Altered Rocks Associated with the Mystery Island Intrusive Suite, Echo Bay, Northwest Territories

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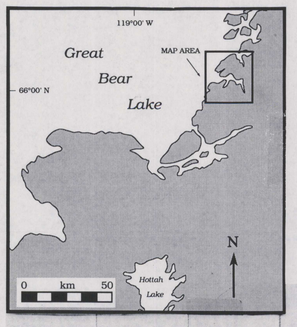

LEGEND

LITHOLOGIES

Middle Proterozoic

d — Gabbro and diabase: near vertical north-south and east-west trending dykes and sub-horizontal sheets

Early Proterozoic

GREAT BEAR BATHOLITH

G3dk | G3a | G3ga — Monzogranite (a), syenogranite (k), and granodiorite (g); coarse-grained, hornblende-biotite (chlorite-epidote) bearing; G3d, Dowdell Pluton

Gd — Diorite, fine-grained, altered; age uncertain, however, the degree of alteration suggests that it is older than G3 plutons

Gm — Monzonite and quartz monzonite, fine- to medium-grained, leucocratic; age uncertain, but found only within the LaBine Group

ALTERED ROCKS ASSOCIATED WITH PLUTONS OF THE MYSTERY ISLAND INTRUSIVE SUITE

Albite zone

Characterized by pervasive replacement of the host rock by albite; altered rocks are red-brown to pale pink to white; veins and pods of albite are present locally; commonly overlaps with the magnetite-apatite-actinolite and pyrite zones

Magnetite-apatite-actinolite zone (MAA)

Defined by the presence of at least two of the three minerals magnetite, apatite or actinolite which occur as disseminated crystals, veins, pods, and breccias

Pyrite zone

Characterized by the presence of disseminated pyrite crystals or pods up to several centimeters in diameter which form visible rusty patches on weathered outcrop surfaces, or extensive gossans where pyrite is locally abundant. Veins of pyrite to 1 cm occur locally; commonly overlaps the MAA zone. A chalcopyrite zone east of Port Radium is characterized by the presence of finely-disseminated chalcopyrite within the groundmass and within amygdules in andesitic lava flows

G1md — **Mystery Island intrusive suite:** medium-grained dioritic phase; occurs in sharp contact with the Tut pluton

G1m — **Mystery Island intrusive suite:** diorite - monzodiorite - monzonite - quartz monzodiorite - quartz monzonite - granodiorite; fine- to medium-grained, seriate; biotite-hornblende-bearing. An augite-bearing border phase occurs locally

LABINE GROUP

Lc — **CAMERON BAY FORMATION:** sandstone, planar and cross-bedded, volcanic-lithic and feldspathic; ripple-laminated siltstone and mudstone with mud cracks; hematitic polymictic conglomerate mainly of volcano-plutonic provenance; thin beds and erosional remnants of devitrified ashstone; local talus and explosion breccias near volcanic flow domes; ash flow tuff units not designated as informal members (Lt); cauldron collapse breccias interfingered with ash flow tuff members. The Cameron Bay Formation contains clasts of altered (MAA) rock locally, and is cut by a pluton of the Mystery Island suite. Includes the following members in the map area:

Laa — **Achook andesite:** andesite; flows and explosion breccias, amygdaloidal, aphanitic to porphyritic; dominant phenocrysts are plagioclase and hornblende; intercalated with several ash flow tuff members; more amygdaloidal and less porphyritic than andesite in the Echo Bay Formation

Lmt — **Mackenzie tuff:** tuff; composite ash flow sheet containing less than 10 per cent crystals of plagioclase, quartz and potassium feldspar

Llt — **Lindsley tuff:** tuff; ash flow sheet containing up to 25 per cent crystals, zoned from mostly quartz near the base to mostly plagioclase near the top; moderately to densely welded

The Echo Bay Formation interfingers with the Cameron Bay Formation

ECHO BAY FORMATION

Lef — **Sparkplug Lake member:** andesite; porphyritic flows and breccia, distinguished only by their stratagraphic position above the Mackenzie Tuff; includes a small cone and vent complex south of Lindsley Bay (Lef')

Les — **Surprise Lake member:** andesite; porphyritic (hornblende-augite-plagioclase) flows and breccia; many flows are trachytic; some flows oxidized to a brick-red colour; includes thin sedimentary interbeds (Les') and minor laharic breccia

Lec — **Cobalt Porphyry member:** porphyry; intrusive hornblende-plagioclase porphyry and microdiorite

Lem — **Mile Lake member:** andesite; porphyritic flows interbedded with volcanogenic sandstone and conglomerate, and andesitic lapilli tuff and ashstone

Lp — **PORT RADIUM FORMATION:** siltstone and sandstone; thinly bedded, fine-grained with at least two carbonate interbeds less than 1 m thick; all exposures lie within alteration halos of the Mystery Island intrusive suite

clear area C
wooded area ..... W
geologic contact (defined, approximate) .....
unconformity .....
fault (defined, approximate) .....
limit of alteration zone .....
chalcopyrite subzone .....
bedding, tops known (inclined) .....
bedding, tops unknown (inclined) .....
flow banding (inclined) .....
mine (abandoned) ..... ★

1. Port Radium; 2. Echo Bay; 3. Bonanza; 4. El Bonanza; 5. Contact Lake

Sample locations:

Whole-rock geochemistry only ..... ◇
D/H whole rock analysis ..... ▲
$^{18}O/^{16}O$ whole rock analysis ..... ▼
D/H and $^{18}O/^{16}O$ whole rock analyses ..... ◆
magnetite-apatite-actinolite (mineral isotope analyses) ..... ■
$^{34}S/^{32}S$ mineral analysis ..... ▽
quartz-carbonate vein (mineral isotope analyses) ..... ●

Plutonic rock names after Streckeisen, 1973. Geology from Geological Survey of Canada Map 1546A (Hildebrand, 1980). Revisions and alteration zones by N.C. Reardon, 1988-89. Mapping (1988-89) was assisted by S. M. Lagacé. Stable isotope data by N. C. Reardon, 1989-90. Field work was supported by the Northwest Territories - Canada Mineral Development Agreement and the Geological Survey of Canada, project 860002 (R. S. Hildebrand). Critical review of the map by J.B. Henderson greatly improved its content and form.

Scale 1:25 000

1 0 1 2 3

Kilometers

ALTERED ROCKS AND MAGNETITE-APATITE-ACTINOLITE DEPOSITS ASSOCIATED WITH THE MYSTERY ISLAND INTRUSIVE SUITE, ECHO BAY, NORTHWEST TERRITORIES

Marginal Notes

Introduction

Magnetite-apatite-actinolite deposits occur as pervasive replacement, veins, pods and breccias within wall rocks to the plutons of the Mystery Island intrusive suite at Echo Bay, District of Mackenzie, Northwest Territories. The plutons and their altered wall rocks host previously-mined pitchblende, native Ag, Ni-Co arsenide veins. Although numerous studies were carried out on the pitchblende, native Ag, Ni-Co arsenide veins (see Reardon 1992a,b for references), the origin of the altered rocks which host them remains uncertain. Hildebrand (1986) mapped two of the plutons and associated altered and mineralized rocks in the Camsell River area and recognized zoned alteration haloes within, and adjacent to, the plutons. He concluded that the alteration was the result of replacement and brecciation of the country rocks by high-temperature, highly acidic, chlorine-dominated fluids derived from the plutons of the Mystery Island intrusive suite.

The plutons of the Mystery Island intrusive suite intrude a complex of andesitic stratovolcanoes of the LaBine Group, within the 1.87 Ga Great Bear magmatic zone of Wopmay orogen (Hildebrand, 1984, 1986). The plutons are compositionally heterogeneous, sheet-like bodies of intermediate composition. The plutons are synvolcanic and were emplaced at a depth of 2 to 3 km at two distinct stratigraphic levels within the LaBine Group: within the Port Radium Formation and the lowermost part of the conformably overlying Echo Bay Formation, and within andesitic lava flows of the Echo Bay Formation (Hildebrand, 1986). At 1.84 Ga the stratovolcanoes and plutons were folded such that the tops and bottoms of the plutons are exposed (Bowring, 1984). After 1.84 Ga, the area was cut by northeast-trending transcurrent faults and diabase dykes and sills (Hoffman, 1984). Pitchblende, native Ag, Ni-Co arsenide mineralization probably occurred during a period of reactivation of the faults at 1.667 Ga (Bowring et al., 1989).

Altered rocks

All plutons of the Mystery Island intrusive suite have associated zoned alteration haloes, although the zones are somewhat irregular and discontinuous. Three zones of altered rocks were mapped in the Echo Bay area: 1) an inner zone of albite; 2) an intermediate zone of magnetite-apatite-actinolite (MAA); and 3) an outer zone of disseminated sulphides. The zones overlap spatially, and geologic and petrographic evidence show that temporally, the albite zone was formed first, followed by MAA and finally pyrite.

Albite zone

The albite zone is characterized by pervasive replacement of the host rock by very fine- to coarse-grained albite; albitized rocks are red-brown to pale pink. Extensively altered rocks, found in close proximity to the plutons, are white both on the fresh and weathered surfaces. Albitized rocks generally occur within 100 m of the pluton roofs, but extend up to 1 km above the plutons locally. Altered rocks also occur locally within and below the plutons. Veins and pods of albite are present in some highly altered areas. The albite zone commonly overlaps with the magnetite-apatite-actinolite and pyrite zones.

Magnetite-apatite-actinolite zone

The magnetite-apatite-actinolite (MAA) zone is defined by the presence of at least two of the three minerals: magnetite, apatite or actinolite. These minerals also occur as disseminated crystals, veins, pods, and breccias above the plutons, and locally, within and below them.

The mode of occurrence of magnetite, apatite and actinolite varies with original lithology. In andesitic lava flows, these minerals are present disseminated throughout the rock, and constitute up to 35% of the rock. In sedimentary rocks, beds are preferentially replaced by albite, actinolite, or magnetite. Limy beds at Port Radium are replaced by massive magnetite. Locally, pervasively altered andesite flows and sedimentary rocks are cut by veins of magnetite-apatite-actinolite or magnetite-actinolite. The most common assemblages of these alteration minerals in both replacement and veins/pods, in order of abundance, are: 1) actinolite + magnetite; 2) actinolite + apatite; and 3) magnetite + apatite + actinolite. Locally, near their contacts, the plutons are cut by veins of actinolite or actinolite-apatite.

Veins of MAA up to 80 cm wide are discontinuous and generally exposed along strike for less than 2 m. The veins have various orientations, but generally strike E-W and N-S and are steeply dipping. Pods are generally less than 1 cm in diameter, but many are up to several decimetres across. Actinolite is the most abundant mineral and occurs as laths to 5 cm in length. Magnetite occurs as sub- to euhedral crystals up to 8 cm across, but generally less than 1 cm.

Hydrothermal breccias, typically present near pluton contacts, comprise angular to sub-rounded fragments of country rock up to 1 m in diameter in a matrix of medium- to coarse-grained magnetite (± pyrite, chalcopyrite), actinolite, apatite, epidote and albite. Actinolite-rich breccias, which occur as pink (albitized?) fragments in a dark, actinolite-magnetite matrix, are found near pluton contacts locally.

Pyrite zone

The pyrite zone is characterized by the presence of disseminated pyrite crystals or pods up to several centimeters in diameter which form visible rusty patches on weathered outcrop surfaces, or extensive gossans where pyrite is locally abundant. Veins of pyrite to 1 cm wide occur locally. The pyrite zone occurs principally above the plutons, but locally within and below them. The zone is irregular and discontinuous, and is generally found at some distance above the roofs of the plutons. However, one gossan, more than 1 km across, is present directly above the northern portion of the Glacier Lake pluton. The pyrite zone commonly overlaps the MAA zone.

A chalcopyrite zone east of Port Radium is characterized by the presence of finely-disseminated chalcopyrite within the groundmass and within amygdules in andesitic lava flows. The zone may represent a subzone of the pyrite zone, and is subparallel to stratigraphy. Within both zones, higher concentrations of pyrite and chalcopyrite are present in sedimentary rocks than in andesites.

Whole-rock Geochemistry

Whole-rock geochemistry of the altered wall rocks above the plutons shows that Na_2O correlates negatively with SiO_2, K_2O, Ba, and Rb for altered andesitic lava flows within the alteration haloes of some of the plutons (Reardon, 1992a,b). Gd, Dy, Be, Yb, Y, Sm, MgO and Na_2O correlate negatively with K_2O; Ba and Rb correlate positively with K_2O. Na and K vary antithetically in the plutons, but other elements do not show regular variations with Na or K. The Tut pluton is relatively unaltered and shows a normal magmatic trend of increasing K and decreasing Na with increasing SiO_2 content. The Contact Lake and Bertrand Lake plutons are Na-metasomatized locally, as indicated by high Na contents. Part of the Glacier Lake pluton is K-metasomatized, as indicated by elevated K_2O not correlative with an increase in SiO_2. Profiles of SiO_2, Na_2O and K_2O with height in the Contact Lake and Glacier Lake plutons show a regular, antithetic variation of Na_2O and K_2O. The Contact Lake pluton is reversely zoned, and K_2O and SiO_2 decrease with increasing height in the pluton.

Stable Isotope Geochemistry

Wall rocks

Whole rock oxygen and hydrogen isotopic data were used to map the aerial extent of alteration and to characterize the nature and origin of the fluids responsible for the alteration. Rocks of the LaBine Group and Mystery Island intrusive suite were analyzed for their hydrogen and oxygen isotope ratios. Isotopic data are reported by Reardon (1992a,b). Variation of $\delta^{18}O$ within the plutons and their altered zones is limited. Most whole-rock $\delta^{18}O$ and δD are higher than +6‰ and -70‰, respectively, consistent with alteration under low water to rock ratios by dominantly magmatic fluids. Lower values suggest involvement of a minor component of seawater, connate water, or evolved meteoric water, and some input of surficial waters is probable.

MAA and pyrite zones

Stable isotopic data for actinolite, epidote, biotite, apatite, quartz and magnetite were used to calculate a range of isotopic compositons ($\delta^{18}O$ and δD) of the fluids which deposited the minerals, based on known mineral - water isotopic fractionations for a range of temperatures. The data indicate that the fluids which deposited these minerals ranged from about +5.0‰ to +12.0‰ for $\delta^{18}O$ and from -60‰ to -30‰ for δD, assuming a temperature of 400°C. These values fall within the range of magmatic fluids, and $\delta^{18}O$ and δD are distinctly higher than expected for meteoric water or seawater (see Taylor, 1986). A minor component of seawater, connate water, or evolved meteoric water cannot be ruled out. Pyrite and chalcopyrite from gossans, pods and veins within the pyrite and chalcopyrite zones were analyzed for $\delta^{34}S$. Most of the $\delta^{34}S$ data for pyrite and chalcopyrite at Echo Bay are typical for igneous rocks and are consistent with a magmatic source for the sulphur.

Quartz-carbonate veins

Knowledge of the fluids which formed the mineralized (pitchblende, native Ag, Ni-Co arsenide) and unmineralized quartz-carbonate veins in the Echo Bay area is necessary in order to assess the influence of these fluids on the rocks in the area. Estimation of the effects of overprinting during the formation of quartz-carbonate veins is difficult, since fluids responsible for formation of the quartz veins ranged from lighter than, to the same in $\delta^{18}O$ from +9.12‰ to +0.47‰; Changkakoti et al., 1986) as the fluids which formed the MAA zone alteration. However, no large-scale zoning of $\delta^{18}O$ is evident in the wall rocks surrounding the veins. $\delta^{18}O$ and $\delta^{13}C$ of carbonate minerals from unmineralized quartz-carbonate veins in the Echo Bay area are similar to those of carbonate minerals from the mineralized veins.

Summary

All of the Mystery Island intrusive suite have zoned alteration haloes comprised of three zones: 1) an inner zone of albite; 2) an intermediate zone of magnetite-apatite-actinolite; and 3) an outer zone of disseminated sulphides. The zones overlap spatially, and geologic and petrographic evidence show that temporally, the albite zone was formed first, followed by MAA and finally pyrite.

Whole-rock geochemistry of the altered wall rocks above the plutons shows that Na_2O correlates negatively with SiO_2, K_2O, Ba, and Rb for altered andesitic lava flows within the alteration haloes of some of the plutons. Gd, Dy, Be, Yb, Y, Sm, MgO and Na_2O correlate negatively with K_2O; Ba and Rb correlate positively with K_2O. Na and K vary antithetically in the plutons, but other elements do not show regular variations with Na or K. The plutons are Na-metasomattized and K-metasomatized locally.

Whole-rock $\delta^{18}O$ and δD of altered rocks associated with the plutons of the Mystery Island intrusive suite are not zoned, and range from +5.7‰ to +12.3‰ and -70‰ to -57‰ respectively for the plutons; and from +5.3‰ to +11.7‰ and -92‰ to -56‰ respectively for altered andesitic lavas and their cogenetic andesitic porphyries and volcaniclastic rocks. Most $\delta^{18}O$ and δD are higher than +6‰ and -70‰, respectively, consistent with alteration under low water to rock ratios by magmatic fluids. Lower values suggest involvement of a minor component of evolved surface water. Based on stable isotopic data from whole-rock samples and mineral separates, the magnetite-apatite-actinolite deposits formed from fluids of a dominantly magmatic origin, having $\delta^{18}O$ of about +5.0‰ to +12.0‰ and δD of -60‰ to -30‰.

Overall, the formation of magnetite-apatite-actinolite veins, pervasive replacement of rocks by albite and magnetite-apatite-actinolite, and hydrothermal brecciation by magmatic fluids is consistent with geologic and isotopic data. Thus, it is inferred that these deposits formed by replacement in a hydrothermal system dominated by magmatic fluids exsolved by cooling epizonal plutons of the Mystery Island intrusive suite.

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Northwest Territories Energy, Mines and Petroleum Resources

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