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Article abstract

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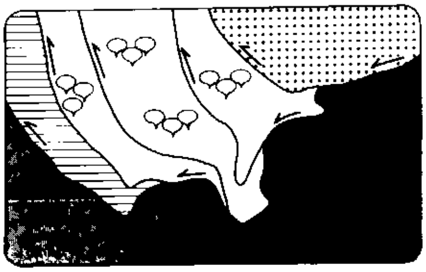

Geochemical constraints on the origin of mafic rocks from the Cape Smith Belt [1]

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Summary
The Trans-Hudson Orogen in Canada represents an early Proterozoic mountain belt similar to Phanerozoic orogens formed by plate tectonic processes. Volcanic rocks in northern Manitoba and Saskatchewan resemble island arc terranes, while continental rift and oceanic volcanic rocks dominate in the Cape Smith Belt in northern Quebec. Pb-Pb whole rock isotopic data for the ophiolitic Watts Group of the Cape Smith Belt yield an age of 1980 ± 30 Ma. Pb-Pb metamorphic (?) ages of 1890 Ma and 1700 Ma were determined for rift-related igneous rocks of the Povungnituk Group and transitional volcanic rocks of the Chukotat Group, respectively. Sm-Nd isotopic compositions are consistent with a magmatic evolution characterized by involvement of lithospheric mantle in Povungnituk Group volcanism, and depleted asthenospheric magma sources for MORB-like Chukotat Group basalts. Sm-Nd isotopic compositions of the Watts Group show the characteristics of both Povungnituk and Chukotat Group basalts, suggesting similar sources.

Introduction
The Cape Smith Belt in northeastern Canada represents a segment of the early Proterozoic Trans-Hudson Orogen that was thrust onto basement of the Superior Province after collision of the Rae and Superior Provinces (Hoffman, 1985, 1988). The belt is presently exposed about 70 to 100 km south of an inferred suture zone (Hoffman, 1985; St-Onge *et al.*, 1988). The Cape Smith Belt can be subdivided into three major igneous units interpreted to reflect magmatism in a continental rift, transitional crust and ocean floor settings (Francis and Hynes, 1979; Baragar and Scoates, 1981; Hynes and Francis, 1982; Francis *et al.*, 1983; St-Onge *et al.*, 1988; St-Onge and Lucas, 1989; Picard, 1986, 1989a,b; Picard and Lamothe, 1989; Picard *et al.*, in prep.). U-Pb zircon geochronology indicates emplacement of the rocks of the Cape Smith Belt between *ca.* 2000 Ma and *ca.* 1900 Ma, and ages for late intrusive tonalites suggest that construction of the thrust belt occurred between *ca.* 1900 Ma and *ca.* 1840 Ma (Parrish, 1989a; St-Onge and Lucas, in press).

This report summarizes the principal results of a Sm-Nd and Pb-Pb whole rock isotopic study of the eastern Cape Smith Belt (Figure 1). The paper will first present the Pb isotopic results, then the Sm-Nd results, and finally a discussion of the tectonic implications.

Pb isotopic results
Povungnituk Group. The Povungnituk Group is interpreted as a continental rift facies, and consists of a lower sedimentary and an upper volcanic section (Hynes and Francis, 1982; St-Onge and Lucas, in press). The volcanic rocks are continental tholeiites with minor alkali basalts and rhyolite (Hynes and Francis, 1982; Gaonac'h *et al.*, 1989). U-Pb zircon dating of a rhyolite from the uppermost Povungnituk Group yields an age of 1959 Ma that can be interpreted as a minimum depositional age (Parrish, 1989a, b - this issue, p. 126-130).

$^{206}Pb/^{204}Pb$ and $^{207}Pb/^{204}Pb$ isotopic compositions of ten mafic samples from lava flows and syn-volcanic sills form a linear trend with a slope of 1900 ± 30 Ma (MSWD = 13). This date is similar to the timing of thermal peak metamorphism at *ca.* 1880 Ma (St-Onge and Lucas, in press; Parrish, 1989a) and may reflect resetting of the U-Pb isotopic system during this event.

Chukotat Group. The Chukotat Group comprises komatiitic basalts and related tholeiitic basalts similar to mid-ocean ridge basalts (MORB) (Francis *et al.*, 1979, 1981). The lithologic evolution of the group is characterized by eruption of early, moderately incompatible element enriched komatiitic basalts and late incompatible element depleted MORB-like basalts. Major and trace element data for the Chukotat Group rock sequence were interpreted to reflect an origin in a transitional continental to oceanic setting (Francis *et al.*, 1983). The U-Pb zircon age of 1918 Ma for a gabbro from a mafic-ultramafic sill, possibly co-magmatic with the oldest rocks of the Chukotat Group (Thibert *et al.*, 1989 - this issue, p. 140-144), suggests that the bulk of the Chukotat Group may have been deposited between *ca.* 1920 Ma and about 1900 Ma (inferred age for start

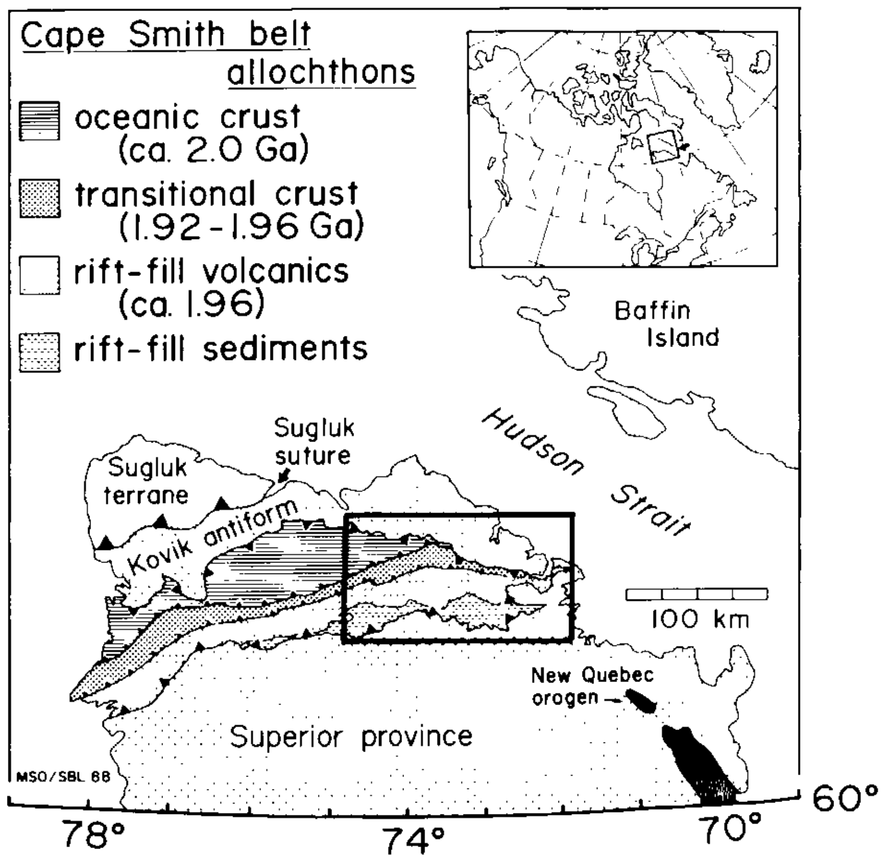

Figure 1 *Location map of the Cape Smith Belt in northeastern Canada (Hoffman, 1985, diagram from St-Onge and Lucas, in press). Shown are the lithotectonic units of the belt, the Superior Province basement and an inferred suture zone (Sugluk Suture) separating the Sugluk terrane from the Kovik antiform. The sampled area is outlined.*

[1] Geological Survey of Canada Contribution No 18689

of deformation, Parrish, 1989a, b - this issue, p. 126-130). This inference awaits corroboration by direct dating of the Chukotat Group basalts.

Pb isotopic compositions of five komatiitic basalts and gabbros yield an age of 1700 ± 200 Ma (MSWD = 0.1), which is much younger than the youngest possible emplacement age of the group. The Pb-Pb whole rock age is similar to a Pb-Pb whole rock age of 1600 ± 100 Ma reported by Brevart *et al.* (1986) and a Re-Os model age of 1740 ± 60 Ma reported by Luck and Allègre (1984). These ages all suggest metamorphic resetting. This interpretation conflicts with the generally lower metamorphic grade observed in the Chukotat Group compared with the Povungnituk and Watts Groups (Bégin, 1989). In fact, the Watts Group yields a Pb-Pb whole rock age similar to its crystallization age (see below).

Watts Group. The sheeted dykes, pillow basalts and mafic-ultramafic layered complexes of the Watts Group show close similarity to Phanerozoic ophiolite sequences (St-Onge *et al.*, 1988, 1989; St-Onge and Lucas, in press). The U-Pb zircon age for a layered gabbro from the Watts Group indicates crystallization at 1998 Ma (Parrish, 1989a, b - this issue, p. 126-130), significantly earlier than the MORB-like rocks of the Chukotat Group. The age of the Watts Group is also much older than the possible minimum age of 1958 Ma for the Povungnituk Group, thus illustrating the complex age relationships in the Cape Smith Belt.

Pb isotopic compositions of mafic-ultramafic cumulates, sheeted dykes, and pillow basalts form an isochron with a slope of 1980 ± 30 Ma (MSWD = 1.4), in excellent agreement with the more precise U-Pb zircon age. Studies of ocean floor basalt indicate that significant redistribution of U and Pb during sea-floor metamorphism is primarily caused by hydrothermal activity at a spreading ridge. Therefore, we interpret the Pb-Pb whole rock age for the Watts Group to be the age of sea-floor metamorphism shortly after eruption. This concurs with the results of Parrish's (1989a) U-Pb zircon study, which revealed secondary growth in Watts Group mafic cumulates at 1977 Ma which was ascribed to sea-floor metamorphism. The contrasting behaviour of the U-Pb system in the Watts, Chukotat and Povungnituk Groups is surprising in light of evidence for a single thermal peak metamorphism at about 1880 Ma (St-Onge and Lucas, in press).

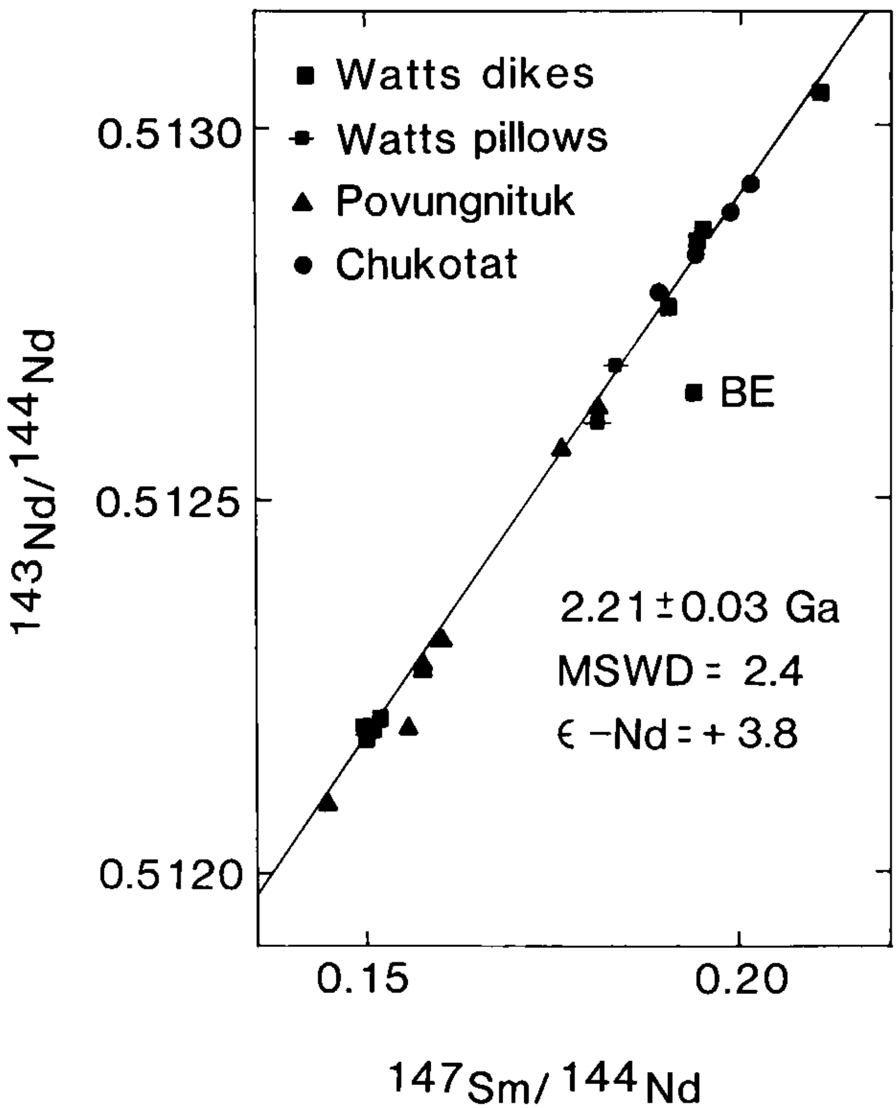

Figure 2 *Sm-Nd isochron diagram for the ca. 1900 Ma to ca. 2000 Ma volcanic rocks of the Cape Smith Belt. All data plot on a common trend with a slope of 2200 Ma interpreted to reflect mixing of lithospheric and asthenospheric magma sources. BE represents the bulk Earth value.*

Sm-Nd isotopic results

A Sm-Nd isochron diagram (Figure 2) for Povungnituk and Chukotat Group basalts, and sheeted dykes and pillow basalts from the Watts Group shows that all analyses plot on a common trend with a slope of about 2200 Ma. This date is significantly older than the inferred depositional age of *ca.* 2000 to 1920 Ma (Parrish, 1989a, b - this issue, p. 126-130) for these sequences. The trend is interpreted to reflect mixing of magmas from (1) the Early Proterozoic LREE-depleted asthenosphere and, (2) incompatible element-enriched and isotopically less evolved lithospheric mantle. The latter reservoir is assumed to represent a portion of depleted late Archean mantle which was locally modified by incompatible element fluids after development of a lithospheric keel. An alternative explanation for the old Sm-Nd isotopic array is magma contamination by older continental crust. This process is common in continental volcanics and probably has also affected some mafic volcanics in the Cape Smith Belt, as is indicated by the presence of sparse rhyolites. However, we consider crustal contamination as an unlikely explanation for the Nd isotopic compositions and light REE-enrichment in Povungnituk Group basalts and sheeted dykes of the Watts Group, because their high MgO values (up to 12%, Francis *et al.*, 1983; Scott *et al.*, 1988, 1989) preclude prolonged storage in the crust and extensive contamination. We note that model initial Pb isotopic compositions argue strongly against magma contamination with upper and lower crust of Archean age, but do not preclude contamination by only slightly older crust.

Povungnituk Group volcanic rocks. Tholeiitic basalts and rare alkali basalts from the Povungnituk Group have geochemical characteristics of continental and intraoceanic basalts (Francis *et al.*, 1983; Gaonac'h *et al.*, 1989). In general, the tholeiitic basalts analyzed in this study show a moderate light REE enrichment, as has also been noted by Francis *et al.*, (1983). However, two samples also indicate presence of basalts with little light REE enrichment (Figure 2). The latter characteristic is common in basalts from the Chukotat and Watts Groups (Figure 2; Francis *et al.*, 1983; Picard and Lamothe, 1989; Picard *et al.*, 1989 - this issue, p. 130-134). The Nd isotopic compositions of the tholeiitic and alkalic

Povungnituk Group basalts correspond to ϵ_{Nd} values (1959 Ma) from 1.8 to 3.7 (Figure 2; Gaonac'h *et al.*, 1989). These values are lower than those for the Early Proterozoic depleted mantle involved in the genesis of the Trans-Hudson Orogen, which has an inferred valued of ϵ_{Nd} + 5 (Chauvel *et al.*, 1986; Hegner *et al.*, in press). The Povungnituk Group ϵ_{Nd} values are consistent with a component from an isotopically less evolved lithospheric mantle reservoir.

Chukotat Group basalts. Sm/Nd in Chukotat Group basalts indicate slightly enriched to depleted light REE patterns (Figure 2). More extensive data sets indicate a magmatic evolution of the Chukotat Group from eruption of early moderately enriched to late MORB-like depleted magma types (Francis *et al.*, 1983; Picard and Lamothe, 1989). ϵ_{Nd} values for 1918 Ma range from +2.7 to +4.5.

Watts Group. Sm/Nd of the sheeted dykes reveal moderately enriched and flat to light REE depleted types, encompassing the range in other rock units of the Cape Smith Belt (Figure 2; Scott *et al.*, 1988, 1989a, b - this issue, p. 144-147). Their initial ϵ_{Nd} values (+1 to +5) overlap the range in other rocks from the Cape Smith Belt, and suggest mixing of similar source material as that involved in the genesis of the continental Povungnituk Group basalts and MORB-like Chukotat Group basalts.

Tectonic implications

The Sm-Nd isotopic evidence in the Cape Smith Belt supports previous models of an origin in an evolving continental to oceanic rift (Hynes and Francis, 1982; Francis *et al.*, 1983). The basalts of the Povungnituk Group have geochemical characteristics consistent with a component from old lithospheric mantle, mixed into magmas derived from ascending asthenosphere. Sm-Nd isotopic data of the Chukotat Group are in agreement with magma generation during on-going stretching of crust and thinning of lithospheric mantle, until asthenosphere represents the sole magma source during late Chukotat Group volcanism (Francis *et al.*, 1983). However, the age and structural data for the Cape Smith Belt are not as easily accommodated as the chemical data in this simple model of a progressing rift. The minimum age limit for Povungnituk Group basalts of 1959 Ma, and the possible maximum limit of 1918 Ma for Chukotat Group basalts (we note that the maximum age of the Chukotat Group basalts is poorly constrained and that deposition up to 1959 Ma is also possible; see Parrish, 1989b - this issue, p. 126-130) suggests a hiatus in magmatism of up to 40 Ma and possibly formation at different locations. Furthermore, the layered gabbros and sheeted dykes of the Watts Group, interpreted as an ophiolite of oceanic origin, are much older than the MORB-like Chukotat Group basalts and also relatively old compared with the inferred upper age of 1959 Ma for the Povungnituk Group (Parrish, 1989a, b - this issue, p. 126-120). In order to solve this discrepancy, investigators proposed a two basin model for the Cape Smith Belt and an origin of the Watts Group in a northern basin (*e.g.*, St-Onge and Lucas, in press; Picard and Lamothe, 1989). However, to date, there is no independant evidence for a northern basin, such as pre-2000 Ma rift volcanism and a crustal block separating it from the southern basin.

A highly interesting feature of the Watts Group is the sheeted dyke complex, indicating formation in an extensional setting. However, the origin of the dyke complex is controversial. The Nd isotopic source characteristics of the sheeted dyke complex and associated cumulate rocks are similar to those involved in both rift and oceanic MORB-like volcanism. The light REE enriched and depleted patterns, in conjunction with low and high initial ϵ_{Nd} values from +1 to +5, are in agreement with an origin in a transitional continental to oceanic setting where both lithospheric and asthenospheric mantle sources are involved. A possible modern example can be found on the eastern margin of the Red Sea rift, where rifting of stretched continental crust facilitated formation of extensive dykes, including locally developed sheeted dykes (up to 4 km wide) and layered cumulates (*e.g.*, Coleman and McGuire, 1988). This occurred about 20 Ma before sea-floor spreading and eruption of incompatible element-depleted MORB in the central Red Sea rift (Coleman and McGuire, 1988). The dyke complexes in the western Arabian Shield are very similar to those of the Watts Group in that they show variable input from lithospheric and asthenospheric sources (Hegner and Pallister, in press). Alternatively, the sheeted dykes of the Watts Group may represent a chemically anomalous ridge segment produced near mantle plumes (Scott *et al.*, 1988, 1989), or a fragment of a chemically anomalous oceanic crust formed at fracture zones. The Nd and Pb isotopic results and other evidence presented in this volume clearly illustrate the need for more geochronological constraints before reliable evolution models can be developed for the Cape Smith Belt.

Acknowledgements

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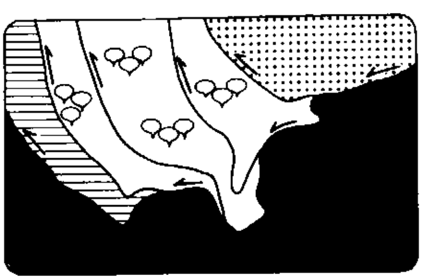

P-T conditions of metamorphism inferred from the metabasites of the Cape Smith Belt, northern Quebec

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Summary

In the Cape Smith Belt, lower greenschist- to middle-amphibolite facies metabasites are exposed in an oblique cross-section displaying over 18 km of structural relief. Mapping of regional mineral isograds has documented the nature and relative timing of the thermal responses to southward directed crustal thickening. In the belt's foreland, hot-side-down metamorphism followed a stage of regular-sequence thrusting. Syn-thermal peak out-of-sequence thrusting was reponsible for local inversion of the isograds in the footwall of the out-of-sequence domain. In the belt's hinterland, post-thermal peak out-of-sequence faulting produced pervasive retrogression to greenschist facies and truncation of the thermal peak isograds.

Résumé

Dans la bande du Cap Smith, des métabasaltes de facies schiste vert à amphibolite moyen, affleurent en section oblique sur plus de 18 km de relief structural. Une cartographie des isogrades à l'échelle régionale a permis d'établir la séquence des événements thermaux associés à un épaississement crustal survenu dans la bande du Cap Smith. Dans l'avant-pays, un gradient métamorphique normal a suivi l'emplacement initial des nappes de charriage. Des chevauchements désordonnés, synchrones à l'apogée thermique, sont responsables d'une inversion locale des isogrades dans le domaine sous-jacent aux failles hors-séries. Dans l'arrière-pays, des failles de chevauchement tardives ont produit un métamorphisme rétrograde au facies schiste vert et un recoupement des structures thermales progrades.

Introduction

The Cape Smith Thrust Belt trends east-west across the northern part of the Ungava Peninsula in northern Québec. The belt was developed during southward-directed thrusting of Proterozoic cover units over the underlying Archean craton of the Superior Province, during the 1900 Ma Trans-Hudson Orogen (St-Onge and Lucas, in press). A well-preserved metamorphic succession, from lower greenschist to middle amphibolite facies (Bégin *et al.*, 1988), is exposed in oblique section over more than 18 km of structural relief (Lucas, in press). Regional mineral isograds were mapped in metabasites, which constitute the principal rock type within the belt. This was followed by a detailed petrological and microprobe study of mafic mineral assemblages sampled at the various structural levels within the belt (Bégin, in prep. a and b). This paper presents the major findings of the regional metamorphic study, with an emphasis on the distinct thermal events recorded by the metabasites of the Cape Smith Belt.

Geologic Setting

Three major tectonostratigraphic suites are recognized in the Cape Smith Belt. From south (foreland) to north (hinterland), these are: (1) the continental rift-fill clastic sediments and tholeiitic basalts of the Povungnituk Group (Francis *et al.*, 1983; Hynes and Francis, 1982; Picard, 1986, 1989); (2) the highly magnesian (komatiitic) and tholeiitic basalts of the Chukotat Group interpreted as transitional crust (Francis *et al.*, 1983; Hynes and Francis, 1982; Picard, 1986, 1989); and (3) the ophiolitic units of the Watts Group (St-Onge *et al.*, 1988). Crustal thickening of the Povungnituk Group rocks took place during early pre-thermal peak regular- (piggyback-) sequence thrusting (Lucas and St-Onge, 1989 - this issue, p. 122-126). In the hinterland, re-imbrication of the earlier thrust stack was accomplished by late out-of-sequence thrusting, active at syn- and post-thermal peak conditions (Lucas and St-Onge, 1989 - this issue, p. 122-126). The thermal consequences of these two thrusting episodes are recorded in the mafic rocks of the belt.

Metamorphic Mineral Zones

Mapping mineral isograds in the Povungnituk Group metabasites documents a normal (hot-side-down) prograde sequence of metamorphic zones (Figure 1). The mineral zones are exposed in oblique cross-section due to post-metamorphic cross-folding of the thrust belt about north-south axes. From high structural levels in the west, to low structural levels in the east, the mineral zones are:

(1) actinolite + albite; (2) hornblende + actinolite + albite; (3) hornblende + actinolite + oligoclase; (4) hornblende + oligoclase; and (5) garnet/clinopyroxene + hornblende + andesine. Epidote, chlorite, calcite, quartz, sphene and ilmenite are