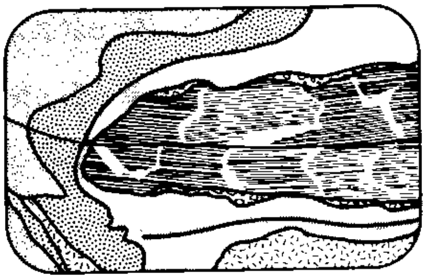

# On the Basement of Canadian Greenstone Belts: Discussion

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## Introduction

Dr. Glikson has ably sketched in the positions of both sides in the debate concerning the nature of the early crust of the earth and has argued persuasively on behalf of the simatists, if we may call them that. Because of our recent contribution to this debate on the opposite side, he has kindly invited us to reply. In the interests of providing a counterbalancing viewpoint we are glad to do so, but we are not convinced that sufficient evidence is yet available to give great confidence to either side.

Our position is based upon observations made in the Canadian Shield and is simply that the volcanics and sediments were emplaced upon a continuous sialic basement. From this beginning a model for the Archean earth can be developed which attempts to reconcile these observations with geochemical theory, but it is purely a working hypothesis subject to change as observations become more detailed.

In this discussion we will review briefly the field observations and the deductions which follow from them, describe the model we favour for the early crust and the evolution of the greenstone belts, and then return to Glikson's paper to deal with specific criticisms of our previous paper.

## Observations and Deductions

1) Age determinations of rocks composing the greenstone belts in the Canadian Shield do not exceed about 2.7 to 2.8 Ga, whereas a number of dates have been obtained from plutonic rocks which exceed 3.0 Ga. The older plutonic rocks are tonalites or granodiorites. An obvious deduction is that a substratum of granodiorites and tonalites existed prior to the formation of the greenstones.

2) The greenstone belts comprise a thick assemblage of volcanic rocks which commonly evolve from a mafic base to a felsic top, but may include more than one such cycle and may be divided further by an unconformity within the total succession. Sediments interlayered with the volcanic rocks contain material of at least partly granitic provenance and are generally more abundant in the upper than in the lower part of the assemblage. Nevertheless, granitic (commonly tonalitic) clasts are found at low stratigraphic levels and have been reported from the lower sequence in belts that are divided by an unconformity. The simplest deduction to be made from these observations would appear to be that a granitic terrane was in place at the time the volcanic rocks were accumulating and sufficiently close as to be able to contribute material to the subsiding volcanic basin.

3) Unconformities between the volcanic assemblage of a greenstone belt and an underlying granitic (generally tonalite or granodiorite) foundation have been observed or interpreted in a number of places in both the Slave and Superior Provinces. Again the obvious deduction is that the greenstones rest upon a granitic basement.

## The Model

Very briefly, the model is as follows: A universal sialic crust evolved at an early stage in earth history at a time when geothermal gradients were high and separation of the LIL elements from the mantle could be expected to be achieved fairly readily. A major part of the material constituting the present continental blocks was contained in this early crust, which would have formed a thin, more or less continuous layer around the earth and been covered by a universal ocean (see also Hargraves, 1976). The greenstone belts represent the products of early volcanism which penetrated the primitive crust and accumulated on its surface. As they thickened, the underlying crust was depressed into regions of higher temperature, resulting in partial or total melting at its base with subsequent rise of the melts to higher levels. Thus the greenstone belts are the loci of families of younger plutons enriched to varying degrees, depending upon the extent of partial melting, in the less refractory minerals. A consequence of the entire process of volcanism, downbuckling, melting, and redistribution of the melt products, would be a thickening of the crust in the region of activity. Adjoining belts of volcanism of contemporaneous or successively younger ages could result in a thickened crust throughout a region of considerable size. Such a region would emerge above sea level as a continental mass and be subject for the first time to the weathering and erosional agencies of the atmosphere. Henceforth, sediments of continental provenance would form an important part of the geological record and deformations would be influenced by the buttressing effect of a stabilized craton. This appears to have occurred in different parts of the earth at different times; in North America it would mark the Archean-Proterozoic boundary.

The attractiveness of this model is that it explains not only the three sets of observations that we have noted above, but also the vertical tectonics that appear to characterize the Archean, the lack of evidence for the existence of a plate tectonics regime, and the scarcity of platformal or continental sediments in the Archean (early Archean in the southern hemisphere). It is also consistent with Veizer and Compston's (1976) observations that the $^{87}$Sr/$^{86}$Sr ratios of carbonate rocks which presumably reflect the Sr ratios of contemporary sea water rise abruptly at the Archean-Proterozoic boundary and continue at a high level to the present time. Until continental masses emerged in volume from beneath sea level the influence of sialic crust on Sr ratios of sea water would be minimal. Finally, it accounts for the remarkable uniformity of basaltic compositions from Archean greenstone belts to present day low-K tholeiites. An example of some averages are compared in Table I (cf. also Moore, 1977, p. 144). Admittedly, Hart (1970) showed that Rb and Cs contents in Archean basalts were considerably

**Table I**

*Comparison of average analyses of basalts through time*
*(Adapted from Table I in Baragar (1972). Data from a variety of sources acknowleged in original references.)*

| | **No. of Analyses** | **$SiO_2$** | **$Al_2O_3$** | **$Fe_2O_3$** | **FeO** | **MgO** | **CaO** | **$Na_2O$** | **$K_2O$** | **$TiO_2$** | **MnO** | **$CO_2$+$H_2O$** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Archean (Greenstone Belts) | 447 | 49.8 | 14.7 | 2.6 | 9.0 | 6.1 | 9.0 | 2.4 | 0.34 | 1.1 | 0.20 | 4.5 |
| Aphebian (Labrador Trough) | 22 | 48.8 | 14.1 | 2.4 | 9.8 | 7.3 | 10.1 | 2.5 | 0.22 | 1.1 | 0.22 | 3.4 |
| Neohelikian (Grenville) | 29 | 48.0 | 14.7 | 1.9 | 10.3 | 8.1 | 9.8 | 3.3 | 0.20 | 1.1 | 0.19 | 3.3 |
| Oceanic Tholeiites | 25 | 49.3 | 16.9 | 2.1 | 6.8 | 7.5 | 11.6 | 2.8 | 0.18 | 1.4 | 0.18 | 1.1 |

higher than in present oceanic basalts and attributed this to their derivation from a less depleted mantle. However, had the mafic lavas of the greenstone belts erupted prior to the extraction of the sialic crust from the mantle, subsequent eruptions would surely have shown effects of this massive depletion of the LIL elements in more respects than simply the lowering of Rb and Cs contents.

## Criticism of the Evidence for an Early Sialic Crust

Let us now examine some of the specific criticisms which Glikson directs at the evidence which we presented in support of our viewpoint, that the greenstone belts were underlain by a sialic crust.

*1) Unconformities.* As pointed out in our paper, unconformities between greenstone belts and sialic basement are rarely so clearly defined as to be conclusive. A refreshing exception is the unconformity recently described by Henderson (1977) at Point Lake, N.W.T., where mafic volcanics and interbedded conglomeratic sediments clearly overlie granitic basement. Dykes which intrude a granitic body but not an adjoining stratified sequence may be an indication of the age relationships, but as pointed out by Glikson, are not compelling evidence. In the case we described at Ross Lake, N.W.T., a mafic dyke swarm intrudes both the Ross Lake granodiorite and the adjoining Yellowknife mafic lavas, but not the conformably overlying Yellowknife sediments. The volcanic-sedimentary sequence faces away from the granodiorite and although the contact itself is not interpretable in terms of either unconformable or intrusive relationships, the volcanics parallel the contact, whereas in places the foliated granodiorite is truncated by it. A conglomeratic lense interbedded locally with the volcanic sequence contains granitic clasts identical to the Ross Lake granodiorites (A. Davidson, pers. commun.). Potassium-rich granites invade both the Ross Lake granodiorite and the dyke swarm and emit swarms of pegmatites which penetrate the volcanic sequence. The obvious interpretation is that the granodiorite represents a pre-greenstone basement and the mafic dykes, which are identical in composition to the volcanics, are feeders to the flows. An alternate explanation would require strong evidence to the contrary.

*2) Type and abundance of granitic detritus within greenstone belts.* The apparent increase upwards in the abundance of granitic detritus in the stratigraphic column of greenstone belts is an interpretation based upon the observations of a number of workers in widely scattered areas of the Superior Province. It was interpreted as indicating upwelling of sialic basement on one or both sides of a subsiding volcanic trough or basin. Glikson suggests that this is the opposite trend to that which might be expected if the granitic substratum were progressively covered by a growing volcanic pile. Clearly the source must be considered to be exterior to the volcanic basin itself. An analogy might be the continental plateau basaltic provinces which commonly interfinger upwards into thick, overlying sequences of sialic sediments apparently washed into the subsiding basin from surrounding positive regions. Examples are the Coppermine River, Keweenawan, and Seal Lake Provinces. In these cases there can be little doubt but that the sialic crust is essentially continuous beneath the volcanic accumulations.

The scarcity of granulite of K-rich clasts embedded with the greenstones is not detrimental to the theory of an underlying sialic crust. Even today the average composition of the Canadian Shield is close to granodiorite (Eade and Fahrig, 1971) and statistically few K-rich clasts could be expected from its degradation. However, this may not be relevant. Prior to the sequence of events which accompanied the eruption of the greenstone belts and led to the thickening and emergence of continental crust, the sialic layer may have been a relatively simple tonalitic shell, perhaps vertically differentiated to some degree but possessing a fairly uniform upper surface.

*3) Low LIL content of early sialic crust and low initial $^{87}SR/^{86}Sr$ ratios of syn- and post-greenstone intrusives.* Since the primitive sialic crust would have originally been derived from the mantle, its LIL content can be expected to be low relative to the partial melts developed from it during and following the eruption of the greenstone volcanics. The low $^{87}Sr/^{86}Sr$ ratios of many of the syn- and post-greenstone intrusions is more difficult to explain. As Glikson has pointed out, if these intrusions were derived from partial melting of the original sialic layer, the initial ratios might be expected to be high if the crust predated this event by more than a few 100 Ma. We do not have an explanation for this beyond those which we have already suggested and which were noted by Glikson. His objection that these are in conflict with observations in Archean gneiss-granulite terranes is difficult to evaluate since we have no way of knowing where such rocks may have been originally positioned in the primitive crust.

*4) Significance of the Archean-Proterozoic contrast.* The contrast between Archean and Proterozoic volcanic-sedimentary deposits enlisted by Glikson as evidence against the existence of sialic crust beneath Archean greenstone belts is essentially the contrast imposed by a stable versus a mobile crust. The thin sialic crust postulated for the early Archean in the model we've described above is not assumed to be stable until after it has buckled and thickened at the time of Archean volcanism. The Circum-Ungava belt of Proterozoic age appears to have been deposited on a sialic basement (Dimroth *et al.*, 1970) but is characterized by low-K basalts and in the Cape Smith segment, by magnesian basalts and komatiites (Schwarz and Fujiwara, 1977; Moore, 1977). These were presumably erupted on a thin, mobile crust, since the belt is highly deformed and is everywhere compressed inward onto the Ungava Craton.

## Commentary

The critical evidence for the early Archean model that Glikson favours is the identification of material belonging to an original simatic crust. Like the identification of original sialic crust in the model we advocate, much depends upon interpretation. The age must be older than that of all sialic material in the same region, but even then the evidence is subject to the uncertainties of incomplete sampling or of remobilization of an earlier sialic crust. In the southern hemisphere where discrete superimposed volcanic assemblages can be recognized and the ages of the earlier sequence are among the oldest known, the theory of a primary simatic crust receives its greatest support. In the Canadian Shield the oldest ages obtained have been from granitoid rather than volcanic rocks and the latter all date as yet within a fairly narrow time span. A volcanic sequence of significantly greater antiquity has not been recognized. Possibly it is represented by mafic inclusions in the early granitoid rocks or it may underlie and be covered by the late Archean greenstone belts, as suggested by Glikson. If so, the hard evidence of its existence has yet to be presented. Until then, we believe the simplest interpretation of the evidence is the best to follow. For the Canadian Shield at least there is good reason to believe that the greenstone belts were emplaced upon a sialic foundation. Whether or not this was part of a primitive sialic crust encompassing the earth is as much a matter of conjecture as is the theory of a primary simatic crust. Both have the advantage of stimulating and directing further investigation into the early history of the earth.

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# Field Conference and Symposium on Nickel Sulfide Deposits and Their Host Rocks

A 9-day field conference sponsored by the Mineralogical Association of Canada, devoted to Ni-sulfide deposits, their setting and host rocks, will be held between 11th and 20th October, 1978. The itinerary will include

1) 2 days in Abitibi belt looking at ultramafic lava flows and related Ni-sulfide deposits
2) 3 days in the Sudbury area including visits to two mines, surface features related to the mineralization and evidence relating to the impact hypothesis
3) 3 days in the Thompson Manitoba nickel belt including visits to two mines and surface features of the belt.

The conference will finish in Toronto where a two-day symposium featuring invited international and North American speakers will be held on 21st and 22nd October, just prior to the joint annual meeting of the Geological Society of America, the Geological Association of Canada and the Mineralogical Association of Canada.

Approximate cost for the Field Conference and Symposium (including travel: Timmins-Sudbury-Thompson-Toronto; hotel accommodation and meals) is $1,000. Registration for Symposium only, $20. Only 40 places are available in the Field Conference. We anticipate that registration will be closed about June, 1978.

For further details, write to:
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