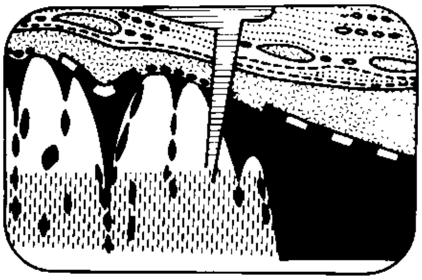

On the Basement of Canadian Greenstone Belts

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Summary

The elucidation of the nature of the crust which originally underlay and delimited Archean volcanic-sedimentary greenstone belts is essential for the understanding of the early Precambrian crustal record - and through it of early terrestrial evolution. Stratigraphic evidence from the Pilbara and Yilgarn cratons in Western Australia is consistent with data from the eastern Transvaal, Rhodesia and southern India, suggesting a fundamental dichotomy of major greenstone sequences. Two assemblages are recognized, including: 1) *early greenstones* which predate, and occur as xenoliths within, the isotopically oldest granites in each craton, and 2) *late greenstones,* which overlie the early greenstones through major paraconformities accompanied by thick chert and acid volcanic units, and may in places overlap the early granites unconformably. The early granites typically consist of tonalite and granodiorite whose geochemical and isotopic parameters indicate derivation from parental basic materials. In this article, the possible relevance of these observations to the question of granite-greenstone relations in the Canadian Precambrian Shield is considered, with particular attention to the Archean crustal foundation of Keewatin (Abitibi) and Yellowknife greenstone belts.

Nature of the Problem

Two broad schools of thought exist regarding the nature of the crust on which Archean greenstones were deposited, namely: 1) a primary simatic crust, possibly analogous to modern oceanic crust or island-arc-trench domains (Bass, 1961; Folinsbee *et al.*, 1968; Green and Baadsgaard, 1971; Ermanovics, 1973; Hubregtse, 1976; Wilson *et al.*, 1974), and 2) an acid igneous-metamorphic sialic basement (Donaldson and Jackson, 1965; Ayres, 1974; McGlynn and Henderson, 1970; Bell, 1971; Frith and Doig, 1975; Henderson, 1975; Baragar and McGlynn, 1976). In the last reference, Baragar and McGlynn assemble an impressive body of evidence which suggests that denudation of granitic rocks has taken place concomitantly with the volcanic evolution of Keewatin (Abitibi) and Yellowknife greenstone sequences. Their evidence and arguments include: 1) observation or inferred existence of basal unconformities; 2) documentation of granite-derived clastic sediments; and 3) the isotopic dating, in places, of about three b.y. old granites. This evidence is used as the basis of an Archean crustal model central to which is proposed existence of a continuous sialic crust prior to the evolution of greenstone belts (Baragar and McGlynn, 1976).

In view of the long time span occupied by the Archean era (defined here as 4.0 to 2.6 b.y. ago), the possibility that significant secular changes have occurred during this time, and differences in the depth of erosion and the crustal level exposed - every terrain represents but a segment in time and space and a synthesis of all available information is required for any model of Archean crustal evolution. Supporters of an original simatic crust point out the abundance of mafic and ultramafic volcanic xenoliths within the isotopically oldest orthogneisses in southwestern Greenland, Labrador, Minnesota, Rhodesia, Swaziland, India and Western Australia (Viljoen and Viljoen, 1969; Anhaeusser, 1973; Glikson, 1971, 1972, 1976a; Naqvi, 1976). In contrast, supporters of the sialic basement hypothesis point out occurrences of granitic clasts within greenstone sequences (Hunter, 1974; E. G. Nisbet, pers. commun., 1976; Baragar and McGlynn, 1976). Of central significance to this problem is the observation of a concomitant development of acid plutonic activity and mafic-ultramafic volcanic activity during at least parts of the Archean era (Fig. 1). Thus, the lithology of the oldest stratigraphic unit, igneous body, xenolith or clastic fragment in any single terrain does not in itself necessarily constitute evidence for the composition of the earliest crust in this region - less of all world-wide. This truism is evident with reference to modern tectonic environments. For example, occurrences of granitic rocks in island arcs (e.g., Gill, 1970) or mid-ocean ridges (Coleman and Peterman, 1975; Engel and Fisher, 1975) are no more in evidence for an underlying sial than are continental flood basalts (which may include low-K tholeiites) for an underlying sima.

Each Archean terrain, however, contains the record of a succession of events which effected a transition from one tectonic environment to another - signifying a *trend* of crustal evolution. These developments may be diachronous (see Fig. 1) - resulting in a spatial and temporal overlap of different stages in different areas. For example, regions in which an advanced stage of cratonization was reached may coexist with adjacent regimes where an older crustal segment has been little modified by younger tectonic and thermal events. The sum-total of the individual evolutionary trends in different parts of the Archean Earth must reflect an overall, though diachronous, trend of crustal development. The central question in this regard is whether greenstone belts developed as: 1) intrasialic depressions; 2) simatic rift zones between diverging sialic plates; or 3) by progressive nucleation of granitic batholiths in ensimatic regimes - the three alternatives are portrayed in Figure 2. It is also possible that two or all three interpretations are applicable to different greenstone belts. Each of these models is

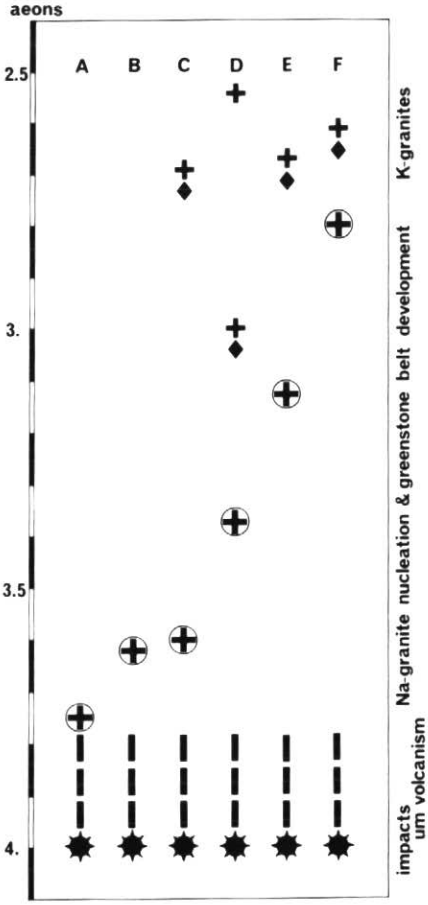

Figure 1

Interpreted distribution of major events in the Archean evolution of southwestern Greenland (A), Nain Province (Labrador) (B), Rhodesian craton (C), Kaapvaal craton (D), Pilbara craton (E) and the Eastern Goldfields Province of the Yilgarn craton (F). Stars - impact events; solid lines - early greenstone crust (ultramafic-mafic volcanics, minor dacites and sediments); circled crosses - tonalite-granodiorite suite; diamonds and arrows - minimum ages of late greenstones; crosses - adamellite and quartz monzonite. Other events - for example, metamorphism, minor igneous activity and sedimentation - are not shown on this diagram.

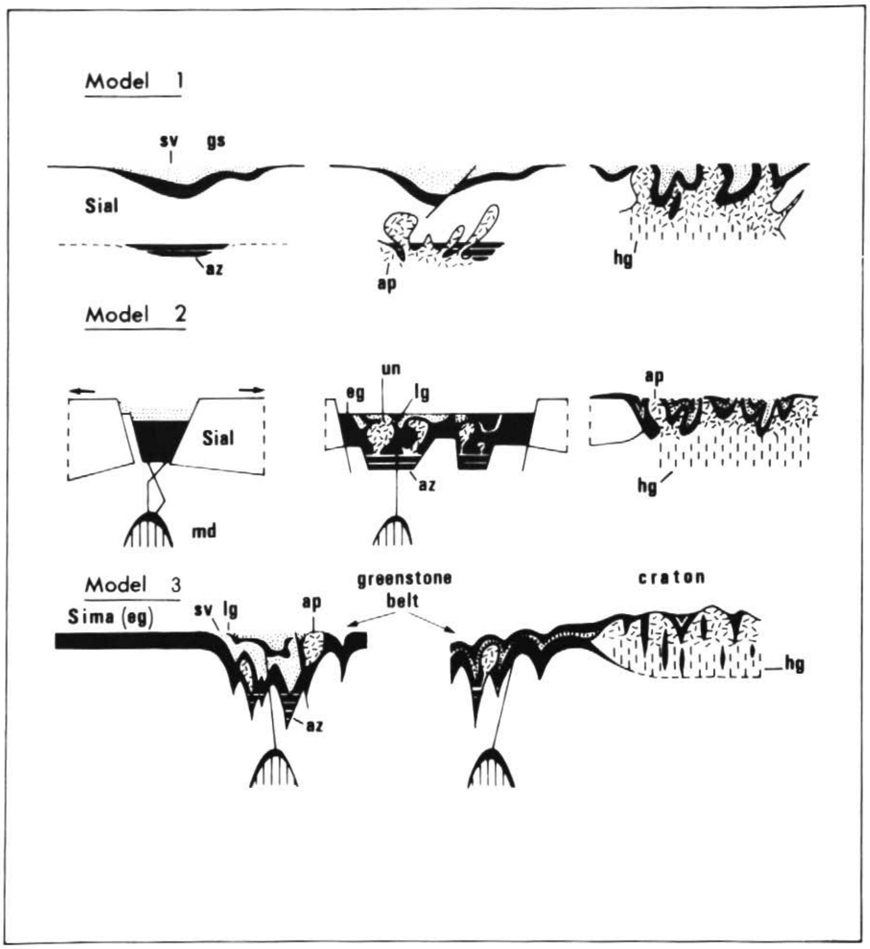

Figure 2

Alternative models of Archean greenstone belt evolution.

Model 1 - *Development of greenstone belts as intrasialic basins - i.e., overlying a granitic-metamorphic basement - accompanied by anatexis in downbuckled infracrustal root zones. Deformation is associated with the ascent of plutons.*

Model 2 - *Development of greenstone belts above oceanic crust formed in a divergent crustal gap of the Red Sea type. Rifting of the basic crust and its partial melting at lower levels results in Na-rich intermediate to acid magma. Concomitant melting in subjacent mantle diapirs beneath the rifted zones results in further mafic-ultramafic volcanic activity. Deformation of the supracrustal rocks results from the ascent of granitic plutons.*

Model 3 - *Development of greenstone belts by rifting and/or downbuckling of a simatic crust, represented by* early greenstone *assemblages. Partial melting in crustal root zones and underlying mantle diapirs results in formation of Na-rich granites and mafic-ultramafic volcanics, respectively - the latter defined as* late greenstones. *The sedimentary units result from erosion of acid volcanic piles and of adjacent cratons - the result of uplift and stabilization of yet older granite-greenstone systems. In this model the sialic crust evolves in stages by the nucleation of Na-rich granites as a progressive and diachronous process.*

Symbols: gs - greenstones; sv - sediments and acid volcanics; ap - acid plutons; hg - high-grade zone; md - mantle diapir; eg - early greenstones; lg - late greenstones; un - unconformity; az - anatectic zone.

consistent with an occurrence of granitic rocks at relatively early stages of greenstone belt evolution. In the following sections, the evidence bearing on these alternatives is examined.

Field Evidence

Arkosic conglomerates occur below greenstones of the Hays River Group (Oxford and Gods Lakes, Manitoba - Campbell *et al.,* 1972), at low stratigraphic levels of the Abitibi Group (Holubec, 1972), in the Miminiska Group (Fort Hope, Ontario) and in other localities (Baragar and McGlynn, 1976). A general upwards increase in the importance of granite-derived sediments suggests progressive uplift and denudation of the granites.

It is less clear, however, whether the exposed granites represented inliers of a continuous sialic basement, as suggested by the first model (Fig. 2) or, alternatively, outcrops of spatially separated sialic plates or nuclei, as suggested by the second and third models, respectively. The two latter models allow for local greenstone-granite unconformities where volcanic activity overlapped peripheral zones of sialic plates or nuclei. Clearly, however, in terms of the second and third models the bulk of the volcanic activity occurred within simatic environments, i.e., above newly formed oceanic crust or older greenstones, respectively, whereas sial basement-greenstone unconformities would be relatively rare. How extensive is the evidence for basal unconformities and granite basement outcrops *underneath* Keewatin (Abitibi) and Yellowknife volcanic sequences? A review suggests that, in most instances, such occurrences have been inferred from:

1) Occurrences of granite-derived sediments and cross-bedded quartzite within, or at the base, of volcanic sequences.
2) Differential distribution of basic dykes - namely, their denser occurrence within granites than within adjacent greenstones. These relations were taken as evidence for an older age of the granites, suggesting that the dykes were feeders of the volcanic flows (e.g., Heywood and Davidson, 1969).
3) The structural complexity of granitic batholiths is sometimes regarded as evidence for their older age relative to less deformed greenstones.
4) An absence in places of contact metamorphic aureoles along granite-greenstone contacts is sometimes regarded as an indication of a relatively younger age of the greenstones.

It is suggested below that none of the above observations is necessarily implicit of a granitic basement. As pointed out before, granite-derived sediments could be derived from neighbouring sialic plates or granitic nuclei. The abundance of dykes within granitic terrains is to a large extent controlled by the highly fractured nature of these rocks, as contrasted to the ductile layered nature of the supracrustal greenstones. The Pilbara granite-greenstone terrain in Western Australia contains clear examples of Proterozoic dykes which intrude granites but fail to transgress granite-greenstone boundaries (Fig. 3). Nor is the third criterion listed above implicit of granite-greenstones age relations: Inherent in the development of composite plutonic bodies is the progressive intrusion of magmatic increments into semi-consolidated granite - a process associated with syn- to late-magmatic deformation, development of folding and gneissosity. Superposed intrabatholithic structures cannot therefore be considered evidence for an older age relative to less-deformed adjacent greenstones. The structure of the latter is clearly determined by the external configuration and mode of emplacement of the batholiths (Anhaeusser *et al.,* 1969; Hickman, 1975), bearing little relation to the internal endemic features of these plutons. An absence of thermal metamorphic aureoles along some granite-greenstone contacts does not in itself suggest unconformable relations be-

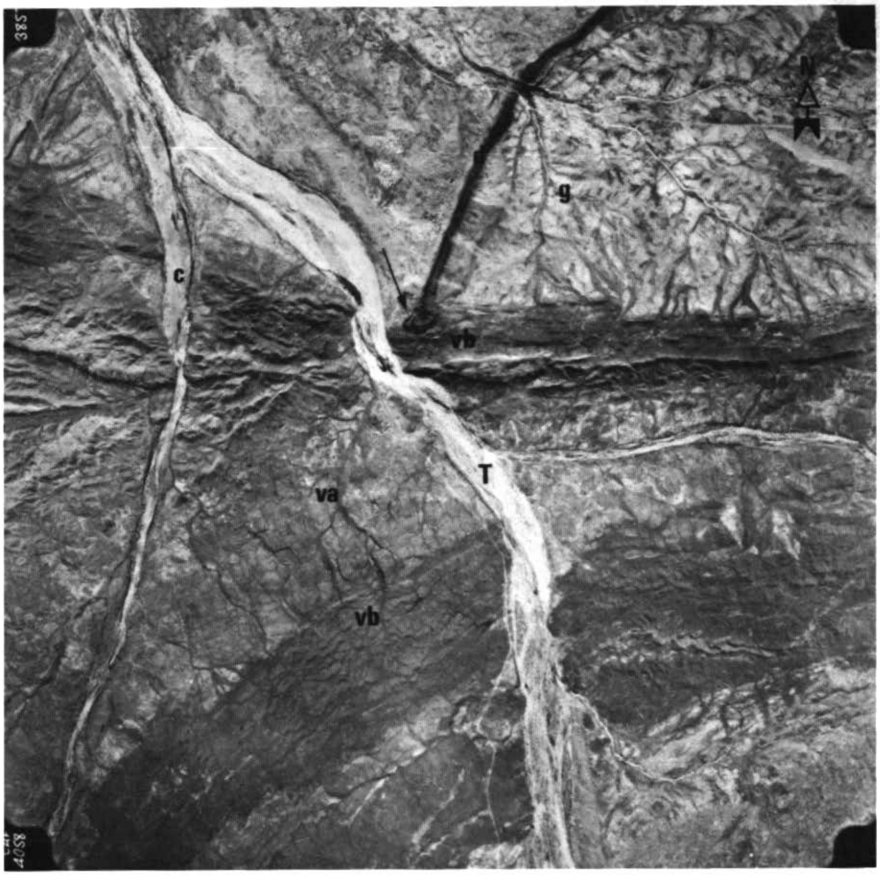

Figure 3
An aerial photograph showing the relations between a basic dyke, granite and greenstones in an area north of Marble Bar, Pilbara region, Western Australia. The area shown is about 19 km across. Symbols: d - dyke; g - granite; vb - basic volcanics; va - acid volcanics; T - Talga River; C - Coongan River. Arrow indicates the area where the dyke thickens and terminates against the greenstones of the Talga-Talga Subgroup (which are intruded by the granite).

cause: 1) the development of contact metamorphism is not an even process and its extent is controlled by availability of heat-transfer media - namely volatiles; and 2) faulting and shearing along granite-greenstone boundary zones (which constitute mechanically weak loci) may dislocate unmetamorphosed wall rock segments opposite granite.

The above reservations do not, of course, preclude an existence of granite-greenstone unconformities. However, they suggest that an extensive occurrence of the latter is yet to be demonstrated. The observed increase in the importance of granitic detritus with higher stratigraphic level is an opposite trend to that expected had the volcanic extrusions progressively sealed from erosion a subsiding granitic substratum. Clearly, upfaulting and emergence of granite-dominated blocks is indicated. The scarcity of clasts of differentiated K-rich granite and absence of granulite pebbles within the greenstone belts are likewise significant, indicating that neither geochemically-evolved sial nor deeply eroded infracrustal root zones were exposed in the vicinity of these troughs. As is pointed out below, the geochemical and isotopic characteristics of the granites are consistent with their origin as ensimatic plutonic nuclei coeval with acid volcanic members of the greenstone belts. The uplift and emergence of such nuclei concomitant with volcanic activity in the greenstone belts are consistent with continuous vertical isostatic adjustments in a tectonically mobile crust, involving upfaulting of light granite-dominated blocks and rifting of denser greenstone-dominated troughs.

Models (2) and (3) (Fig. 2) require that the Keewatin (Abitibi) and Yellowknife greenstones were to a major extent laid over older simatic rocks. The question whether such early greenstones are observed in the Canadian Shield is considered below.

Do Early Greenstones Occur in the Canadian Shield?

In Table I the stratigraphic evidence for an existence of at least two major greenstone assemblages in Western Australia, India, Rhodesia and the Transvaal is summarized. This dichotomy, namely the occurrence of early and late greenstones, is exemplified for parts of the Yilgarn, Pilbara and Rhodesian cratons in Figure 4. The field

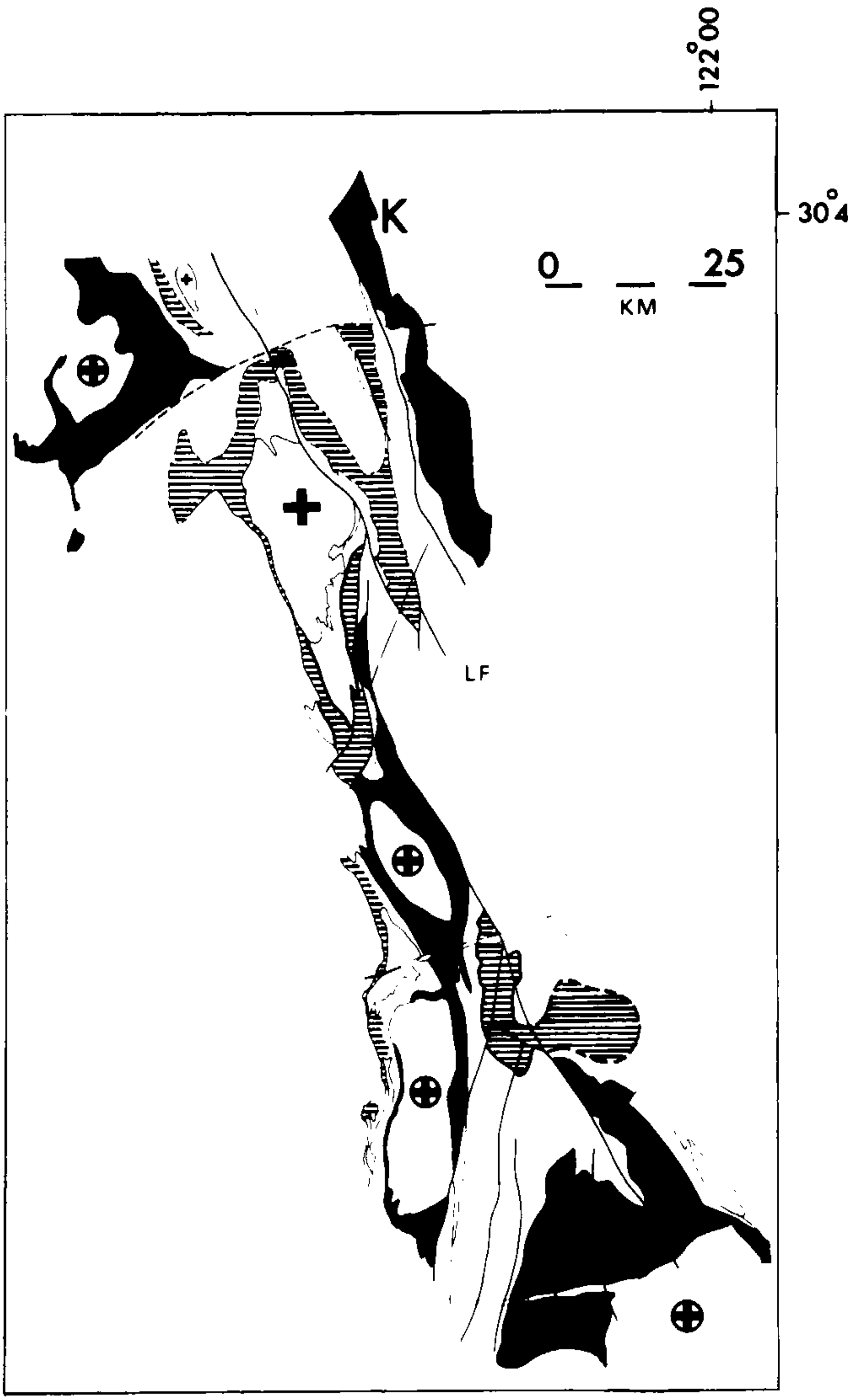

Figure 4
Spatial distribution of major rock units in several Archean granite-greenstone terrains. A - Kalgoorlie-Norseman area, Eastern Goldfields Province, Western Australia (after Gemuts and Theron, 1976). Solid areas - early greenstones (sequences 1-3); blank areas - acid volcanics and sediments (sequences 4-5); striped areas - late greenstones (sequence 6); circled crosses - granodiorite plutons; crosses - adamellites. K - Kalgoorlie.

Table I

Early greenstones, late greenstones, intervening paraconformities and unconformities, and early granites in Western Australian, Indian, South African and Rhodesian Archean terrains. This is not a stratigraphic correlation table. Whereas the early greenstones may be contemporaneous world-wide, the early granites, accompanying unconformities and the late greenstones are known to be diachronous (see Fig. 1).

	Early Greenstones	**Early Granites**	**Para/Un-Conformities**	**Late Greenstones**
Kalgoorlie-Norseman, Yilgarn	sequences 1-3; Coolgardie, Kalgoorlie-Kambalda, Norseman, Widgiemooltha	Coolgardie, Widgiemooltha, Pioneer, Norseman domes	Widgiemooltha Chert Marker	sequence 6. Yilmia-Red Lake, Higginsville
Kurnalpi and Edjudina areas, NE of Kalgoorlie, Yilgarn	Moreland Formation	tonalites in the Edjudina and Carey anticlines	unconformity at base of Mulgabbie Formation	Mulgabbie Formation, Kalpini Formation
Murchison Province, Yilgarn	lower basic sequence			upper basic sequence
eastern Pilbara	Talga-Talga Subgroup	Mount Edgar, Shaw and Corruna Downs granodiorite-adamellite batholiths	Marble Bar Chert	Salgash Subgroup
western Pilbara	Friendly Creek Formation	older granodiorites	Hong Cong Chert	Empress Formation
southern India	Kolar, Holenarispur, Nugihalli belts	tonalitic to granodioritic gneisses of Peninsular Gneiss Complex	local unconformities at base of Dharwar greenstones	Dharwar greenstones: Shimoga, Chituldrug belts
eastern Transvaal	Tjakastad Subgroup (lower Onverwacht Group)	"ancient tonalites" - Kaap Valley, Nelshoogte, Soltzburg plutons	Middle Marker chert and acid volcanics	Geluk Subgroup (upper part of Onverwacht Group)
Rhodesia	Sebakwian Group and equivalents	tonalitic gneisses (Rhodsdale, Mashaba, Selukwe)	unconformity and/or basal conglomerate in Que-Que and Gwelo areas	Bullawayan Group and equivalents

evidence suggests that the early greenstone successions merge continuously with xenolith trains in the isotopically oldest granite and orthogneiss in the respective terrains. Can such dichotomy be recognized in the Canadian Shield? Do all the greenstone tracts in the Superior Province represent segments of one and the same volcanic-sedimentary megacycle, or can some of them represent relicts of older, pre-Keewatin, volcanic sequences?

As facilitated by isotopic data for Archean granites and gneisses of the Laurentian and North Atlantic Shields, at least four supracrustal assemblages can be temporally defined:

1) Volcanic and sedimentary xenoliths within the Amitsoq Gneiss (Isua Series, Aikilia Association), Uivak Gneiss (Upernavik Supracrustals) and Minnesota River Gneiss - all dated as at least 3.8 to 3.6 b.y. old (Moorbath, 1976; Goldich and Hedge, 1974).

2) Enclaves of greenstones in gneisses dated as ca 3.0 b.y. old in the Rice Lake area (Manitoba) (Ermanovics, 1973; Krogh *et al.*, 1973) and in southern parts of the English River gneiss belt (Krogh *et al.*, 1976).

3) Keewatin (Abitibi) and Yellowknife greenstone sequences, which, in the main, postdate the 3.0 b.y. old tonalite and diorite (Baragar and McGlynn, 1976) but are intruded by the ca 2.7 b.y. old (Laurentian) granodiorite and adamellite.

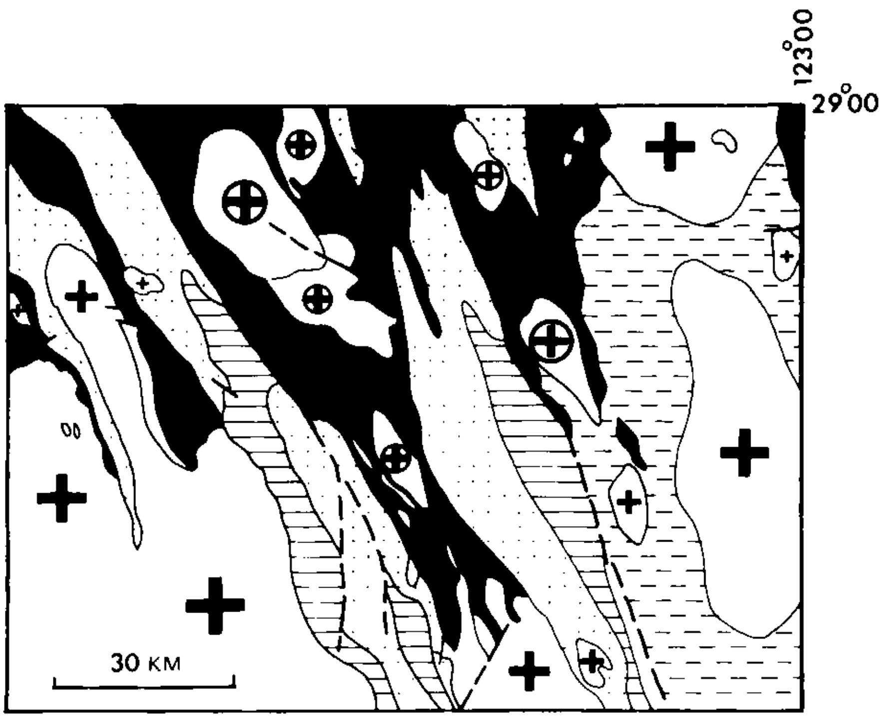

Figure 4 (Cont'd)

B - Edjudina 1:250,000 Sheet area, northeast of Kalgoorlie, Western Australia (after Williams et al., *1977). Solid areas - early greenstones (Moreland Formation); dotted areas - acid volcanics and clastic sediments (Gindalbie Formation); striped areas - acid volcanics and clastic sediments (Gindalbie Formation); striped areas - late greenstones (Mulgabbie Formation); circled crosses - granodiorite, tonalite and adamellite plutons; crosses - adamellite and quartz monzonite; dashed areas - migmatite.*

Figure 4 (Cont'd)

C - Eastern Pilbara craton, northwestern Australia (after Hickman, 1975 and Hickman and Lipple, 1975). Solid areas - early greenstones (Talga-Talga Subgroup); open diamonds - late greenstones (Salgash Subgroup); crosses - composite granodiorite-adamellite batholiths; stippled areas - xenolith-rich zones in the batholiths.

4) Turbidite and conglomerate of the Timiskaming series, accompanied by alkaline volcanic rocks.

Because of difficulties inherent in the correlation of greenstone units across wide tracts of intervening granite and gneiss, as well as problems in determining original (igneous) ages of volcanic rocks, the identification of the stratigraphic assemblages listed above poses many uncertainties. Because greenstone belts constitute isostatically negative crustal zones subjected to recurrent subsidence, in the long term they may collect *several* temporally distinct supracrustal sequences. The corresponding hiatuses between the latter may be represented by thick units of chert or banded iron formation in central parts of the troughs and by angular unconformities toward their margins. Examples of such breaks within greenstone belts in Western Australia, Transvaal and Rhodesia are listed in Table I. However, due to deformation and metamorphism paraconformities are difficult to identify. It follows that, just as composite Archean batholiths often show evidence of more than one temporally distinct event, greenstone depositories may contain a number of sequences - each formed at a different stage and bearing a different temporal relation to the granites. Whereas no older isotopic age limits have as yet been defined for early greenstone units, the age ranges of late greenstones are delimited by crystallization dates of older and younger granites (Table I).

There is no evidence for outcrop of sialic crust contemporaneous with the *early* greenstones, for example, the lower Onverwacht Group, Sebakwian Group, Talga-Talga Subgroup or Coolgardie Greenstones (Table I). Wilson *et al.* (1974) describe similar units from Manitoba, and Hubregtse (1976) regarded the Hays River Group as a segment of early oceanic crust, unconformably underlying an island-arc-like assemblage represented by the Oxford Lake Group. In the Abitibi greenstone belts ultramafic-mafic volcanic sequences and incorporated acid volcanic rocks, volcanogenic and chemical sediments of the Malartic and Kinojevic Groups, may conceivably predate the oldest granites of this terrain. A multiplicity of greenstone sequences in the Canadian Shield is thus a distinct possibility. Possibly, early greenstone units of two, and possibly parts of a third,

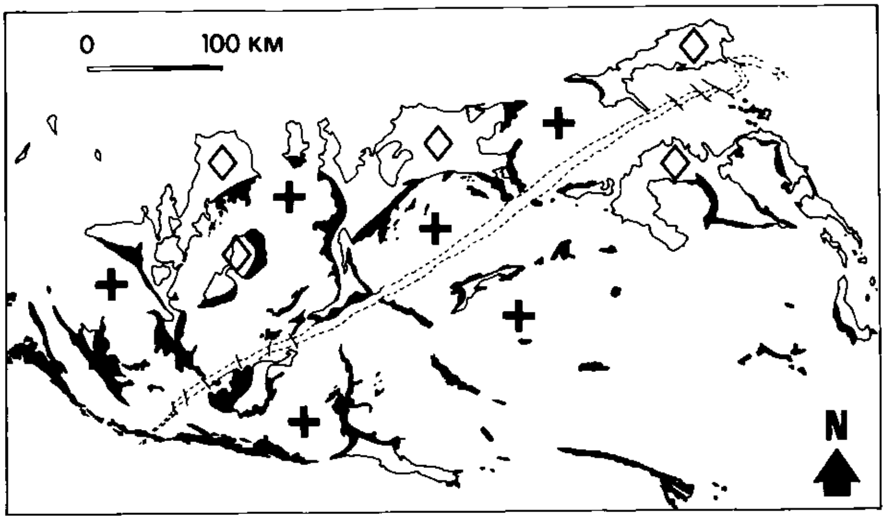

Figure 4 (Cont'd)

D - Rhodesian craton (after Fripp, 1976). Solid areas - Sebakwian Group (early greenstones); diamonds - Bullawayan and Shamvaian Groups (late greenstones and sediments); crosses - composite batholiths: stipple-rimmed area - Great Dyke.

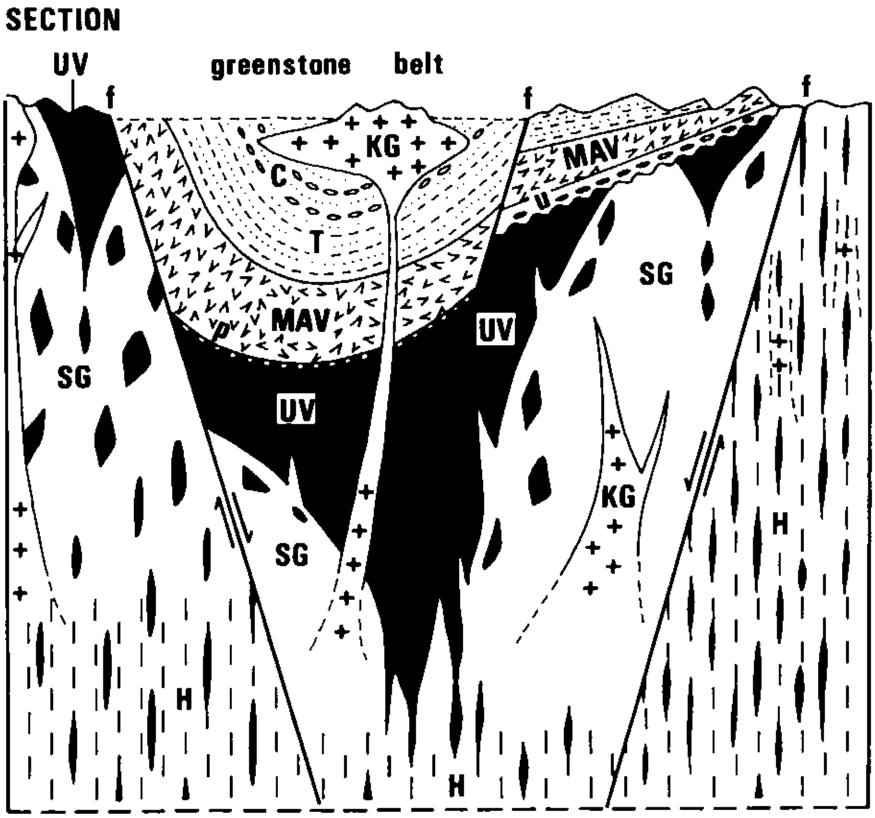

Figure 4 (Cont'd)

E - An illustration of the concept on granite-greenstone relations supported in this paper (after Glikson, 1976). UV - early greenstones; Sg - Na-rich granites; MAV - late greenstones; T - turbidites; C - conglomerate-greywacke assemblage; KG - K-rich granites; H - high-grade root zones of the granite-greenstone system; p - paraconformity (often marked by chemical sediments); u - angular unconformity; f - fault.

greenstone sequences listed above (supracrustal associations 1, 2 and 3) represent segments of an early volcanic crust caught up in diachronous cratonization events, whereas late greenstone units in these regions developed concomitantly with or after the emplacement of granites (Fig. 2). As suggested below, geochemical and isotopic data for both the greenstones and the granites lend strong support to this concept.

Geochemical and Isotopic Constraints

Geochemical investigations of volcanic and plutonic members of Archean granite-greenstone terrains of southern hemisphere shields indicate the following geochemical trends:

1) Tholeiitic basalts of early greenstone assemblages are dominated by low-LIL (large ion lithophile elements) ocean-floor-like types, whereas those of late greenstones include a range between low-LIL and intermediate-LIL island-arc-like types (Glikson, 1971; Hallberg and Glikson, 1977).

2) Archean granites display a secular evolution from Na-rich tonalites and granodiorite-adamellite plutons to adamellite, quartz monzonite and minor syenite (Viljoen and Viljoen, 1969; Anhaeusser, 1973; Hickman and Lipple, 1975; Glikson and Lambert, 1976).

It is significant that the ca 3.8 to 3.6 b.y. old gneisses reported from Greenland, Labrador and Minnesota, and the ca 3.0 b.y. old granites reported from the Slave and Superior Provinces (Frith *et al.*, 1973; Frith and Doig, 1975; Krogh *et al.*, 1973; Krogh *et al.*, 1976) are dominated by Na-rich types - notably tonalite. The approximately 2.7 b.y. old Laurentian plutons appear to consist of granodiorite and to a lesser extent adamellite, whereas the late Algoman plutons are dominated by differentiated varieties. A transition from oceanic-like to island arc-like basic volcanic rocks with time was documented by Hubregtse (1976). It thus appears, tentatively, that similar geochemical trends may apply in the Canadian and southern hemisphere shields.

The generally low LIL levels in Archean tonalites, and to a lesser extent granodiorites, render highly unlikely their derivation by partial melting of similar or more differentiated crustal rocks - because this process should result in the elevation of LIL contents and of ratios such as Rb/Sr and Rb/Ba. In contrast, the tonalites and granodiorites are geochemically and petrogenetically consistent with fractional melting or crystallization of basic rocks or magmas, respectively (Arth and Hanson, 1975; Glikson and Lambert, 1976). Rare Earth element distribution in Archean tonalites in northeastern Minnesota indicates extensive fractionation of garnet and/or amphibole, suggesting basic parental materials (Arth and Hanson, 1975). Furthermore, in analogy with Archean granites in Western Australia, granites of the Superior Province display low initial Sr^{87}/Sr^{86} values (Fig. 5), which place narrow limits on the crustal history of acid precursors of these rocks. Most rocks have R_i values of less than 0.703, implying that any sialic parental materials (minimum Rb/Sr = 0.15) must have been separated from the mantle at most 300 m.y. before the granites cooled, and for most data much shorter time spans are implied. No such limits apply to petrogenetic models according to which tonalitic and granodioritic melts are produced by partial melting of subsiding crustal root zones of the early greenstones, whose low Rb/Sr (less than 0.1) and LIL levels are consistent with their derivation from the mantle in the early Archean and with their role as parental materials for the tonalites. Similar considerations pertain to dacites and rhyolites associated with the greenstone belts.

Baragar and McGlynn (1976) interpreted the Laurentian intrusions in terms of the anatexis and palingenetic mobilization of a downbuckled sialic basement beneath the Keewatin greenstone belts (Fig. 2a). To account for the low R_i values they invoked two arguments; 1) a depletion of sialic infracrustal source regions of the granites in Rb, resulting in a slower growth rate of the Sr^{87}/Sr^{86} value; and 2) istopic exchange of Sr between mantle and crust, or "zone refining", resulting in lowering of the crustal Sr^{87}/Sr^{86} ratio. However, these arguments invoke unknown diffusion processes and also appear to be in conflict with observations in Archean gneiss-granulite terrains - the logical representatives of infracrustal root zones of granite-greenstone systems. Thus, tonalitic gneisses in southwestern Greenland and in Labrador commonly contain K and Rb-rich bands (Bridgewater and Collerson, 1976). Further, these high-grade suites show no evidence of mantle-crust geochemical or isotopic exchange which, if applicable, should have resulted in isotopic age resetting - i.e., younger ages - in relation to granite-greenstone terrains. However, there is no evidence for inverse relations between metamorphic grade and isotopic age in Archean metamorphic terrains. Recently, Bridgewater and Collerson (1976) have questioned the significance of low R_i values, suggesting that they may have been secondarily depressed by Rb metasomatism. These authors have not explained, however, how new isochrons can be produced without isotopic equilibration of Sr, which of necessity would result in a higher R_i value.

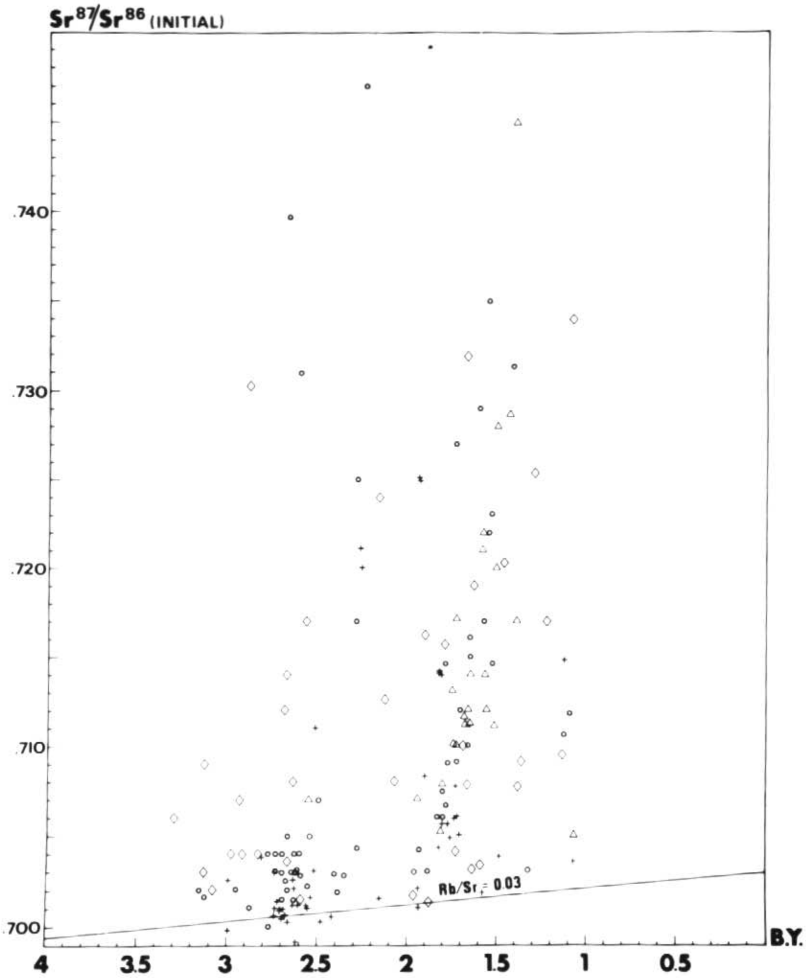

Figure 5

Plots of initial SR^{87}/SR^{86} ratios against corresponding Rb-Sr isochron ages for Archean and early to middle Proterozoic acid igneous rocks from the Australian and Canadian Shields.

Circles - granitic rocks (Australia); crosses - granitic rocks (Canada); triangles - acid volcanic rocks (Australia); diamonds - gneisses (Australia). Sources of data are not listed, to save space. The compilation is only about ¾ complete for Australia and less than ½ complete for Canada.

Significance of the Archean-Proterozioc Contrast

The nature of the Archean crustal record is best appreciated when compared to that of the Proterozoic. Volcanic-sedimentary basins which evolved during the latter era are, in the main, intrasialic - overlying Archean granite-greenstone basement or its recycled and reworked derivatives (Frarey, 1976; Wynne-Edwards, 1976; Kroner, 1977). Proterozoic cratonic basins are dominated by intermediate to high-K tholeiites, high-K rhyolite, cross-bedded quartzite, carbonate sediments and shale, and in the early part of this era - banded ironstones. Proterozoic mobile belts may also contain thick units of greywacke-shale turbidite and calcflysch, and may display the miogeosynclinal-eugeosynclinal pairing characteristic of Alpine orogenic belts (Hoffman, 1973; Dimroth *et al.*, 1970). However, no direct evidence for oceanic crust is apparent, and paleomagnetic data increasingly point out constant relative positions of the cratons within a continuous sialic crust (Piper, 1976; McElhinny and McWilliams, 1977).

The relevance of the above summary to the question of the nature of the pre-Keewatin crust is evident: Had the greenstone belts been underlain by a continuous sialic basement, their tectonic environment could be expected to bear a fundamental similarity to Proterozoic domains. However, in sharp contrast, Archean greenstone belt assemblages are dominated by komatiitic lavas, low-LIL tholeiites, andesite, dacite and Na-rich rhyolite and their hypabyssal equivalents (e.g., Viljoen and Viljoen, 1969; Anhaeusser *et al.*, 1969; Baragar and Goodwin, 1969; Hallberg and Williams, 1972). Thus, whereas Proterozoic suites reflect a combination of mantle fusion and ensialic anatexis, it is suggested that Archean series represent a combination of mantle fusion and ensimatic palingenesis. Most instructive in this regard are the differences between the R_i and LIL element levels and ratios in Archean and Proterozoic acid plutonic rocks (Fig. 5). Whereas Archean tonalites, granodiorites and adamellites in both the Australian and the Canadian Shields have R_i values mostly below 0.704, the Proterozoic ranges are mainly between 0.706-0.717 in Australia and 0.704-0.708 in Canada. The evidence is thus implicit of an addition of new mantle-derived crustal materials during the Archean, and extensive recycling and reworking of the sialic crust during the Proterozoic.

Conclusions

It is suggested that the Archean crustal record reflects progressive and diachronous transformation of simatic into sialic tectonic regimes - a trend represented by field relations in several Archean granite-greenstone terrains, by the secular geochemical evolution of volcanic and plutonic Archean series and by isotopic parameters. The isotopically oldest gneisses contain volcanic and sedimentary xenoliths representing early laterally extensive simatic associations, of which lowermost ultramafic-mafic members of greenstone belts in Western Australia, India, Rhodesia and the Transvaal are the most complete representatives. There is no evidence for an existence of granites during the formation of these assemblages, whose temporal coincidence with major meteorite impact events on the moon (4.1 to 3.8 b.y. ago, Schmitt, 1974) is significant to their origin (Green, 1972; Glikson, 1976b).

The evolution of greenstone belts continued during and after the emplacement and emergence of tonalitic and granodioritic nuclei. The vertical isostatic uprise of granite-dominated blocks between subsiding volcanic troughs resulted in the shedding of granitic detritus, contained in late-stage greenstone sequences with which the Keewatin (Abitibi) volcanic-sedimentary assemblage may be analogous. Principal Keewatin troughs may have been superposed on yet older pre-3.0 b.y. greenstones, whose deformation, downbuckling and partial melting gave rise to tonalites of this age. In agreement with the observation of granite-derived sediments intercalated with Keewatin greenstones, the latter accumulated in troughs delimited by, and in part overlapping, upfaulted granite-dominated blocks. In this concept, the basement of Keewatin greenstone belts was heterogeneous, consisting of the relicts of a yet *older granite-greenstone system.* It is suggested that each stage of evolution of the Canadian Shield has resulted in an overall increase in the crustal granite to greenstones (sial to sima) ratio, as follows:

4.1 to 3.8 b.y. ago - formation of simatic crust through major volcanic events genetically related to meteorite impacts.

3.8 to 3.6 b.y. ago - tonalite nucleation and cratonization in the Greenland-Labrador and Minnesota regions, consequent on the deformation, downbuckling and partial melting of simatic crust in these areas.

About 3.0 b.y. ago - further nucleation of tonalite in several areas of the Canadian Shield, including the Slave, Rice Lake (Manitoba) and Grenville regions.

3.0 to 2.7 b.y. ago - accumulation of Keewatin (Abitibi) and Yellowknife volcanic-sedimentary sequences above the granite-greenstone terrain formed about 3.0 b.y. ago - deposition concentrated above subsiding greenstone basement sectors located between upfaulted granite-dominated blocks.

2.7 to 2.6 b.y. ago - intrusion of Laurentian granodiorites produced by anatexis at the root zones of subsiding greenstone-dominated blocks. Intensive denudation of the granitic blocks accompanied by late-stage alkaline volcanic activity resulted in the formation of Timiskaming series, a cycle completed by the intrusion of post-orogenic Algoman granites.

This model is offered as a combination of concepts extended from observations in the Western Australian shield and impressions from the Canadian literature. I have little or no direct acquaintance with Archean terrains of the Canadian Shield. I am grateful to Drs. W. R. A. Barager and J. C. McGlynn for their encouragement to submit this paper and for their comments and criticism. This paper is published with the permission of the Director, Bureau of Mineral Resources, Geology and Geophysics.

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