

## DISTRIBUTION OF ALTERATION MINERALS AND METALS IN THE FIRE TOWER ZONE AT BRUNSWICK TIN MINES LTD., MOUNT PLEASANT AREA, NEW BRUNSWICK.

GASTON POULIOT<sup>1</sup>, BERNARD BARONDEAU<sup>1</sup>,  
PIERRE SAUVE<sup>2</sup> AND MICHAEL DAVIS<sup>1</sup>

<sup>1</sup>Département de Génie Minéral, Ecole Polytechnique, C.P. 6079, Succ. "A",  
Montréal, Qué. H3C 3A7

<sup>2</sup>Société de Développement de la baie James, 800 est, blvd. de Maisonneuve,  
Montréal, Qué. H2L 4M6

### ABSTRACT

The distribution of quartz, topaz, fluorite, chlorite, mica, feldspars and kaolinite in the Fire Tower zone, Mount Pleasant area, was determined by quantitative X-ray diffraction analysis of more than 180 samples from 10 drill holes in section 406N at the mine. The samples studied were 15-meter composites regularly spaced at 15-meter intervals in the drill holes. The ore zone is associated with a greisen alteration where original quartz-feldspathic porphyries have undergone intense mineralogical and chemical modification. Outward from the center three concentric zones may be distinguished: (a) an inner quartz-topaz greisen, (b) an intermediate quartz-iron-rich chlorite-mica greisen, (c) an outer quartz-mica-chlorite greisen. The inner zone hosts the mineralization. It is largely composed of quartz (60-80%) and topaz (5-28%) with only accessory layer silicates and marks the locus of the most intense alteration. Chemical analyses indicate that the alkalis have been almost completely removed from this zone. The intermediate zone carries 5-25% chlorite and indicates important addition of iron to the original rocks. The outer mica zone is broad and extends beyond the section investigated. Fluorite (0.5-5%) is present throughout the three zones but is mainly concentrated within the mineralized quartz-topaz rocks. Hydrogen and fluorine metasomatism has resulted in nearly complete alteration of feldspars throughout the three zones. Both the quartz-topaz alteration and the W-Mo-Bi mineralization commence near the same depth, presumably owing to the marked pressure change that accompanied the ascent of the hydrothermal solutions into fractured and brecciated rocks.

### SOMMAIRE

La distribution du quartz, de la topaze, de la fluorine, de la chlorite, des micas, des feldspaths et de la kaolinite dans la zone de Fire Tower, région de

Mount Pleasant, a été déterminée par l'analyse diffractométrique quantitative de plus de 180 échantillons provenant de 10 forages situés dans la région 406N de la mine. Les échantillons prélevés tous les 15 mètres, représentent chacun 15 mètres de sondage. La zone minéralisée est associée à une vaste altération de type greisen. Les porphyres quartzo-feldspathiques originels ont subi d'importantes modifications minéralogiques et chimiques. Trois zones d'altération concentriques peuvent être identifiées: (a) la zone centrale est un greisen à quartz et topaze; (b) la zone intermédiaire est un greisen à quartz, chlorite riche en fer et micas; (c) la zone extérieure est un greisen à quartz-chlorite-mica. La zone centrale renferme la minéralisation et identifie la région où l'altération a été la plus intense. Les roches y sont surtout constituées de quartz (60-80%) et de topaze (5-28%) avec des quantités accessoires de phyllosilicates. Les analyses chimiques révèlent que les alkalis en ont été quasi totalement lixiviés. La zone intermédiaire qui contient de 5 à 25% de chlorite, témoigne d'une addition importante de fer aux roches originelles. La fluorine (0.5-5%) est présente partout dans les trois zones mais se trouve concentrée surtout dans la zone minéralisée à quartz et topaze. Le métasomatisme hydrogéné et fluoré a conduit à la destruction quasi complète des feldspaths dans les trois zones. Nous attribuons le fait que la zone à quartz-topaze et la minéralisation W-Mo-Bi débutent à une même profondeur à la chute de pression des solutions hydrothermales au cours de leur montée dans les roches fracturées et bréchifiées.

### INTRODUCTION

The aim of this work is to describe the distribution of alteration minerals and related chemical trends in a vertical section across a well-documented example of greisen-type mineralization. The work originated with a project to IREM-MERI† (Pouliot 1973); its

<sup>2</sup>Formerly with the Sullivan Mining Group, Montréal, Qué.

†Institut de Recherche en Exploration Minérale — Mineral Exploration Research Institute.

purpose was to describe, semi-quantitatively, the distribution of alteration minerals in the Fire Tower zone of the Mount Pleasant deposit in New Brunswick. After encouraging initial results the work was expanded to encompass a larger number of samples and was rendered more quantitative by using improved analytical methods. Also, a large amount of chemical data supplied by the Sullivan Mining Group enabled us to study the distribution of certain metals in the section investigated.

#### GENERAL GEOLOGICAL SETTING

Brunswick Tin Mines Ltd. is developing in the Mount Pleasant area of southern New Brunswick, a large W-Mo-Bi body within a silicified and greisenized subvolcanic felsic intrusion. Two distinct W-Mo-Bi bodies, approximately 1000m apart, occur within narrow felsic intrusive units on the property. The present study is concerned exclusively with the southern mineralized body known locally as the Fire Tower zone. The geology of the area is known principally from Hosking (1963), Ruitenberg (1963, 1967), van de Poll (1967), Parrish & Tully (1971) and Dagger (1972). Ruitenberg (1967), Dagger (1972) and Petruk (1973) have provided detailed accounts of the ore mineralogy and alteration in the deposits. Parrish (1977) has given an up-to-date list of the minerals identified in the deposits.

The Mount Pleasant area is located near the northwestern margin of the Middle Devonian St. George batholith (Fig. 1). The batholith was emplaced during the Acadian orogeny; after-

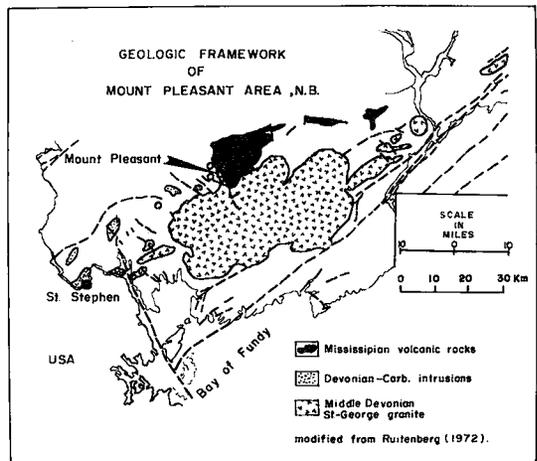


FIG. 1. Geologic framework of the Mount Pleasant area.

wards, in Early Carboniferous times, the region was the site of important tectonic activity marked by fracturing, major wrench and block faulting and associated volcanic activity (Ruitenberg 1967, 1972). The siliceous volcanic rocks of the Mount Pleasant area and associated W-Mo-Bi-Zn-Sn mineralization were formed during that period. The volcanic rocks comprise gently dipping zoned ash-flow tuffs of quartz latite composition and an extrusive unit separated into two formations, the Rothea porphyry and the overlying Sealy porphyry. On Mount Pleasant itself (Fig. 2), intrusive feldspar porphyry

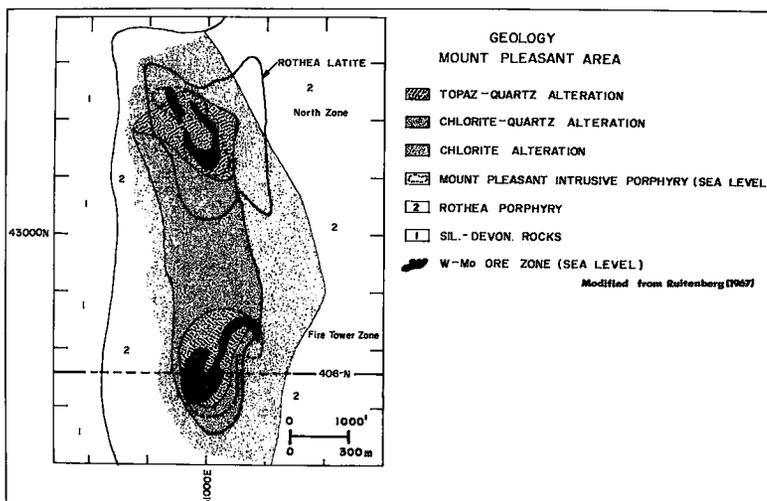


FIG. 2. Geology of Mount Pleasant area (modified from Ruitenberg (1967), with additions by the geological staff of Brunswick Tin Mines Ltd.).

considered equivalent of the extrusive Rothea porphyry has been invaded by two plugs of distinctly finer grained quartz-feldspar porphyry. The latter has variously been named lithic tuff, altered banded quartz feldspar porphyry (Ruitenbergh 1963, 1967), tuffite (Parrish & Tully 1971) and fine-grained porphyry (Dagger 1972). Tully (pers. comm. 1977) definitely hesitates in correlating the intrusive feldspar porphyry at Mount Pleasant with the extrusive feldspar porphyry (Rothea) lying further to the north. He considers the Mount Pleasant volcanic rocks as forming a separate basin, distinct from the one generally referred to as the Mount Pleasant appendage.

The finer grained quartz-feldspar porphyry, here designated as the Mount Pleasant porphyry, occurs as two plugs approximately 1200m apart, regarded by most investigators as sites of former volcanic vents or necks (Hosking 1963, Ruitenbergh 1967, Dagger 1972). The shape, size and composition of the plugs and the presence in them of numerous breccia pipes and dykes (Tait 1965) clearly support such an origin. Recent geological information from deeper probing (Parrish & Tully 1977) indicates that the Mount Pleasant porphyry is in contact at depth with a fresh-looking, little altered quartzofeldspathic rock called transition rock. The latter grades at depth into microgranite that probably underlies most of Mount Pleasant.

The two large zones of W-Mo-Bi mineralization present in the northern and southern plug of Mount Pleasant porphyry (Fig. 2) are called the Northern zone and the Southern or Fire Tower zone respectively. W-Mo-Bi mineralization occurs in both as disseminations and narrow veinlets in fractured, brecciated, silicified and greisenized porphyry. The main ore minerals are, in order of abundance, arsenopyrite, wolframite, molybdenite and native bismuth. Genetically related to this episode of mineralization, but irregularly related to it in space, is a base-metal-type Zn-Sn-Cu-Pb-In mineralization. This sulfide mineralization is scattered as numerous occurrences, veins, pods, mineralized pipes, within and above the deeper-seated W-Mo-Bi mineralized zone. Principal minerals are sphalerite, chalcopyrite, galena, cassiterite, stannite and arsenopyrite.

The rocks on Mount Pleasant show various degrees and types of alteration. The alteration minerals related to mineralization are principally quartz, mica, chlorite, topaz, fluorite, kaolinite and feldspars. Ruitenbergh (1967) recognized two centres of strong silicification and greisenization, each coinciding with one of the intrusive

plugs (Fig. 2). These centres are surrounded and joined by a broad zone of silicification and chloritization; a third zone of chlorite alteration, approximately 300m wide, surrounds the second zone. Similarly, Dagger (1972) described a central zone of silicification and topaz and fluorite formation, surrounded by a zone dominantly of chloritic alteration with less pronounced silicification. Parrish & Tully (1971) have distinguished and shown diagrammatically the distribution of silicic, chloritic, hematitic, fluoritic, potassic and sericitic alterations. The pattern of distribution is complex and the abundance of these minerals can vary much over short distances.

### *The Fire Tower zone*

This study is concerned solely with the Southern or Fire Tower zone. At the surface, the intrusive plug is 400m long and 150m wide; it is 550m long and 300m wide at sea-level elevation (335m below the surface of Mount Pleasant). A large part of the Fire Tower plug is strongly silicified and greisenized to the extent that original textures and structures are largely obliterated. Results of deep drilling and of our mineralogical investigation indicate that the greisen zone extends vertically to a depth of approximately 390m; it bottoms fairly uniformly at elevation 60m below sea level where it is underlain by progressively less altered felsic rocks. The transition from highly altered rocks to less altered rocks takes place over a vertical range of 120m, from elevation 30m above sea level to 90m below sea level. The main W-Mo-Bi mineralization lies in the lower part of the greisen zone (Fig. 3).

### MATERIALS AND METHODS OF STUDY

Study material was provided to us as a series of homogenized powdered core samples, each a composite representing a 15m length of core. These samples were obtained at 15m intervals from ten drill holes contained in section 406N across the Fire Tower zone (Figs. 3, 4). Thus, more than 180 samples, including some larger composite samples, were examined in the present study. Because each sample analyzed represents the average mineralogy of a 15m section of core, our study attempts to depict quantitatively the overall or bulk alteration pattern associated with mineralization. This needs to be stressed, for concentrations reported here would differ appreciably from estimates obtained from a similar study based on hand specimens. As

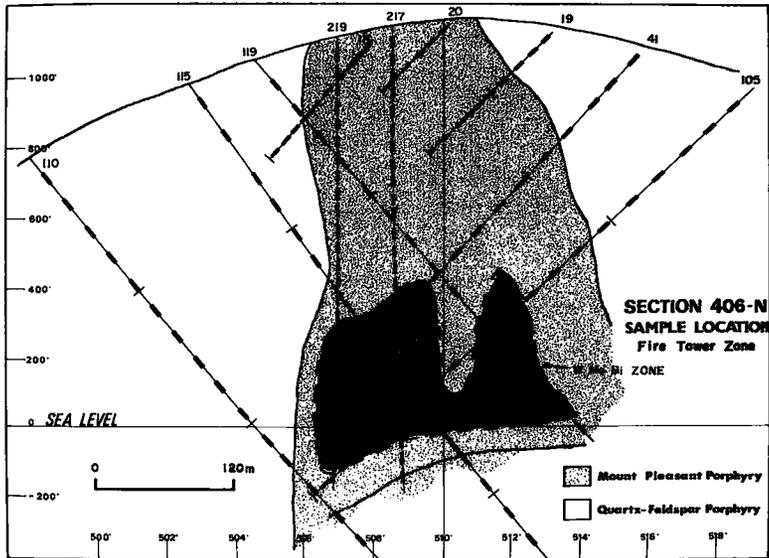


FIG. 3. Geologic section 406N across the Fire Tower zone, illustrating the location of samples used in the present study.

fractures and breccias are important features in controlling alteration (Dagger 1972, Petruk 1973), these structures are locally the sites of intense alteration characterized by nearly monomineralic assemblages, such as quartz and topaz-

rich rocks, kaolinite-rich pipes, and massive chlorite seams. The study of composite samples permits us to smooth out these high values and depict the broader pattern of alteration and metal distribution.

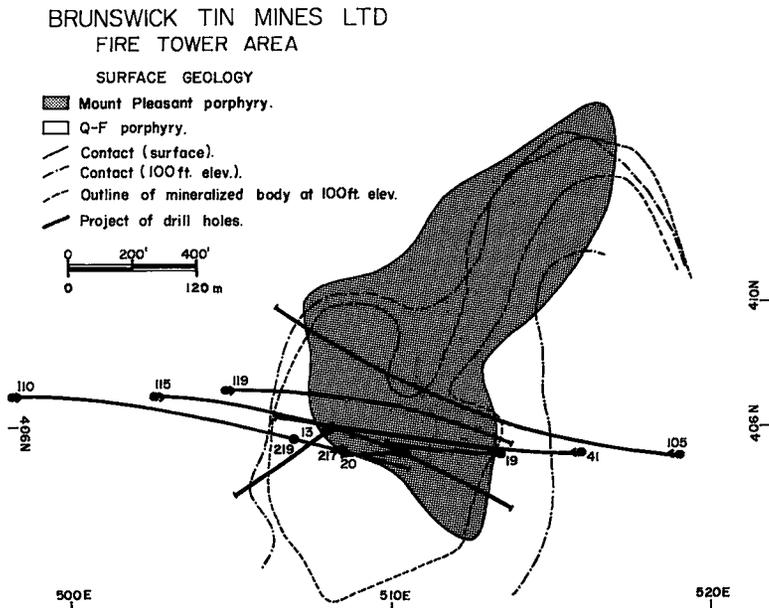


FIG. 4. Schematic map of the Fire Tower zone illustrating the drill-holes studied in section 406N.

Quartz, fluorite, topaz, feldspars, chlorite and kaolinite were quantitatively determined in the samples by means of diffractometer techniques. Standard mixtures of these minerals were prepared in a finely ground quartz matrix and used to establish working curves. Details of the methods used are given in appendix form at the end of the paper.

Although surprisingly low limits of detection and good reproducibility could be achieved, some assumptions and simplifications were obviously necessary in dealing with the more complex mineral groups such as layer silicates. Dark green iron-rich chlorite from the Fire Tower zone (hole 115, 112.5m) was used as a standard for the working curve and all chlorite analyzed were assumed to be of this type, although both 14Å and 7Å chlorites and a third variety have been identified (Petruk 1973; pers. comm. 1975). Likewise, serpentine reported by Petruk (1973) has a basal reflection that would interfere with that of chlorite; it has not been considered in the present work. Well-crystallized normal 7Å kaolinite was used as standard for the working curve although both normal 7Å kaolinite and dickite have been identified in the deposit (Dean 1964). Similar simplifications were also necessary in determining the micas. Common musco-

vite was used for the working curves even though several micas (hydromica, sericite, muscovite, lepidolite and secondary biotite) have been reported.

Reproducibility tests on artificial mixtures allowed us to estimate at approximately 10% the relative accuracy of determinations of amounts of simple minerals such as quartz, fluorite and topaz. Because of the assumptions and simplifications used in dealing with the layer silicates, the relative accuracy of those determinations is somewhat lower than the estimates derived from the reproducibility tests, and probably of the order of  $\pm 20\%$ . However, this lower accuracy seems quite acceptable, as distributions outlined for these minerals are well corroborated by the chemical data on the samples.

A large amount of chemical data was provided by the Sullivan Mining Group. Each diamond-drill core has been analyzed in 3m sections at the mine for W, Bi, Mo, Sn, Cu, Zn, Pb and As by X-ray fluorescence methods. These determinations have been checked repeatedly by commercial laboratories. In the present study, these data have been weighed in 12 to 15m samples to compare with the mineralogical sections. Similarly, all drill core from holes studied in section

TABLE 1. CHEMICAL ANALYSES OF ROCKS FROM THE FIRE TOWER ZONE (1)

Spec. no.	1	2	3	4	5	6	7	8	9	10	11	12
SiO <sub>2</sub>	70.38	75.90	75.47	73.82	73.67	75.09	77.46	74.36	76.88	73.75	73.72	75.25
Al <sub>2</sub> O <sub>3</sub>	14.86	13.41	10.72	10.16	10.90	10.48	10.85	9.49	12.0	10.94	11.58	10.65
Fe <sub>2</sub> O <sub>3</sub>	2.84	1.56	5.6	6.18	5.94	6.05	4.38	6.24	4.05	7.27	5.44	5.49
MgO	0.83	0.45	0.0	0.48	0.69	0.60	0.36	0.78	0.59	0.15	0.13	0.50
CaO	1.16	0.47	3.25	3.04	3.37	3.21	2.62	3.84	1.65	1.41	1.43	2.99
Na <sub>2</sub> O	3.79	2.95	0.12	0.18	0.06	0.06	0.04	0.06	0.06	0.36	0.88	0.08
K <sub>2</sub> O	5.62	5.21	0.92	0.95	1.01	1.52	0.26	0.74	0.21	3.10	3.50	0.80
TiO <sub>2</sub>	0.49	0.21	0.05	0.06	0.13	0.04	0.08	0.04	0.10	0.25	0.29	0.07
MnO	0.01	0.03	0.09	0.09	0.10	0.11	0.06	0.10	0.05	0.11	0.07	0.08
L. I. (2)	-	-	3.83	3.80	3.70	3.28	4.12	4.12	3.19	2.77	3.10	3.72
Total	99.98	100.19	100.05	98.76	99.57	100.44	100.23	99.77	98.78	100.11	100.14	99.63

(1) Analyses 3 to 11 by V. Kubat, Laboratoire de Géochimie analytique, Ecole Polytechnique.

(2) Loss on ignition (1000°C, 2 hrs).

**Specimens:** 1. Fresh Rothea latite, av. of 3 analyses given by Dagger (1972, p. 81). 2. Fresh Rothea porphyry, av. of 5 analyses given by Dagger (1972, p. 81). 3. Greisen-0: large composite sample from 872 meters of drill core within the W-Mo-Bi zone, from elevation +30 to -60 meters. 4. Greisen-250: large composite sample from 786 meters of drill core within the W-Mo-Bi zone from elevation +30 to +120 meters. 5. Bechtel no. 1: large composite sample taken at elevation 0 to +90 meters in the northern part of the Fire Tower zone. 6. Bechtel no. 2: large composite sample taken from elevation -60 to +60 meters in the southern part of the Fire Tower zone. 7. Bechtel no. 3: large composite sample taken from elevation +90 to +150 meters, overlying Bechtel nos. 2 and 4. 8. Bechtel no. 4: large composite sample taken from elevation -60 to +60 meters in the western part of the Fire Tower zone. 9. Bechtel no. 5: large composite sample from adit, at elevation +238 meters. 10. Composite sample from hole MPS-105 in section 406N (5 to 150 meters from hole collar), representative of altered Rothea quartz feldspar porphyry on the eastern side of the Fire Tower zone. 11. Composite sample from hole MPS-110 in section 406N (3 to 200 meters from collar), representative of altered Rothea quartz feldspar porphyry on the western side of the Fire Tower zone. 12. Average composition from analyses 3 to 9; this composition is probably fairly representative of the altered Mount Pleasant porphyry.

406N was analyzed at the mine for Fe, Ca, Ti, K and Al by an X-ray fluorescence method. Although not strictly quantitative (a simple technique using pelletized powder was used), these data have been used to illustrate the chemical variations in section 406N. To complement these data, and in order to estimate bulk chemical changes in the Fire Tower zone, chemical analyses were obtained for a series of large composite samples, some involving nearly 1000m of core. Details concerning the composite samples are given in Table 1.

All diagrams illustrating mineral and metal distributions in the present work were derived by computer programs developed by one of us (M. D.) The program first analyzes the spatial autocorrelation of the data and from this, provides by kriging an optimal interpolation. The interpolated surface is represented by bicubic splines (program COVPAC) and contours are drawn by computer from the spline representation (program NIVEAU).

#### DISTRIBUTION OF ALTERATION MINERALS

##### *Topaz*

The distribution of topaz outlines well the centre of the alteration pattern (Fig. 5). Topaz is largely confined to the intrusive plug of Mount Pleasant porphyry where it forms a zone nearly 240m wide and extending from surface to a depth of about 360m. The maximum topaz content recorded in a single sample is 28 wt. % whereas the average content in the portion of the intrusive plug sampled is approximately 14%. Its detection limit is 2 wt. %.

The distribution of topaz is asymmetric with regards to the contacts of the intrusive plug, as indicated by the presence of several maxima close to the western contact of the plug. Outwards from the contacts, topaz content decreases rapidly and the mineral is generally not detected in specimens located more than 90m from the plug. The outline of the W-Mo-Bi mineralized body in section 406 appears to coincide with two important topaz maxima (Fig. 5); below the mineralized body, topaz content decreases gradually and the mineral is almost absent from rocks located deeper than elevation -60m.

In general, the topaz content of the rock increases upward; regions of high topaz alteration coincide with regions of high silicification. Topaz is also inversely correlated with chlorite+mica+feldspars. A poorly defined and possibly insignificant correlation with fluorite may exist for regions of low to moderate (<10%) topaz

content. Cell-edge determinations of six topaz concentrates from the zone, using the data of Rosenberg (1967), indicate that the mineral has a high fluorine content (18.5%), close to fully fluorinated topaz (20.7%). Fluorine content of topaz varies only slightly (17.9 to 19.2%) and does not seem to reflect height in the alteration zone.

##### *Quartz*

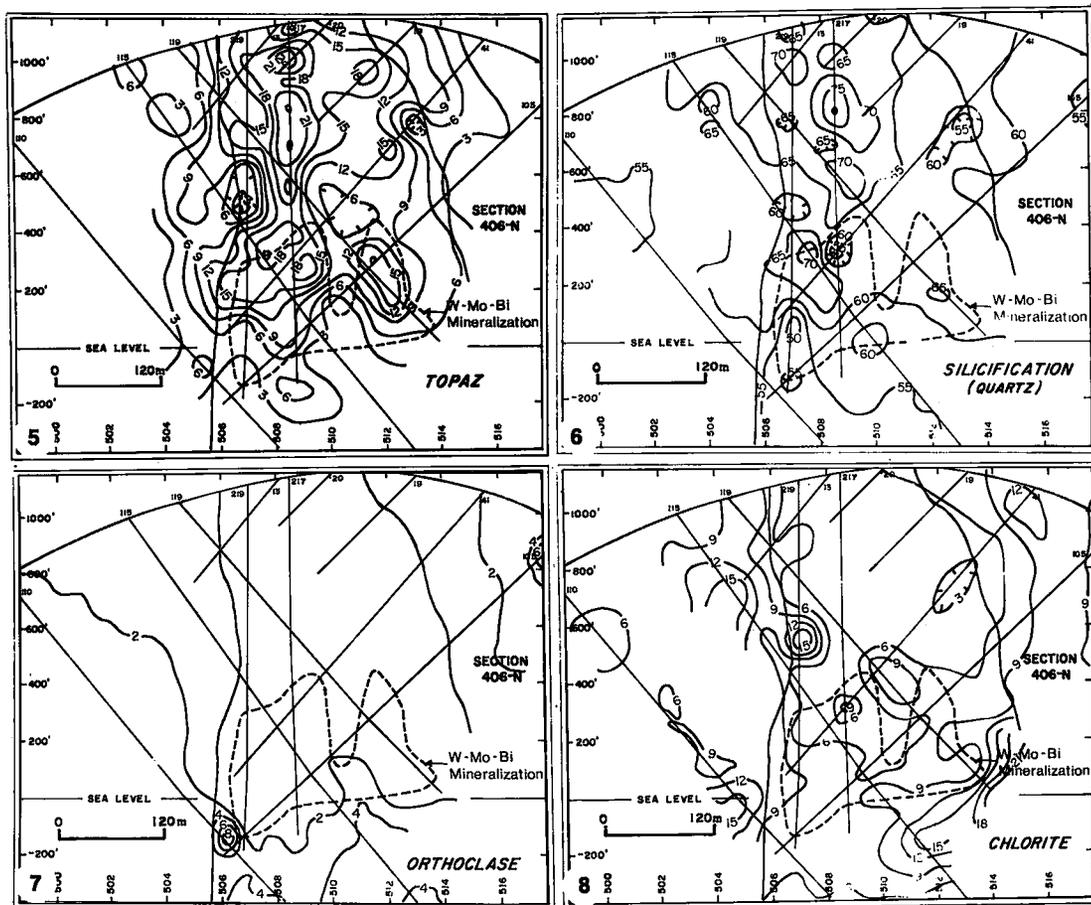
Quartz dominates the mineralogy of all samples, with concentrations ranging from 45 to 80 wt.%. What is determined by the X-ray diffraction method is the bulk quartz content, which includes 1) original quartz in the rocks, 2) quartz liberated during the alteration of feldspars to micas, chlorites and topaz, and 3) introduced or vein quartz. As evident from silicified and quartz-veined fragments in breccia pipes and dykes (Tait 1965), silicification proceeded early in the development of the mineralized zone. Petruk (1973) recognized three stages of silicification which probably proceeded more or less continuously during the evolution of mineralization. These relations probably account for the pervasive distribution of quartz in the alteration zone (Fig. 6).

The average quartz content of the portion of the intrusive plug above sea level is approximately 60 wt.%; it is less than this (50-55 wt.%) at elevations below sea level but increases toward the surface to 65-70%. Although the distribution of quartz is broader and more diffuse than that of topaz, the main regions of intense silicification coincide with regions of high topaz concentration. Both minerals seem to increase with height in the intrusive plug, suggesting that the quartz-topaz greisen zone might have extended to a significant height above the present erosion surface of Mount Pleasant.

##### *Feldspars*

Although orthoclase and albite could be detected in amounts as low as 1 wt.%, one of the most remarkable features of the alteration zone is the almost complete alteration of feldspars in the original quartz-feldspar porphyry (Fig. 7). Indeed, within a 240m radius from the surface centre of the quartz-topaz zone, feldspars have been almost totally altered to mica, chlorite and topaz, this alteration resulting from hydrogen and fluorine metasomatism (Dagger 1972).

The orthoclase content of the quartz-topaz zone is generally less than 2 wt.% (Fig. 7). Minor concentrations slightly in excess of this value have been encountered in rare samples;



FIGS. 5-8. Distribution of topaz, quartz (silicification), orthoclase and chlorite in section 406N.

these may contain feldspars that escaped alteration or possibly feldspars resulting from local feldspathization such as described by Dagger (1972). Albite follows a pattern similar to that of orthoclase except that its concentration is lower, perhaps reflecting its greater susceptibility to alteration.

Primary potassium feldspars can be detected only in the less altered rocks beneath the W-Mo-Bi zone and in some samples from drill holes located in the flanks of the alteration zone. Feldspar content increases with depth beneath the mineralized body. Here, the rocks are fresher and contain subhedral perthitic potassium feldspars and accessory biotite. These rocks probably correspond to the transition rock recognized by Parrish & Tully (1977).

The X-ray work failed to identify a possible pre-greisen phase of feldspathization (the apogranite stage) common to many greisen occur-

rences (Stemprok 1970, Janecka & Štemprok 1967). If this alteration occurred, it was probably removed either by erosion or by the particularly intense greisenization reactions.

#### *Chlorite and micas*

The limitations and assumptions introduced in the X-ray analysis of micas and chlorite, as discussed earlier, mainly involve assuming constant composition and mineralogical types for these layer silicates. Detection limits obtained for chlorite and mica in a quartz matrix are 1 and 2 wt.%, respectively.

Chlorite forms a well-defined aureole mantling the quartz-topaz zone (Fig. 8). The mineral is practically absent (less than 3%) in the greisen above the W-Mo-Bi mineralized body and is concentrated principally along the margin of the quartz-topaz rock, where individual samples

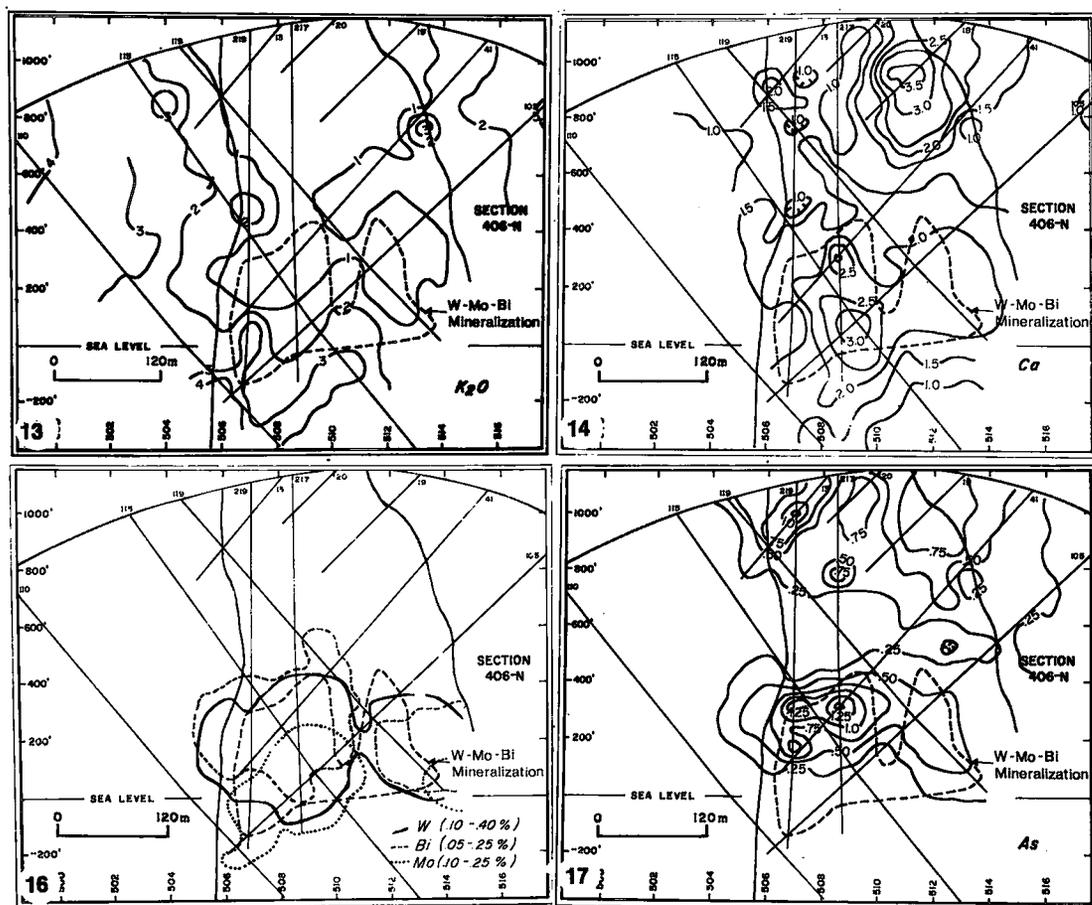
may exceed 25% chlorite. As for silicification and topaz formation, the chlorite zone appears more intensely developed along the western side of the intrusive plug. In fact, the isolated chlorite maxima shown on the western side of the plug (Fig. 8) may be a continuous vertical zone, nearly 120m in width alongside the intrusive plug. The presence of significant chlorite at depth, below the W-Mo-Bi mineralized body, attests to the gradual termination of the quartz-topaz zone.

As evident from X-ray and chemical data (Petruk 1964), the chlorites are iron-rich, probably of the thuringite type (Dagger 1972). Their distribution on the border zone of the quartz-topaz greisen involved important addition or redistribution of iron.

The micas, principally sericite or muscovite, are peripheral to the quartz-topaz zone (Fig. 9). Mica is practically absent (less than 3%) from

the part of the quartz-topaz greisen above sea level; its concentration increases away from the greisen. The mineral coexists with chlorite in the chlorite zone but is most abundant away from the chlorite zone, as indicated by prominent mica concentrations in the upper part of drill holes 110 and 115. The presence of significant mica at depth below the W-Mo-Bi mineralized body concurs with chlorite distribution in pointing to the gradual downward termination of the quartz-topaz rock.

The high degree of alteration in the western part of section 406 (Fig. 9), indicated by high mica and very low feldspar contents, is perplexing. It is not yet known whether the increase in micas near the western limit of section 406N is related to alteration that centres on the intrusive plug or whether this part of the section was subjected to a separate quartz-mica-fluorite alteration.



FIGS. 9-12. Distribution of mica (sericite), fluorite, kaolinite and total iron ( $\text{Fe}_2\text{O}_3$ ) in section 406N.

### Fluorite

Fluorite is present in all samples studied, with concentrations ranging from 0.5 to 5%. Despite low concentrations and a somewhat diffuse distribution (Fig. 10), the principal fluorite concentrations seem to occur within the quartz-topaz zone. A principal fluorite zone coincides and underlies the W-Mo-Bi mineralized body. Fluorite of various colors has been observed in the greisen zone, in cases associated with tin and base-metal mineralization (Ruitenbergh 1963; Petruk 1973). These cases probably account for the isolated fluorite highs in the upper part of the intrusive plug. The ubiquitous distribution of fluorite in the rocks and the prominence of the quartz-topaz zone attest to the important role of fluorine in the mineralizing processes. The concentration of fluorite near the W-Mo-Bi mineralized body is probably significant when considered in the light of the chemical studies of Studenikova *et al.* (1970). These authors have underlined the role of calcium, precipitating as fluorite, in inducing the precipitation of tungsten from potassium oxyfluorotungstate-bearing solutions.

### Kaolinite

Kaolinite was determined from HCl-treated samples (see appendix) with a detection limit of 0.5%. Trace to distinct amounts, rarely reaching as high as 3%, can be detected in most samples (Fig. 11). In some underground workings, the mineral is concentrated in specific structures such as kaolinite-rich pipes and vugs (Ruitenbergh 1967; Dagger 1972). It is probable that much of the kaolinite from these structures was washed away during drilling, thereby introducing a negative bias in the bulk estimation of the mineral. In spite of this bias, however, examination of the kaolinite profile along individual drill holes indicates that the concentration of the mineral increases with height in the alteration zone (Fig. 11). Kaolinite occurs principally in a broad zone extending above the W-Mo-Bi mineralized body. The distribution of kaolinite seems to crudely parallel the pattern of base-metal mineralization, suggesting that the mineral was associated principally with the sulfide phase of mineralization.

### CHEMICAL TRENDS OF ROCK ALTERATION

The chemical effects of rock alteration are best emphasized when considered in the light of the original fresh-rock chemistry. Dagger (1972) discussed the geochemistry and provided

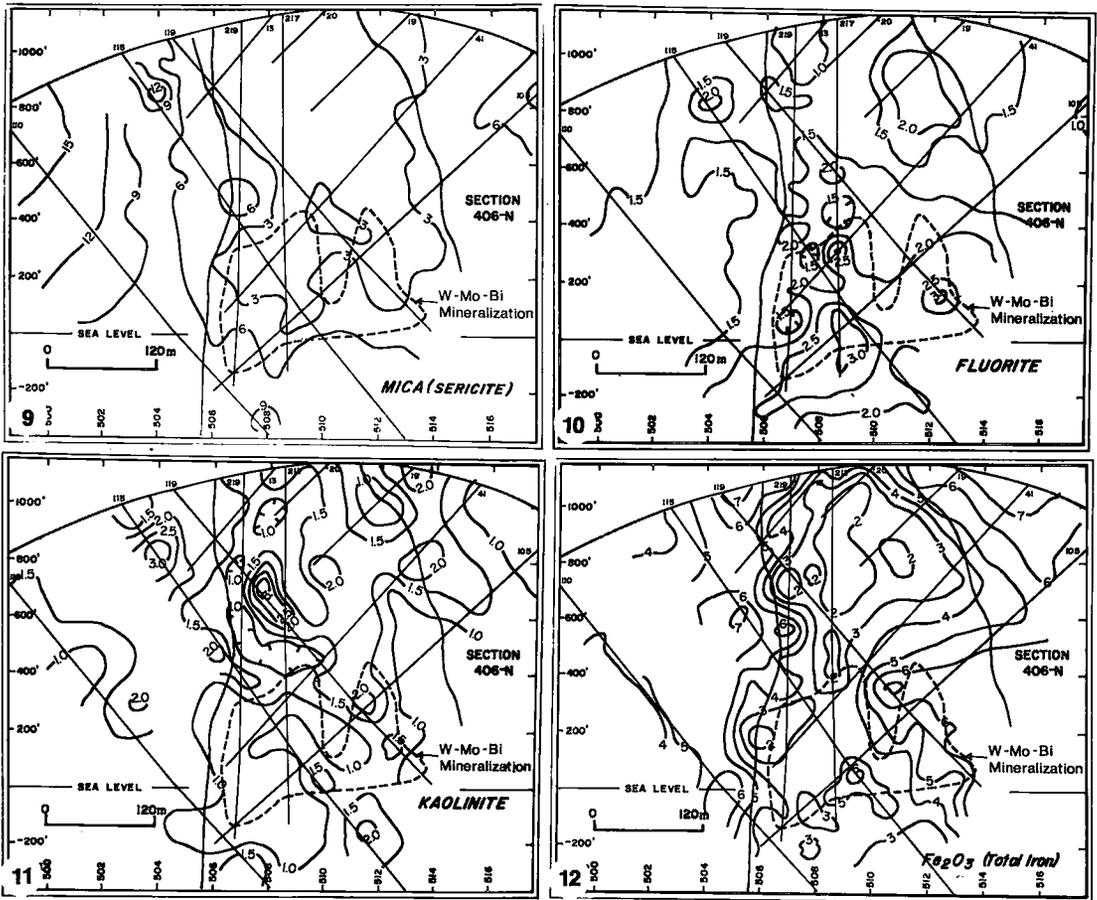
several chemical analyses of unaltered Mississippian volcanic rocks of the Mount Pleasant area. Dagger distinguished two groups based on SiO<sub>2</sub> and TiO<sub>2</sub> contents. The low SiO<sub>2</sub>, high TiO<sub>2</sub> group consists of latite or feldspar porphyry (no. 1, Table 1) the high SiO<sub>2</sub>, low TiO<sub>2</sub> rocks correspond to quartz latite or quartz-feldspar porphyry (no. 2, Table 1). Dagger also provided evidence that the TiO<sub>2</sub> content of the rocks was not appreciably modified during alteration and could be used as a differentiation index. Based on this index, Dagger considers the TiO<sub>2</sub>-poor intrusive plug of Mount Pleasant porphyry as a late differentiate related to regional acid magmatism. Because of pervasive alteration, there are no unaltered equivalents of the Mount Pleasant porphyry. However, its low TiO<sub>2</sub> content (0.2 to .13 wt.%) suggests that its original composition was comparable and slightly more felsic than that of the quartz-feldspar porphyry. For comparison purposes, we may reasonably assume that intrusive Mount Pleasant porphyry had the following approximate composition: SiO<sub>2</sub>~76%, Al<sub>2</sub>O<sub>3</sub>~14%, CaO~0.4%, TiO<sub>2</sub>~0.05%, MgO~0.3%, Fe<sub>2</sub>O<sub>3</sub>~1.3%, K<sub>2</sub>O~5% and Na<sub>2</sub>O~3%.

### Iron

The distribution of total iron, expressed as Fe<sub>2</sub>O<sub>3</sub>, is shown in Figure 12. Although some of the iron in the rocks is locally contributed by sulfide minerals, mainly arsenopyrite and sphalerite, the distribution of iron follows fairly closely the distribution of chlorite (Fig. 8). The iron contents depicted on the diagram may be slightly overestimated, especially those in the quartz-topaz zone, as some contamination, possibly 0.5 to 1%, was introduced at the mining property in pulverizing the rocks with a steel pulverizer. The average Fe<sub>2</sub>O<sub>3</sub> content of the chlorite zone is approximately 7% whereas the major part of the quartz-topaz greisen contains only 2 to 4% Fe<sub>2</sub>O<sub>3</sub>. Comparison of these values with that estimated for the fresh Rothea porphyry and least affected Mount Pleasant porphyry, 1.6% and 1.3% respectively, shows that an important addition or redistribution of iron accompanied mineralization.

### Potassium and sodium

One of the most significant effects of the alteration has been the extensive removal of potassium from the rocks of the intrusive plug. The K<sub>2</sub>O content of the quartz-topaz greisen is generally less than 1%, compared with a probable original content of approximately 5%. The



Figs. 13-14, 16-17. Distribution of  $K_2O$ , Ca and ore elements W, Bi, Mo, As in section 406N.

potassium distribution (Fig. 13) essentially follows the combined mica and orthoclase distribution. The progressive increase in  $K_2O$  on either side of the greisen is due mainly to mica whereas the buildup of potassium underneath the W-Mo-Bi mineralized body reflects the presence of mica and progressive increase of K-feldspar with depth.

Sodium was not systematically analyzed in the samples studied. However, chemical analyses of composite samples from the greisen and Rothea country rocks indicate extensive removal of sodium (Table 1). The greisenized intrusive plug is practically devoid of sodium: 0.08%  $Na_2O$  in contrast to an inferred original content of approximately 3%. Likewise, Rothea porphyry from the distant flanks of the alteration zone (11 & 12, Table 1) have much lower sodium content than the original Rothea porphyry, indicating that the aureole of sodium leaching is

as extensive and possibly larger than that of potassium removal.

#### Calcium

A generally low calcium content characterizes the fresh volcanic rocks of the Mount Pleasant area (1 & 2, Table 1). From previous discussions, we assume that the intrusive Mount Pleasant porphyry also had a low original calcium content, probably comparable to that of the Rothea quartz-feldspar porphyry. The post-alteration calcium values (Fig. 14) seldom reach such low values; the distribution of calcium closely follows that of fluorite (Fig. 11) and locally reaches concentrations in excess of 3%. Thus calcium was added as fluorite in the alteration zone; its origin probably involved leaching of calcium from rocks at depth by fluorinated solutions and precipitation as fluorite in the fractured and

brecciated greisen zone.

### Titanium

Dagger (1972) has presented evidence that the  $\text{TiO}_2$  content was not appreciably changed during alteration. The  $\text{TiO}_2$  content provides a useful criterion at the mine for distinguishing the low- $\text{TiO}_2$  Mount Pleasant porphyry from the surrounding higher- $\text{TiO}_2$  Rothea porphyry. The  $\text{TiO}_2$  distribution in section 406 is shown by means of a computer-derived block diagram (Fig. 15). The low- $\text{TiO}_2$  trough on the diagram (rocks between .02 and .10%  $\text{TiO}_2$ ) outlines the intrusive plug of Mount Pleasant porphyry; the valley walls, containing .2 to .3%  $\text{TiO}_2$ , correspond to the enclosing Rothea porphyry.

### Aluminum

Because the X-ray fluorescence method used in the systematic analysis of the rocks did not incorporate absorption corrections, alumina values are not sufficiently accurate to enable a graphic display of the behavior of Al. However, examination of the alumina content of large composite samples from the Fire Tower zone (3-10, Table 1) does suggest that some aluminum was lost during alteration. The greisenized plug has fairly uniform  $\text{Al}_2\text{O}_3$  content (~10.6%), approximately 2 to 4% less than that estimated for the fresh quartz-feldspar porphyry. This loss, however, may be somewhat exaggerated because of the poor recovery of layer silicates during the drilling. In spite of this, the  $\text{Al}_2\text{O}_3$  decrease may well be real; Al leached at depth may have been redeposited in the upper parts of the Fire Tower zone, possibly to form topaz-rich or kaolinite-rich zones.

### Silicon

X-ray diffraction analyses have shown that quartz is the major constituent of all samples from the Fire Tower zone, ranging from 45% to 80%. This amount of quartz, greater than that in the unaltered porphyries, results from the combined effects of the alteration of silica-rich minerals such as feldspars, and the presence of numerous quartz veinlets which invaded the altered rocks. The presence of such veinlets and the spectacular transformation of sizeable volumes of porphyry into a white, glassy-looking, highly siliceous rock made up essentially of quartz and topaz attest to the intensity of silicification. The importance of silicification raises the question of the overall chemical gains and losses in the porphyry rocks during alteration.

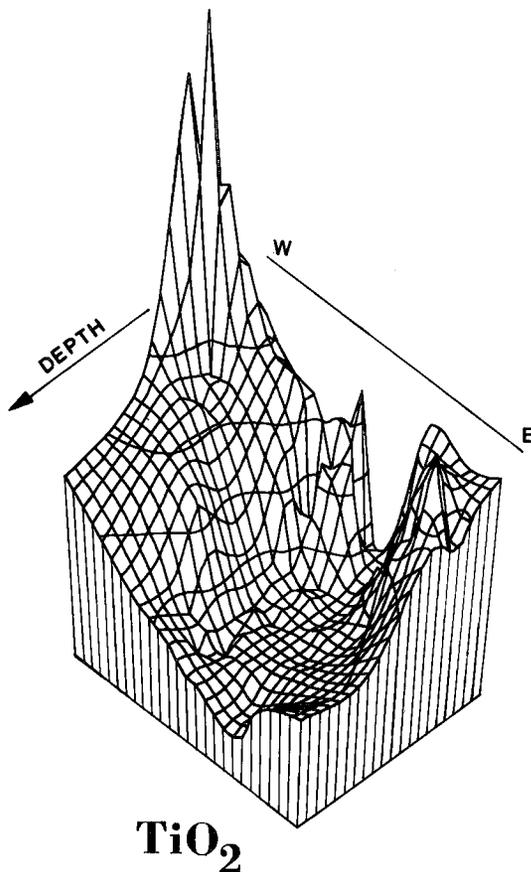


FIG. 15. Computer-derived three-dimensional diagram illustrating  $\text{TiO}_2$  distribution in section 406. The highest peak corresponds to 0.30%  $\text{TiO}_2$  and the minimum to approximately 0.02%  $\text{TiO}_2$ .

Although the chemistry of the Mount Pleasant porphyry prior to alteration may be reasonably approximated on the basis of its  $\text{TiO}_2$  content, basic information required for gains-and-losses calculations, *i.e.*, the extent of volume change in the fractured and brecciated porphyry, the hydrogen concentration in the altered rocks and the specific gravity of the analyzed core sample, is lacking. However, if constant volume is assumed and large volumes of altered rocks are considered by means of composite samples (3-10, Table 1), it is evident that significant amounts of iron and calcium were added to the rocks whereas the bulk  $\text{SiO}_2$  content did not change appreciably. This strongly suggests that changes in the silica content of large volumes of rocks were comparatively slight or negligible, and that silicification proceeded principally by

local dissolution of silica and redeposition or redistribution in nearby fractures.

#### ORE-METAL DISTRIBUTION

Whereas modification of the major-element chemistry of the rocks by alteration may conceivably be interpreted in terms of the combined effects of contemporaneous leaching and redistribution of leached materials, the intrusive plug was also significantly mineralized with the introduction of an impressive suite of elements, principally F, As, W, Mo, Bi, Zn, Cu, Sn, Pb and In. Detailed paragenetic studies of the ore minerals have been provided by Petruk (1964, 1973), Ruitenberg (1963, 1967) and Dagger (1972). Though differing in minor details, the various parageneses proposed recognize the early development of the W-Mo-Bi mineralization accompanied by arsenopyrite and minor cassiterite, followed by a base-metal phase of mineralization involving principally Zn, Cu, Pb and Sn minerals. Because of the complex mineralogy of the late sulfides and their uneven distribution controlled to a large extent by vein structures, section 406 provides only an incomplete picture of the metal distribution in the Fire Tower zone. In spite of this, the graphic representation of the ore metals in this section support the two-fold paragenetic sequence recognized by earlier workers.

Within the quartz-topaz greisen, a twofold vertical zoning about a separation plane at approximately +150m elevation appears significant. The lower zone hosts the principal W-Mo-Bi mineralization (Fig. 16). The base of the mineralized zone coincides with the base of the quartz-topaz greisen whereas the centre coincides with regions of intense topaz formation and silicification (Fig. 5). The principal Mo values tend to lie near the base of the mineralized mass whereas the coincident maxima in W and Bi distribution lie slightly above the Mo values. As for the topaz and quartz distributions, the higher metal values lie in the western part of the greisenized plug. Significant amounts of arsenopyrite accompany W-Mo-Bi mineralization, as shown by the well-defined concentration of arsenic (Fig. 17) straddling the upper half of the mineralized body. The two-fold distribution of arsenic in section 406 tends to support the paragenetic sequence of Petruk (1973); the early deposition of arsenopyrite seems to have continued until the beginning of the base-metal phase of mineralization.

Tin, zinc and copper values are not abundant in section 406. Their distribution is shown schematically on Figure 18, where areas of

significant concentrations have been contoured. Tin has only minor importance and seldom reaches concentrations higher than 0.05% Sn; higher concentrations occur only rarely and lie above the W-Mo-Bi mineralized body. The coincidence of high tin and zinc values probably reflects the common association of stannite with sphalerite. Low contents of zinc, between .03 and .20%, are fairly common in the upper part of the greisen. The higher zinc concentrations, between .30 and .50%, form isolated highs immediately above the zone of W-Mo-Bi mineralization. Similarly, although low copper values between .02 and .05% occur sporadically in the upper part of the greisen, the highest concentrations between .10 and .25% are located within the W-Mo-Bi mineralized mass, straddling the W, Mo and Bi maxima.

#### SUMMARY AND DISCUSSION

The mineralization in the Fire Tower zone is associated with a prominent quartz-topaz greisen developed within a narrow neck-line felsic intrusion (Mount Pleasant porphyry) which marks the site of a former volcanic vent. The original quartz-feldspar porphyry has been intensely modified both mineralogically and chemically. Considering that the original Mount Pleasant porphyry and enclosing Rothea porphyry had almost identical mineralogical and chemical compositions, the locus of alteration, its intensity and its zonal distribution in all likelihood result from the favorable physical conditions provided by the highly fractured and brecciated neck-like intrusion. The distribution of several topaz maxi-

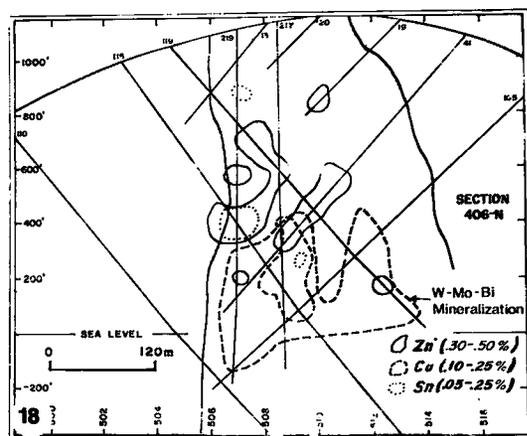


Fig. 18. Distribution of Zn, Cu and Sn in section 406N.

ma and centres of intense silicification near the border of the intrusive body reflect the structural control afforded by the Mount Pleasant porphyry.

The overall pattern of alteration is well revealed by the study of weighted core samples. The alteration pattern is concentric with respect to the centre of the intrusion, as similar mineralogical and chemical variations are encountered laterally or vertically downward from the intrusion. From the centre outward, three greisen types or zones (A, B, C) may be distinguished on the basis of mineralogical and chemical data:

A) An inner quartz-topaz greisen, approximately 250m wide and approximately 400m deep, marks the locus of most intense alteration. The rock is composed mainly of quartz and topaz and carries only accessory amounts of layer-silicate minerals. Besides important additions of ore elements, principally As, W, Mo, Bi, Zn, Sn, Cu, Pb and particularly F, metasomatic processes resulted in the almost complete leaching of sodium and potassium from the quartzofeldspathic rocks. Whereas some aluminum was possibly removed, significant amounts of calcium and iron were added to the zone, the former as fluorite and the latter as iron-rich chlorite and arsenopyrite. Despite strong silicification, the bulk silica content of large samples was not appreciably changed, suggesting that most of the silica was derived locally.

B) An intermediate quartz-iron-rich chlorite-mica greisen forms a mantle around the quartz-topaz zone. The chlorite zone is 100 to 150m wide and reaches maximum chlorite concentrations some 50m from the contacts of the intrusive plug. The high concentration of  $Fe_2O_3$  (~6%) in the chlorite zone attests to the important addition of iron to the original quartzofeldspathic rocks.

C) An outer quartz-mica-chlorite greisen marks the transition from altered to unaltered rocks. With the gradual decrease in chlorite, the mica content increases outward. Locally, near the edge of section 406 approximately 300m from the centre of the quartz-topaz greisen, remnants of orthoclase and leached biotite are present.

Small amounts of fluorite are present in all samples from the three zones. However, the principal fluorite concentrations are found within the mineralized quartz-topaz zone and probably result from an intimate association with the various phases of mineralization. Similarly, small amounts of kaolinite are widely distributed throughout the altered rocks. The tendency for kaolinite to be slightly more abun-

dant in the upper part of the greisen probably reflects its association with base-metal sulfide mineralization. A gross vertical zoning is also apparent in the distribution of metals, with Mo, W and Bi concentrated at depth near the base of the quartz-topaz greisen and Zn, Pb, Cu and Sn lying above.

The gradual and uniform bottoming of the quartz-topaz greisen and of the W-Mo-Bi mineralization at the same depth in both the Fire Tower and the North zones is significant. The determining role of pressure gradients over temperature gradients in inducing precipitation from ascending hydrothermal solutions has been stressed by several workers (Laffitte 1963; Ivanov 1970; Jankovič 1970; Poubá 1970). The marked pressure drop resulting from the access of the hydrothermal solutions into the fractured and brecciated parts of the intrusive plugs at Mount Pleasant was a determining factor in initiating at this level both hydrothermal alteration and deposition. Although specimen coverage of the rock enclosing the greisenized intrusive plus permits only a generalized picture of the alteration zones, their concentric distribution about the greisen may be related to a process of outward migration and diffusion from the center of intense alteration. In this process, important amounts of iron, either introduced or leached at depth and redistributed, were added to the enclosing Rothea porphyry to form the chlorite zone. The action of hydrogen metasomatism (Hemley & Jones 1964) with resulting destruction of feldspars to form mica and liberation of silica and alkalis, proceeded to a large distance outward from the quartz-topaz greisen. Present data indicate that this zone of alteration extends well beyond 250m from the central portion of the Fire Tower zone.

#### ACKNOWLEDGEMENTS

This work was made possible by the complete collaboration of the Sullivan Mining Group in Montreal and the personnel at Brunswick Tin Mines Ltd., who kindly provided all samples and information required for our study and made available to us a large number of chemical data on metal distribution in section 406N. The particular collaboration of Messrs. J. Nunes, J. V. Tully and I. S. Parrish is gratefully acknowledged. At Ecole Polytechnique, Messrs. Y. Beauchemin, M. Dagbert and M. David were largely responsible for the preliminary computer analysis of the mineralogical and chemical data. The authors would also like to thank R. Darling, G. Valiquette and J. V. Tully for reading

the manuscript and suggesting useful improvements.

## REFERENCES

- DAGGER, G. W. (1972): Genesis of the Mount Pleasant tungsten-molybdenum-bismuth deposit, New Brunswick, Canada. *Inst. Mining Met. Trans.* 81, B73-102.
- DEAN, R. S. (1964): Mineralogical examination of two samples of kaolin minerals from Mount Pleasant Mines Ltd., Charlotte County, New Brunswick. *Mines Branch, Test Rep.* MPT 64-15.
- HEMLEY, J. J. & JONES, W. R. (1964): Chemical aspects of hydrothermal alteration with emphasis on hydrogen metasomatism. *Econ. Geol.* 59, 538-569.
- HOSKING, K. F. G. (1963): Geology, mineralogy and paragenesis of the Mount Pleasant tin deposits. *Can. Mining J.* 84, 95-102.
- IVANOV, S. N. (1970): Hydrothermal ore formation under sea and on continents and the vertical extension of ore bodies. In *Problems of Hydrothermal Ore Deposition* (Z. Pouba & M. Štemprok, eds.), *Int. Union Geol. Sci. Ser. A* 2, 168-172.
- JANECKA, J. & ŠTEMPROK, M. (1967): Endogenous tin mineralization in the Bohemian massif. In *A Technical Conference on Tin* (Int. Tin Council, London) 1, 247-262.
- JANKOVIC, S. (1970): On the vertical extent and the sources of metal of some hydrothermal ore deposits formed at subvolcanic levels. In *Problems of Hydrothermal Ore Deposition* (Z. Pouba & M. Štemprok, eds.), *Int. Union Geol. Sci. Ser. A* 2, 172-177.
- LAFFITTE, P. (1963): Mécanisme et durée de la formation des dépôts filoniens. In *Symposium on Problems of Postmagmatic Ore Deposition* (J. Kutina, ed.), *Geol. Surv. Czech.* 1, 438-445.
- PARRISH, I. S. (1977): Mineral catalog for the Mount Pleasant deposit of Brunswick Tin Mines. *Can. Mineral.* 15, 121-126.
- & TULLY, J. V. (1971): Molybdenum, tungsten and bismuth mineralization at Brunswick Tin Mines Ltd. *Can. Mining Met. Bull.* 64 (707), 51 (abstr.).
- & ——— (1977): Porphyry tungsten zones at Mount Pleasant, New Brunswick. *Can. Mining Met. Bull.* 70 (779), 71 (abstr.).
- PETRUK, W. (1964): Mineralogy of the Mount Pleasant tin deposit in New Brunswick. *Mines Branch Tech. Bull.* TB 56.
- (1973): The tungsten-bismuth-molybdenum deposit of Brunswick Tin Mines Limited: its mode of occurrence, mineralogy and amenability to mineral beneficiation. *Can. Mining Met. Bull.* 66 (732), 113-130.
- POUBA, Z. (1970): The depth of formation and the vertical extent of ore deposition — a review of contributed papers. In *Problems of Hydrothermal Ore Deposition* (Z. Pouba & M. Štemprok, eds.), *Int. Union Geol. Sci. Ser. A* 2, 147-156.
- POULIOT, G. (1973): Mineralogical study of rock alteration at Brunswick Tin Mines Ltd. *Mineral Exploration Research Institute, Rep.* P001, Ecole Polytechnique, Montréal, Qué.
- ROSENBERG, P. E. (1967): Variations in the unit-cell dimensions of topaz and their significance. *Amer. Mineral.* 52, 1890-1895.
- RUITENBERG, A. A. (1963): *Tin Mineralization and Associated Rock Alteration at Mount Pleasant, Charlotte County, New Brunswick*, M.Sc. thesis, Univ. New Brunswick, Fredericton, N.B.
- (1967): Stratigraphy, structure and metallization, Piskahegan — Rolling Dam area (northern Appalachians, New Brunswick, Canada). *Leidse Geol. Mededelingen* 40, 79-120.
- (1972): Metallization episodes related to tectonic evolution, Rolling Dam and Mascarene — Nerepis Belts, New Brunswick. *Econ. Geol.* 67, 434-444.
- ŠTEMPROK, M. (1970): Continuity or discontinuity of processes leading to wall-rock alterations? In *Problems of Hydrothermal Ore Deposition* (Z. Pouba & M. Štemprok, eds.), *Int. Union Geol. Sci. Ser. A* 2, 355-358.
- STUDENIKOVA, Z. V., IVANOVA, G. F. & BRYZGALIN, O. V. (1970): On the possible source and transportation of tungsten in the formation of deposits of greisen type. In *Problems of Hydrothermal Ore Deposition* (Z. Pouba & M. Štemprok, eds.), *Int. Union Geol. Sci. Ser. A* 2, 89-92.
- TAIT, S. E. (1965): *Breccias of the Mount Pleasant Tin Deposit, New Brunswick*. M.Sc. thesis, McGill Univ., Montreal, Que.
- VAN DE POLL, H. W. (1967): Carboniferous volcanic and sedimentary rocks of the Mount Pleasant area, New Brunswick. *N.B. Dep. Nat. Resour. Mineral Resour. Branch* 3.

Received July 1977; revised manuscript accepted February 1978.

## APPENDIX: TECHNIQUE OF X-RAY DIFFRACTION ANALYSIS

All specimens studied were provided to us in powder form. However, as sieving tests indicated large variations in grain size, all samples were reground prior to X-ray work. A fixed quantity (10 g) was pulverized for 90 seconds using a shatter box equipped with tungsten carbide discs. This procedure yielded a homogeneous powder (92%-325 mesh) for subsequent X-ray diffraction work.

Identification of the principal minerals in the altered rocks was facilitated by the fact that quartz

TABLE 2. X-RAY DIFFRACTION ANALYSIS

Mineral	Anal. Peak	Detect. Limit <sup>†</sup>	Rel. Error*	Least-squares equation	Range
quartz	(100), 4.25Å	-----	11%	$y = .03117x + .0262$	20-80%
topaz	(112), 2.94Å	2%	10%	$y = .0292x + .00297$	2-20%
fluorite	(111), 3.15Å	0.5%	10%	$y = .2147x - .0471$	1-15%
chlorite	(002), 7Å	1%	10%	$y = .0709x - .0196$	1-15%
mica	(001), 10Å	2%	8%	$(a = .0780; b = .1637); y = ae^{bx}$	2-16%
albite	(002), 3.20Å	0.5%	11%	$y = .01818x + .1347$	2-15%
orthoclase	(002), 3.24Å	1%	10%	$y = .0797 - .0016$	2-14%
kaolinite	(001), 7.1Å	0.5%	16%	$y = .3347x + .7865$	1-10%
magnesite	(104), 2.74Å	-----	---	internal standard	15% wt

<sup>†</sup>Detection limit measured in a quartz matrix.

\* Expressed as percent of the amount present.

is the major constituent of all samples. The other peaks of the diffractometer charts can be attributed to variable though smaller quantities of topaz, fluorite, mica, chlorite+kaolinite and more rarely, orthoclase and albite. Occasionally very minor peaks of molybdenite, sphalerite and arsenopyrite were also present. Diffraction patterns for the pure minerals were obtained and used to construct a plastic template listing the principal peaks of these minerals. The superposition of the template on the diffractometer charts permitted rapid systematic identification of the principal minerals.

Quantitative diffraction analysis of the minerals in the altered rocks was made from peak-height measurements obtained on diffractometer recordings. The procedures were as follows:

1) Instrumentation: Norelco diffractometer equipped with rotating specimen holder and graphite monochromator; radiation  $CuK\alpha$ , 35 kV, 20mA; speed  $1^\circ 2\theta/\text{min}$ .; time constant 4; scale  $4.10^2$  cps; beam slit  $1^\circ$ , receiving slit  $1/6^\circ$ ; chart 600 mm/hr; scanning  $50^\circ$  to  $4^\circ 2\theta$ .

2) Specimen: A fixed amount of powder (aliquot) packed in a die-type holder that fits into the rotating specimen of the diffractometer.

3) Internal standard: Preground (-325 mesh) mag-

nesite was used as internal standard; 15 wt.% was added to the sample and mixed for 30 minutes in a mixer mill.

4) Standards and curves: Dark green, massive chlorite from hole 115 (130m) in the Fire Tower zone was used as a standard. The other minerals (quartz, muscovite, fluorite, topaz, albite, orthoclase and kaolinite) were selected from the mineral collection at Ecole Polytechnique. Standard mixtures of these minerals in a finely ground quartz matrix were prepared; we added 15 wt.% of preground magnesite as internal standard. Determinative curves were constructed from peak-height ratios of minerals to internal standard as measured on diffractometer recordings; details of the analytical routine are summarized in Table 2. Because of the overlap of the basal reflections of kaolinite and chlorite, kaolinite was determined separately from a specimen in which chlorite was destroyed by boiling the specimen for 45 minutes in 2N HCl. A correction for the kaolinite interference with the chlorite peak was applied where necessary. The acid treatment was amply sufficient to destroy the chlorite; longer treatment resulted in the gradual destruction of kaolinite, probably because HF was generated by the HCl attack on fluorite and topaz. The average closure of the mineralogical analysis was 88% ( $\delta=10\%$ ).