TIN-BEARING SKARNS OF THE THIRTYMILE RANGE, N.T.S. SHEET 105 C 9: A PROGRESS REPORT

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ABSTRACT

This report summarizes the results of geological mapping of the Thirtymile Range, Sheet 105 C 9, and an investigation of tin skarns at the Mindy (MINFILE 105C 054) and Ork (MINFILE 105C 038) prospects. The Thirtymile range is a tectonic mélange of Upper Palaeozoic and (3) siliciclastic and carbonate sediments, the more competent members of which survive as sheared and brecciated disrupted units or phacoids surrounded by highly foliated ultramylonite of slaty appearance. These have been deformed by later low angle thrusting, moderate angle faulting and extensional faulting and have been intruded by Mid Cretaceous granitic plutons. Tin-tungsten-boron-fluorine-bearing skarns have formed in the aureoles of the granites. A granitic stock about 6 km in diameter which occurs north of the Thirtymile Range, a smaller granite at the Ork prospect further south, and the fluorine-boron mineralized skarns at the Ork and Mindy prospects were mapped in detail. Initial petrographic and analytical work shows that the Mindy skarn horizons are predominantly pure diopside-andradite or diopside-actinolite ± pyrrhotite/arsenopyrite assemblages, with complex retrograde assemblages containing magnetite, magnesium borate/fluoride and cassiterite/tin borate mineralization. The Ork showing contains abundant fluorite and axinite but little metallic mineralization. Mapping indicates that extensional faulting played an important role in control of the tin-tungsten mineralization at the Mindy prospect.

RÉSUMÉ

Ce rapport résume les résultats de la cartographie géologique de la chaîne Thirtymile sur la feuille 105 C 9 et d'une étude des skarns stannifères dans les zones d'intérêt Mindy et Ork. La chaîne Thirtymile est un mélange tectonique de sédiments du Paléozoïque supérieur, de sédiments siliciclastiques (3) et de sédiments carbonatés dont les membres les plus compétents persistent sous forme d'unités perturbées ou phacoïdes cisaillées et bréchifiées entourées d'ultramylonite très feuilletée d'apparence ardoiseuse. Elles ont été déformées par un ultérieur charriage à faible angle d'incidence, par la formation de failles à un angle modéré et par la formation de failles de distension en plus d'avoir été pénétrées par des plutons granitiques au Crétacé moyen. Des skarns renfermant de l'étain, du tungstène, du bore et du fluor se sont formés dans les auréoles des granites. Un petit massif intrusif de granite d'un diamètre d'environ 6 km situé au nord de la chaîne Thirtymile, une masse de granite plus petite dans la zone d'intérêt Ork plus loin au sud et les skarns minéralisés en fluor et en bore des zones Ork et Mindy ont fait l'objet d'une cartographie détaillée. Les travaux pétrographiques et analytiques initiaux indiquent que les horizons skarnifiés de la zone Mindy sont des assemblages principalement purs de diopside et andradite ou de diopside et actinolite ± pyrrhotine et arsénopyrite avec des assemblages rétrogrades complexes renfermant des minéralisations en magnétite, en borate/fluorure de magnésium et en cassitérite/borate d'étain. L'indice minéralisé Ork renferme en abondance de la fluorine et de l'axinite mais peu de minéralisation métallique. La cartographie indique que la formation de failles de distension a joué un rôle important dans la détermination de la minéralisation en étain et en tungstène dans la zone Mindy.

INTRODUCTION

The Thirtymile Range is located between the Wolf and Nisutlin Rivers 25 miles (40 km) northeast of Teslin and is found on the west half of Yukon NTS map 105 C 9. This study is based on 13 weeks of fieldwork in the central and northern parts of the Thirtymile Range, between 1987 and 1989. The work focused on areas around the Ork (MINFILE 105C 038) and Mindy (MINFILE 105C 054) prospects and the granitic stock 9 km to the north (Fig. 1). It forms part of a larger study of regional geology, tectonics and metallogeny of the Thirtymile Range: in particular the petrology and geochemistry of the Cretaceous granitic intrusions, differentiates and "specialized" fluorine-rich facies, their metamorphic aureoles and the tin-tungsten or base metal prospects within them. Distinctly anomalous amounts of boron and fluorine minerals were noted in the assessment work filed by various companies working on prospects in the area (Mindy, Mindy 3 and Ork). The distribution of these elements and their relation to the tin mineralization is an important part of the present study.

This paper describes field geology and the limited petrographic and analytical data obtained to date. Detailed coordinates are given for the localities discussed, based on the 1000 m Universal Transverse Mercator grid covering map sheets 105 C 9 and 10.

REGIONAL GEOLOGY

The Thirtymile Range encompasses an unstudied area of Paleozoic metasedimentary rocks (Englishman's Group) which are intruded by Mesozoic granitoids similar to those of the Hake and Seagull Batholiths to the SE (a significant tin province). The region lies immediately east of the Teslin Suture Zone (Fig. 2), the boundary between the Intermontane Belt (Mesozoic volcanic and sedimentary rocks) and the Omineca Crystalline Belt (Paleozoic metasedimentary rocks intruded by Mesozoic to Cenozoic intermediate to felsic plutons). The Teslin Suture is the root zone for nappe structures thrust to the NE. The Englishman's Group rocks are probably derived from the Teslin Suture Zone.

The Englishman's Group is a tectonic mélange according to the definition of Raymond (1984). It consists of Upper Paleozoic and (?)Mesozoic siliciclastic and carbonate cataclasites, which lie between the Teslin Suture Zone and sedimentary rocks of the Cassiar Platform. Disruption of the sediments forming the cataclasites prevents the tracing of individual lithologic units along strike for more than 5 km.

Tempelman-Kluit (1979, p. 20) considered that cataclasis in the Teslin Suture Zone occurred between the Late Triassic and Early Jurassic and involved blocks from both the Stikine Terrane and North America, while transport of allochthons took place during the late Early Cretaceous. In the case of the Englishman's Group, low angle thrust faulting, probably during the Early Cretaceous, juxtaposed different allochthonous units; then the thrust planes were gently folded, either by compression or as a result of non-planar thrust geometry.

Later steep, east and ENE-trending extensional faults caused relatively minor vertical displacements within the mylonitic sequence. These faults are believed to have controlled the emplacement of mid-Cretaceous granitic plutons (Armstrong, 1988; Sinclair, 1983). The stocks of the Thirtymile Range form the NW limit of the tin district, which also includes the Seagull and Hake batholiths.

Mulligan (1963) divided the Englishman's Group metasediments into a lower carbonate unit and an upper unit (the cataclasites of this study) of "slate, quartzite and chert with minor arkose and conglomerates", the cataclastic nature of the allochthon not being recognized at that time. Lithologies range from highly sheared quartzite/arkose and marble, to phyllonite, mylonite and ultramylonite. Middle Mississippian macrofossils are reported from the lower carbonate unit (Mulligan, 1963), but the exact structural relationship between this and the adjacent cataclasites is unknown - they could be separated by either high angle reverse or low angle thrust faults.

Regional correlation is problematic; the Englishman's Group could still be part of the Omineca Crystalline Belt. Two interpretations have been suggested:

(a) The clastic sequence generally resembles the Devono-Mississippian sequence mapped by Gordey (1982) in the Indigo Lake map sheet to the northeast, although some units of the mylonitic sequence (the phyllonites) are more easily correlated with the Klondike Schist of Gordey's allochthon. The phyllonites could represent tectonic slices or inclusions as described by Raymond (1984).

(b) Templeman-Kluit (1979) suggested that arkoses of the Englishman's Group might be the protolith for the mylonites found in the McNeil Klippe, which lies 60 km to the NE. The present work recognizes the Englishman's Group as a totally disrupted mylonitic sequence and suggests a direct correlation with the McNeil Klippe.

Where limestone occurs in the aureoles around the granitic plutons it is metamorphosed to skarn and marble which at some localities carry significant tin-tungsten-arsenic mineralization.

GEOLOGY OF THE THIRTYMILE RANGE

During this study, the mylonitic siliciclastic sequence which represents the upper part of Mulligan's (1963) Unit 3, was mapped, along with two of five granitic stocks of the Thirtymile Range (Fig. 3). Coordinates given pertain to the 1000 metre UTM grid shown on 1:50,000 scale map sheets 105 C 9, 10. The following map units were identified (see sketch of mylonite stratigraphy, Fig. 5 and cross section, Fig. 4):

Unit A. The topographically lowest unit consists of quartzite which forms outcrops and felsenmeer on ridges east of the Mindy prospect. Like all quartzite (phacoid) units within the

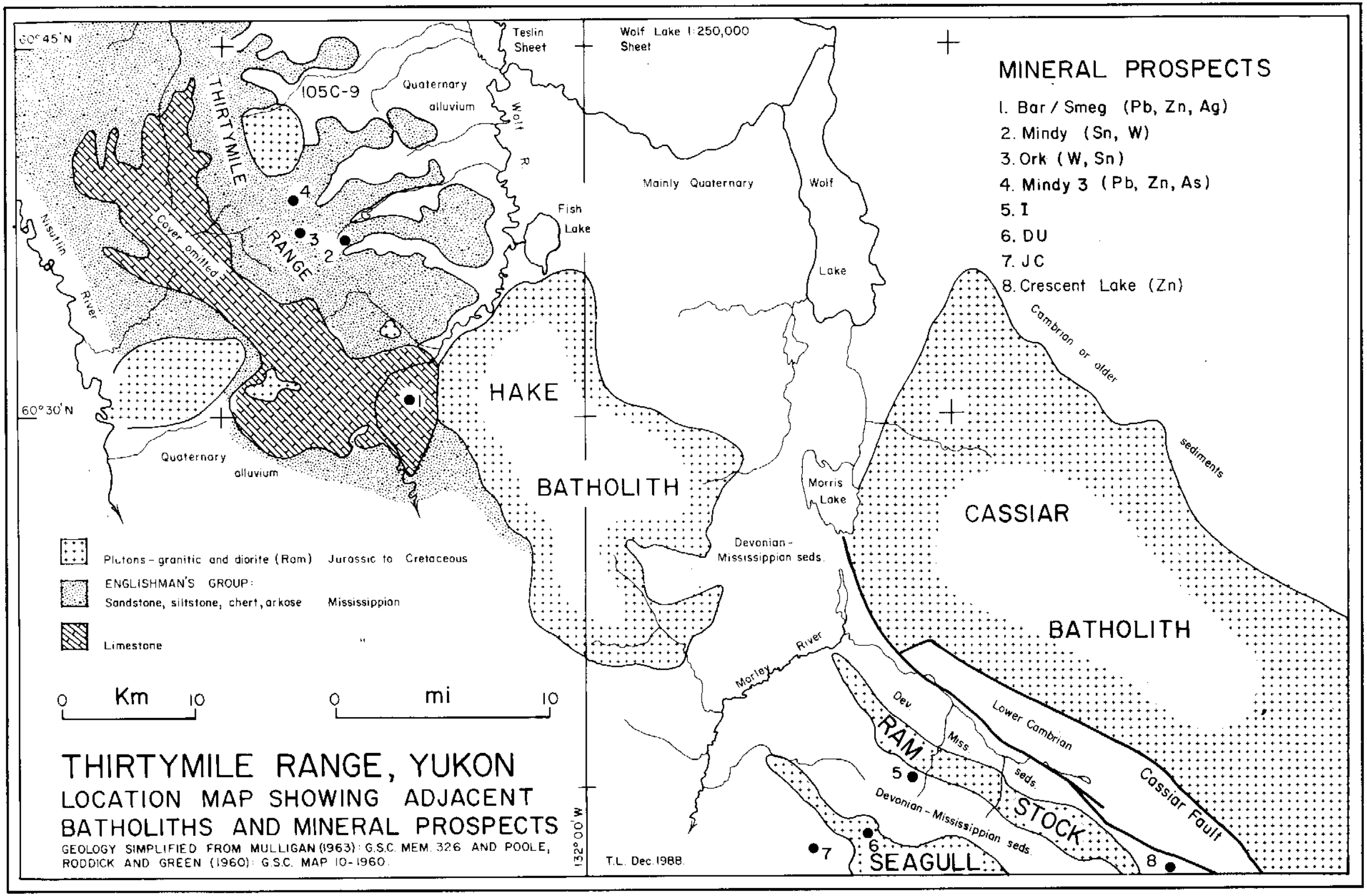

Figure 1. Location map and regional geology.

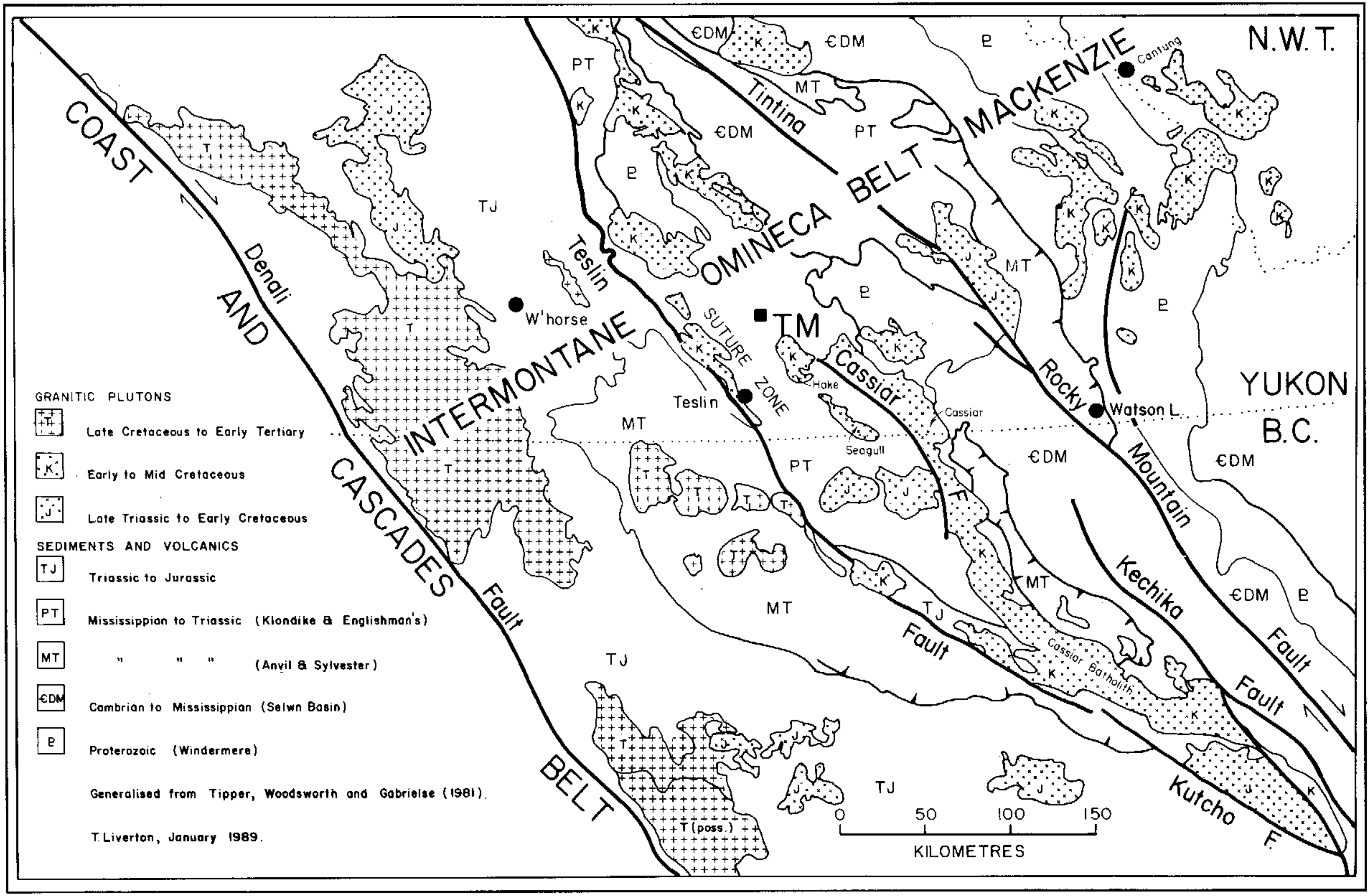

Figure 2. Tectonic setting.

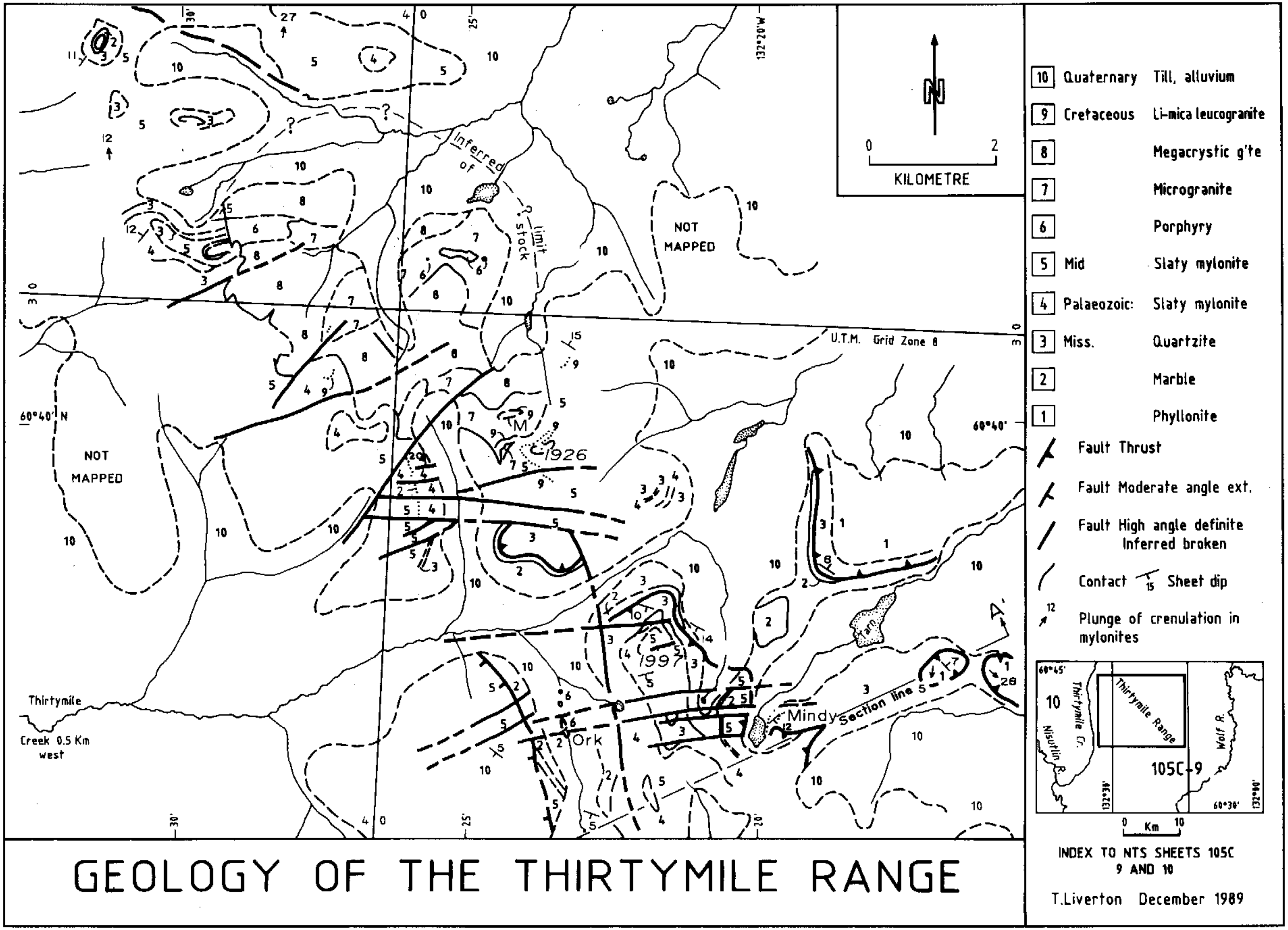

Figure 3. Geology of the Thirtymile Range.

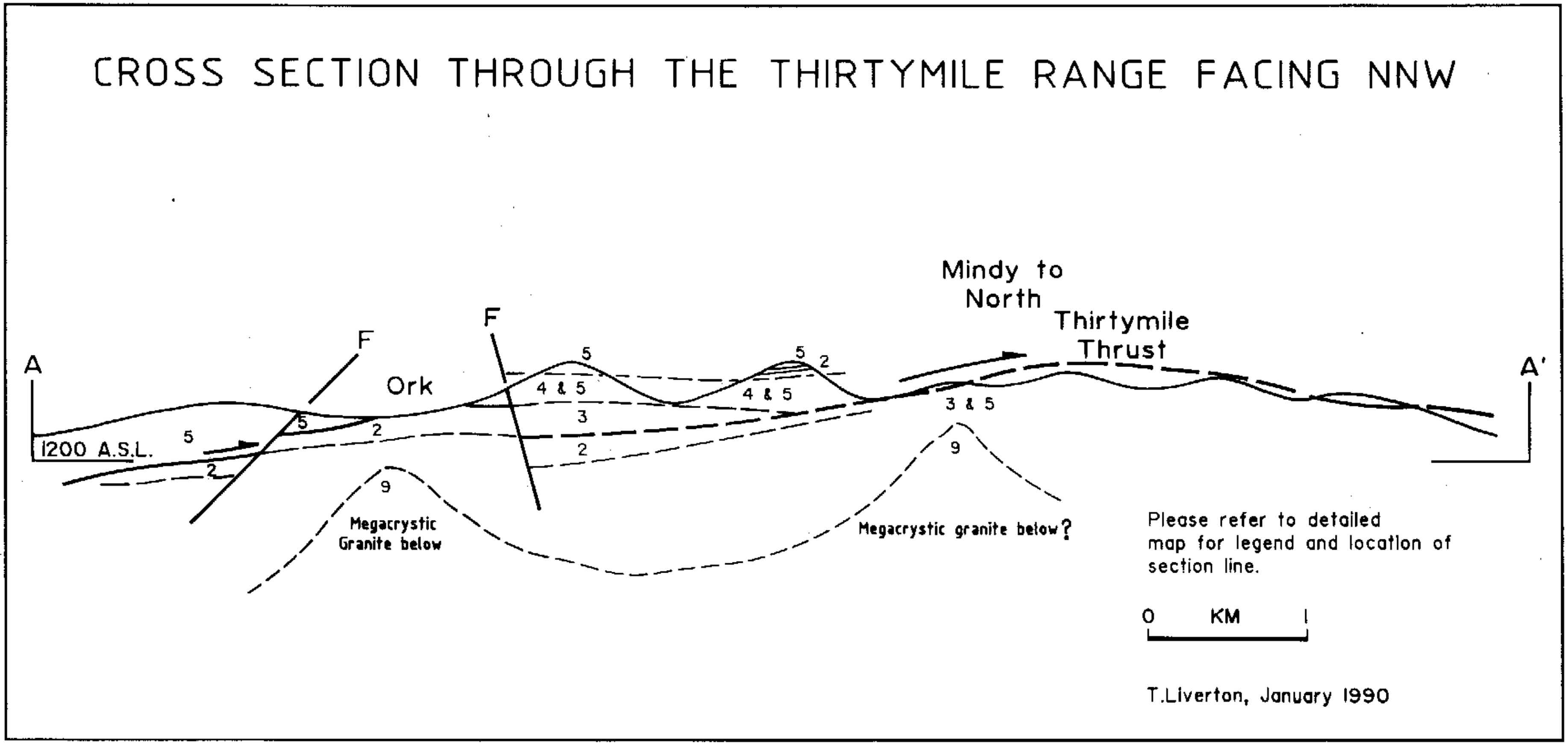

Figure 4. Cross section through the Thirtymile Range.

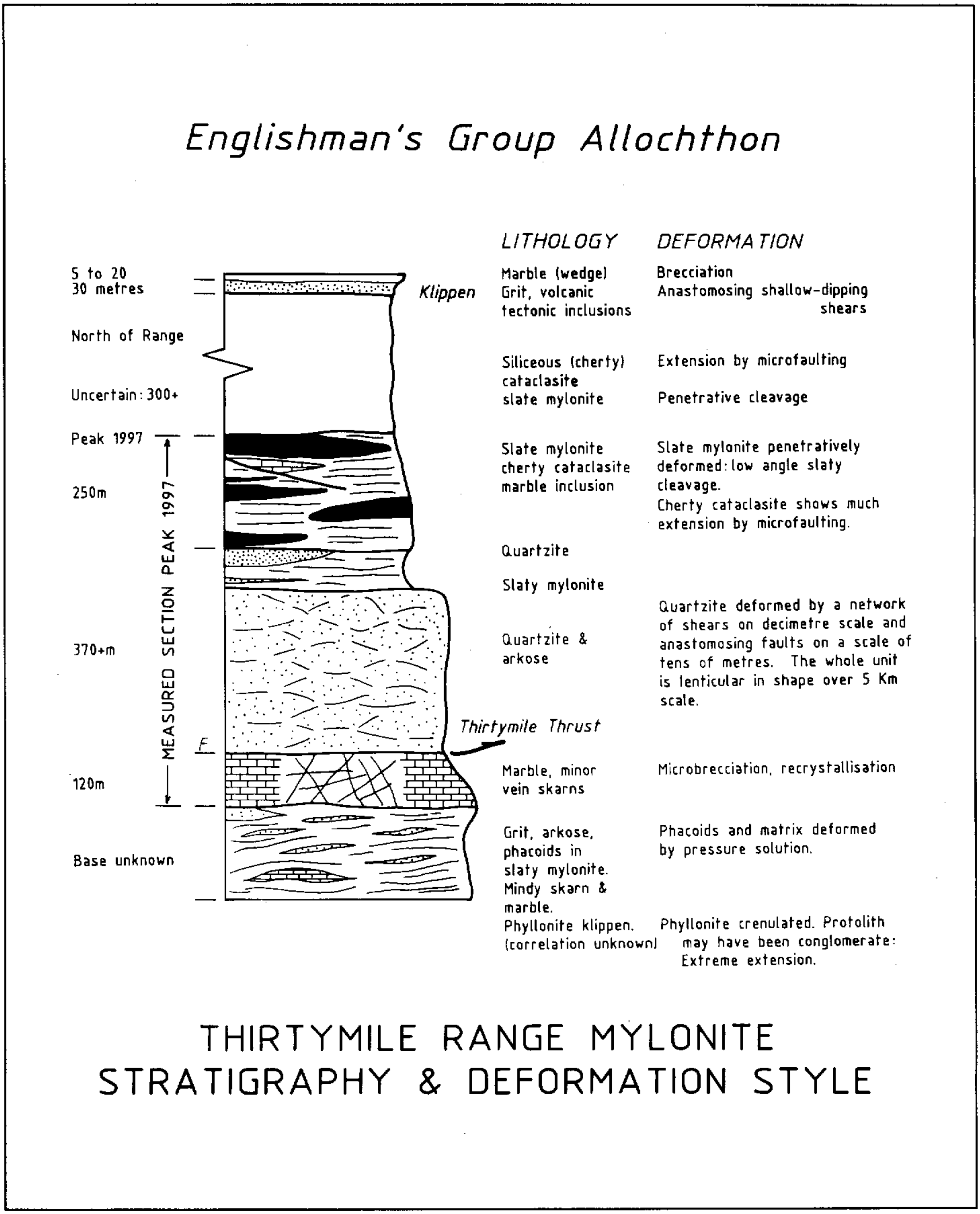

Figure 5. Thirtymile Range cataclasite stratigraphy.

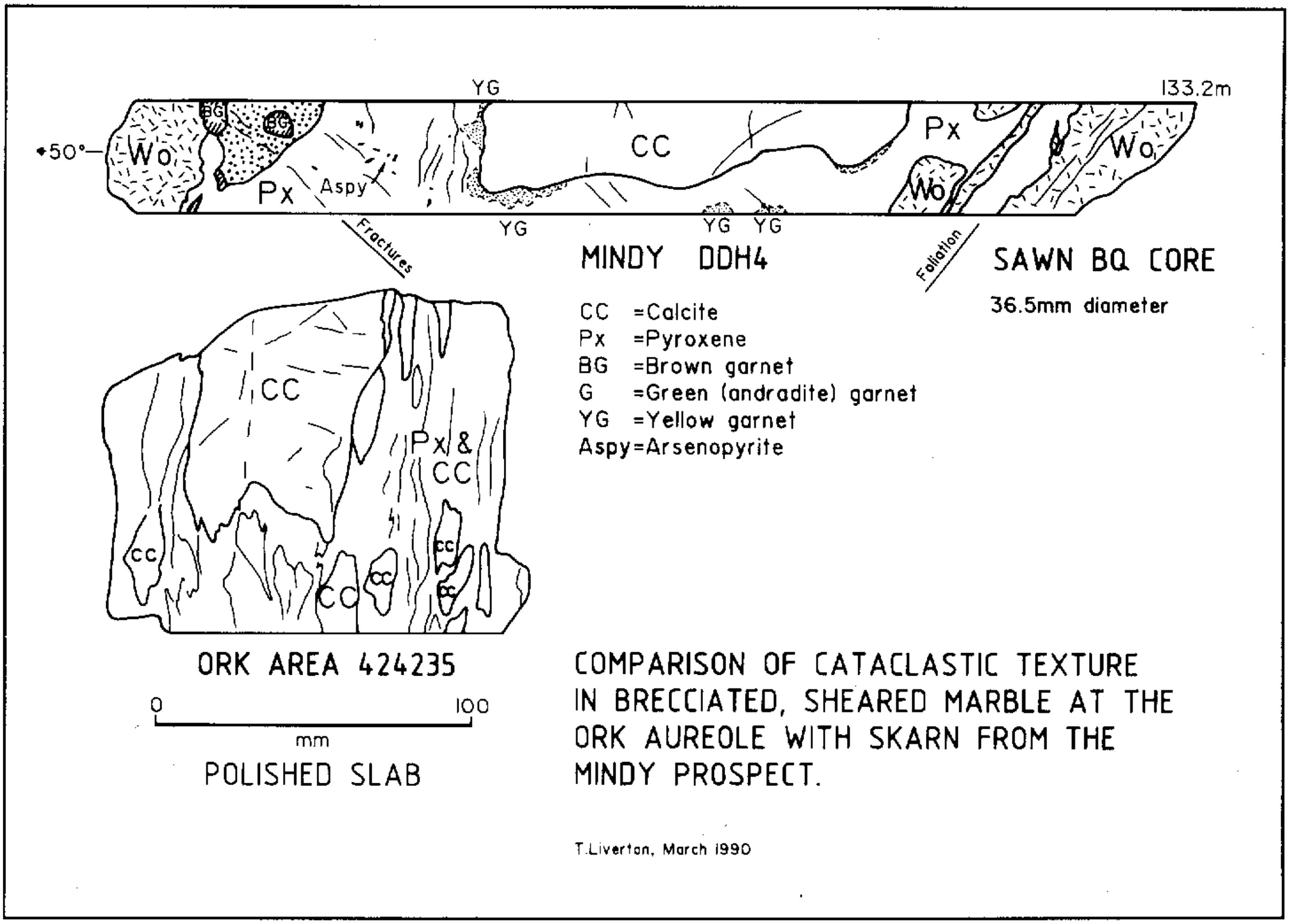

Figure 6. Cataclastic texture in marble, Ork and Mindy Showings.

mylonites, this one shows considerable small-scale shearing. A low angle pressure solution (PS) cleavage is visible in places.

Unit B. This sequence adjacent to the Mindy prospect consists of mylonitic, silty metasediments containing clasts and phacoids of quartzite and arkose from a few centimetres to several metres across. In outcrop, the dominant foliation is a metamorphic pressure-solution cleavage which dips at a shallow angle. The only evidence of bedding is grading in the disrupted sandy layers, which is recognizable in thin section and oriented at a few degrees to the PS cleavage. One major and several minor marble/skarn layers occur in Unit B at the Mindy prospect. The main mineralized (lower) skarn varies considerably in thickness along strike, as indicated by diamond drill hole intersections, and appears boudinaged on a scale of several hundred metres. This marble may not correlate with either the major carbonate unit to the northwest or the minor marble unit found about 750 m to the west.

Unit C. Below Peak 1997 in the main range (UTM Coordinates 443248), quartzite which possibly correlates with unit (A) is overlain by thick white calcite marble. The marble consists of totally recrystallized calcite grains 2 to 5 mm in size, and lacks sedimentary structures. A section measured down the northeast spur of this peak traversed a true thickness of 120 metres. Cliff exposures on the north side of the peak reveal that the marble is extensively brecciated down to a centimetre scale. Exposures west of the Ork prospect show a striking cataclastic texture (Fig. 6). Minor wollastonite-veined skarns are developed within the unit. The cliff exposure north of Peak 1997 shows a strong, nearly horizontal foliation developed in a 3 m thick diopside-rich zone at the top of the marble, and chevron folding in the lowest metre or two of overlying quartzite. These features are inferred to indicate a thrust faulted contact which postdates the main cataclasis of the Englishman's Group. To the west, a fault truncates the top of the marble at a moderate angle and the marble thins rapidly toward the south.

Unit D. This consists of 290 m of massive quartzite, overlain by 80 m of intercalated quartzite and slate mylonite. The quartzite is brecciated and cut by small shears spaced every few decimetres throughout the succession. The slaty rocks are

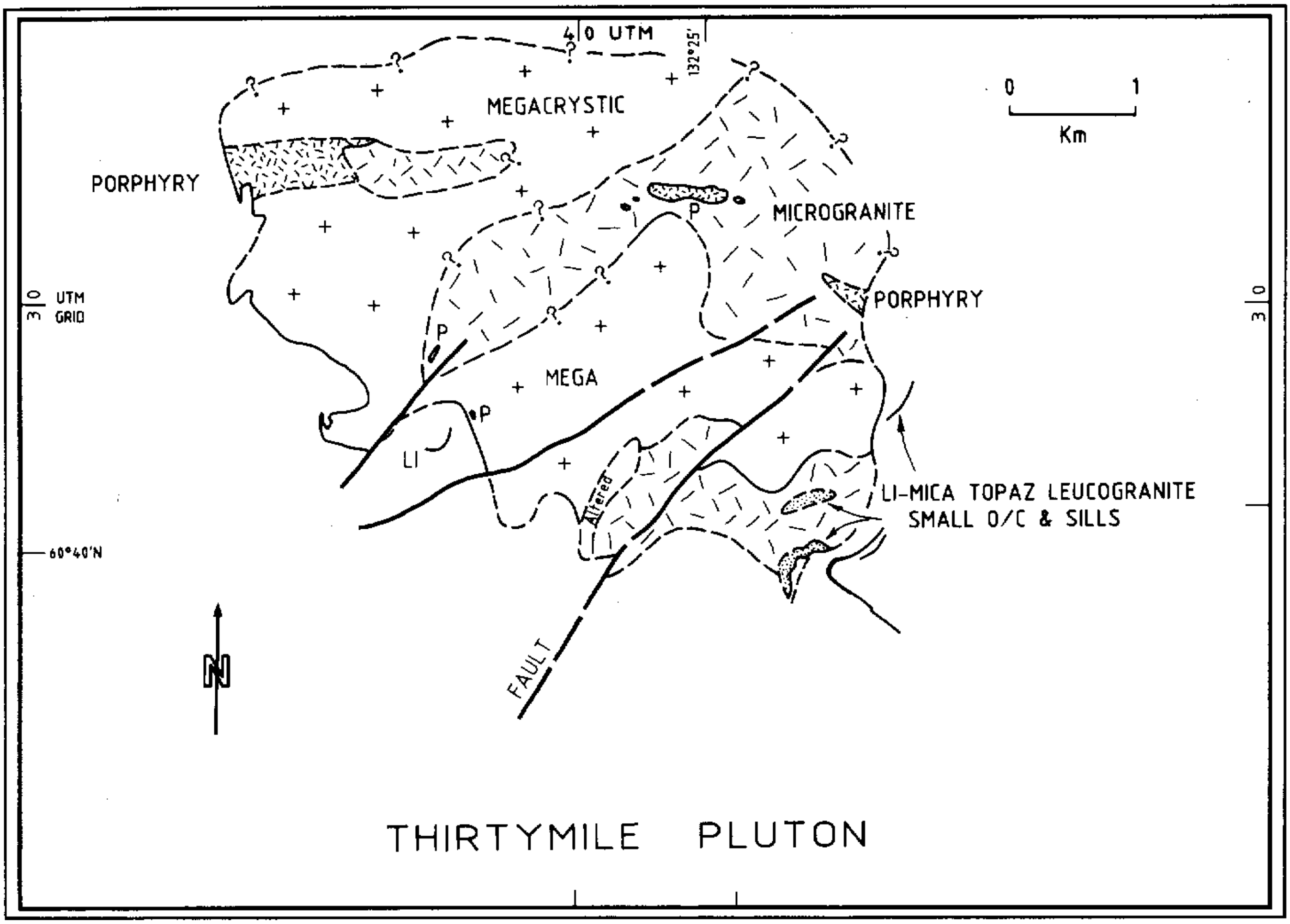

Figure 7. Facies map of the Thirtymile stock.

mylonitic and have a chaotic cleavage or foliation which shows abrupt variations in dip up to 30°. The attitude of this foliation is not reflected in the sheet dip of the lithologic units: the tectonic cleavage is likely deflected around phacoids of more competent rock, which are on a scale of tens of metres.

Unit E. Above unit D, some 240 m of intercalated massive chert, cherty mylonite and slate mylonite are exposed on the northeast spur of Peak 1997. A five-metre thick tectonic slice of marble exposed on the spur 80 metres northeast of the peak is also assigned to this unit. On the northwest spur, the thickness of individual "chert" units varies from 10 to 105 metres. A marble/calc-silicate hornfels unit 4.5 km northwest of the peak occurs in a possibly equivalent chert/mylonite sequence.

Unit F. In the northwest part of the map area (360330), slaty mylonite is overlain by a grit unit. Whether this represents a separate clastic unit structurally and stratigraphically higher than unit B is uncertain. At UTM 365329, sheared intermediate volcanic rocks form a tectonic inclusion within this grit at (365329).

Unit G. At location 350340, a thin marble overlies the grit and rapidly thickens toward the NE, from 5 m to over 20 m. East of the Mindy showing (UTM 475266 & 490247), highly deformed phyllonites overlie the Unit A quartzite. These show many open disharmonic folds on a decimetre scale, with sheet dips varying from 8° SW to 30°E between individual exposures. They are lithologically similar to the thick phyllonite sequence that outcrops west of Thirtymile Lake (105 C 15, UTM 270420) and might represent tectonic inclusions of Big Salmon Complex metamorphic rocks within the Mississippian sequence; however their position within the general mylonite stratigraphy is uncertain.

INTRUSIONS

Two granite intrusions have been mapped in the Thirtymile Range: a small poorly exposed leucogranite at the Ork prospect, and the Thirtymile Pluton, a roughly elliptical exposure 8 km across (Fig. 7). A low angle dip at the western contact of the Thirtymile Pluton suggests that the present exposures on the centre ridge may be within 400 vertical metres of the original roof. The Thirtymile Pluton is considered to be an apophysis of a large batholith that may underlie the whole range. In order of emplacement, the various facies which make up the Thirtymile Pluton are:

(a) Porphyry mingled with tonalite or diorite, which exists as isolated remnants within microgranite.

(b) Microgranite (equigranular).

(c) Megacrystic granite, which forms more than half of the exposed pluton.

(d) Leucocratic topaz and fluorite-bearing microgranite, which occurs as a marginal facies in the main stock, as adjacent sills in the overlying metasediments, and forms a stock and dykes at the Ork prospect to the south (UTM 429236, 435248, 438237).

Porphyry

At the west limit of exposure in the map-area (UTM 407309) the predominant lithology is porphyritic. The texture is frequently dominated by euhedral to subhedral equant quartz phenocrysts, some with their margins intergrown with the grains of the groundmass. Anhedral to euhedral single-twinned perthite phenocrysts 4 to 10 mm long often occur in clusters with very little quartz between (a cumulus texture) and occasionally show rapakivi texture. Plagioclase is finer grained (2 to 4 mm), subhedral to rarely euhedral, and often shows both albite and carlsbad-albite twinning and oscillatory zoning. Rare subhedral hornblende xenocrysts, often altered to biotite and chlorite, are up to 3 mm long. Deep brown biotite, often chloritized and very ragged, forms phenocrysts up to 2 mm in size, and smaller (0.5 mm) grains in the groundmass. The micas contain some euhedral zircon inclusions and are occasionally intergrown with anhedral monazite. Occasional clusters of biotite, very fragmented hornblende (0.5 mm), monazite, pyrite and apatite are seen. Monazite is common in the groundmass as anhedral grains up to 0.8 mm, and allanite is also common, forming subhedral to euhedral crystals up to 1 mm long. Quartz and K-feldspar form the bulk of the groundmass. Quartz is the most common mineral in the groundmass, forming grains of approximately 0.5 mm across which poikilitically enclose the feldspar. The porphyry frequently contains rounded enclaves of dark grey fine grained tonalitic rock up to 0.5 metres across, which in turn enclose centimetre-sized darker rounded dioritic enclaves. Similar enclaves have been interpreted as clear evidence of magma mixing (Chandra Kumar, 1988; Vernon, 1983; Vernon, Etheridge and Wall, 1988).

East of this exposure the intrusion consists entirely of tonalite. Enclaves of tonalite are found in both the microgranite and megacrystic granite at widely separated locations, so the porphyry-tonalite body is considered to be the earliest intrusion.

Microgranite

The microgranite consists of perthite (30-40%), plagioclase (10-15%) and quartz (40-55%). The texture varies from fine grained (0.2 to 0.5 mm) to more coarse-grained and porphyritic. Chloritized, dark biotite occurs in small amounts, generally 1% or less and rarely up to 5%. Accessory minerals include occasional fluorite, monazite, zircon, allanite and pyrite. At the southern contact, the equigranular microgranite is red due to alteration, the feldspars are extensively sericitized and kaolinized and the micas are altered to sericite and opaque minerals. Blocks of microgranite occur in megacrystic granite near their contact.

Megacrystic Granite

This is a coarse grained facies with 6-15 mm potash feldspar megacrysts. The megacrysts are subhedral, microperthitic and often zoned, some zones being altered to a red sericite-iron oxide mixture. Plagioclase feldspars are finer grained (1 to 8 mm), and show normal zoning and frequently cloudy cores. Zoning is optically distinct, and microprobe analysis indicates compositions of An_5 in the groundmass and a variation from An_{47} in the cores of quartz phenocrysts to An_{28} in the rims. Quartz is usually anhedral and occurs in phenocrysts up to 5 mm across. Deep red-brown biotite flakes up to 2 mm across have very ragged margins and often contain numerous apatite inclusions and very fine grained zircons surrounded by pleochroic halos up to 0.05 mm across. Biotite forms occasional pseudomorphs after hornblende also occurs as clusters up to 4 mm diameter. Groundmass crystals 0.5-1 mm in size make up less than 50% of the rock. Accessory minerals include apatite, monazite, zircon, allanite (occasional 2 mm euhedral crystals) and, less commonly, pyrite and interstitial topaz or fluorite. Alteration is ubiquitous, but is limited to slight kaolinization of feldspars, particularly perthite. Mineral proportions vary from: perthite 30-40%; plagioclase 20-10%; quartz 40-45% and micas <1 to 5%. Occasional centimetre-sized miarolitic cavities containing quartz and tourmaline occur close to the margins of the pluton.

Leucocraticzinnwaldite-topaz-fluoritebearingmicrogranite

This rock has a striking texture: equant quartz phenocrysts 2 to 4 mm across occur in a groundmass dominated by 1 mm subhedral to euhedral plagioclase. Some plagioclase crystals are poikilitically enclosed in quartz. At some localities, perthite feldspar predominates in the groundmass. Between 1 and 15% of the rock consists of pale lithium mica, which is present as anhedral, often skeletal phenocrysts 1 to 4 mm across. Accessory minerals are rarely included in this mica. Proportions of the other minerals vary greatly between localities (K feldspar 10 to 50%, plagioclase 60 to 30%). Topaz is a common interstitial mineral and may constitute 3% of the rock by volume. Fluorite is also common in this facies. Schorl, apatite and allanite are occasional accessories.

Surprisingly, the K-feldspar is the only mineral showing slight alteration. Where they form sills, (as at 421279), rocks of this facies show a preferred orientation of plagioclase laths (flow banding). Although no intrusive rocks are evident on the east side of the Thirtymile Range at the Mindy prospect, rocks of this facies are the probable source of the fluorine in the skarns.

Greisens, miarolitic cavities

At the southeast corner of the Thirtymile stock the microgranite is cut by greisen veins up to 1 cm wide and spaced about 10 cm apart. The greisen veins consist of topaz, quartz and zinnwaldite. Miarolitic cavities up to 0.5 metres long were observed in the adjacent small body of leucocratic microgranite.

Lamprophyres

One hornblende lamprophyre dyke a few metres wide cuts hornfels at the southwest contact of the main stock (392290).

Ork Stock

The intrusion in this region resembles the leucocratic topaz-bearing microgranite of the Thirtymile Stock to the north. Four exposures were sampled between the contact and a point 250 metres to the north. The northernmost exposure shows a texture characterized by subhedral equidimensional quartz phenocrysts of 2-4 mm across, and finer (0.5 mm) albite which makes up about 40% of the rock by volume. Ragged anhedral grains of pale (lithium?) mica enclose the smaller feldspars and make up less than 2% of the rock.

Closer to the contact the intrusion is slightly finer grained (1 - 3 mm) and contains less quartz (30%). Both potash feldspar (45%) and albite (25%) are evident, but only occasional mica phenocrysts are present. A few crystals of topaz were noted in a specimen taken from the contact. The contact with the calc-silicates is very sharp and can be seen on the scale of a thin section. Both potash feldspar (50%) and albite (40%) are found within 3 cm of the calc-silicate contact.

In the contact zone, fine-grained untwinned plagioclase feldspar with fluorite occurs both interstitial to and included in the feldspars over a 2 cm width, forming a possible endoskarn. Zircon is present as occasional tiny euhedral crystals. Included in the fluorite are nordenskioldine (?) and tiny, high relief inclusions producing brilliant purple haloes. Titanite was identified in thin section in the fluorite zone. The presence of crystals which fluoresce under ultraviolet light suggests that some of the titanite is be the malayaite variety. Massive vesuvianite occurs in 10 mm long crystals which include some fluorite. A few millimetres of fibrous cebollite (normally an alteration product of melilite) mark the transition to coarse marble (8 mm grain size), occuring within half a metre of the contact. Also found at the contact are two-metre wide pegmatite dykes consisting of 20 cm green orthoclase microperthite with coarse violet mica (zinnwaldite?) and quartz.

West of the exposed granite is a cliff exposure of two cataclastic marble layers separated by aphanitic calc-silicate hornfels. The hornfels has abundant vertical fractures filled with axinite crystals up to 20 mm long. The upper carbonate is a sheared breccia with grey calcite phacoids with carbonate pressure shadows surrounded by diopside marble. In the lower marble unit, epidote and axinite have developed around many of the calcite clasts.

Three smaller topaz-bearing aplite bodies occur northeast and east of the "Ork" contact. Based on limited outcrop, these appear to be dykes 5 to 10 metres wide. The easternmost dyke lies immediately above (north of) tin-tungsten soil anomalies reported by the JC Syndicate.

STRUCTURE

(1) Thrust Faults.

The upper surface of marble unit (C) is at least partly bounded by a low-angle thrust fault. This structure may be gently warped and correspond to a fault underlying a klippe of phyllonite at location UTM 475266. Many other low angle faults probably exist, but the mylonite stratigraphy does not permit these to be traced.

(2) Extensional faults.

Figure 3 shows steep east to northeast-trending faults, probably extensional, which cut the entire sequence but usually show vertical displacements of less than 50 metres. Good field evidence exists for many of the faults shown, the remainder being inferred from airphoto interpretation. Only one fault noticeably offsets the granite facies, and some are traceable as zones of close-spaced joints extending into the intrusion. It is suggested that the faulting immediately preceded intrusion of the granite.

Where the southernmost of two east-west faults is exposed immediately northwest of the Mindy showing (UTM 459240) is exposed, carbonate breccia is locally converted to diopside-pyrrhotite-(scheelite) skarn, indicating that the fault zone has acted as a conduit for hydrothermal fluids.

The thick marble unit (C) is partly or completely bounded to the west by a fault dipping about 45°SW (UTM425232). The north-south faults are probably related to granite emplacement.

At the Mindy prospect, micro-faulting abounds: near-vertical normal faults cut the upper skarn every few metres. Most of the faults are downthrown to the west a few centimetres to a metre.

(3) Fields

The outcrop pattern of the major lithologic units indicates a gentle warping of the mylonitic sequence with sheet dips of up to ten degrees. Small-scale structures suggestive of later folding are not evident.

MINERALIZATION

The Mindy Prospect, UTM 463237 (MINFILE 105C 054)

Although granite is not exposed at surface, it probably occurs at a shallow depth below the Mindy showing. An exotic skarn mineralogy is present. Fig. 8 shows the outcrop geology of the Mindy prospect, and a longitudinal section through it. Two skarn/marble horizons occur in outcrop. An upper unit of calc-silicate hornfels and skarn about 2 m thick is exposed in a cliff. The hornfels shows alternating bands of birefringent, sector-twinned red grossular garnet and diopside grading to a central skarn of massive garnet with coarse vesuvianite. The coarse skarn contains scheelite crystals up to 5 mm across (visual estimate $<0.3\%$ WO_3). The exposures show abundant metre-spaced, small-scale, extensional faults with 10-50 cm of movement, downthrown to the southwest. Thin sections show fracturing normal to the layering and some re-crystallization of the fracture cleavage fabric is evident. The upper horizon is considerably more aluminous than the pure calcite marble of the lower horizon (maximum values of 0.13% MgO, 0.65% FeO and 3.30% MnO were obtained from microprobe analyses of calcite from the lower layer). Kwak (1987) classified such skarns as bimetasomatic, implying transfer of Al and Si from surrounding pelite, and Ca in the opposite direction, across an original limestone/pelite contact.

The lower skarn-marble horizon is up to 15 metres thick in surface exposures and can be traced discontinuously along strike in exposures and float for 1100 metres (see Fig. 8). From south to north the skarn mineralogy changes as follows:

(1) Diopside-actinolite-humite-fluorite-pyrrhotite (surface exposure).

(2) Massive marble with vein skarns of pale brown garnet-arsenopyrite and green (pure andrandite) garnet-diopside-fluoborite. In diamond drill core the marble is tectonically thickened to 80 metres and contains prograde vein skarns up to a metre thick. The massive marble consists of wollastonite $\pm$ garnet and the vein skarns consist mainly of andradite-arsenopyrite.

3) Massive magnetite-diopside-vesuvianite-garnet-epidote-cassiterite-pyrrhotite-chalcopyrite skarn, with highly variable proportions of the above minerals. This skarn contains several rare borates:

vonsenite - a $Fe^{+3}(Fe^{+3},Sn^{+4})O_2BO_3$ to $Mg_2(Fe^{+3},Sn^{+4})O_2.BO_3$ series,
hulsite - a $Mg_2(Fe^{+3},Sn^{+4})BO_4$ to $Fe^{+2}(Fe^{+2},Sn^{+4})BO_5$ series, and
fluoborite - $Mg_3BO_3(F,OH)_3$.

Other borate minerals have yet to be positively identified. (Surface exposure and diamond drill core: see Fig. 9).

4) Impure marble with bands of diopside-pistacite-clinozoisite-scapolite (surface exposures).

The skarns comprise prograde pyroxene-andradite or calcite-scapolite rich assemblages which have been replaced by actinolite, then later by phlogopite- or epidote/chlorite-rich retrograde skarn containing significant tin.
The mineralized assemblages show successive replacement by magnetite, fluorite, cassiterite, vonsenite and hulsite then fluoborite. Magnetite-rich sections have a very low sulphide content.

Between and below the skarns, a succession of metre-sized phacoids of grit and subarkose occur in a pelitic matrix, intercalated with cherty cataclasite. In outcrop, bedding is obliterated by pressure solution cleavage, but can it be recognized in thin section from grading, and lies at a low angle to the flat-lying cleavage. Cleavages in some of the sandy layers show some recrystallization, indicating that the cleaveage formed prior to thermal metamorphism. Cordierite is developed in pelitic layers.

Two types of significant microstructures are recognized: pervasive pressure solution stripes in the pelite and quartzite, which cut the shallow-dipping (up to 15°) lithologic contacts at a low angle, and less common, steeply-dipping fractures containing fluorite and tourmaline which cut brecciated quartzite below the lowest skarn. The low-angle cleavage is related to regional mylonite formation (c.f. Byrne, 1984: S2). The steeply-dipping fractures are believed to be related to the high-angle east-west extensional faults, which probably formed the conduit for metasomatizing and mineralizing fluids at the Mindy prospect.

In Australia, Kwak and Askins (1981) demonstrated that quartz-cassiterite lodes may exist beneath skarn tin deposits, provided there is adequate vertical separation between the granite contact and the skarn. There appears to be good potential for drill targets of this type beneath the Mindy prospect. Newmont's drill logs from the Mindy prospect (Nebocat and Oneschuck, 1981) described several "bleached zones" in silty mylonite above the lower skarn, and bleaching can still be seen around fractures in surviving remnants of the core. Kwak (1987) attributed such bleaching of graphite-bearing sediments above skarns to oxidation of the sediment by rising $CaCl_2$ rich solutions associated with skarn formation.

Diamond drill core (hole 4) shows a phacoid of calcite marble surrounded by diopside skarn, and massive andradite where the foliation curves around it. Away from the phacoid, wollastonite layers define the foliation. A strikingly similar texture is seen in sheared, brecciated marble at the Ork aureole, where calcite-rich phacoids occur in a more magnesian matrix (UTM 425234)(Fig. 6). The textural evidence suggests that at least some of the magnesian skarns at Mindy may reflect the chemistry of the marble after the layers were dismembered and redistributed by cataclasistic processes. Formation of the main skarn minerals then required only the addition of silica, and in places iron.

Table 1 shows that prograde skarn pyroxenes have variable MgO/FeO ratios but are predominantly diopside.

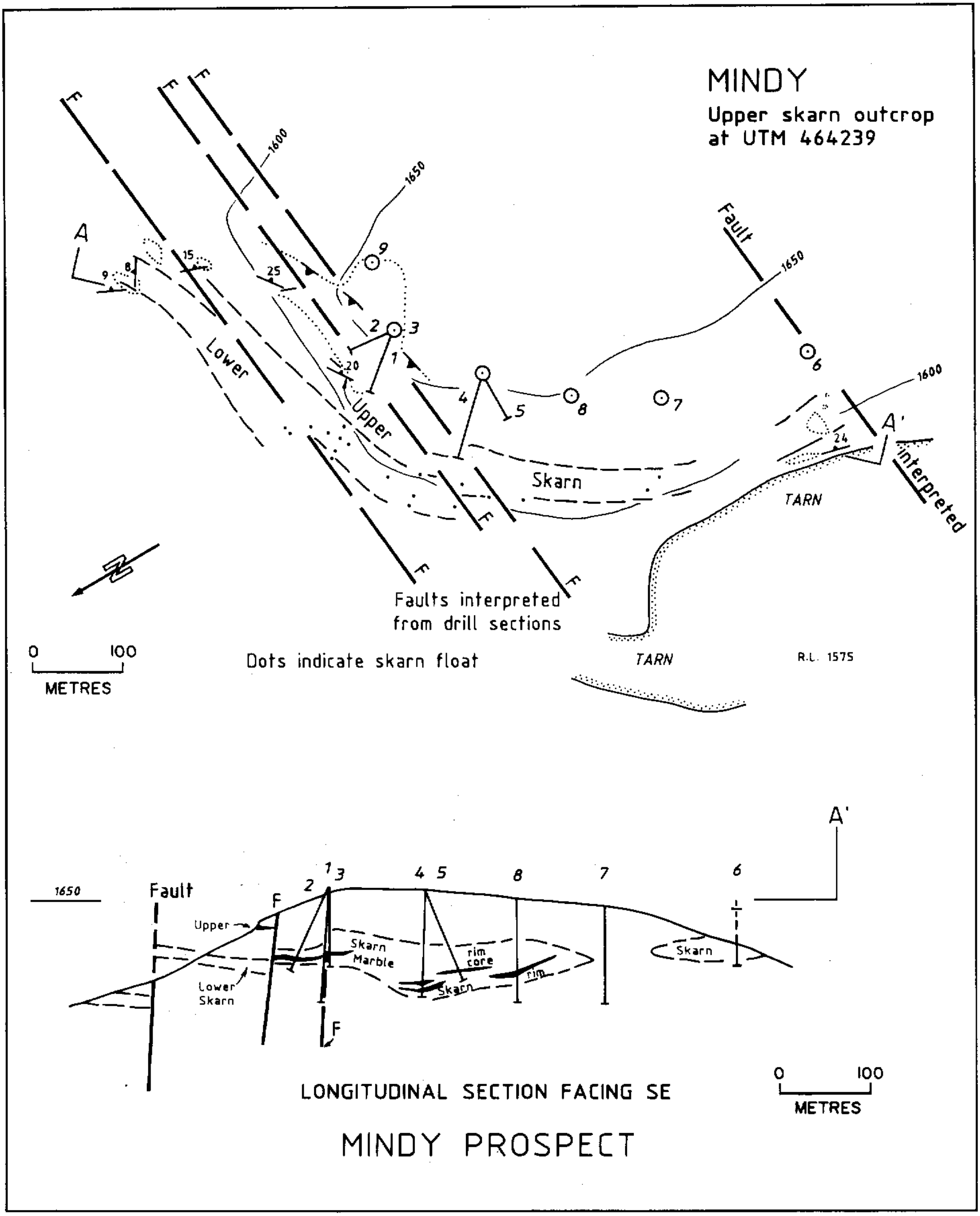

Figure 8. Geology of the Mindy prospect.

Mineralized skarns have erratic MgO/FeO ratios on a centimetre scale, and pyroxene compositions range from diopside to ferrosalite, reflecting iron introduction during mineralization. Garnets (table 2) are andradite and vary only in iron and manganese content. No significant amounts of MgO or $A1_2O_3$ were noted. Skarn mineral paragenesis is summarized in Table 3.

DISCUSSION:

Granites

Four granitic facies were observed: porphyry/diorite, even-grained microgranite, megacrystic biotite granite and highly leucocratic topaz-fluorite granite. The globular mafic enclaves noted in the porphyry facies are considered clear evidence of magma mixing early in the intrusion process. The porphyry could represent remnants of a linear intrusion controlled by an east-west extensional fault that preceded the main granite emplacement. The model for tin granites proposed by Plimer (1987) involves passive introduction of water-poor magma in regional extensional shear zones, and the formation of a pressure-quenched carapace which allows internal crystallization of the intrusion. Fluid release by hydro-fracturing and repeated hydrothermal activity introduces mineralization to the aureole and causes the development of porphyritic textures and oscillatory zoning of feldspars in the outermost phase of the pluton. Such features are characteristic of the Thirtymile stock.

The low angle of the intrusive contacts around the Thirtymile stock indicates that roof of the pluton may lie less than a few hundred metres below the central ridge of the Thirtymile Range. The leucocratic facies may therefore represent a highly differentiated facies in the roof of a cupola.

A metasomatic subsolidus origin was proposed by Stone and Exley (1985) for fluorine-rich granite in the Cornubian Batholith. However, such a concentration of fluorine in Thirtymile Stock can be explained by extreme differentiation. This would be consistent with the occurrence of the fluorine-rich facies as frequent small sills and dykes. The occurrence of biotite mostly as interstitial grains, as in the microgranite and megacrystic facies, is cited by Plimer (1987) as evidence of high fluorine fugacity. Future research will investigate whole rock major and trace-element chemistry, and the mica chemistry of the various facies, particularly with regard to the elements Mg, Li, Fe^{2+}, Fe^{3+}, Cl, F, and Sn. The degree of specialization of the facies and the tin content in the granite will also be examined (see Henderson and Martin, 1989; Scott, 1988).

Skarn Mineralogy

The classification of Sn and W skarns by Kwak (1987) can be applied to the skarns in the Thirtymile Range. The following features of Kwak's type II-2a skarns are relevant to the Mindy skarns:

(a) Tin skarns can be both magnetite and silicate-rich if associated with high B and F.

(b) Tungsten and most tin skarns have high pyrrhotite to pyrite ratios.

(c) There is no correlation between the tin content of skarns and the magnetite or sulphide content. However, if a magnetite-rich assemblage does occur, it hosts 75% of the tin.

(d) Tin and tunsten show an inverse relationship. The upper skarn at the Mindy deposit contains scheelite but no tin minerals and would conform to Kwak's magnesian bimetasomatism type (type II) as it grades from massive vesuvianite skarn through garnet to calc-silicate hornfels and pelite. Kwak also noted that the type of Fe-bearing skarn minerals formed varies with oxygen fugacity. Where an early, oxygen-rich fluid, presumably derived from a magnetite series granite interacts with graphite-free marble, an andradite garnet skarn is the result. If oxygen fugacity is low due to reduction of the fluid by graphite, a Ca-Fe pyroxene and either grossularite or anorthitic plagioclase is formed. In the main carbonate/skarn section of the Mindy prospect, where the original carbonate was mostly pure calcite, prograde andradite (vein) skarns are found. At the northern limit of exposure, where relict carbonates are almost black, a more varied mineralogy has resulted. Kwak (1987) also noted that if the original sediments contain graphite, the reduction of fluids released during skarn formation produces bleached zones. In the upper Mindy skarn, where thin carbonate layers are tectonically interlayered with pelitic cataclasites, bleaching occurs adjacent to cross-cutting veins, indicating oxidation by fluids exhausted by the metasomatism.

Based on Kwak's table of mineral assemblages (Kwak, 1987: table 8.2) the Mindy deposit belongs to the oxidized magnetite type. The retrograde borate-rich skarn assemblages of the mineralized lower horizon possibly reflect a magnesian marble protolith in that limited area.

Extensional Faulting

The Mindy prospect lies immediately south of an east-west fault. This fault probably controlled the mineralization by providing a conduit for fluid rising from the buried pluton. Continued tectonism during contact metamorphism probably allowed the operation of a continuous crack-seal mechanism described by Bucher-Nurminen (1989), and minerals were deposited along small-scale fractures. This hypothesis is supported by the following evidence:

(a) An exposure of the east-west fault on the ridge 750 m west of Mindy tarn shows a calcite breccia partly replaced by pyroxene and mineralized with pyrrhotite and

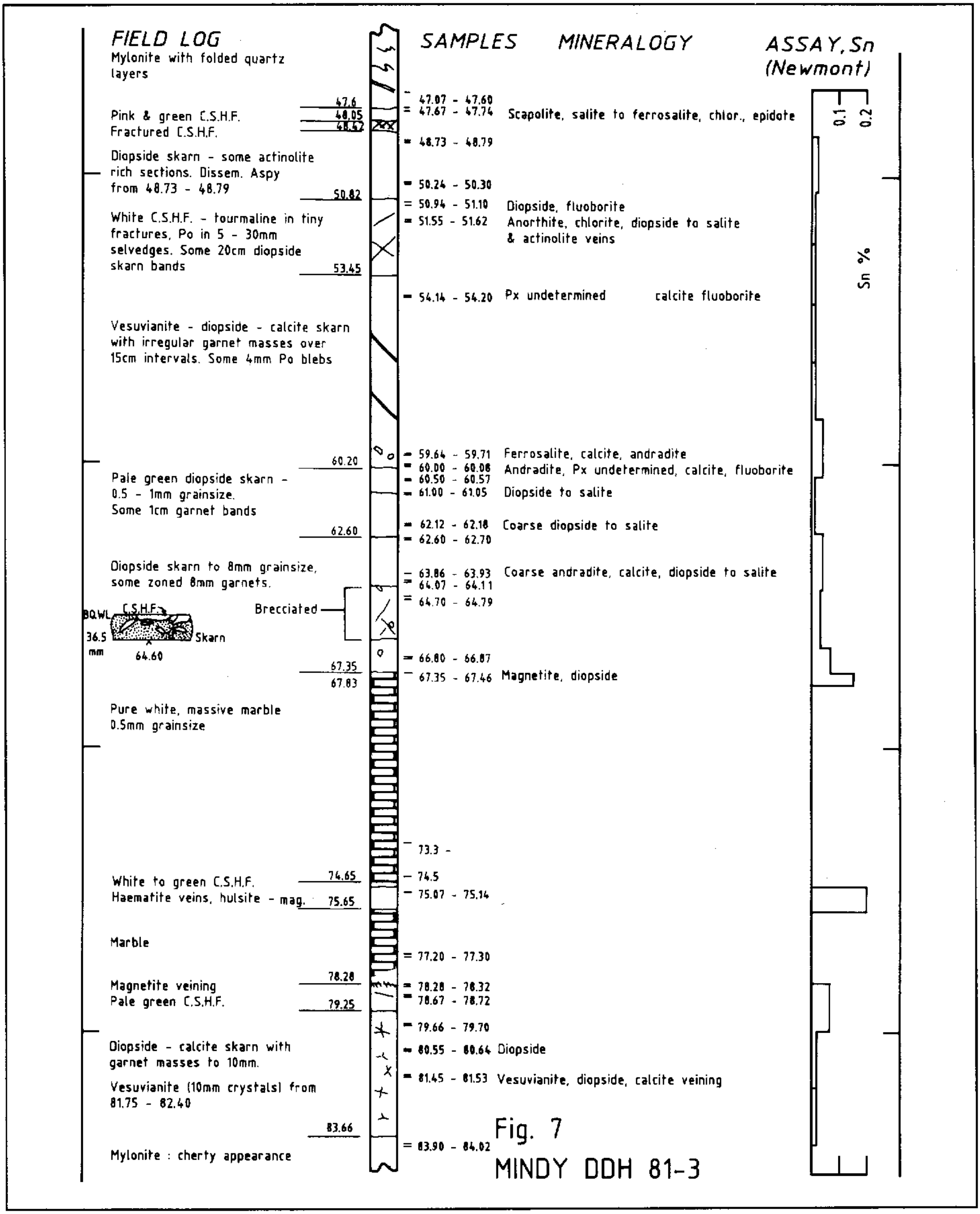

Figure 9. Field and drill section through the Mindy prospect.

scheelite, indicating fluid transfer up the fault to a level some hundreds of metres higher than the Mindy.

(b) Cherty mylonite in the deepest drill core from Mindy shows fractures mineralized with pyrrhotite or tourmaline and fluorite, which cut the near horizontal pressure solution fabric at a steep angle.

(c) The garnet-vesuvianite skarn is highly fractured in places, indicating hydraulic fracturing probably followed primary skarn development.

(d) Many small, zoned retrograde skarn veins are developed along fractures in the marble.

CONCLUSIONS

The Thirtymile Range consists of cataclasites derived from Middle Palaeozoic to Mesozoic siliciclastic and carbonate sediments which have been deformed by:

(1) cataclasis and transposition in broad shear zones.

(2) low angle thrust faulting, the full extent of which is unknown.

(3) high-angle extensional faults striking east-west, which pre-date the emplacement of mid-Cretaceous granitic plutons. Some movement appears to have continued during emplacement of the granite.

(4) moderate-angle normal faults striking north-south, which appear to be contemporaneous with granite emplacement.

Skarns formed in the aureoles of the granites contain tin-tungsten-boron-fluorine mineralization. Carbonate units (mega-boudins) in the cataclasite sequence formed a stratigraphic control on the location of mineralization.

Extensional tectonics are believed to have controlled the granite emplacement and provided the conduits for movement of tin- and tungsten-mineralizing fluids in the overlying sediments. Small-scale movement on the faults continued during mineralization, allowing successive mineralization of steeply dipping veins in carbonate megaboudins by a fracture-reaction-seal mechanism. Tin and tungsten-bearing stockworks may well exist within the extensional fault systems.

On the east side of the Range, at the Mindy prospect (MINFILE 105C 054), very coarse skarn is developed with a highly variable mineralogy. Boron and fluorine are associated with the later stages of mineralization. Scheelite is confined to the upper (bimetasomatic) skarn unit, and the first retrograde skarn assemblage at the southwest limit of the main skarn, where no tin is evident. There is clearly an inverse relationship between the occurrence of W and the occurrence of Sn.

On the west side of the range, hornfels more than 100 m thick is sporadically developed in cataclastic dolomite but coarse skarn is absent. At the Ork prospect (MINFILE 105C 38), boron occurs as axinite along micro-fractures in the hornfels, and fluorine occurs as fluorite at the granite contact. The JC syndicate documented, but did not adequately test, geochemical anomalies in the Ork area. The 100 metre thick carbonate section which overlies the "specialized" granitic stock is mostly covered by glacial drift and appears to have excellent exploration potential for tin and tungsten deposits.

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TABLE 1: PYROXENE ANALYSES (Microprobe).

The range shown is for the lowest and highest silica analyzed in the one thin section. The number of analyses per section is shown in brackets.

(1) Pyroxene-dominated skarns with little or no mineralization:

DIOPSIDE TO SALITE PYROXENE:

SAMPLE	SIO_2	CaO	MgO	FeO	MnO	
50.94 (4)	From	55.4	26.3	16.5	1.8	0.5
	to	55.1	25.6	15.7	2.2	0.2
61.00 (6)	From	55.9	26.5	15.8	2.5	0.3
	to	52.4	25.4	9.1	12.6	1.3
62.12 (8)	From	55.8	26.7	15.7	1.9	0.3
	to	53.0	25.3	9.5	11.4	1.5
67.35 (4)	From	55.9	26.3	15.7	1.8	0.5
	to	54.6	26.7	15.4	2.8	0.6
80.55 (13)	From	56.4	26.7	16.2	1.2	0.2
	to	54.9	26.5	15.2	2.7	0.4
81.45 (16)	From 56.7	27.2	16.3		-	
	to	55.3	26.9	16.3	1.1	0.2

(2) Skarns with mostly garnet or retrograde assemblages and significant mineralization:

SALITE TO FERROSALITE PYROXENE:

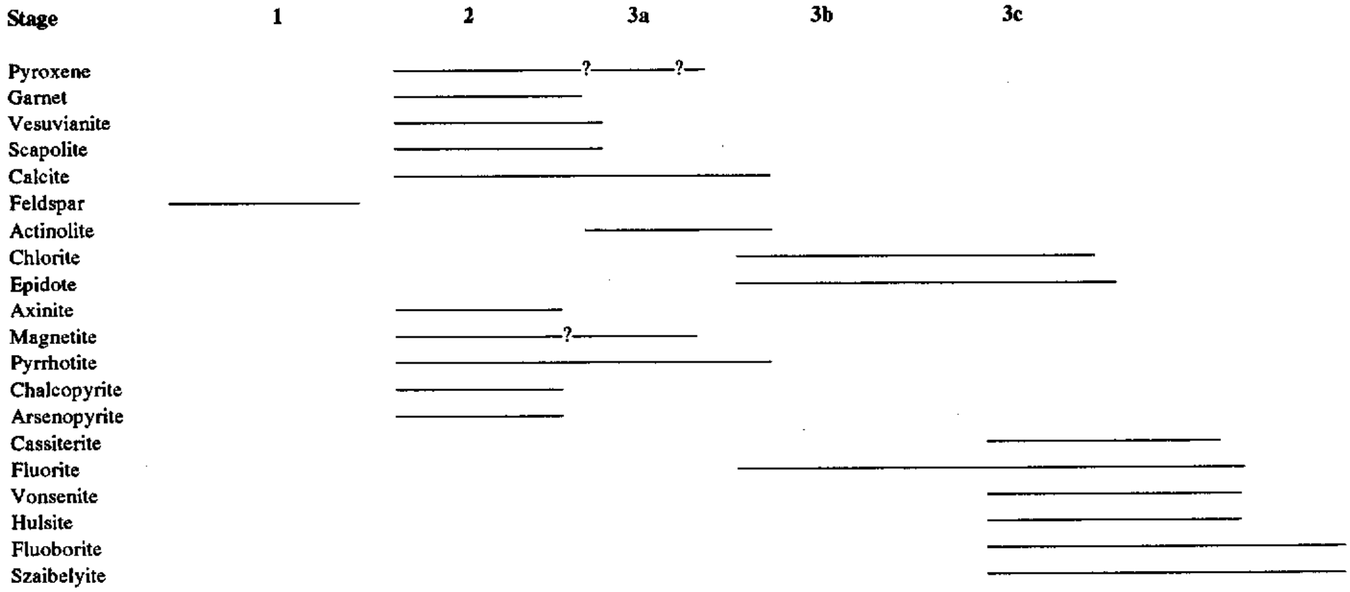
47.67 (4)	From	52.8	24.7	10.2	9.8	1.0
	to	51.5	24.1	6.6	17.0	1.2
51.55 (4)	From	56.1	26.1	15.9	1.5	0.4
	to	54.6	25.9	12.3	6.7	0.6
52.05 (1)		51.9	22.7	9.1	15.0	1.1
59.64 (2)	From	52.1	24.3	6.5	15.5	2.5
	to	51.0	24.5	6.1	16.9	2.2
63.86 (7)	From	54.9	27.1	14.8	2.6	0.4
	to	53.4	25.1	12.0	7.5	1.8

TABLE 2: GARNET ANALYSES (Microprobe)

ANDRADITE:

59.64 (2)	From	38.1	35.4	0.0	17.1	1.4
	to	38.1	35.1	-	17.2	1.2
60.00 (11)	From 38.0	34.7	-	21.7	1.3	
	to	37.0	34.7	-	22.6	0.8
63.86 (1)		37.0	34.1	-	25.9	0.7

TABLE 3: SKARN MINERAL PARAGENESIS



1 = Primary (prograde) skarn, including vein skarns.
2 = First retrograde skarn
3a = Hydrous retrograde alteration
3b = Main tin mineralization
3c = Late fluorine mineralization