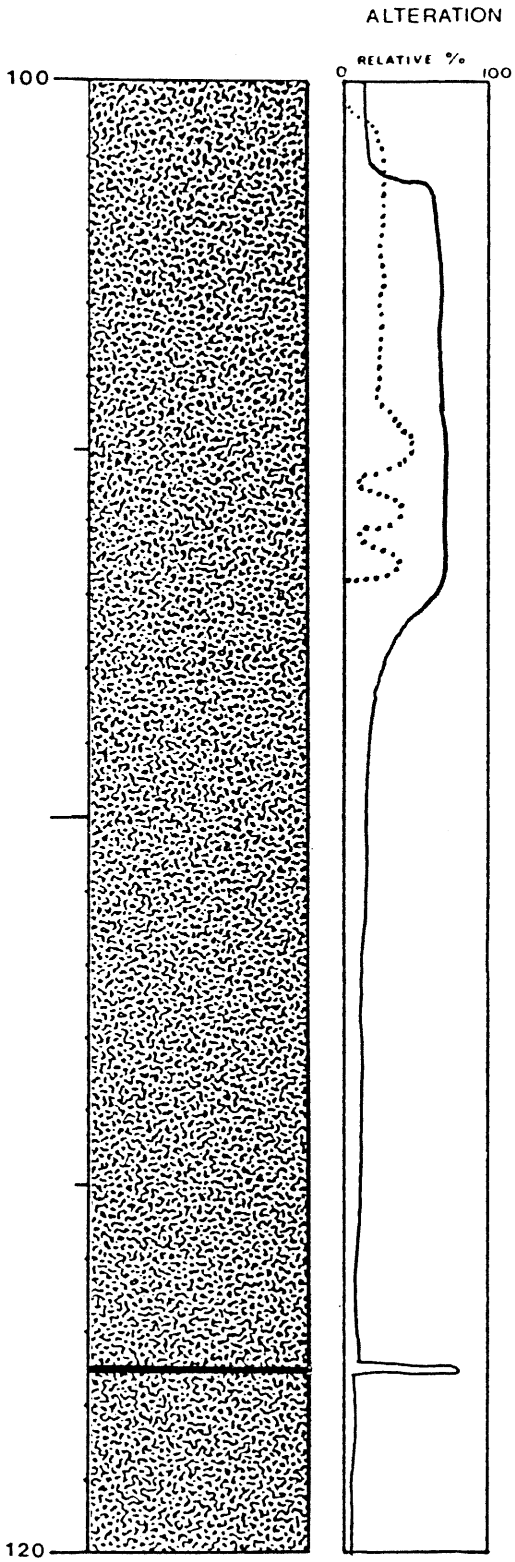
76.00 - 101.25
Greenish-pink color; locally more green than pink due to abundant chlorite veining; becomes slightly sericitized towards 101.25 and is more altered around chlorite veins; calcite and quartz veins become more common towards 101.25.



DESCRIPTION

86.58 - 86.99
Large calcite vein (1cm) running parallel to core axis.

86.99 - 93.10
Enrichment in disseminated pyrite.



DESCRIPTION

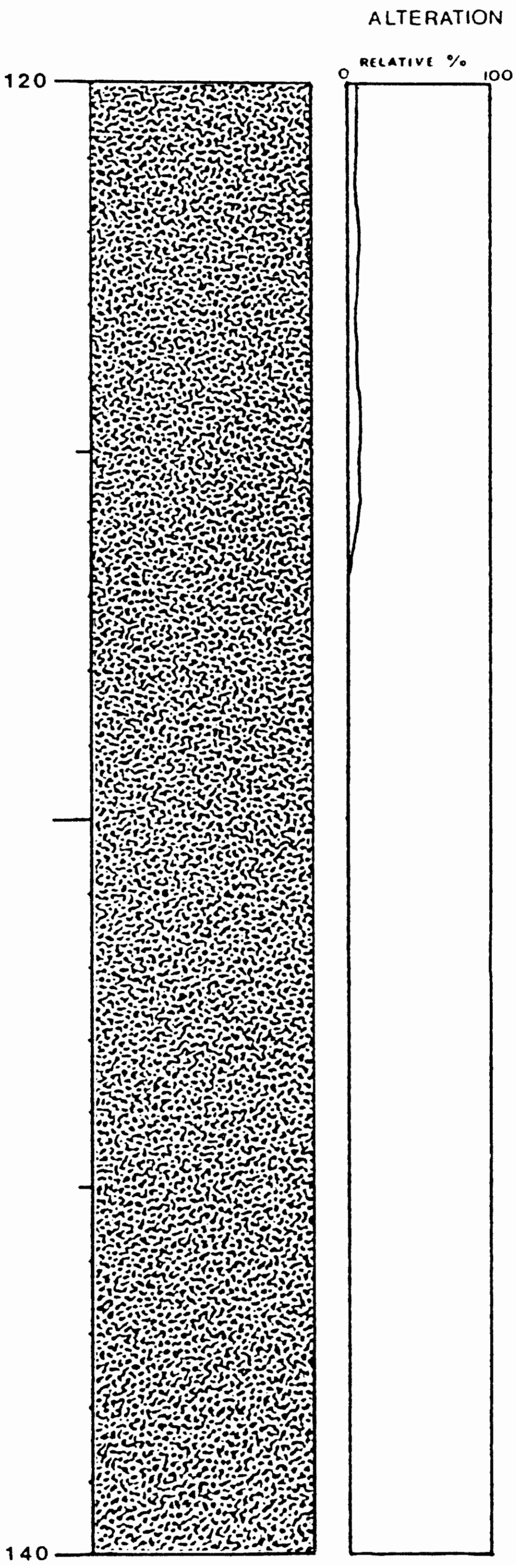
101.25 - 106.75
Green color; sericitized and highly fractured by crisscrossing calcite veins; small areas of unsericitized PMG exist over the last 2m.

106.75 - 117.50
Transition zone from green to pink PMG; upper boundary is quite abrupt but not sharp; numerous quartz veins which run parallel to the core axis; most of the chlorite has disappeared by 106.80.

117.50 - 117.60
Aplite breccia dyke
Contains angular clasts of pink PMG in a chlorite-rich aplitic matrix; no alteration halo visible.

117.50 - 232.01
Porphyritic Microgranite

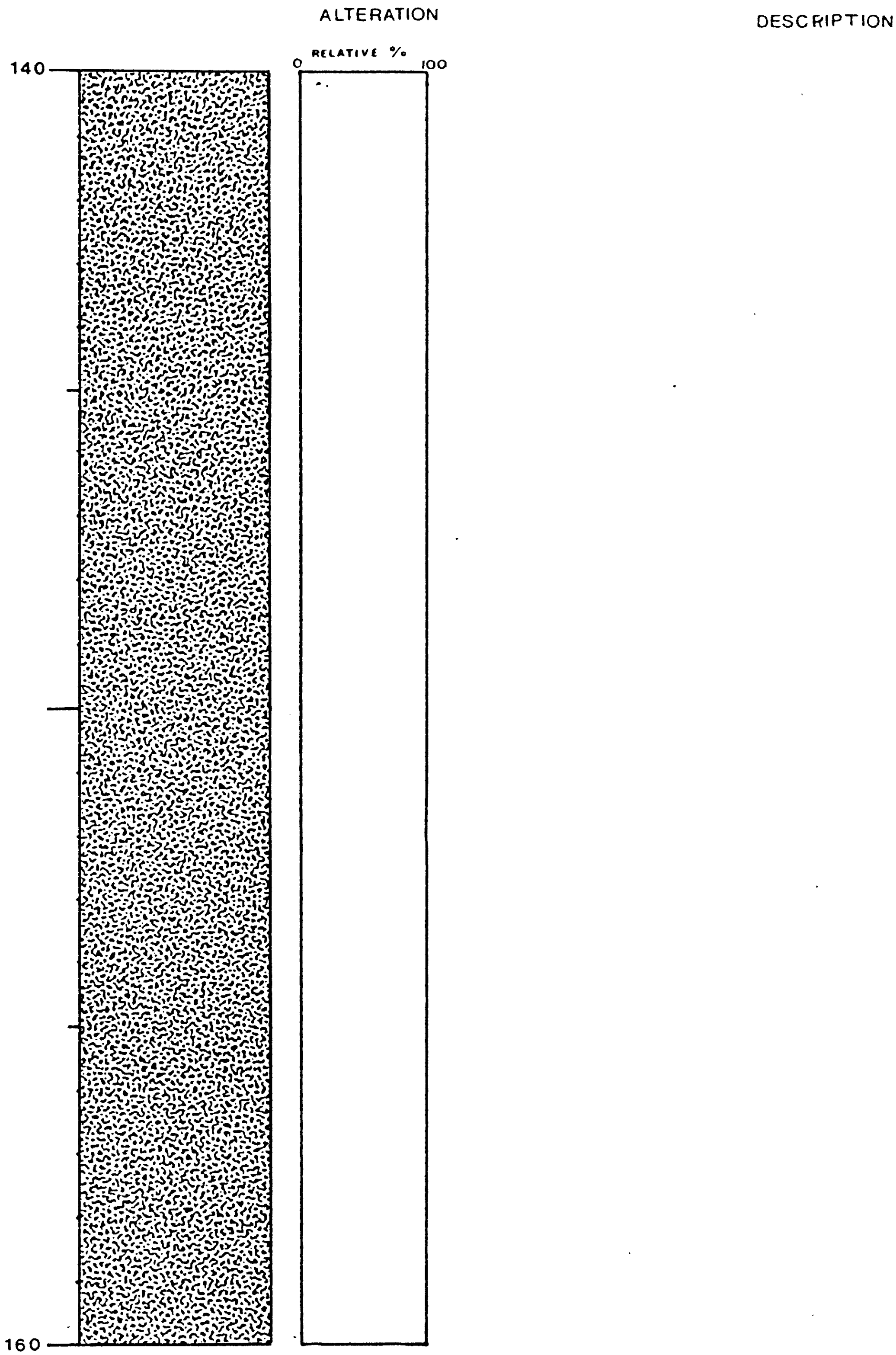
117.50 - 126.30
Same as 106.75 - 117.50; carbonate and quartz veins are scattered throughout the core from here to the bottom.

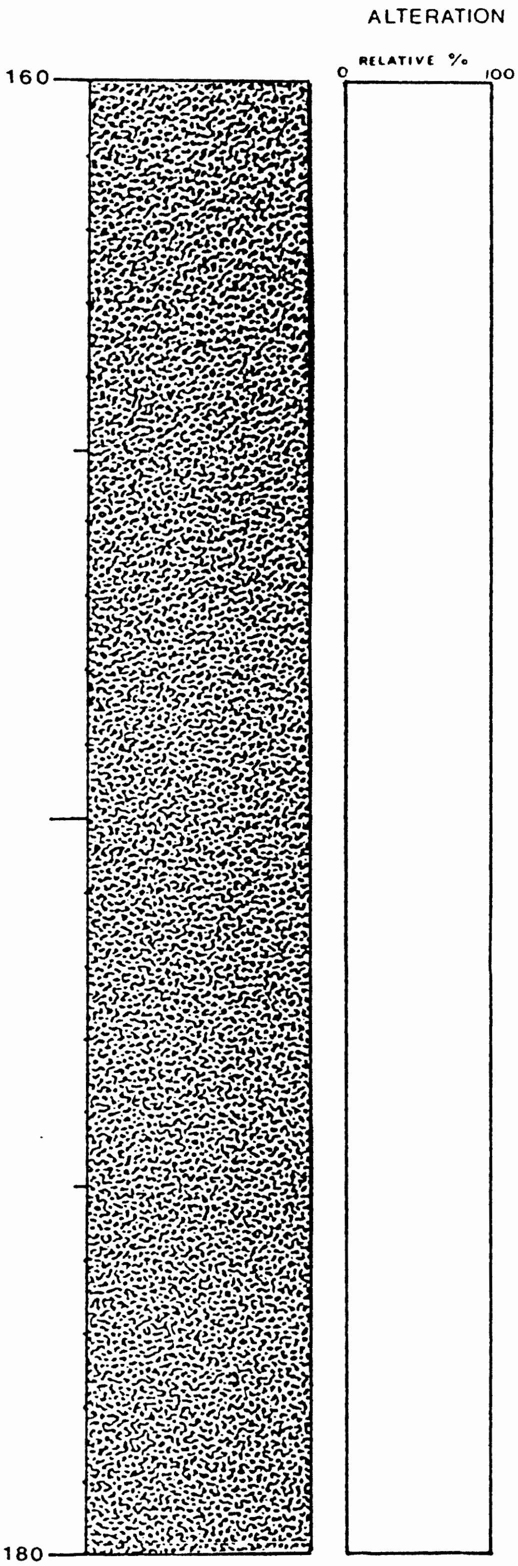


DESCRIPTION

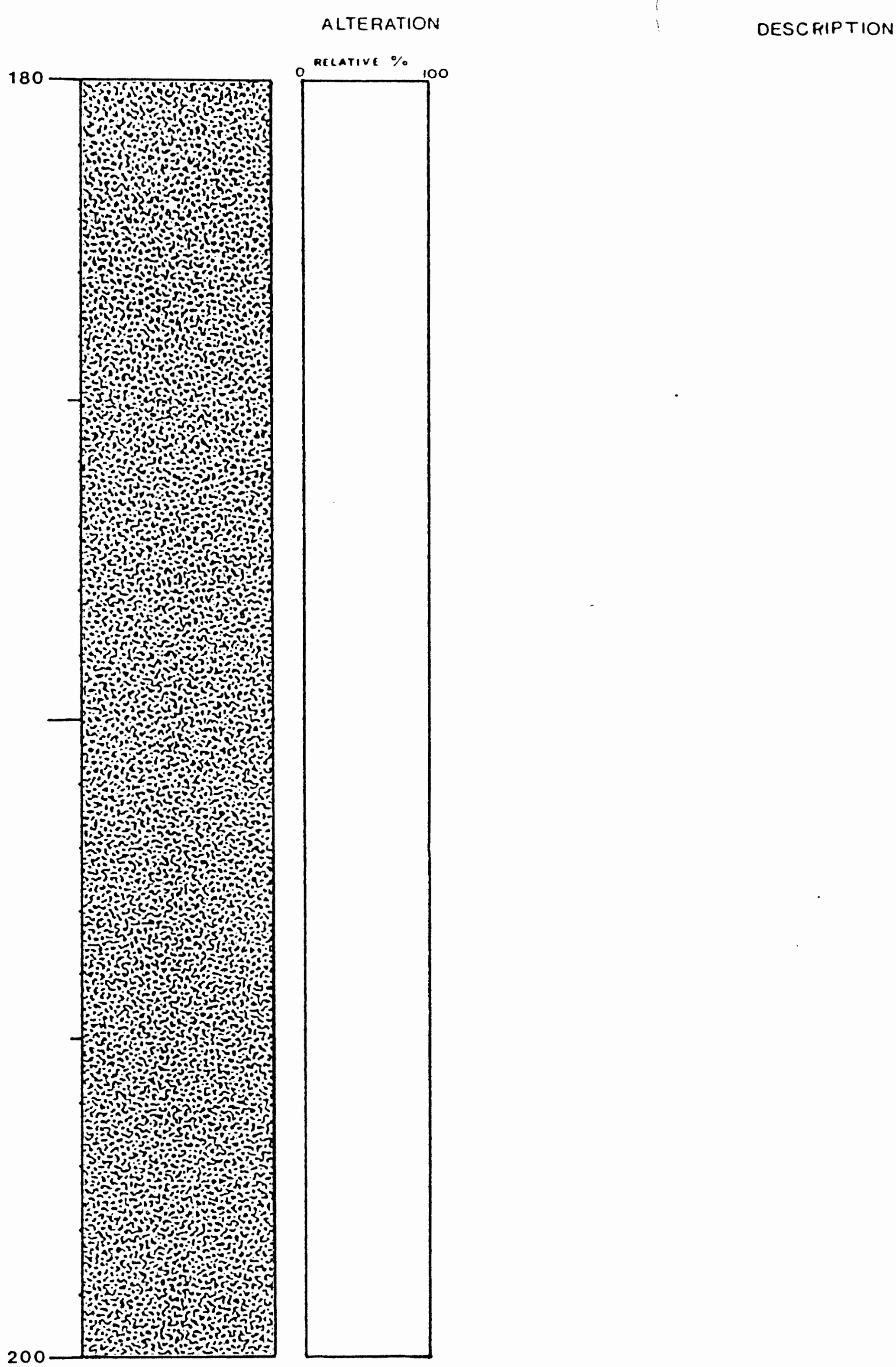
126.30 - 232.01

Pink-red color; cut by scattered milky and white quartz, calcite, and chlorite veins.


ALTERATION
DESCRIPTION
RELATIVE %
0
100
140
160

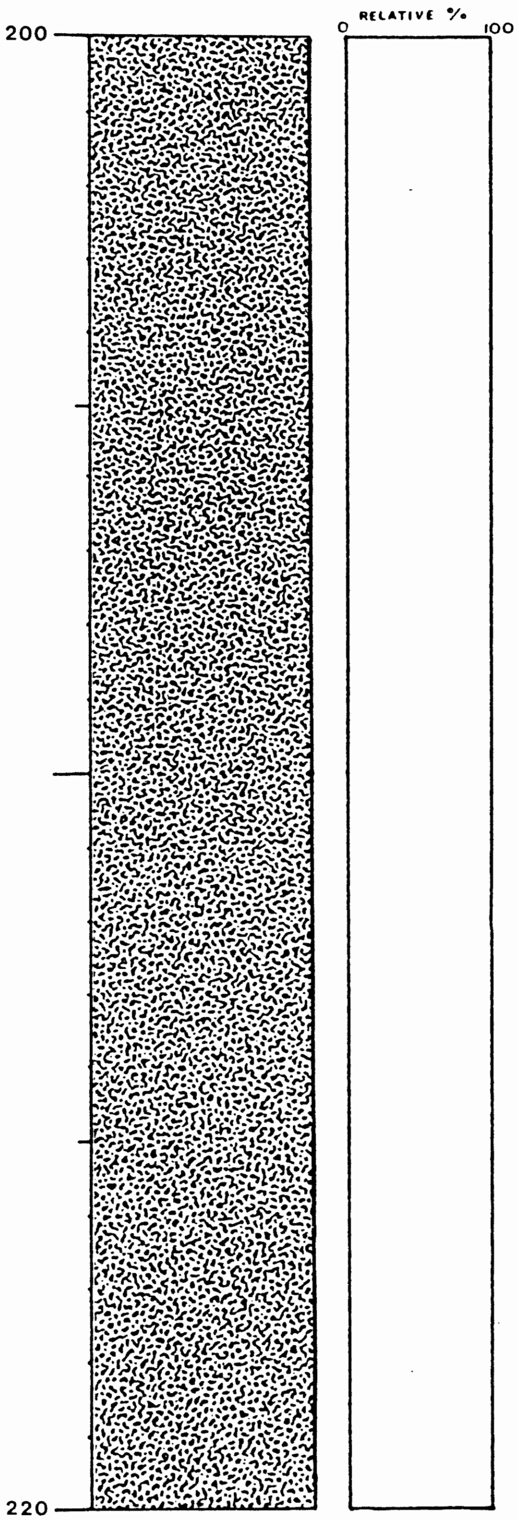


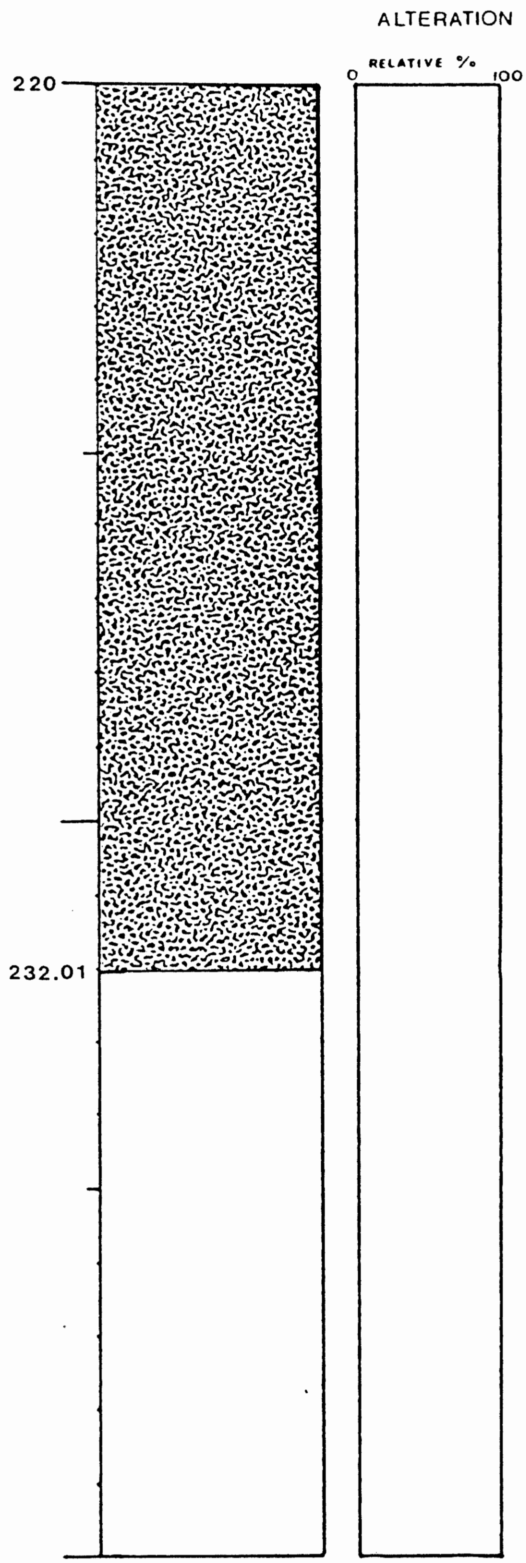
DESCRIPTION


ALTERATION
RELATIVE %
0
100
180
200
DESCRIPTION

ALTERATION

DESCRIPTION





DESCRIPTION

228.60

Carbonate-rich red band; many more of these bands are scattered over the lengths of core than have been indicated.

APPENDIX B

SAMPLE NUMBER: 85-SD-18
LITHOLOGY: LMPT
LOCATION: Outcrop sample

MINERALOGY:

MINERAL	%	SIZE
quartz	50	2.5mm
plagioclase	10	2.0mm
chlorite	12	1.2mm
K-feldspar	25	1.3mm
zircon	<1	<1.0mm
apatite	<1	1.0mm
opaques	2	<1.0mm

TEXTURE: Phenocrysts of quartz, plagioclase and K-feldspar set in cryptocrystalline groundmass.

NOTES: Contains partially assimilated metasedimentary clasts; feldspars are quite altered even in this fresh sample; most quartz phenocrysts occur as shards of crystals.

SAMPLE NUMBER: 85-SD-35
LITHOLOGY: Pebble dyke
LOCATION: SOL-3; 56.70m

MINERALOGY:

MINERAL	%	SIZE
hematite	30	<1.0mm
chlorite	10	1.0mm
flourite	2	<1.0mm
quartz	40	1.5mm
plagioclase	17	1.0mm
opaques	1	<1.0mm

TEXTURE: PMG clasts set in hematite-rich rock flour and quartz fragments; 60% clasts, 40% matrix.

NOTES: Feldspars in clasts are altered; clasts are sub-rounded shape and are up to 1 cm across; flourite seems to have been brecciated at the time of pebble dyke formation; chlorite is a secondary mineral.

SAMPLE NUMBER: 85-SD-47A
LITHOLOGY: Vein material
LOCATION: SOL-1; 7.75m

MINERALOGY:

MINERAL	%	SIZE
quartz	71	5.0mm
chlorite	20	1.0mm
hematite	3	<0.1mm
flourite	2	0.5mm
pyrite	3	1.2mm
clays	<1	<0.1mm
Fe-oxide	<1	<0.1mm
zircon	<1	<1.0mm

TEXTURE: Large crystals to cryptocrystalline.

NOTES: Several different generations of silica represented in this sample; very good sample for determining relative timing of fluid injection. Sulphides found enclosed in chlorite.

SAMPLE NUMBER: 85-SD-48
LITHOLOGY: Granite enclave
LOCATION: SOL-1; 8.00m

MINERALOGY:

MINERAL	%	SIZE
K-feldspar	25	3.2mm
plagioclase	35	4.0mm
quartz	35	4.0mm
chlorite	5	1.2mm
pyrite	<1	0.1mm
apatite	<1	0.2mm

TEXTURES: Granitic, myrmekitic.

NOTES: All quartz grains in the granite are surrounded by a rim of myrmekite; chlorite is a secondary mineral, an alteration of biotite (?) and feldspars. Sample is cross cut by a vein of quartz which contains chlorite and pyrite.

SAMPLE NUMBER: 85-SD-49
LITHOLOGY: Carbonate-rich enclave
LOCATION: SOL-1; 8.80 m

MINERALOGY:

MINERAL	%	SIZE
quartz	60	0.5mm
chlorite	30	1.8mm
carbonate	10	2.0mm
sericite	1	<1.0mm
zircon	<1	<1.0mm
apatite	<1	<1.0mm
K-feldspar	1	1.0mm
opaques	<1	<1.0mm

TEXTURES: Porphyritic, myrmekitic

NOTES: There is a reaction rim around the enclave; it is composed of quartz, k-feldspar, chlorite and minor opaques, and displays myrmekitic texture. The majority of the thin section is PMG.

SAMPLE NUMBER: 85-SD-51
LITHOLOGY: PMG
LOCATION: SOL-1; 15.80m

MINERALOGY:

MINERAL	%	SIZE
plagioclase	25	6.0mm
K-feldspar	22	5.0mm
quartz	50	2.0mm
zircon	<1	<1.0mm
Fe-oxide	3	<0.1mm
apatite	<1	<1.0mm

TEXTURE: Porphyritic

NOTES: This sample shows typical hematite alteration of the PMG around the breccia zone. All pyrite has been oxidized. Quartz and hematite veins-cross cut the sample; disseminated hematite also present.

SAMPLE NUMBER: 85-SD-57
LITHOLOGY: Vein Material
LOCATION: SOL-1; 32.25

MINERALOGY:

MINERAL	%	SIZE	
quartz	52	variable	
flourite	30	variable	
chlorite	15	variable	generally
hematite	3	variable	<.01mm

TEXTURE: All mineral phases occur as veins; some are rich in inclusions.

NOTES: This sample illustrates the numerous periods of fluid injection and variation in fluid composition. Also present is a small fragment of similar composition which is most probably a fragment of vein material which was broken off from higher up and has fallen the open space in the fracture.

SAMPLE NUMBER: 85-SD-61
LITHOLOGY: Aplite breccia dyke
LOCATION: SOL-1; 52.25m

MINERALOGY:

MINERAL	%	SIZE
quartz	81	0.45mm
plagioclase	2	0.2mm
chlorite	6	<0.1mm
sericite	10	<0.1mm
pyrite	<1	<0.1mm

TEXTURE: Porphyritic, sericitized

NOTES: Phenocrysts are quartz and feldspar (altered) and constitute only about 15% of the thin section. The rock has been fractured and injected with thin veinlets of fine grained quartz and minor chlorite. Overall appearance is somewhat similar to a tuff. Contains numerous large, angular fragments of essentially unaltered pink PMG.

SAMPLE NUMBER: 85-SD-66
LITHOLOGHY: Granite enclave
LOCATION: SOL-1; 124.20

MINERALOGY:

MINERAL	%	SIZE
quartz	30	4.0mm
K-feldspar	30	3.0mm
plagioclase	37	4.0mm
chlorite	3	1.0mm
apatite	<1	0.2mm

TEXTURES: Granitic, myrmekitic

NOTES: All quartz grains have myrmekite rims; all feldspars are altered; contains disseminated fine grained pyrite; generally unaltered sample, very little chlorite.

SAMPLE NUMBER: 85-SD-67
LITHOLOGY: Aplite dyke and Aplite breccia dyke
LOCATION: SOL-1; 126.80m

MINERALOGY: Aplite dyke

MINERAL	%	SIZE
quartz	35	0.5mm
plagioclase	15	0.25mm
K-feldspar	30	0.3mm
pyrite	5	0.1mm
chlorite	15	0.6mm
apatite	1-3	0.5mm
zircon	<1	0.05mm

TEXTURE: All grains approximately the same size ; Granitic

NOTES: Pyrite grains have rims of chlorite; alteration zone of (~1cm) due to aplite breccia dyke.

MINERALOGY: Aplite breccia dyke

MINERAL	%	SIZE
quartz	50	<.05mm
chlorite	25	<.001mm
PMG clasts	30	3.0mm
pyrite	<1	0.02mm
sericite	1-2	<.01mm
zircon	<1	<.01mm

TEXTURE: Same as above except for presence of clasts.

NOTES: Matrix is finer grained than aplite dyke; clasts are subangular to subrounded; there is a poorly formed chill margin at contact with aplite dyke.

SAMPLE NUMBER: 85-SD-70
LITHOLOGY: LMPT
LOCATION: SOL-2; 12.80m

MINERALOGY:

MINERAL	%	SIZE
quartz	53	1-3 mm
plagioclase	10	1-2.0mm
K-feldspar	20	1-1.5mm
chlorite	15	up to 1.5mm
pyrite	1	<1.0mm
zircon	<1	<1.0mm
apatite	<1	<1.0mm

TEXTURE: Unwelded tuffaceous; porphyritic

NOTES: All feldspars are altered to clay minerals; extensively chloritized; crosscut by several small veinlets of quartz.

SAMPLE NUMBER: 85-SD-78
LITHOLOGY: Aplite breccia dyke
LOCATION: SOL-2; 139.70m

MINERALOGY:

MINERAL	%	SIZE
quartz	30	0.1mm
chlorite	15	0.2mm
pyrite	5	0.1mm
rock flour	10	<0.1mm
PMG clasts	40	1-30mm

TEXTURE: Porphyroclastic; chloritized

NOTES: Matrix is a mixture of rock flour, clasts of PMG, quartz, chlorite and other green clays with minor pyrite; PMG clasts are angular with partial rims of chlorite, they also have a myrmekitic texture and are up to 3 cm in size.

SAMPLE NUMBER: 85-SD-79
LITHOLOGY: PMG (Red band)
LOCATION: SOL-3; 205.00m

MINERALOGY:

MINERALS	%	SIZE
K-feldspar	80	2.0mm
chlorite	3	0.08mm
quartz	10	0.17
pyrite	1	<0.01
calcite	4	0.3mm
hematite	1	<0.01
apatite	<1	<0.1

TEXTURE: Myrmekitic, granitic, porphyritic.

NOTES: Calcite is found in surrounding PMG but is much more concentrated in the red band. The band gets its appearance from an enrichment of K-feldspar and a depletion in quartz and plagioclase. The quartz is incorporated in myrmekite; calcite is enriched in opaque inclusions; all feldspars are altered to clays.

SAMPLE NUMBER: 85-SD-79
LITHOLOGY: PMG
LOCATION: SOL-3; 205.10m

MINERALOGY:

MINERAL	%	SIZE
plagioclase	30	up to 8.0mm
K-feldspar	23	up to 8.0mm
chlorite	1	<1.0mm
quartz	45	up to 3.0mm
zircon	<1	up to 0.3mm
apatite	<1	up to 1.0mm
calcite	<1	up to 2.0mm
pyrite	<1	<1.0mm

TEXTURE: Myrmekitic, porphyritic, rapakivi

NOTES: Plagioclase is almost completely altered to sericite, faint twinning lines still remain; long apatite grains scattered throughout; some plagioclase grains are overgrown by K-feldspar; calcite and chlorite occur in close association; some pyrite with chlorite rims.

APPENDIX C

MICROPROBE ANALYSES

MINERAL: CHLORITE

OXIDE (wt.%)	85-SD-47A	
	1	2
SIO2	25.93	26.33
TIO2	0.10	0.00
AL2O3	21.21	20.58
CR2O3	0.06	0.04
FEO	31.75	30.24
NIO	0.00	0.00
MNO	1.21	1.06
MGO	8.10	7.46
CAO	0.10	0.09
NA2O	0.08	0.00
K2O	0.00	0.01
TOTAL	88.54	85.81

host rock:
1)-2) Vein material

OXIDE (wt.%)	85-SD-67			
	1	2	3	4
SIO2	28.58	25.00	28.30	26.75
TIO2	0.06	0.00	0.05	0.12
AL2O3	20.41	18.63	21.41	20.62
CR2O3	0.04	0.02	0.00	0.10
FEO	28.05	28.76	29.23	31.35
NIO	0.00	0.00	0.00	0.00
MNO	0.51	0.61	0.55	0.73
MGO	9.58	9.71	7.77	8.67
CAO	0.24	0.25	0.10	0.10
NA2O	0.01	0.05	0.03	0.03
K2O	0.22	0.00	0.76	0.00
TOTAL	87.69	83.03	88.19	88.45

host rock:
1)-2) Aplite breccia dyke
3)-4) Aplite dyke

OXIDE (wt.%)	85-SD-49			
	1	2	3	4
SIO2	24.80	26.32	25.04	29.14
TIO2	0.00	0.03	0.00	0.02
AL2O3	20.40	18.53	20.65	21.29
CR2O3	0.01	0.05	0.01	0.05
FEO	32.23	32.39	31.29	27.57
NIO	0.00	0.00	0.00	0.00
MNO	1.19	0.76	0.77	0.74
MGO	8.51	9.82	8.64	8.37
CAO	0.06	0.03	0.13	0.15
NA2O	0.07	0.00	0.05	0.03
K2O	0.00	0.00	0.00	0.63
TOTAL	87.27	87.92	86.58	87.99

OXIDE (wt.%)	85-SD-49		
	5	6	7
SIO2	27.12	25.13	33.42
TIO2	0.01	0.07	0.04
AL2O3	21.69	20.31	21.78
CR2O3	0.00	0.04	0.02
FEO	31.05	32.80	23.35
NIO	0.00	0.00	0.00
MNO	1.06	1.32	0.61
MGO	8.51	7.69	6.13
CAO	0.04	0.14	0.15
NA2O	0.01	0.08	0.03
K2O	0.37	0.00	2.28
TOTAL	89.86	87.57	87.82

host rock:
1)-4) Carbonate enclave
5)-7) PMG

OXIDE (wt.%)		85-SD-61	
	1	2	3
SIO2	26.71	27.71	25.49
TIO2	0.03	0.00	0.00
AL2O3	20.30	19.58	18.73
CR2O3	0.09	0.01	0.00
FEO	26.66	26.96	23.19
NIO	0.00	0.00	0.00
MNO	0.71	0.90	0.51
MGO	13.62	12.19	15.05
CAO	0.05	0.07	0.10
NA2O	0.02	0.06	0.00
K2O	0.00	0.00	0.00
TOTAL	88.19	87.47	83.07

host rock:
1)-3) Aplite breccia dyke

OXIDE (wt.%)	85-SD-47B
	1
SIO2	25.53
TIO2	0.08
AL2O3	19.94
CR2O3	0.04
FEO	29.97
NIO	0.00
MNO	0.79
MGO	7.21
CAO	0.18
NA2O	0.03
K2O	0.16
TOTAL	83.94

host rock:
1) PMG

OXIDE (wt.%)		85-SD-66
	1	2
SIO2	38.20	25.11
TIO2	0.05	0.00
AL2O3	25.56	21.13
CR2O3	0.05	0.04
FEO	16.87	29.15
NIO	0.00	0.00
MNO	0.35	0.74
MGO	5.59	11.73
CAO	0.06	0.06
NA2O	0.05	0.02
K2O	4.93	0.00
TOTAL	91.69	87.97

host rock:
1)-2) Granite enclave

MINERAL: PLAGIOCLASE

OXIDE (wt.%)	85-SD-67		
	1	2	3
SIO2	69.46	69.93	65.05
TIO2	0.00	0.00	0.00
AL2O3	18.89	19.62	18.33
CR2O3	0.00	0.00	0.00
FEO	0.47	0.25	0.04
NIO	0.00	0.00	0.00
MNO	0.02	0.00	0.00
MGO	0.12	0.04	0.00
CAO	0.26	0.11	0.09
NA2O	10.73	11.51	11.58
K2O	0.00	0.00	0.00
TOTAL	99.95	101.45	95.09

host rock:
1) PMG clast in aplite breccia dyke
2)-3) Aplite dyke

OXIDE (wt.%)	85-SD-66	
	1	2
SIO2	67.43	69.16
TIO2	0.00	0.00
AL2O3	20.05	19.81
CR2O3	0.06	0.00
FEO	0.17	0.00
NIO	0.00	0.00
MNO	0.00	0.00
MGO	0.04	0.02
CAO	0.31	0.04
NA2O	7.94	10.81
K2O	3.15	0.00
TOTAL	99.16	99.83

host rock:
1)-2) Granite enclave

MINERAL: K-FELDSPAR

OXIDE (wt.%)	85-SD-49
	1
SIO2	64.63
TIO2	0.00
AL2O3	18.19
CR2O3	0.01
FEO	0.00
NIO	0.00
MNO	0.01
MGO	0.03
CAO	0.00
NA2O	0.40
K2O	16.39
TOTAL	99.66

host rock:
1) Myrmerkite rim

OXIDE (wt.%)	85-SD-61
	1
SIO2	64.43
TIO2	0.00
AL2O3	18.49
CR2O3	0.01
FEO	0.07
NIO	0.00
MNO	0.04
MGO	0.02
CAO	0.00
NA2O	0.49
K2O	15.93
TOTAL	99.47

host rock:
1) Aplite breccia dyke

OXIDE (wt.%)	85-SD-47B
	1
SIO2	65.57
TIO2	0.02
AL2O3	18.32
CR2O3	0.05
FEO	0.08
NIO	0.00
MNO	0.08
MGO	0.01
CAO	0.00
NA2O	0.36
K2O	16.28
TOTAL	100.75

host rock:
1) PMG

OXIDE (wt.%)	85-SD-70	
	1	2
SIO2	58.01	47.33
TIO2	1.00	0.05
AL2O3	26.23	27.76
CR2O3	0.03	0.01
FEO	2.17	2.55
NIO	0.00	0.00
MNO	0.03	0.10
MGO	1.14	1.56
CAO	0.17	0.09
NA2O	0.00	0.08
K2O	6.56	7.33
TOTAL	95.34	86.85

host rock:
1)-2) LMPT

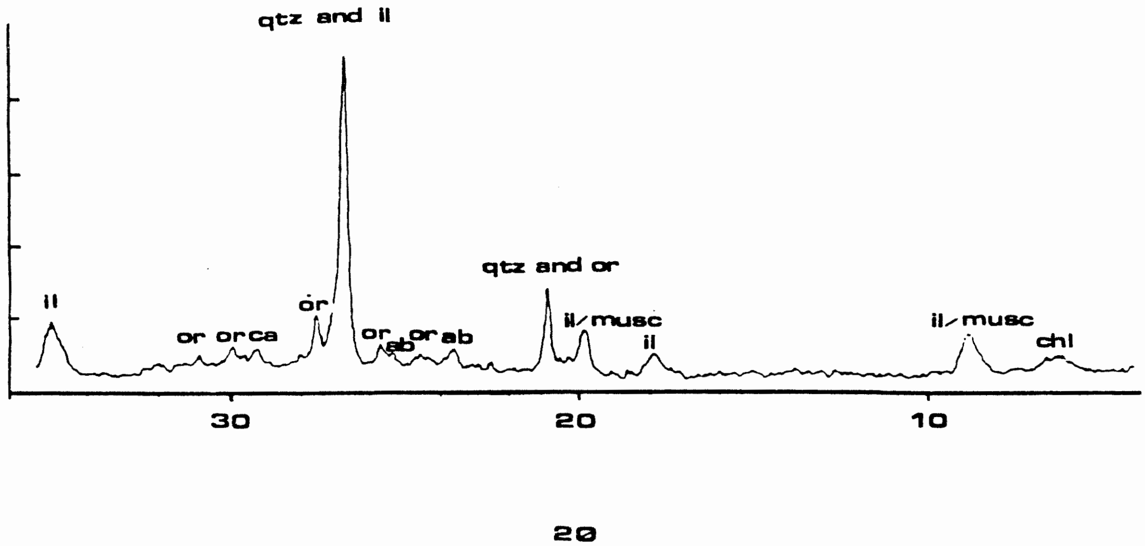
APPENDIX D

X-ray Diffraction Patterns of Clay Minerals

Identification of clay minerals found in intensely altered sections of the drill core was done by the author, at Dalhousie University, using a Phillips X-ray Diffractometer.

The diffractometer was set up as follows:

RADIATION	: CuK alpha
FILTER	: Nickel
Kv/mA	: 40/20
SCAN SPEED	: one degree per minute
CHART SPEED	: one centimeter per minute
RANGE (C.P.S.)	: 1 x 1000



XRD Pattern for: Quartz (qtz)

Illite (il)

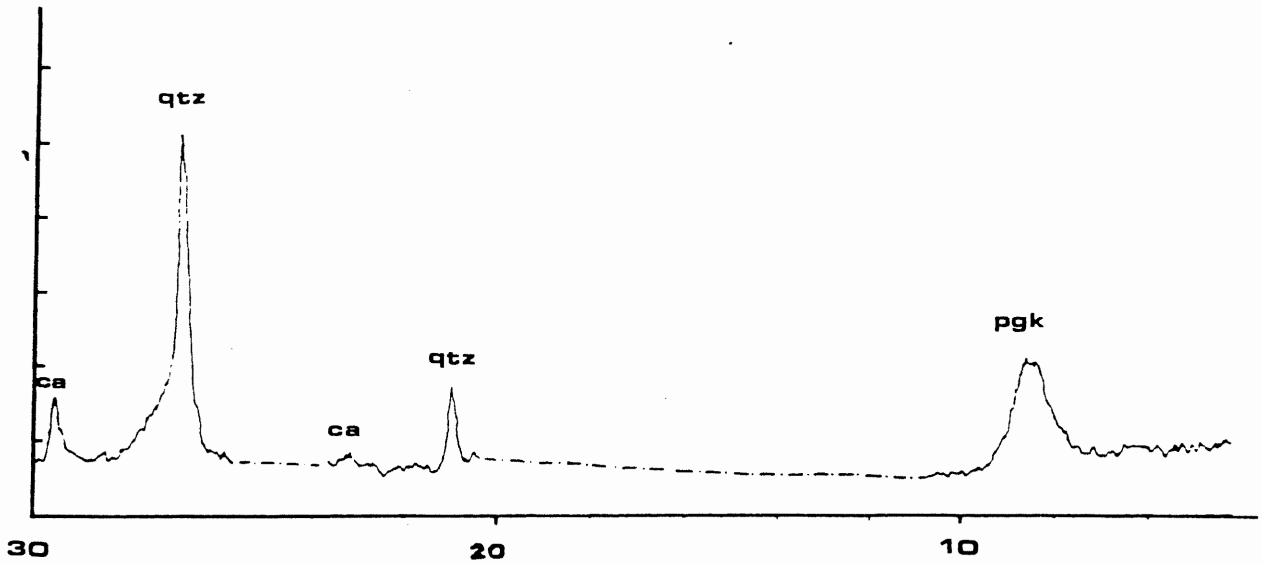
Muscovite (musc)

Orthoclase (or)

Albite (ab)

Calcite (ca)

Chlorite (chl)



2θ

XRD Pattern for: Quartz (qtz)

Calcite (ca)

Palygorskite (pgk)

APPENDIX E

X-RAY FLOURESCENCE ANALYSES OF ROCK POWDERS

OXIDE (wt.%)	HFL-1	85-SD-39	85-SD-45	85-SD-48	85-SD-49	85-SD-65
			SAMPLE NUMBER			
SiO_2	59.47	71.48	73.55	73.53	71.17	67.63
Al_2O_3	22.19	14.65	13.90	14.68	14.54	14.84
Fe_2O_3*	7.23	1.64	2.51	1.47	2.84	3.34
MgO	2.10	1.14	1.04	1.04	1.35	1.20
CaO	0.23	1.96	0.48	0.16	0.25	1.76
Na_2O	1.57	0.44	0.58	0.47	2.13	3.51
K_2O	4.44	6.30	5.50	7.74	6.46	4.92
TiO_2	1.01	0.17	0.62	0.18	0.53	0.66
MnO	0.08	0.07	0.05	0.04	0.07	0.08
P_2O_5	0.12	0.12	0.17	0.10	0.14	0.19
total	98.44	97.99	98.41	99.41	99.48	98.12
L.O.I.	2.2	3.0	2.4	1.4	1.3	1.9
trace elements						
Ba	889	943	691	915	903	965
Rb	214	333	384	456	391	198
Sr	203	81	38	75	93	139
Y	34	26	34	30	37	37
Zr	195	87	397	88	353	409
Nb	23	10	20	11	18	18
Th	15	8	15	6	19	13
Pb	24	25	18	14	30	18
Ga	29	24	22	27	24	24
Zn	113	39	62	44	65	75
Cu	21	n.d.	n.d.	n.d.	n.d.	n.d.
Ni	45	38	**47**	**52**	50	29
TiO_2	1.06	0.18	0.59	0.19	0.46	0.53
V	114	13	30	15	28	37
Cr	108	6	6	10	4	11

NOTES: (1) HFL-1 is the internal standard of the XRF centre.
(2) L.O.I. means loss on ignition (wt%).
(3) All trace element values are in ppm except TiO_2 (wt.%).
(4) Fe_2O_3* means total iron expressed as Fe_2O_3.

OXIDE (wt.%)	SAMPLE NUMBER 85-SD-66	85-SD-67	85-SD-69	85-SD-71	85-SD-79	HFL-1 (repeat)
SiO_2	73.26	68.41	72.84	73.71	67.11	59.53
Al_2O_3	14.26	13.73	14.34	14.01	14.91	22.19
Fe_2O_3*	0.89	5.15	2.00	1.48	3.51	7.30
MgO	0.72	1.60	1.12	0.93	1.29	2.09
CaO	0.69	1.29	0.67	0.21	1.74	0.23
Na_2O	2.49	2.77	0.88	2.09	3.64	1.91
K_2O	7.20	4.42	6.93	6.27	5.18	4.43
TiO_2	0.15	1.07	0.30	0.29	0.64	1.02
MnO	0.03	0.09	0.07	0.03	0.08	0.08
P_2O_5	0.16	0.31	0.07	0.07	0.18	0.12
total	99.83	98.83	99.22	99.10	98.27	98.90
L.O.I.	0.9	1.6	2.0	1.1	2.1	2.2
trace elements						
Ba	966	679	520	576	976	902
Rb	310	216	375	278	160	216
Sr	116	78	32	66	166	205
Y	21	42	37	34	36	36
Zr	94	268	235	243	391	194
Nb	15	19	16	17	18	22
Th	3	11	18	14	9	17
Pb	19	12	23	22	14	25
Ga	19	24	26	22	24	28
Zn	31	93	59	39	71	116
Cu	5	n.d.	n.d.	n.d.	n.d.	30
Ni	33	34	43	32	23	45
TiO_2	0.15	0.91	0.28	0.30	0.61	1.07
V	15	77	12	9	42	115
Cr	2	n.d.	11	6	6	109

NOTES:
(1) HFL-1 is the internal standard of the XRF centre.
(2) L.O.I. means loss on ignition (wt%).
(3) All trace element values are in ppm except TiO_2 (wt.%).
(4) Fe_2O_3* means total iron expressed as Fe_2O_3.