

WERNECKE BRECCIAS AND Fe, Cu, U MINERALIZATION: QUARTET MOUNTAIN-IGOR AREA (NTS 106 E)

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ABSTRACT

The "Wernecke Breccias" are enigmatic, but significant features of the Middle Proterozoic Wernecke Supergroup in the Wernecke and Ogilvie Mountains. This report describes the breccias near Quartet Mountain and the Igor prospect in the Wernecke Mountains. Widespread, pervasive metasomatism and greenschist facies metamorphism of both the breccias and wall rocks is demonstrated by the development of chlorite, calcite, dolomite, siderite, albite, hematite, sericite, biotite, and quartz. Altered fragments are multicoloured and give the appearance that they are transported, and exotic, but all are locally derived. Structures in relatively unaltered breccias suggest that brecciation was accompanied by mylonitization and faulting. Repeated brecciation, metasomatism, and faulting characterize development of the breccias. Small gabbro and diabase dykes and sills are associated with the breccias. The breccias contain numerous, small occurrences of copper, iron, barium, molybdenum, uranium, cobalt, gold, and silver. Crustal extension and detachment faulting, and large buried intrusions beneath the breccias are suggested as possible genetic mechanisms.

RÉSUMÉ

Les "brèches de Wernecke" sont énigmatiques, mais représentent des éléments significatifs du supergroupe de Wernecke, d'âge protérozoïque moyen, dans les monts Wernecke et Ogilvie. Dans ce rapport, on décrit les brèches situées à proximité du mont Quartet et le gîte possible d'Igor présent dans les monts Wernecke. Le métasomatisme et le métamorphisme du faciès des schistes verts, étendus et omniprésents, qui ont touché à la fois les brèches et les roches encaissantes, se sont traduits par l'apparition de chlorite, de calcite, de dolomite, de sidérite, d'albite, d'hématite, de séricite, de biotite et de quartz. Les fragments altérés sont multicolores et semblent avoir été transportés, et ont une apparence exotique, mais tous ont une provenance locale. Dans les brèches relativement non altérées, les structures observées suggèrent que la bréchification a été accompagnée de processus de mylonitisation et de la formation de failles. La bréchification répétée, le métasomatisme et l'apparition de failles caractérisent le développement des brèches. De petits dykes et filons-couches de gabbro et de diabase sont associés aux brèches. Ces dernières contiennent de nombreuses et petites venues de cuivre, fer, baryum, molybdène, uranium, cobalt, or et argent. On a suggéré comme mécanisme possible de génèse l'expansion de la croûte et les failles formées par décollement, et la présence de vastes intrusions enfouies au-dessous des brèches.

INTRODUCTION

"Wernecke Breccias" (an informal term) are conspicuous rocks; in their most spectacular form composed of pink or maroon albitite fragments resting in an identically coloured or green "rock flour" matrix. These and similar breccias have a regional although spotty distribution in the Proterozoic (meta)sediments of the Wernecke and Ogilvie Mountains. They appear to be an important component of the local geology and a key to interpretation of the regional geotectonics, magmatism and metallogeny.

The breccias were almost simultaneously introduced into the literature in the late 1970s by Morin (1976), Bell and Delaney (1977) and Laznicka (1976, 1977a). Subsequent studies of the "Wernecke Breccias" emphasized their regional distribution, setting and stratigraphy (Bell 1978, 1982, 1986; Delaney 1981); exploration significance (Archer and Schmidt, 1978); and detailed geology and petrology of local alteration-mineralization centres (Laznicka 1977b, Laznicka and Edwards, 1979). All the above contributions included observations on the Cu, Fe, U, Co, Au and Ag occurrences, widespread within and in the immediate vicinity of the breccias.

In the summer of 1985, Laznicka and Gaboury assisted by Brian Carlson studied breccia localities in a 15 x 5 km strip between the Quartet Mountain and Igor prospects (S.E. corner of Wind River

1:250,000 map sheet; Fig. 1). The study was supported by contracts from the Department of Indian and Northern Affairs.

ACKNOWLEDGEMENTS

Thanks are due to Jim Morin who suggested the project and provided the logistic support. R.T. (Dick) Bell shared his considerable experience with us. A.R. Archer kindly gave us the permission to study the mining properties owned or managed by Archer, Cathro and Associates (1981) Ltd and supplied many valuable pieces of non-proprietary information. ESSO Minerals kindly donated one day of their helicopter time, to fly us into the Igor camp.

REGIONAL SETTING

The core of the Wernecke Mountains is underlain by the Middle to Late Proterozoic Wernecke Supergroup (Delaney, 1981). The lower and middle portions of the Supergroup comprise monotonous thin to medium-bedded, recrystallized to greenschist-metamorphosed siltstone, argillite and quartzite of the Fairchild Lake and Quartet Groups (estimated by Delaney to be at least 9,000 m thick). The upper portion, conformably overlying the lower, is a dolomite-rich sequence assigned to the Gillispie Lake Group. The Wernecke Supergroup, at least its lower division, resembles the Belt-Purcell Supergroup as developed along both sides of the U.S. - Canada

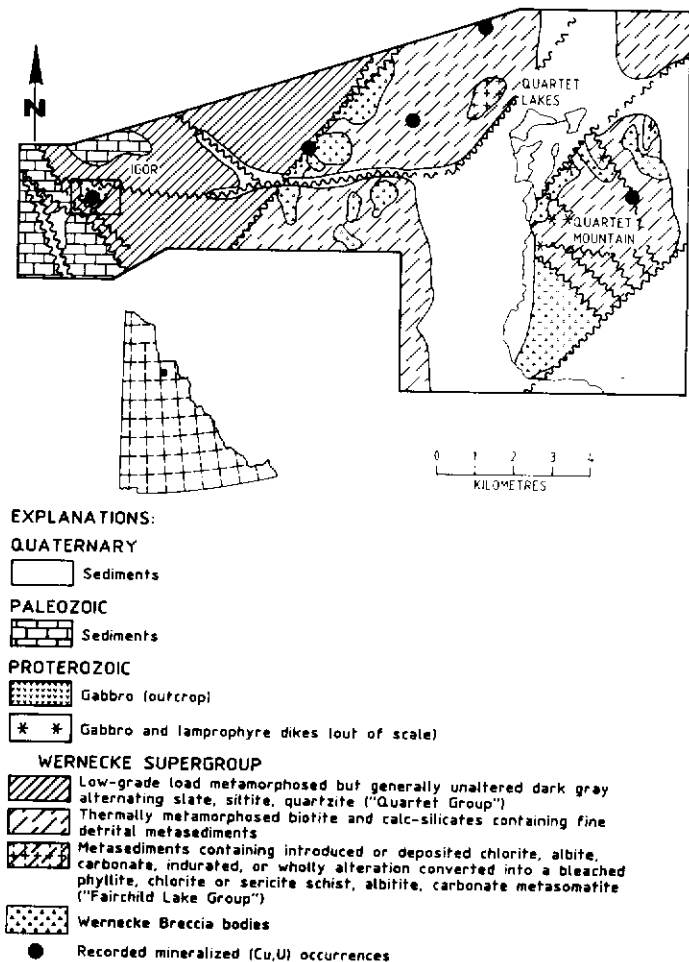


Fig. 1 Quartet Lakes-Igor area: location and reconnaissance geology

border and both supergroups probably originated in a similar, although not necessarily synchronous, setting. The base of the Wernecke Supergroup is not seen. Delaney (1981) provided substantial paleocurrent data, indicating an east-west trending depositional axis and northerly derivation of the terrigenous detritus.

The Wernecke Supergroup is locally unconformably overlain by varicoloured sediments of the "Pinguicula" and Rapitan Groups, and is in fault contact with Proterozoic sediments of the Knorr Range Succession east of the Knorr Fault (Norris, 1979). Cambrian to Cretaceous terrigenous sedimentary rocks, having a transgressive or tectonic contact, envelope the Proterozoic outcrop area on all sides. The entire region is devoid of magmatic intrusions. Minor gabbro and diabase sheets and small masses representing less than 0.1% of the outcrop area intrude the Wernecke Supergroup. Even rarer are lamprophyre and ultramafic dykes.

The earlier Proterozoic core is a broad uplift ramified and intersected by the northwest-trending Richardson Fault Array and broken by northeast-trending faults. Bell (1986) recorded isolated northerly and south-westerly dipping thrusts in the Wernecke Supergroup, but open folding and shallow to moderate dips predominate except near breccias. There, segments of tight isoclinal folding complicated by cleavage grade into "broken formations" and into breccias that are of several probably related and unrelated varieties. Bell (1986) introduced the term megabreccia to account for "breccia bodies (that) contain clasts in the kilometre-size range" which, although "laterally connected and following an arcuate pattern", are interpreted as derived from the lower levels and compared with the South Australian "diapirs".

LOCAL GEOLOGY

Figure 1 is a compilation map of the study area. The local geology includes three divisions: the Proterozoic core; the Paleozoic sedimen-

tary rocks west of Igor; and the Quaternary cover. Our efforts were devoted to the study and interpretation of Division 1 and the alteration and mineralization superimposed on it.

The Proterozoic strata have been correlated with the Fairchild Lake Group and the overlying Quartet Group, (Bell, 1986; unpublished mineral occurrences and compilation geological map provided by A.R. Archer), or their earlier correlatives (Hcs and Hs; Blusson, 1974).

Our work, however, failed to confirm any substantial lithologic difference between rocks mapped as Fairchild Lake and those mapped as Quartet Groups and we suggest that, at least in the present study area, the more "massive" Fairchild is a metamorphically and metasomatically modified equivalent of the Quartet, exposed in structurally positive areas that are at least in part thermal domes. Because the intensity and style of alteration are to a considerable degree influenced by the original lithology, an impression of stratigraphic contacts and superimposition is strong.

The often considerable petrographic (and geochemical) variety of rock types encountered at hand specimen to outcrop scales primarily reflect the style and intensity of deformation, and the composition, intensity and style of alteration. Both are superimposed on a small number of very simple and persistent original rock types. Breccias and cataclasites are part of the entire package, transitional and fully gradational into the undisturbed (meta) sediments and cannot be considered separately as has often been the case in the past.

Lithologic variation in the lower Wernecke Supergroup here, as in the Dolores Creek area (Laznicka, 1976) reflect variation of grain size and ratios of three common minerals: (1) quartz; (2) light micro- to macro-mica (sericite to muscovite), derived from original clay minerals; (3) detrital or authigenic K and Na-Ca feldspar. The rock-forming minerals have been partially to fully recrystallized under conditions of at least zeolite but more commonly greenschist facies, so the rocks are technically metamorphic. The simplest rock is a (meta)quartzite composed of an equigranular crystalline mosaic of 0.1 - 0.3 mm diameter quartz grains, in which scattered grains of sodic plagioclase and/or muscovite are the main accessory. Our evidence indicates that the pure quartzites are the result of tectono-metamorphic refinement of originally finer-grained and impure arenites, and that the discontinuous bodies are structurally controlled. Sericite (muscovite) quartzite is a much more widespread and truly (meta)sedimentary rock, forming persistent beds and horizons. This rock was probably a well-sorted terrigenous quartz-rich sublitharenite.

With decreasing quartz grain size (below 0.1 mm) and increasing mica/ quartz ratio, sericite quartzite grades into a fine (meta)sediment intermediate between "quartzite" and "argillite", termed "siltite" in the Belt Supergroup (Harrison and Jobin, 1963).

In addition to the three major component minerals listed above, the (meta) sediments also contain chlorite, carbonate (calcite or dolomite in the "rocks", grading to siderite in the "ore zones"), biotite, albite and hematite pigment. Additional (introduced) quartz and sericite (muscovite) also occur. All these minerals are characteristic for rocks of the "Fairchild Lake Group" which form units distributed over distances of several kilometres. In the "Quartet Group" the minerals have a spotty distribution, usually clearly related to disturbance. Even in the Fairchild Lake Group, individual rock types (e.g. carbonate, chloritic phyllite) are impermanent in the sense that they do not form a single bed or a bedset traceable for distances of several hundred metres away from a disturbance/alteration centre, without changing their mineralogical facies. We interpret the above minerals to result from post-depositional alteration.

Carbonate-rich rocks

Delaney (1981) made a wide use of markers, particularly carbonate horizons which he considered sedimentary, to establish the Fairchild Lake Group and its subdivision. We can now state with a high degree of confidence that all the "rock" (as well as "ore") carbonate occurrences in the Quartet Lakes are post-depositional metasomatites. They formed in several stages by preferential replacement of certain beds or by almost total replacement of an entire rock body. Replacement carbonate can be easily recognized in thin sections by (1) its corrosion of quartz or sericite-rich bands; (2) by widespread trains

of impurities discordant to the trend of the carbonate body; (3) by gradation of high grade carbonate into tongues of partial replacement; (4) by the presence of poikilitic or internally homogeneous metacryst rhombs.

It is uncertain whether sedimentary carbonates are missing in the Quartet Lakes area only, or whether they are absent in the entire lower Wernecke Supergroup. All the carbonates I have newly examined or re-examined (e.g. those associated with the Gremlin chalcopyrite orebody, Kiwi Lake; those at Dolores Creek and vicinity; Laznicka and Edwards, 1979) are metasomatites. Even the rhythmically banded "ribbed-weathering limestone-siltstone member" in Cobalt Cirque is "secondary", although it could have formed by metamorphic recrystallization of a sedimentary carbonate causing partial corrosion of the adjacent quartz or silicate bands.

Biotite-rich rocks

Biotite substitutes for sericite (muscovite quartzites and less commonly, "siltites". Such biotite is fine-grained and is visible only as brownish shades on the rocks. The biotite-containing (meta)sediments tend to be hard and massive. At this stage, we interpret them as products of the highest-grade prograde thermal metamorphism achieved in the region. Biotite is relatively rare, and in less than 5% of the rocks.

Chlorite-rich rocks

Chlorite is substantially more widespread and more abundant than biotite in the metasediments. (1) Flaky chlorite substitutes for sericite in certain "slate" and is both a product of prograde or even-grade sericite replacement, and retrograded from earlier biotite. The former chlorite is more widespread, particularly in association with a concurrent albitization; (2) flaky chlorite substituting for interstitial mica in quartzite; (3) hydrothermal or hydrothermal-metamorphic interstitial structureless, metacolloform, radiating, fibrous, etc. chlorite replaces matrix and partly replaces large grains in quartzites, metasomatic carbonates and other rocks. It also fills a variety of dilational openings and is widespread in breccia matrix.

The most conspicuous chloritic rocks (chloritic phyllite or schist) occur in alteration-mineralization centres marked by breccias and mafic intrusions. In the talus derived from a poorly accessible cirque about 6 km southwest of Quartet Lakes, dark-green well-foliated chloritic schists and spotted-chlorite rocks grade into breccia on both sides of a "slate" and quartzite/gabbro (diabase) contact. Less advanced chloritized rocks occur on the N.W. slope of Quartet Mountain, where chlorite substitutes for sericite in the originally dark-gray mixtites.

Some of the chlorite-rich rocks ("greenschists, greenstone") are probably mylonitized and sheared, hydrated gabbros/diabases, but most are clearly metasomatically modified metasediments. Chloritization is the result of magnesian metasomatism of which at least some is attributable to postemplacement destruction of mafic intrusions followed by outward-progressing Mg fronts. Much (but not all) chloritization is concurrent with albitization.

Albite-rich rocks

Albite is the most conspicuous of altered breccias and of mafic intrusions, and it also overprints adjacent metasediments producing a variety of metasomatites and dilation fillings. The "overprinting albite", however, did not travel far from the centres of sodic metasomatism and is a good proximity indicator to such centres.

The most common result of albitization is a pseudomorphic replacement of quartz-rich metasedimentary bands, leaving adjacent sericite bands intact. The quartz-replacing granoblastic albite mosaic usually maintains the grain of size of earlier quartz mosaic or is 10-20% larger. The albite may be slightly clouded by the impurities inherited from its precursor. Unless fracture-controlled, albitized bands grade into the quartz mosaic, showing a diminishing proportion of wholly albitized quartz grains.

In folded and fractured zones, replacement albite alternates with fracture, fold and bedding dilation-filling albite. This variety shows

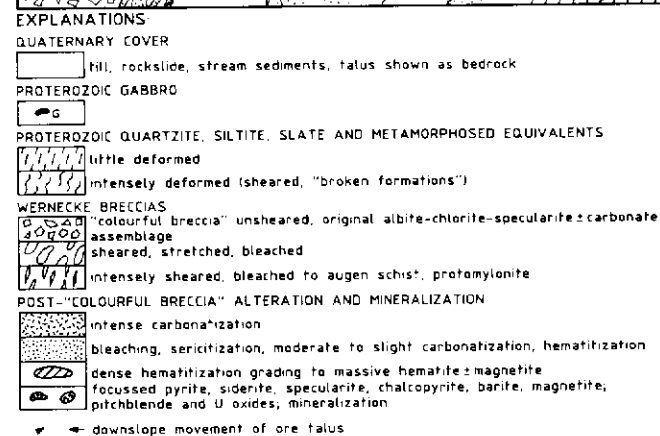
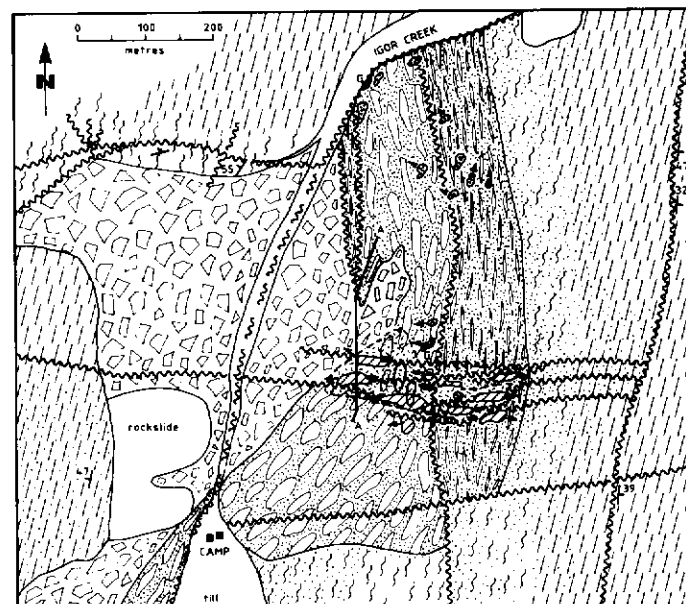


Fig. 2 Igor Prospect, geology, alteration, mineralization map

rapid variations in crystal size (0.01 to 3 mm) reaching exceptional lengths of 12 mm. Such albite is free of impurities, is usually twinned and its mosaic has a high proportion of idioblastic grains. Replacement and open space filling albites are contemporaneous, or they may belong to two or more different generations indicated by cross-cutting relationships.

Bleached rocks ("phyllites")

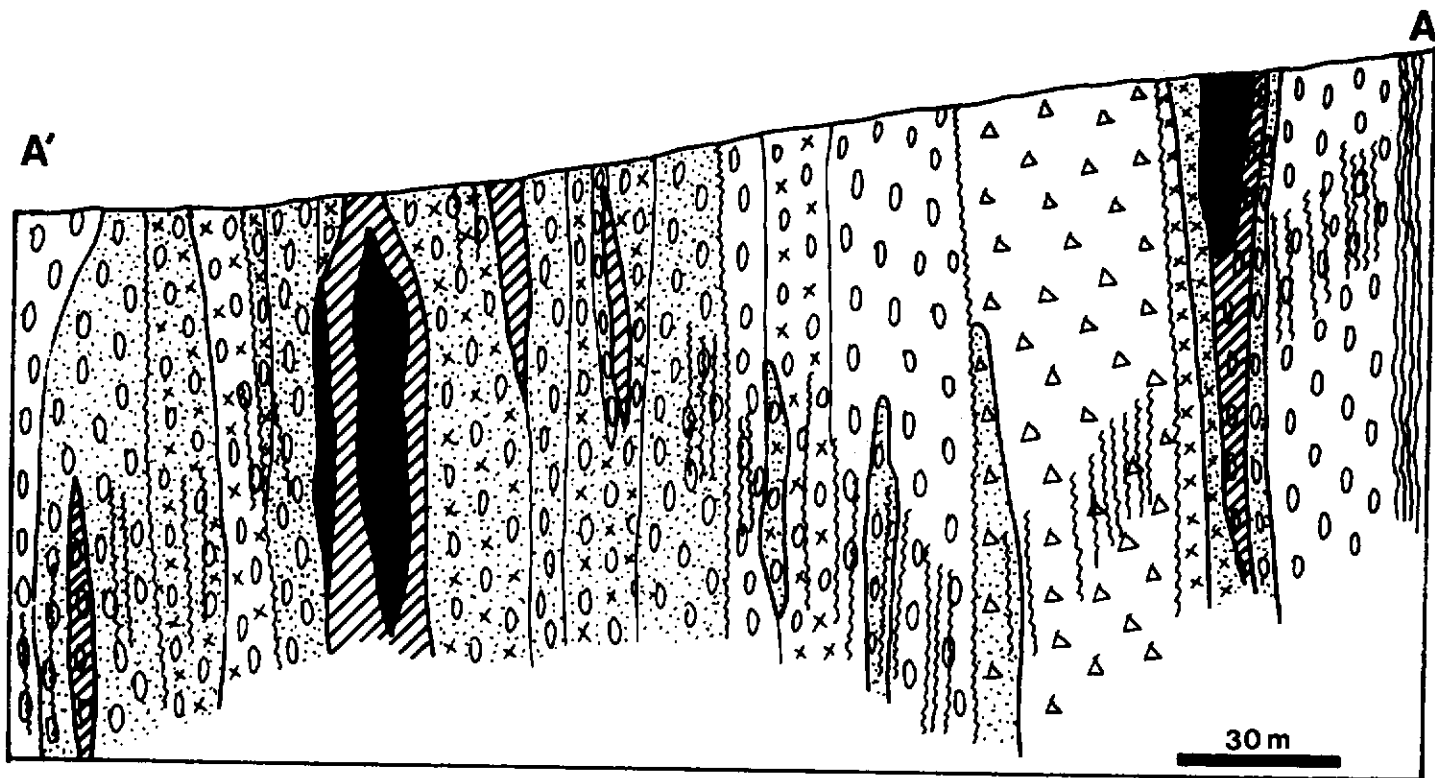
These are light-green, lustrous banded rocks composed of sericite and chlorite laminae enclosing usually discontinuous thin lenses of granoblastic albite, white quartz or ankeritic carbonate. Kinks, crenulations as well as a variety of dilations filled by mobilisates are common. Much of these rocks are tectonites and are either the result of pigment bleaching from previously unaltered "siltites" and "slates", or they form by retrogressive sericitization of an earlier albitite, mylonite or cataclasite. A variety of gradations into other rock types exists. Alteration-mineralization centres contain most of the "bleached rocks" and fault zones contain minor occurrences.

Silicified rocks


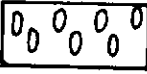

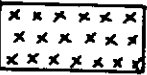
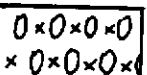
Silica is displaced from quartzite and "siltite" during albitization and is responsible for silicification and veining of some densely fractured rocks (e.g. the "spires" at the southwest side of the Quartet Mountain).

Intrusive rocks

Altered gabbro to diabase form small bodies in the breccia-



EXPLANATIONS

-  "Colourful breccia", massive, pink and green spotted (albite-chlorite association), minimal re-brecciation
-  Strained, bleached, partly stretched breccia, relic fabric still preserved and recognizable
-  Shears, marked by sericite schist with occasional relics of augen, original breccia fabrics are completely obliterated
-  chloritized microbreccia
-  chloritized partly stretched breccia

MINERALIZATION: estimated percentage of magnetite, hematite, barite, pyrite, chalcopyrite and uranium oxides



slip surfaces, gouge filled/coated fractures

Fig. 3 Igor Prospect, north-south cross-section between drill holes 80100 and 801012.

crushed aggregates of albite grains 0.1 - 1 mm in size enveloped by dominant fine sericite or paragonite schist. Most of the fine micas formed at the expense of the original breccia constituents (mainly albite and chlorite) so the shearing had to be concurrent with hydration, potash metasomatism and Mg removal. Outside of the limit of the early breccia, however, much of the "sericite" was probably derived by retexturing of the metasedimentary "slate" or "siltite".

The sericitic mylonitic schists differ from TB's by their pastel shades and an almost uniform beige colour and are gradational into TB's via an intermediate member mapped as "pastel-coloured breccias". The "pastel breccias" tend to have a high content of sideritic to ankeritic carbonate of both pre-shearing and post-shearing genera-

tion. The former appear as stretched augen, while the latter replaces the relics of albite, siderite and fills dilations.

"Re-breccias" are most common along late crosscutting fault zones previously unaffected by shearing and fine mica generation. The original TB's were milled partly along the earlier fragment boundaries, partly across them and the rock is now a hard, cohesive cataclasite without fluxion structure in which a wide range of 2 - 20 mm large porphyroclasts is embedded in a compositionally equivalent finer matrix. Higgins' (1971) term "microbreccia" is probably the most fitting.

Preferential orientation of constituents is rarely apparent. Introduced chlorite and specularite fill the pores produced by dilation

dominated alteration centres (Quartet Mountain, 6 km southwest of Quartet Lakes, Igor). Intensive cataclasis and alteration of both the mafic rocks and surrounding breccias and metasediments make the intrusion indistinct and almost impossible to outline.

The least altered variety obtained from float is a coarse olivine-pyroxene gabbro rich in accessory sphene. Deuteric alteration probably caused uralitization of pyroxenes and around 30% of phases postdate cataclasis and part of the overall areal alteration. Epidote, chlorite and albite are the dominant alteration minerals. Epidote is the most proximal and is confined exclusively to the intrusive rocks, whereas albite and chlorite display no such preference. With increasing proportions of late alteration minerals, the original ophitic texture is reduced to relics before disappearing altogether. A coarse crystalline (3-4 mm) albite-chlorite "syenite" found in float is a metasomatite resulting from replacement of the original gabbro by albite and chlorite.

Olivine-biotite lamprophyre dykes ("kimberlite")

Olivine-biotite lamprophyre have been recorded on the western and northern slopes of the Quartet Mountain. They form dykes 10-30 cm thick, and postdate the main alteration phase (they enclose xenoliths of the intruded albitized and hematitized metasediments), but are offset by late faults. These rocks are fine grained, gray, grayish-green to bluish-gray weathering tan to light-brown (white when talc-altered). They contain scattered inclusions of cellular serpentinized olivine, isolated sheets of biotite or phlogopite, up to 2 cm wide crystals of Ti-magnetite, and minor perovskite grains up to 1 cm wide. The contacts are unaltered, or there is a recrystallization band 3-10 cm thick.

BRECCIA

A large petrographic variety of breccias occur in float, particularly in stream beds (Fig. 3). Bedrock occurrences, however, are less satisfactory for study because most are covered by talus and virtually no breccia body is exposed in three dimensions and an unequivocal understanding as to its shape, contacts and origin is not possible.

"Typical" (or "Werneck", "Colourful") breccia (TB)

The most "typical" or spectacular breccia is composed of light angular to subrounded pink or maroon fragments surrounded by chlorite and/or specularite-rich "rock flour" matrix. "Typical breccias" are widely distributed through the Werneck and the Ogilvie Mountains.

"Typical breccias" are a heterolithic to pseudoheterolithic rud-rock (Laznicka, 1987), composed of multicoloured angular to rounded fragments set in a recrystallized or metasomatic groundmass. All fragments are locally derived and their great visual variety is to a considerable degree a consequence of alteration, rather than the original lithology. The pink and maroon fragments are composed of albite granoblastite: a chert-like, dense and hard, massive or faintly laminated rock that is textural equivalent of (meta) quartzite and is composed of a mosaic of hypautomorphic albite crystals having an average dimension of 0.1 - 0.2 mm. The only difference between the pink and maroon variety is the state of the pigments hematite, which is red, fine powdery in the first case and specularitic in the second. Tiny flakes of specularite are almost uniformly distributed throughout the rock.

Fragments range in size from rock flour through an average 1-3 cm to blocks over 1 m long. The small fragments are usually equidimensional, structureless to faintly laminated. Most large blocks are slabs of banded albitized (meta)quartzite or "siltite". Superimposed carbonatization causes brown weathering colours and still greater visual diversity of breccia fragments. The honey-yellow to light brown-weathering siderite rhomb meta-crystals scattered on the aphanitic pink or maroon albitite background make the fragments resemble felsic porphyries, with which they were originally confused.

The breccia matrix is a "microbreccia" (recrystallized and cemented rock flour), the grain size of which ranges from about 3 mm to about 0.01 mm. Typically a mixture of albite fragments, albite crystalloclasts, chlorite and sericitite fragments are recrystallized and cemented by a new generation of albite and chlorite with specularite and carbonate.

The whole transitional sequence between two end-members: the fractured protolith (sericite quartzite to "siltite") and the roundstone transported breccia (fractured quartzite - crackle breccia - mosaic breccia - breccia with rotated angular fragments - roundstone transported breccia) is represented, although the intermediate members are most "typical" preferred orientation of fragments and the matrix is rare.

Transition of the "typical breccia" into a less evolved protolith ("pre-breccia")

The transition of TB into an albitized quartzite or "siltite" petrographically identical with the breccia fragments has already been outlined above. Another series of transitions can be observed in a gully opposite (northwest of) the Igor property. There, a TB is partly transitional into, partly fault-separated from, a well-bedded outcrop of thick, planar, pink and maroon albitite beds with thin chlorite schist partings. These altered rocks are separated by a 115° trending fault from a hill to the north-east which is underlain by "tortured" quartzite-"slate" metasedimentary mixtite. Original sedimentary bedding is generally discernible and dips 35° NW, but the cataclastic quartzite is broken by a dense network of tectonically polished mylonitic slip surfaces into a black silvery mylonite in place of the former "slate" partings. Melange-like sections of attrition-rounded quartzite blocks in a silvery mylonite matrix and transitional arrangements, also occur.

This rock is not substantially hydrothermally altered and the transition from partly and fully altered equivalents is recorded in blocks in talus and in the creek under the Igor property. Hydrothermal metasomatism resulted in pseudomorphic conversion of the brittle quartzite component into albitite fragments and the ductile silvery and slickensided mylonite into a crystalline chlorite matrix.

Several tens of metres under this outcrop, alternating quartzite and "slate" are interrupted by numerous unaltered cataclastic zones, peneconcordant with bedding, in which rafts of dismembered cataclastic quartzite are embedded in a silvery matrix of sericitic blastomylonite or mylonitic schist. Both in turn are interrupted by tongues and lenses of a "slurry breccia". The breccia is of local derivation, but was clearly transported for a short distance into its present site. Its contacts with the immediately overlying and underlying mylonitic "slate" are sharp, but this is largely due to the ductility contrast. Lacking alteration, this rock is unspectacular and inconspicuous, spotty, greenish-gray and of low cohesion, so it is an insignificant component of talus and float that easily escapes attention. A variety of breccia bodies also fill superimposed crosscutting faults and fractures.

In another gully 1 km to the west, equivalent peneconcordant "slurry breccia" has been block-faulted and hydrothermally converted into the typical maroon, pink and green-spotted variety.

Transition of TB into repeatedly fragmented, sheared and hydrothermally altered breccias (re-breccias and ploy breccias).

At the Igor property and at several other places, the TB's formed early and were overprinted by several phases of deformation and alteration. These modifications were not confined to and controlled by the original breccia and they extend beyond it, but it was within the breccia where the products are most complex.

At Igor, the structural framework for the post-breccia modifications appears to be a wide north-trending shear zone and several parallel, discontinuous shears. These are cut by numerous east, northeast and northwest-trending faults. Along the highest strain zones within the shear, TB's have been converted into a sericitic mylonitic schist and augen schist (using Higgins' 1971 terminology) by concurrent cataclasis and neomineralization-recrystallization. Such a rock has a distinct fluxion texture (cataclastic foliation) and consists of subordinate augen or groups of grains of albite porphyroblasts, or

(expansion) in the time of origin, and replace earlier constituents. Another re-breccia variety is high in ankeritic to sideritic carbonate. At Igor, re-breccias are the most consistently mineralized hosts. Examination of several tens of thin sections indicated up to ten pulses of re-brecciation and a variety of fluxion-textured schists or microbreccia-schist hybrids superimposed on earlier microbreccias.

Other breccia varieties

Combinations of the "key varieties" of the Wernecke Breccias described above with the various types of hydrothermal alteration, can produce hundreds of varieties of "custom-made" breccias to be enjoyed by a breccia connoisseur, best of all in boulders in the stream draining the Igor valley. The most consistent feature of Wernecke Breccias thus appears to be their variability. Other, less spectacular breccias are also locally present:

- Concordant sharpstone to roundstone breccias or conglomerates within the unaltered and unshaped Wernecke Supergroup (meta)sediments. Several blocks found in the float consist of quartzite clasts supported by siltite matrix. These are probably intraformational debris flows. In tectonized and altered sections such as N.W. of Igor, similar rocks are indistinguishable from the syntectonic breccias.
- Mosaic breccias resulting from expansion along fracture cleavage and/or foliation surfaces and a variety of fold and fault breccias, some of them carbonatized, are on the fringe of alteration-mineralization centres.
- Crackle to rubble breccias superimposed on earlier metasomatic or dilation-filling carbonates.
- A variety of fault breccias cemented by carbonate or quartz.
- Sharpstone conglomerate zones in the Paleozoic sediments, widespread in float and drift.
- Cemented recent talus breccias.

ALTERATION AND MINERALIZATION

Five named copper, iron and/or uranium showings, all discovered by Archer, Cathro and Associates, and several tens of minor occurrences of the same metals, are known in the area covered by Figure 2. Only the Igor property has been explored by drilling and trenching. Over 2454 m (8171 ft) of diamond drilling was completed between 1976 and 1982.

Igor showings

Igor is on a low ridge on the south-eastern slope of a valley about 14 km southwest of Quartet Lakes. Concentrated mineralization underlies an area about 700 x 300 m aligned north-south. A broad north-trending shear zone and numerous east-west and other faults and fractures discussed in connection with the re-breccias and poly-breccias control mineralization. Most of the Igor property is talus-covered and accurate mapping is next to impossible. Only several "key faults" are shown on our map; drill core reveals thousands of microbreccia, mylonite and gouge-coated and filled slip and fracture surfaces with a wide range of coherence. Semi-coherent and incoherent cataclasites are the youngest and probably at least partly reflect repeated reactivation of older surfaces over a long period of time. The wide spread of radiometric ages obtained for U occurrences affiliated to breccias in the Wernecke Mountains (Archer et al., 1986) suggests late faulting and therefore a depth range of several kilometres and greenschist-stable to near-surface conditions.

Mineralization is in a "typical" albitite-chlorite breccia body measuring 700 x 700 m adjacent sericite quartzite, "siltite", and "slate" of the Wernecke Supergroup. Two small mylonitized and altered mafic intrusions have been recorded in the original TB. Repeated faulting, shearing, fracturing and brecciation were synchronous with

or overlapped hydrothermal alteration and mineralization. The hydrothermal fluids apparently issued simultaneously from many "emanation centres", rather than a single discrete point conduit such as a vent or a diatreme. Most were probably faults and their intersections. As a consequence parageneses and mineralization-alteration zonings are local and interfere with one another, although it is possible to put together a composite local paragenetic diagram based on statistical maxima.

Alteration contemporary with metallic mineralization (albitization, sericitization and paragonitization, chloritization, spotty growth of hydrothermal biotite and/or muscovite metacrysts, hematitization) is identical with the breccia-forming alterations, already discussed above. The ore minerals association: siderite and ankerite, magnetite, hematite, pyrite, barite, chalcocopyrite and uraninite is simple and corresponds to the "standard" regional association. The deposits range from haphazardly scattered grains and blebs of chalcocopyrite in virtually all the cataclasites (including the pre-shearing TB's), to a more localized and densely accumulated chalcocopyrite associated with abundant magnetite, specularite, pyrite and/or siderite (ankerite).

Iron minerals form scattered metacrysts (magnetite octahedra, specularite tablets and plates, siderite rhombs, pyrite cubes) that, with increasing density, produce interconnected grain aggregates. Massive magnetite, siderite or martite (hematite replacing magnetite) bodies, however, need not be richer in copper than low-iron hosts.

Barite seems to be widespread but inconspicuous, replacing albite and carbonate in breccia and mixing with the ore minerals mentioned above. Blocks of white or pink crystalline barite enclosing scattered magnetite crystals can be seen in transported breccias in the creek. Several small pods of white to pink fine crystalline barite crop out on the property.

Uranium in the form of pitchblende and several bright yellow, orange and green secondary minerals, occurs as (a) veinlets and coatings on hairline fractures in the pink barite pod near the top of the ridge; (b) as blebs in white to gray barite; (c) as disseminations, scattered grains and blebs in the complex massive siderite, magnetite, pyrite, chalcocopyrite ore; (d) as disseminations and veinlets in the martitized hematite bodies.

Fe, Cu, U, Au and Ag grades and ore tonnages calculated from the drill core assays have not been made available to us, so we are not in the position to provide an economic assessment of the property. No single, sharply outlined medium to high-grade deposit of any element but, perhaps, iron is apparent. Five or six small lenses of almost massive hematite and martite in the southern portion of the mineralized zone would hardly make a mine under the present economic conditions. The low grade "bulk" potential of the entire zone for Cu, U, Au and Ag, if any, has not been released.

Alteration zoning at Igor is imperfectly developed, mostly because it resulted from several superimposed events by fluids moving from numerous centres. Briefly, the early stage breccia-associated albitite-chlorite (hematite) alteration appears to either terminate abruptly against virtually unaltered rocks, or it fades away into alteration ankerite having the form of scattered rhomb metacrysts, fracture veinlets or slight impregnations in quartzite. The subsequent strong shearing was accompanied by an albite-destructive sericite and/or paragonite alteration. Only small patches of TB, and microbreccia marked by strong chloritization are unaltered. Siltites outside the breccia body are bleached. Siderite and ankerite (carbonatization) coincide with the fine mica alteration mentioned above; intensity and iron content decrease away from the deposits.

Hematitization is widespread and has many forms. Fine (pigment) specularite produced the maroon albite granofels and its formation was prominent in the early stages of TB formation. Subsequently, widespread specularite accompanied chloritization in microbreccias and caused the martitization of magnetite. Martitization of magnetite bodies at or near the ridge top may have been related to near paleosurface oxidation.

Silicification, quartz veining, quartz metacryst and mosaic formation in breccias was (a) early and contemporaneous with albitization, and (b) fairly late replacing albite, carbonate and barite in microbreccias and orebodies.

Quartet Mountain

In contrast to Igor, Quartet Mountain contains only small scattered occurrences of chalcopyrite, siderite, brannerite and probably pitchblende, none of which has been drilled or trenched. Most copper is in chalcopyrite, forming scattered blebs along fractures in carbonatized (meta)sediments and blebs to small masses in albite, chlorite, carbonate and quartz dilation fillings. Most showings are in the impressive scree covering the mountain slopes.

The most interesting radioactive Quartet occurrence prospected by Archer, Cathro and Associates, is on the north-eastern slope of the mountain near the crest. There, thin fracture veinlets contain pitchblende and a metamict Ti-Fe-Si-U mineral that gives the brannerite x-ray pattern after heating. A similar occurrence is in talus on the northern slope of the mountain, where the mineralization corresponds to types 1 and 2 on Figure 2 in Delaney et al (1982). There, the host rock is a partly altered (albitized and chloritized) laminated "siltite", situated between two bodies of TB breccia. A zone of intense parallel shearing is healed by lit-par-lit fillings of alternating coarse ("pegmatitic") albite and fine crystalline mosaic quartz. Brannerite crystals up to 2 cm in size are scattered in albite.

DISCUSSION AND CONCLUSIONS

The origin of the "Wernecke Breccias" has been keenly debated for about ten years because these rocks are, rightly, considered an important clue for interpretation of the geological history of this part of Canada, and because they seem to have an economic potential. Many small pieces of factual data have accumulated so far and several genetic hypotheses and intercontinental comparisons have been proposed but, so far, there is not yet a credible overall synthesis. More research is, clearly, needed.

The present study is based on a single field season and was constrained to a small area by the high cost of logistics. Several observations, however, have been made that constrain some of the recent comparisons made between the Wernecke Breccias and the

Adelaiden diapiric breccias, Mt. Painter and Olympic Dam breccias in South Australia (Bell, 1982, 1986) and contribute to exploration planning

We emphasize the dynamism and polyphase origin of the Wernecke Breccias. Apparently, their initial control is structural. Localized tight folding accompanied by fracture cleavage gradational into cataclastic folding as well as major fault zones provided the framework and produced several broken and mechanically weakened foci partly filled by "pre-breccias". The breccias form low-angle sheets (and their remnants), high-angle (subvertical) sheets and irregular bodies, suggesting contemporaneous low and high angle faulting, and brecciation. Detachment faulting triggered by basement extension documented in the southern Cordillera (e.g. Davis, 1983) could be the answer.

The early and main phases of breccia development in the Wernecke Mountains took place under greenschist facies metamorphism, close to the elasto-frictional and quasi-plastic regimes of Sibson (1977; see also discussion in Laznicka, 1987, p. 640-644). This is indicated by the absence of uncemented or infiltration-cemented fault gouges and breccias and presence of partially pressure-dissolved fragmentites, protoclases, microbreccias and mylonites, in which cementation, replacement and/or blastic recrystallization were contemporaneous with deformation. Deformation was both brittle and ductile, and occurred in a fairly "wet" environment necessary for neomineralization. Fluids could have been the result of (a) metamorphic dehydration at depth; (b) expulsion or convection triggered by the heat of igneous intrusion; (c) both.

The spatial and temporal association of diabase or gabbro dikes and sills; albite, chlorite, carbonate and hematite metasomatism; breccias; and small Fe, Cu, Co, Ag, U, Au, etc. occurrences is a worldwide phenomena (Laznicka, 1985a, 1987) and it is particularly well represented in the Werneckes (Laznicka, 1976; Laznicka and Edwards, 1979). At Dolores Creek, some breccia dykes were clear forerunners of diabase dykes filling the same fractures, as breccia dykes are forerunners of granitic dykes in the roofs of some porphyry copper systems (e.g. at Silver Bell, Arizona). All major occurrences of the Wernecke Breccias near Quartet Lakes contain small altered mafic bodies.

The "typical breccia" clearly originated from a "pre-breccia" by fabric loosening (with or without fragment rotation), albitization and chloritization. The breccias formed at depth and are hardly high-level diatremes, but could have formed in the roof of a buried intrusion. The breccias are all local and autochthonous; fragments only travelled a few metres. This observation has been repeatedly clouded by the conspicuous apparent petrographic variety of the breccia fragments (pink, maroon, white, brown, green, even bluish spotted "heterolithologic breccias"), which is due to alteration of interbedded quartzite, "siltite", "slate", by a variety of hydrothermal fluids. Truly exotic fragments have not been credibly documented. Thus the "homolithologic breccias" of Bell (1986) and other authors are our monochrome "pre-breccias", and "heterolithologic breccias" are the "typical" altered Wernecke Breccias. The lack of truly heterolithologic breccias makes the comparison with the South Australian "diapirs" questionable. Fragment heterogeneity is a strong feature of the breccias at Arkaroola, Oraparinna, Burra, Blinman and Beltana (Laznicka, 1985b and 1981 field visit).

One of the outstanding problems in the Werneckes is the existence, if any, of large buried intrusions. The scattered alteration-mineralization centra that are also foci of anomalous deformation superimposed on the background of an overall "gentle tectonics", would support this interpretation. Unfortunately, there are no geophysical data to support or refute this hypothesis. If there are major intrusions are they; mafic as suggested by the known gabbro/diabase occurrences, "granitic" as suggested by some structural analogies with the southern Cordillera and the high trace Mo contents in some ores recorded by Archer and Schmidt (1978), or peralkaline, alkaline or syenitic like the Cretaceous intrusions in the Tombstone Range as also suggested by the high Mo content? Although an alkaline affiliation of the Wernecke mineral occurrences has been suggested several times, based on the presence of olivine-rich lamprophyres ("kimberlites") in the area and several probably genuine kimberlite-carbonatite diatremes further away (Godwin,

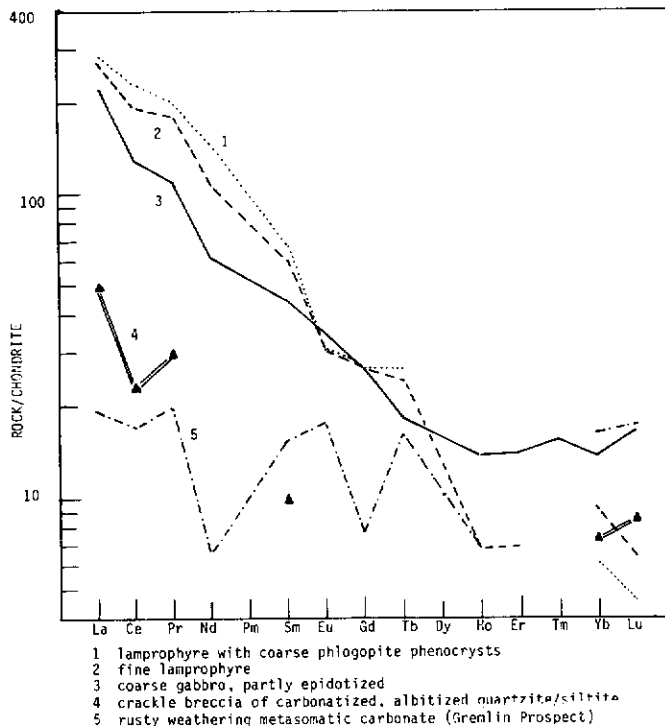


Fig. 4 Chondrite-normalized plot of rare earths elements in Proterozoic intrusives (1-3) and deformed/metasediments (4, 5) including breccia (4) and a completely metasomatic carbonate (5). The plot shows a lack of correlation between both sets, militating against the sub-crustal derivation of the latter. Analyses were performed by the X-ray Assay Laboratories.

1976), the role of widespread alkaline metasomatism in the Wernecke alteration-mineralization centres is not yet clear. Chondrite-normalized plots of rare earths elements in two samples of clearly epigenetic and replacement carbonates, potential carbonates, do not correlate with REE plots of the lamprophyres and gabbros (Fig. 5). Even if the "kimberlites" are real, they tend to be isolated or form separate provinces so they are not necessary indicators of the full development alkaline ultramafic, agpaitic, miaskitic, etc. (compare Laznicka, 1985a, Chapter 33).

Not a single marginally economic ore zone is so far known from the 100 or 50 scattered Cu, Fe, Co, U occurrences. The metal content is everywhere "unfocussed": a bleb of chalcopyrite here, a veinlet there, few scattered grains of brannerite or tetrahedrite, minor pitchblende infiltrations along fault zones and numerous small hematite bodies. Most of the ore metals can be locally accounted for, and their quantities are proportional to the trace metal amounts displaced from rocks and set in motion through destruction of their original carrier

minerals. The estimated amounts of Cu and Co at Dolores Creek balance closely with the interpreted volumes of albitized and chloritized gabbros and their trace Cu and Co losses. Enough iron to form the known orebodies was released during albitization of the mafic intrusions as well as the ordinary (meta) sediments. The source of U is more difficult to pinpoint, although the miniscule amounts found so far could have been easily derived from the "black slate" horizon at the base of the "Quartet Group" (Bell, 1986); its chloritic alteration must have caused the uranium displacement.

Unless there was a major focussing mechanism to collect, channel and locally confine the metal "flow" originating from many scattered centra into a single major structure in which it could accumulate, another Olympic Dam can hardly be expected unless, of course, one invokes the "bowels of the Earth" as Descartes did two centuries ago and Gabelman (1977) did recently, in the case of uranium. This, however, is a different story, difficult to tackle in the wilds of the Quartet country.

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