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COMMENT

Foundation of the Sargur Group

A comment on 'Structural studies in the Archaean Sargur and Dharwar supracrustal rocks of the Karnataka craton' by B. Chadwick, M. Ramakrishnan, M. N. Viswanatha and V. Srinivasa Murthy (*Journal of the Geological Society of India*, Vol. 19, pp. 531-549).

The authors are congratulated on their well-documented account on the structure of the Sargur, Holenarsipur and part of Chitradurga greenstone belts—a terrain which furnishes important clues for the nature of the relations between early and late greenstone sequences and between low and high grade Archaean terrains. The classification of tectonic elements and elucidation of their relations allow an insight into the sequence of events in this part of Karnataka. However, some of the inferences made by the authors with regard to the nature of the pre-Sargur Group crust are open to question. While I am not in a position of contributing new data in relation to this terrain, the similarities which it displays with some Western Australian greenstone-granite terrains may render the following observations pertinent.

The authors cite an occurrence of a quartz-vein pebble conglomerate intercalation in the Sargur Group in the Holenarsipur belt (Tattekere Conglomerate) as evidence for a pre-existing sialic foundation, and make references to a possible inclusion of equivalents of such basement in the Peninsular Gneiss (Chadwick *et al.*, 1978, pp. 538 & 543 and Table I). However, while there is much evidence for existence of granitic rocks prior to and during the deposition of the Dharwar Group, as suggested by basal unconformities, granite-pebble conglomerates and cross-bedded quartzites (Srinivasan and Sreenivas, 1972; Radhakrishna, 1975; Pichamuthu, 1976; Radhakrishna and Vasudev, 1977; Naqvi *et al.*, 1978 a), it has been suggested that the Sargur Group (Naqvi *et al.*, 1978 b) and analogous early greenstone sequences elsewhere (Viljoen and Viljoen, 1969; Anhaeusser, 1973; Glikson, 1970, 1972, 1976) represent relics of an early Archaean simatic crust. For this reason, Chadwick *et al's* (1978) suggestion warrants further examination.

The pebble composition of the Tattekere Conglomerate is described as comprising 'vein quartz and local bladed kyanite' (p. 538) (though it is not clear whether the kyanite is of pre-or post-depositional origin), associated with laminated and locally graded kyanite schist and quartzite. A number of alternatives may be inferred from the description, including (1) derivation from quartz veins included in *any* host rocks, i.e. sialic or simatic. It is pertinent to note in this regard that acid volcanic units are commonly associated with early greenstone sequences in several shields (Table 1), and are not uncommonly intruded by siliceous veins; (2) derivation by redeposition of fragmented subautochthonous quartzites or recrystallized cherts. It should be pointed out in this connection that, in my experience, many Archaean quartzites' represent in fact recrystallized cherts, as borne out by the coarse grained texture of siliceous interbands in metamorphosed banded iron formations (Glikson, 1971). Further, unless substantiated by consistent way-up data, the 'cross-bedding' in some of these rocks is sometimes of tectonic origin. Had the quartz pebbles been derived from quartz veins, the question arises as to why are the host rocks of such veins not represented as clasts in the conglomerate. Moreover, even where granite-pebble conglomerates are found, which is not to date the case for early greenstone sequences, they could be derived from isolated uplifted granitic blocks or from allochthonous continental margins, and not necessarily from an underlying sialic substratum. Acid plutonic rocks occur in island arc domains (Gill, 1970) and even as minor components of mid-ocean ridges (Coleman and Peterman, 1975; Engel and Fisher, 1975), generally consisting of tonalite, trondhjemite and oceanic plagiogranite not unlike the Archaean acid igneous rocks.

It is not clear what is the evidence for pre-Sargur phases in the Peninsular Gneiss. It may appear from the authors' reference to a pre-SgD$_1$ deformation phase of the Peninsular Gneiss—an event not recognized in the Sargur Group itself—as if this tectonic element may furnish evidence for a pre-greenstones age of the gneisses.

Table 1 - Interpreted stages and sequences of events in the evolution of granite-greenstone terrains in south Africa, Western Australia and Canada

Stage/phase	Rhodesia	Barberton Mts, eastern Transvaal	Pilbara, Western Australia	Abitibi Belt, Canada
adamellites, granites and minor tonalites	Chilimanzi, Zimbabwe and Fort Victoria porphyritic granites. Sesombi and Somabula tonalites (2.7-2.6 b.y.)	Nelspruit migmatite, Lochiel granite (ca. 3 b.y.)	post-tectonic adamellites (2.7-2.6 b.y.)	post tectonic syenites and granites (ca. 2.6-2.5 b.y.)
molasse-type stage turbidite stage	))Shamvaian)Group))	Moodies Group Fig Tree Group	))Upper part of Gorge)Creek Group, Mosquito)Creek Group)	)Timiskaming turbid-)ites and conglomer-)ates (+alkaline)volcanics)
late greenstones (greenstone belts)	Bulawayan Group (2.8-2.7 b.y.)	Geluk Subgroup (pre-3 b.y., post 3.37 b.y.)	Salgash Subgroup (3.0-2.7 b.y.)	Blake River Group (2.7-2.6 b.y.)
hiatuses (unconformities and paraconformities)	granite pebble-bearing conglomerate west of Que Que. Paraconformity in the Midlands belt NW of Gwelo	Middle Marker (ca. 3.37 b.y.)	Marble Bar Chert, Hong Cong Chert (3.5-3.4 b.y.). Duffer Formation (dacite-rhyolite agglomerate) 3.45 b.y.	chert and banded iron formations (e.g. Adams Mine)
tonalite-trondhyemite-granodiorite nuclei	tonalitic gneisses (Mashaba, Shabani, Belingwe, Selukwe) (3.6-3.4 b.y.)	"Ancient Tonalites" (3.4-3.2 b.y.)	trondhyerites, granodiorites & qz monzonites (ca. 3.4-3.3 b.y.)	granodiorites and tonalites (c.a. 3.0 b.y.)
early greenstone crust	Sebakwian Group and equivalents (pre-3.6 b.y.)	Tjakastad Subgroup (pre 3.5 b.y.)	Talga Subgroup (pre 3.5 b.y.)	Malartic Group and Kinojevic Group

Some authors use the complex multiphase deformation of gneisses in relation to the simpler ductile deformation of associated greenstones as evidence for a younger age of the latter (Archibald *et al.*, 1978). However, whereas fabrics of any single tectonic domain usefully help to determine relative sequences of events, tectonic-time correlations between rheologically contrasted granite and greenstone domains are fraught with uncertainties which arise from the abundance of endemic late-magmatic deformation elements within the granitic batholiths. The difficulties in utilizing structure in relation to tectonic events is correctly recognized by Chadwick *et al.*, (1978) in connection with the comparative study of Sargur Group and Dharwar Group foliations and lineations. It should be pointed out that, once a penetrative tectonic grain is established, subsequent dislocations would preferentially utilize and reactivate older fabric and discontinuities. For this reason, the similarities between the SgD$_{1-3}$ and DhD$_{1-3}$ deformation sequences in the Sargur and Dharwar Groups, respectively, do not necessarily suggest their coeval deformation, an interpretation supported by the metamorphic discontinuities between these Groups as documented by the authors in the Holenarsipur and Chitradurga belts. As suggested by the dominantly parallel orientation of the greenstone belts, the primary structural grain has been controlled by regional to shield-wide stress fields. However, *in detail* the structures are closely dictated by the oval outlines of individual granitic domes, resulting in locally arcuate greenstone belts as in the classic 'gregarious batholith' patterns in Rhodesia and the Pilbara craton (Macgregor, 1951; Hickman, 1975). The vertical tectonics associated with the diapiric uprise of the domal plutons exert the major tectonic and thermal controls on the invaded supracrustal rocks, as demonstrated by their essential structural concordance, the parallel marginal fabrics and the decrease in metamorphic grade of the supracrustals away from the intrusive contacts. The consanguinity of the plutonic, metamorphic and tectonic features of the granite-greenstone terrain is well illustrated by the data of Chadwick *et al.*, (1978), although the role of vertical intrusive and tectonic movements is somewhat underplayed (p. 547).

The difficulties inherent in structure-time correlations require that a search for possible pre-Sargur Group sialic components in the Peninsular Gneiss should involve the application of advanced isotopic methods, including U-Pb and Sm-Nd, to the study of *both* the gneisses and the greenstones. Too often the intrinsic difficulties in dating basic rocks relative to gneisses yield an apparent impression as if the latter are older. Whereas it is possible that pre- or syn-Sargur Group sialic nuclei existed, geochemical considerations argue against an extensive acid sub-stratum beneath the original volcanic successions. Had such basement occurred, its depression and anatexis beneath the subsiding greenstone troughs should inevitably have resulted in extensive generation of eutectic LIL (large-ion-lithophile) element-enriched adamellite-granite magmas. However, this class of igneous intrusions, which dominates late Archaean and Proterozoic ensialic domains and is characterized by high initial $^{87}Sr/^{86}Sr$ values and negative Eu anomalies (signifying plagioclase fractionation), is uncommon among early Archaean gneisses. The Peninsular Gneiss is dominated by sodic acid igneous rock types, as shown by the geochemical data collated by NGRI (1977) and also reflected by the composition of derived clastic sediments and conglomerates in the Dharwar Group (Naqvi *et al.*, 1978a). The Archaean tonalites and trondhjemites tend to have strongly depleted LIL element levels and strongly fractionated REE patterns—the latter arising from marked depletion in the heavy REE consequent on equilibration of the magmas with amphibole and/or garnet. The implied extensive occurrence of the latter phases provides strong evidence for derivation of the magmas from a basic source. It is unlikely that tonalitic magmas were derived by ensialic anatexis, as they can only form on the eutectic under ca 10 kb H_2O pressures—an unrealistic condition in the crust where dehydration occurs under significantly lower pressures and temperatures. The products of low degrees of ensialic anatexis would segregate and migrate upwards, leaving behind refractory residues of intermediate composition. On the other hand, the generation of tonalite/trondhjemite melts is consistent with ca 20-30 per cent fusion of basic greenstone-type materials (Green and Ringwood, 1968).

To date only minimum isotopic age limits were reported for the Sargur Group (pre-2.9 b.y.) and analogous early greenstones elsewhere (Table I). The common conformity between these ages—which in the main reflect metamorphic events—and ages of the intrusive gneisses suggest a consanguinity between the plutonic and the metamorphic events. No basal stratigraphic contacts were observed anywhere below the early greenstones, and references to the 'base' of these successions (i.e., Chadwick *et al.*, 1978, p. 543) obviously refer to their intrusive boundaries. The authors refer to the contact between the Amitsoq Gneiss and the Malene Supracrustals in southwest Greenland as a possible example for basement-cover relations, although no details are given in support of this suggestion. In so far as that is the case, the Malene Supracrustals (ca 3.0 b.y. old?) and the Isua Supracrustals (pre-3.8 b.y. old) could represent equivalents of late greenstones and early greenstones. However, in view of the extensive obliteration of primary stratigraphic relations in high-grade terrains, perhaps more instructive comparisons can be made between the Karnataka, Western Australian and Southern African granite-greenstone terrains (Table I). There is no intrinsic evidence in the early greenstone successions in these regions for pre-existing sial in their immediate vicinity, i.e., to date no granitic detritus has been identified in the Tjakastad Subgroup (lower Onverwacht Group) (pre-3.5 b.y.), the Sebakwian Group (pre-3.6 b.y.) or the Talga Subgroup (pre-3.5 b.y.), nor has such detritus been found in the Isua enclave (pre-3.8 b.y.) or Nulliak assemblage (pre-3.6 b.y.) of the Greenland-Labrador craton. The importance of komatiites and low-LIL tholeiites in the early greenstone sequences as compared to younger greenstone belts is significant: Because granite-greenstone systems display the characteristic hallmarks of two-stage mantle melting processes (Ringwood and Green, 1967), it is no more necessary for a sialic basement to have existed than it is required, for example, beneath modern arc-trench domains. Reconstructions of the original extension of early greenstone sequences from the distribution of derived xenolith screens in the Pilbara (Hickman, 1975) and South Africa-Rhodesia (Anhaeusser, 1978) demonstrate that these formed shield-wide layers-conceivably the relics of an early Archaean ultramafic-mafic volcanic crust (Glikson, 1972; 1976; Glikson and Lambert, 1976). The possible temporal juxtaposition of this crust with the 4.0-3.8 b.y. period during which the terrestrial planets are thought to have been subjected to major meteorite bombardment (Schmitt, 1972; Green, 1972) is of intriguing genetic significance in this regard.

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AUTHORS' REPLY

We are most grateful to Dr. Glikson for his comments on our paper (Chadwick *et al.*, 1978). Our suggestion that some parts of the Sargur rocks may have been deposited on a sialic foundation is based on two principal lines of evidence, namely, (i) the composition of pebbles in the Tattekere conglomerate and (ii) tectonic relations of amphibolite dykes in the Motha section.

It is clear that many of the coarse-grained quartz lenticles in the Tattekere conglomerate are small augen or discontinuous thin veins that have been generated during metamorphic recrystallisation in the plane of the S fabric parallel to bedding. Such lenticles appear to have led some authors to suggest that the deposit is autoclastic (Sreenivas and Srinivasan, 1968; Ziauddin, 1975; Naqvi *et al.*, 1978a). It is, however, equally evident that some of the lenticles comprise (a) dark or pale grey, fine-grained quartzite with fine-scale banding, (b) grey or black, coarse to fine-grained quartz-schorlite rock and (c) vein quartz of variable grain size. These lenticles with different composition and grain size occur together in certain layers, but they are not compositionally continuous along the strike as they would be if they had originated as boudiné chert seams, quartz veins or quartz-schorlite veins concordant with the S fabric. These features led us to interpret the deposit as a conglomerate. The fact that host rocks to the quartz and quartz-schorlite veins are not present as clasts in the conglomerate is readily accounted for by the very nature of oligomict conglomerates which are mature to supermature residues in which only resistant material such as quartz veins survive prolonged denudation. It is significant to note here that the Dhawar basal conglomerates deposited directly on Peninsular Gneiss in the Bababudan and Neralakatte areas consist almost entirely of vein quartz: only very rarely do they contain pebbles of Sargur fuchsite quartzite. We are glad that Dr. Glikson is willing to concede 'the existence of granitic rocks prior to and during the deposition of the Dharwar Group', the basal conglomerates of which have a pebble composition similar to that of the Tattekere conglomerate.

According to Dr. Glikson's experience many of the Archaean 'quartzities' are recrystallised cherts, but the presence of detrital quartzites is equally well documented in the Archaean (Hunter, 1974; Sutton, 1976; Ramakrishnan *et al.*, 1976), although the evidence comes mostly from younger greenstone belts. A preliminary study of the quartzites of the Sargur Group from Ghatti Hosahalli and Banavara has indicated the presence of rounded zircons suggesting a detrital origin (T. V. Viswanathan, pers. comm., 1978). Recently, a banded chromite-fuchsite quartzite of the Sargur Group containing a detrital heavy mineral suite of chromite, magnetite, ilmenite, tourmaline, rutile and zircon has been identified from Banavara (Ramiengar *et al.*, 1978). Such a heavy mineral suite is found in modern beach placers in southwest India. An analogous occurrence of chromite deposited along the trough beds of a cross-bedded quartzite in the Singhbhum craton (Banerjee, 1972, p. 38) gives further support to the view of a detrital origin of the Sargur quartzites. We agree with Dr. Glikson that there are ambiguities in interpreting the cross laminated structures in the Sargur quartzites which are generally intensely flattened. This is in strong contrast to the unambiguous and consistent way-up data presented by the Dharwar quartzites (Pichamuthu, 1974; Ramakrishnan *et al.*, 1976). We further clarify that the grading reported in the larger lenses and in a quartzite-kyanite schist (Chadwick *et al.*, 1978, p. 538) is ambiguous, and the kyanite in the Tattekere conglomerate is post-depositional. Contrary to the suggestion that these may be acid volcanic rocks, we believe that they could more probably be clastic sediments intimately admixed with conglomerate beds. We wish to emphasise that we do not exclude the possibility that some of the Sargur quartzites may have originated as cherts.

Our second reason for suggesting a sialic foundation to some of the Sargur rocks is that of tectonic relations of amphibolite dykes in the Motha section. Because the dykes are deformed by SgD1, they are presumed to be older than SgD1 and therefore require a host older than SgD1. It follows that the dykes may have been intruded either into gneisses older than the adjacent Sargur rocks, or into gneisses that intruded the Sargur rocks, the dyke injection taking place before SgD1. The interpretation remains ambiguous, but the possibility remains that parts of the Peninsular Gneiss may be older than the Sargur rocks (see also Janardhan *et al.*, 1978). We are therefore entirely in agreement with Glikson that there is an urgent need for geochronological and geochemical studies of Sargur rocks and Peninsular Gneiss. Until such data are available the origin of the Sargur rocks as relics of early Archaean simatic crust remains as speculation.

We agree with Glikson that fabric similarities between SgD1-3 and DhD1-3 do not necessarily imply that they are coeval phases of deformation. We now have unambiguous evidence, based on recent detailed mapping and to be published in due course, that certain Sg phases are older than Dh phases. We should like to emphasise, in Glikson's terms, that so far there is no unambiguous evidence in Karnataka that 'in detail the structures are clearly dictated by outlines of individual granitic domes' or 'diapiric uprise of domal plutons exert the major tectonic and thermal controls on the invaded supracrustal rocks'. Detailed mapping may show that these speculations are correct, but until data are available we prefer to deliberately underplay 'the role of vertical intrusive and tectonic movements'. The Peninsular Gneiss foundation to the Dharwar supracrustal rocks shows variably intense tectonic reactivation, perhaps in part as mantled gneiss domes, in the formation of Dh structures in the Dharwar rocks. In some intances the Peninsular Gneiss foundation may be relatively unaffected. These variations indicate a marked regional heterogeneity in the tectonometamorphic reaction of the Peninsular Gneiss during formation of the irregular basins and linear belts of Dharwar supracrustal rocks in Karnataka. In drawing comparisons with other Archaean areas, Glikson should be aware that tectonic events in West Greenland (where Chadwick and Ramakrishnan have lengthy field experience) include an important period of thrusting before nappe deformation that was closely associated with injection of Nûk gneisses ca. 2800 myr. The nappes were deformed into upright domes and basins either by continued movements related to the injection of Nûk gneisses or by intraplate shearing that concentrated strain in steep linear belts. Full details of the geometry, fabrics and possible mechanisms, together with evidence of the possible Malene-Amîtsoq cover-basement association, will be published shortly (Chadwick and Nutman, in press). We do not consider that the Amîtsoq basement was widespread, most of the Malene rocks (age unknown, but between 3750-2800 myr) probably having formed on a simatic foundation. We suggest that relations between Sargur supracrustal rocks and possible older tonalitic-granitic gneisses, so far unidentified isotopically, within the Peninsular Gneiss of Karnataka may have been similar to those between the Malene supracrustal rocks and Amîtsoq gneisses in West Greenland.

Dr. Glikson has raised the point of the 'base' of early greenstone successions. The Sargur Group is represented as highly migmatised supracrustal relics which were involved in a major invasion of 'juvenile' tonalitic-granitic rocks around 3000 myr (S. Moorbath, pers. comm., 1978; based on samples from the Chikmagalur-Chitradurga area). The Sargur rocks are metamorphosed in middle to upper amphibolite facies, with no lower grades like those of post-3000 myr greenstone belts being present. Because of intense deformation and high grade metamorphism, the Sargur lithologies generally lack way-up criteria to determine the order of superposition. As we emphasised in our paper (Chadwick *et al.*, 1978), the base of the Sargur Group is unknown in the linear belts of Karnataka. There is no positive evidence to support the statements by Naqvi (1976), Glikson (1976) and, more recently, Naqvi *et al.*, (1978b) that the Sargur Group starts with a mafic-ultramafic base. Dr. Glikson is correct in his reference to the boundaries of the Sargur belts being intrusive, i.e. the adjacent Peninsular Gneiss is younger, but some boundaries may be tectonic. While there is an abundance of serpentinised ultramafic rocks in these belts, there are only rare instances of possible spinifex-textured komatiites (Viswanatha *et al.*, 1977). It is true that there are shield-wide xenolithic screens of mafic-ultramafic rocks within the Peninsular Gneiss, but it has yet to be established that all of them form part of the Sargur Group or represent relics of an early Archaean ultramafic volcanic crust (see Ramakrishnan *et al.*, 1976).

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