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Origin of compositional layering and mechanism of crustal thickening in the high-grade gneiss terrain of Sri Lanka

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ABSTRACT

The Highland Complex of Sri Lanka comprises a ~7 km thick succession of banded para- and orthogneisses, at granulite-grade or partly retrograded. We interpret this Complex as a tectonostratigraphic unit in which no primary stratigraphy is preserved. This succession, with a probable depositional age of ~2 Ga, evolved from a rift basin into a foredeep and then into a fold-and-thrust belt prior to severe flattening and transport into the lower crust during the final stages of collision some 550-620 Ma ago. Granitoid rocks were emplaced into the supra-crustal sequence at various stages of the tectonic evolution between ~1950 and ~670 Ma ago, and the original intrusive contacts became obscured or severely modified during progressive non-coaxial ductile deformation. Structures that predate the presently observed layering are preserved in rootless isoclinal folds, boudins and microstructures, and in deformed pre-granulite metamorphic minerals preserved in garnet porphyroblasts. The evolution of the Highland Complex is similar to that of other Precambrian granulite terrains, notably parts of the Grenville Province of Canada, and probably resulted from collisional tectonics, during which the original supracrustal assemblage was detached from its Archaean to Palaeoproterozoic basement. The paucity of structures reflecting the early deformational history is due to severe flattening and ductile deformation during predominantly non-coaxial deformation when the Highland rocks were transported into the lower crust.

1. Introduction

The basement rocks of central and western Sri Lanka consist of a thick package of intensely deformed supracrustal and metaplutonic rocks that have experienced high-grade metamorphism at ~535-600 Ma ago (Hölzl et al., 1994). They are now preserved as granulitic gneisses, charnockites and their retrograded equivalents in the so-called Highland-, Wanni and Kadugannawa Complexes (Kröner et al., 1991; Cooray, 1994; see Fig. 1).

The supracrustal rocks of the Highland Complex (HC) consist of shallow-water metasediments (metaquartzite, quartzo-feldspathic gneiss derived from meta-arkose and impure sandstone, pelitic gneiss derived from greywacke and shale, marble derived from limestone and/or dolomite) and a subordinate bimodal volcanic suite (Pohl and Emmermann, 1991). Geochronological and geochemical data suggest that these rocks were deposited about 2000 Ma ago (Kröner et al., 1987; Hölzl et al., 1991), probably along a rifted continental margin (Pohl and Emmermann, 1991) that evolved into a stable shelf region (Dissanayake and Munasinghe, 1984). Intrusive granitoid rocks were emplaced between ~1950 and ~670 Ma ago (Kröner et al., 1987; Baur et al., 1991; Hölzl et al., 1991, 1994) and include both S- and I-types.

The prevailing structural element in virtually all rocks of the Highland and Wanni Complexes is a pervasive banding (S_t = trans-

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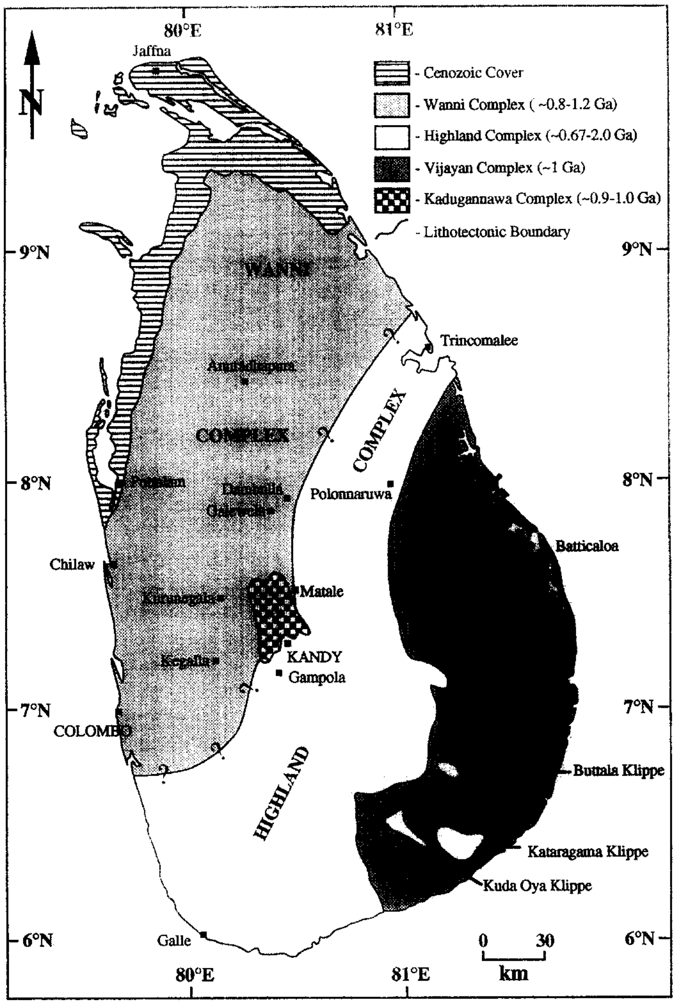

Fig. 1. Simplified geological map of Sri Lanka showing major tectonostratigraphic units and localities mentioned in the text. Modified from Kröner et al. (1991).

posed foliation **), defined by compositional layering at scales between several mm to several tens of metres. This layering is generally flat or dips gently to the west, but has been folded into broad upright folds in the central part of Sri Lanka (Berger and Jayasinghe, 1976; Sandiford et al., 1988; Kriegsman, 1991, 1994; Voll and Kleinschrodt, 1991a; Kleinschrodt et al., 1991). Approaching the eastern contact with the Vijayan Complex, these folds become tighter and more inclined (Kleinschrodt, 1994). Near the western margin of the HC and in the Wanni Complex folding and transposition of this layering is less severe than elsewhere, and this permits recognition of earlier structural elements (Kehelpannala, 1991; Kriegsman, 1991).

The nature and origin of this layering are intimately linked to the early structural evolution of the Sri Lankan granulites and is still controversial. Voll and Kleinschrodt (1991a, b) suggest that S_t represents highly deformed

**In using S_t we follow Tobisch and Paterson (1988) who describe multicomponent foliations in areas of progressive deformation.

sedimentary bedding in the supracrustal rocks, where the original stratigraphy has been preserved. These authors further propose bedding-parallel intrusion of granitoids and basic magmas as the mechanism for crustal thickening. Kröner (1986, 1991), Kehelpannala (1991), Kröner et al. (1991) and Kriegsman (1991, 1994), however, postulate that the original stratigraphy of the supracrustal succession(s) has been destroyed by early isoclinal folding, thrusting, and complete transposition of primary structures.

The origin and evolution of compositional layering in high-grade terrains has received considerable attention in recent years (for summary see Passchier et al., 1990) and is central to an understanding of lower crustal processes (e.g. James and Black, 1981). It is therefore of some general interest to discuss the Sri Lankan situation in detail to see which mechanisms can account for the structures now observed. It also has implications for the tectonic setting of the Sri Lankan high-grade terrain.

2. Origin of compositional layering-field evidence

Much of the early structural history has been obliterated during the generation of S_t, and the following field observations document this development.

(1) Many of the high-grade rocks in Sri Lanka were intruded by mafic material, which now make up hornblende-rich metabasic layers of variable thickness. They can very rarely be seen to cut compositional layering in both ortho- and paragneisses at very shallow angles, but in general they are parallel to layering. There are numerous exposures where these mafic bands are isoclinally folded and significantly flattened so that they are frequently disrupted at their hinges and become rootless folds. The axial planes to these folds cut the fold hinges and are parallel to the pervasive layering or foliation in the surrounding gneisses. This is particularly well documented in Highland Complex rocks in a quarry ESE of Polonnaruwa (Fig. 2), in a river outcrop SE of Gampola (Fig. 3) and in granitic gneiss below the Victoria Dam ESE of Kandy (Fig. 4). At most localities, however, all early folding has been obliterated and the mafic layers are now parallel to the surrounding layering. We interpret them as a mafic dyke swarm, which intruded prior to the main deformation and metamorphism. This situation is similar to the deformed Ameralik mafic dykes and the dykes in the Naqsuggtoquitian belt of West Greenland (McGregor, 1973; Escher et al., 1975; Myers, 1987), and progressive deformation leading to a uniform, parallel-layered gneiss has been illustrated in Passchier et al. (1990). One of the best exposures to demonstrate that these mafic dykes intruded into an already folded supracrustal sequence is preserved NW of Galaha, SSW of Kandy (Voll and Kleinschrodt, 1991b, Excursion Stop 3.1) where a metaquartzite xenolith occurs within a mafic dyke (Fig. 5) whose margins are parallel to the foliation in the surrounding gneisses. The tight fold in this xenolith points to previous deformation in the supracrustal rocks.

(2) Isoclinal and rootless folds defined by compositional layering are remnants of an earlier fabric (Yoshida et al., 1990) and are rarely preserved in the banded gneisses due to very high strains. One such case is illustrated in Fig. 6. In addition, there are rotated mafic boudins showing internal fabrics which are older than the enclosing layering (Fig. 7). In rare cases these boudins themselves consist of banded gneisses, and the enclosing fabric is axial planar to early isoclinal folds of an earlier generation (Fig. 8). An early fabric marked by crenulated sillimanite needles has also been preserved in some garnet crystals (Kehelpannala, 1991; Kriegsman, 1991). It is contended that any coherent stratigraphy once present in the supracrustal rocks of Sri Lanka has been severely affected by this early deformation, and further high strains have led to an apparent

Fig. 2. Oblique view of isoclinally folded and severely flattened mafic dykes (above and below scale) in Highland Complex granulite SE of Mannampitiya, some 10 km ESE of Polonnaruwa.

Fig. 3. Rootless isoclinal folds as remnants of severely flattened and disrupted mafic dykes in foliated khondalitic gneiss, Highland Complex. Tributary to Atabage River some 12 km SE of Gampola. Vertical view, perpendicular to fold axes.

parallelism of contacts between the metasediments (and possible metavolcanic rocks) and the granitoid gneisses. This is not to say that compositional differences were destroyed completely, but that primary sedimentary features such as cross-bedding and graded bedding were lost during recrystallization and early folding and that early thrusting probably led to significant thickening of the original supracrustal pile. Large volumes of the HC are char-

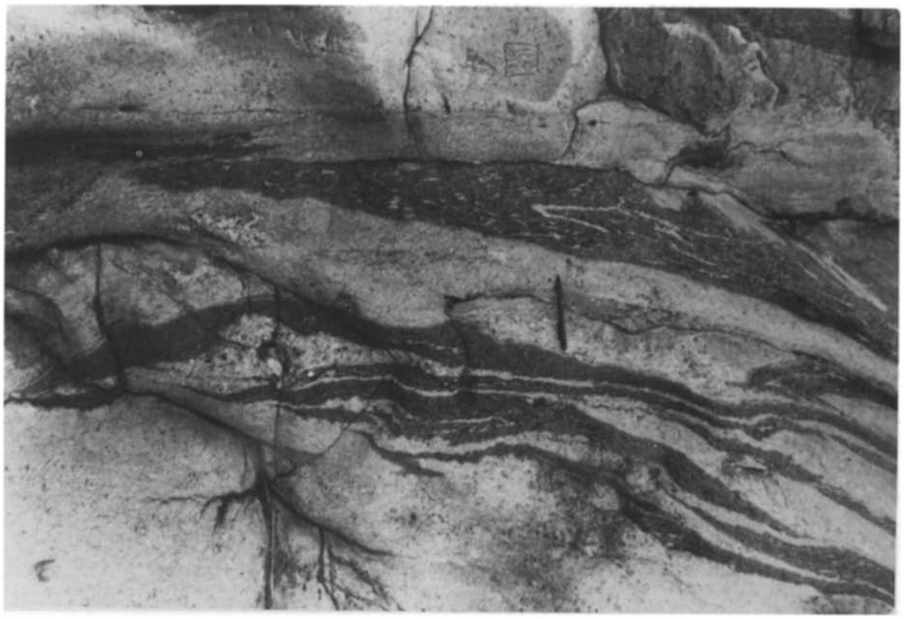

Fig. 4. Isoclinally folded basic dykes (basic sills of Voll and Kleinschrodt, 1991a) in granitic gneiss of the Highland Complex below Victoria Dam, about 17 km ESE of Kandy (Voll and Kleinschrodt, 1991b, Excursion Stop 1.10). Photo taken perpendicular to fold axes. When seen parallel to fold axes, the dykes are apparently parallel to layering in the gneiss.

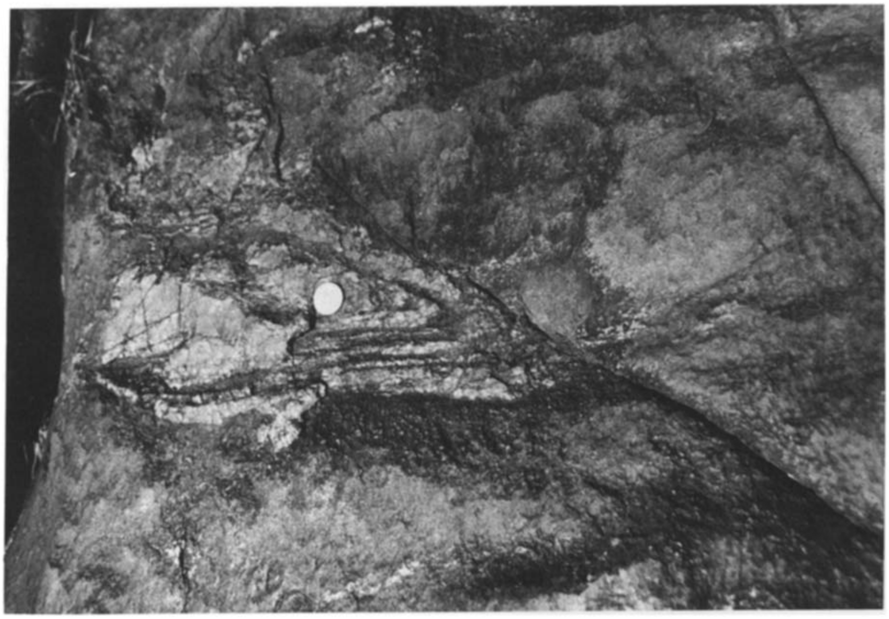

Fig. 5. Fragment (xenolith) of metaquartzite with tight fold in mafic dyke. Highland Complex. Locality 500 m NW of Galaha, some 12 km SSE of Kandy, central Highlands (Voll and Kleinschrodt, 1991b, Excursion Stop 3.1).

acterized by an extremely continuous compositional layering on a centimetre to metre scale (Fig. 9) which suggests very high strain superimposed on granitoid and mafic vein networks intruded into host granitoid gneisses. Similar rocks have been described from the southwest-

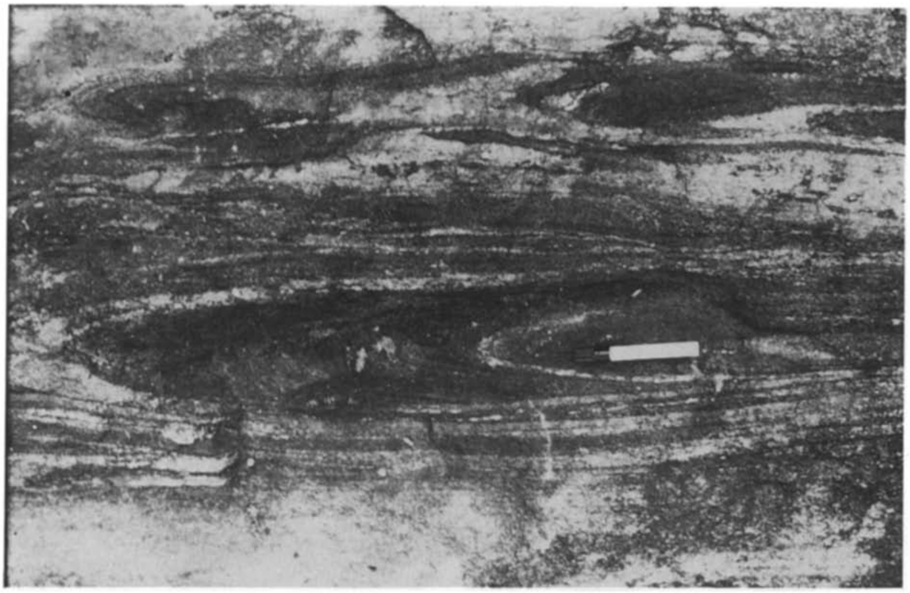

Fig. 6. Rootless isoclinal fold with axial plane parallel to compositional layering in enclosing gneiss. Fold hinges plunge steeply. Wanni Complex near margin with HC, Galewela, some 15 km SW of Dambulla. S_1 is folded by the isoclinal fold, the limbs of which are, in turn, cut by the compositional layering S_1.

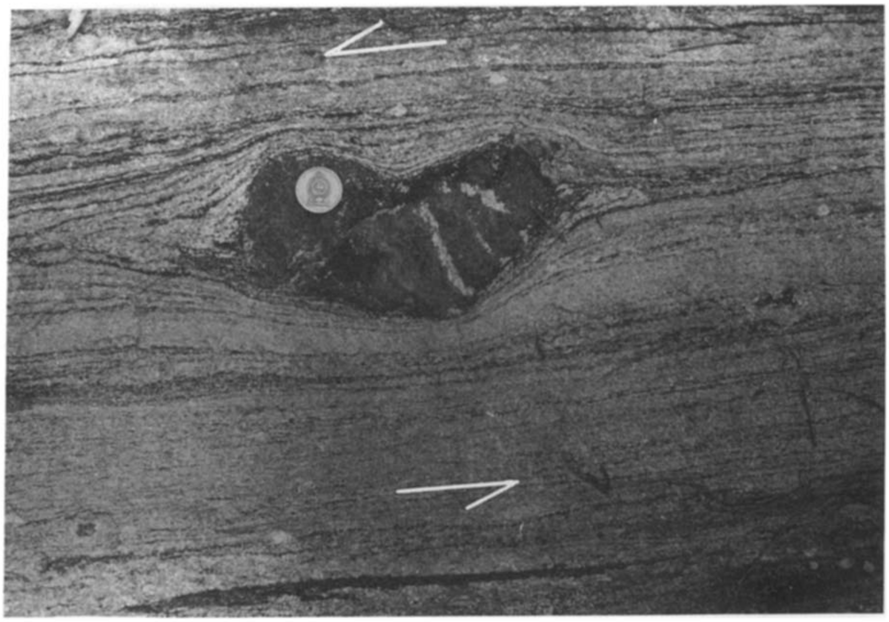

Fig. 7. Boudin of mafic dyke showing internal fabric at an angle to compositional layering in enclosing gneiss. Horizontal view nearly parallel to lineation. The slightly sigmoidal nature of the tectonic clast could indicate a counterclockwise rotation suggesting a left-lateral displacement as shown by white arrows. Note mylonitic nature of the layering. Same locality as Fig. 6.

ckel, unpubl. data). Thus, the two foliations may be separated in time by at least 160 Ma. In the same quarry a ductile shear zone is exposed in which all these granitoid gneisses are severely flattened, resulting in complete transposition of earlier structures and the formation of a parallel-layered, banded gneiss within which the previous intrusive and deformation history can no longer be recognized. This exemplifies the inherent difficulty in reconstructing the early structural history in rocks affected by strong non-coaxial deformation.

Although we suggest that thickening of the Sri Lankan crust was largely brought about by repetition of lithotectonic packages through thrusting, no direct field evidence, apart from the presence of "straight gneisses", for such large-scale early thrusts has yet been found. Despite this lack of clear-cut evidence for early thrusting, it is likely that the reported repetition of metaquartzite layers around Dodangaslanda (~ 15 km NW of Matale) and Ragedara (~22 km NNW of Matale) in the eastern Wanni Complex near the assumed boundary with the HC and the distinct break of the lithological sequence between Dodangaslanda and Maduragoda (~ 14 km NW of Matale, fig. 1 of Kehelpannala, 1991) are suggestive of large-scale transposition of lithologies.

3. Origin of compositional layering—microstructural evidence

In regions where rocks have undergone multiphase deformation and metamorphism, microstructures within porphyroblasts of metamorphic minerals indicate the nature of the deformation(s) and metamorphism prevailing before or during the growth of the porphyroblasts (e.g. Vernon, 1978; Reinhardt and Rubenach, 1989). These and other studies show that an earlier foliation(s) represented by the inclusion trails in porphyroblasts may have been transposed by later foliations outside the porphyroblasts.

In the high-grade rocks of Sri Lanka, microstructural evidence suggests that earlier planar fabrics existed before the present compositional layering (Yoshida et al., 1990; Kehelpannala, 1991; Kriegsman, 1991). An example is presented in Fig. 11 which shows porphyroblasts of garnets with inclusions of sillimanite needles representing an earlier foliation. In some garnet porphyroblasts, sillimanite inclusion trails are crenulated and show microfolds, as in the central garnet in Fig. 11, and in others they are straight. In addition to sillimanite, kyanite and ilmenite have also been found in garnet porphyroblasts (Hiroi et al.,

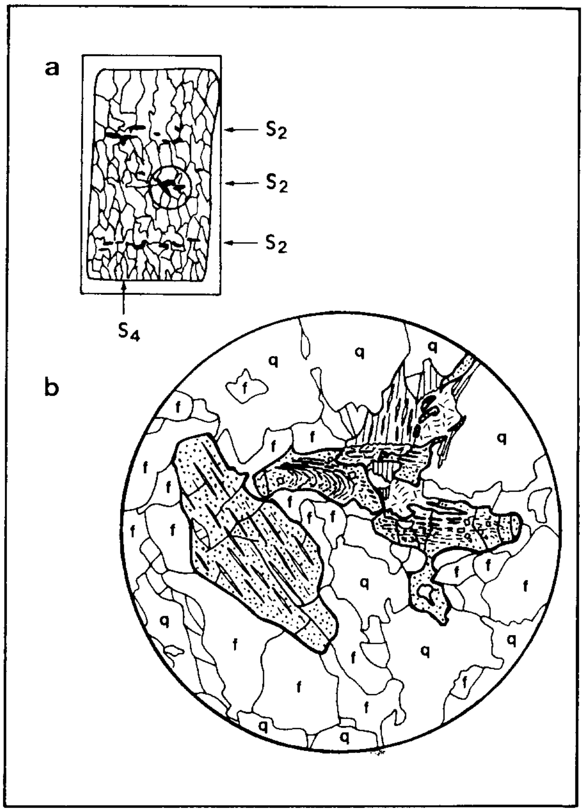

Fig. 11. Sillimanite needle inclusions in garnet porphyroblasts in a gneissic rock, Maduragoda, some 14 km NW of Matale, eastern WC. Drawn from a thin section cut perpendicular to both lineation and foliation. (a) Sketch showing the area enlarged in (b). The compositional layering is a later structure termed here S_2. Flattened quartz oriented parallel to the axial planes of large-scale F_4-folds defines a foliation S_4. The foliation represented by sillimanite inclusions in garnet is S_1. Garnets are stippled, q=quartz, f=K-feldspar. Diameter is 6.8 mm. From Kehelpannala (1993).

1987; Yoshida et al., 1990; Schenk et al., 1991; Raase and Schenk, 1994). Most of the Fe–Ti oxide inclusions found in garnets show a preferred orientation within their hosts which is not controlled by any crystallographic planes in the garnets. The inclusion trails are randomly oriented with respect to the external foliation, the present compositional layering, and to the major lineation and fold axes. For example, *c*-axes of sillimanite needles included in garnets may be perpendicular, oblique, or parallel to this lineation, while the *c*-axes of matrix sillimanites, which are considerably larger than the inclusions, are invariably parallel to it. Such inclusion trails in garnets clearly represent an earlier foliation predating the present compositional layering (e.g. Bell and Rubenach, 1983; Vernon, 1988, 1989), reflecting an early deformational event within the sillimanite stability field.

Yoshida et al. (1990) illustrated isoclinally folded quartz-plates in quartzo-feldspathic gneisses NNE of Kandy. The limbs and the axial planes of these microfolds are now parallel to the major compositional layering. These quartz-plates were flattened parallel to what we refer to as S_1 before they were isoclinally folded. The forms of some quartz-plates even suggest the possibility of more than two phases of folding predating the present banding (Yoshida et al., 1990). All these examples show that the present compositional layering has overprinted and transposed earlier fabrics.

In summary, the pervasive layering now seen in both supracrustal and magmatic rocks in the Sri Lanka basement is the result of severe deformation, obliterating almost all earlier structures and probably postdating several structural events that already led to disruption of the original depositional sequence(s) and intrusive contacts. Bedding, therefore, is everywhere transposed into a tectonic foliation, and presently observed compositional variations no longer reflect stratigraphy. The process we envisage for this occurred during progressive deformation and is similar to that envisaged by Tobisch and Paterson (1988)

4. Proposed early deformational history

The probable early deformational history of the Sri Lankan high-grade assemblages may be reconstructed by looking at geodynamic environments which closely resemble the depositional setting of the Sri Lankan rocks. As stated above, the most likely environment of formation for the supracrustal succession of the Highland Complex is a rift basin, probably initiated some 2000 Ma ago that gradually evolved into a passive continental margin. It may have been during this phase of crustal extension that granitoid rocks with alkaline affinity (Pohl and Emmermann, 1991) intruded the terrain. At some later time, and after at least some of the supracrustal rocks were folded, innumerable mafic dykes intruded the terrain, possibly during distinct phases of crustal extension and by analogy with the formation of mafic dyke swarms elsewhere in the world (Halls and Fahrig, 1990).

The predominantly clastic rocks of such a sequence with intercalated limestones and/or dolomites and marls were probably not subjected to compressional deformation at this stage but may have experienced extension, most likely resulting in detachment faults and thereby first disruption of the original stratigraphy. Lister et al. (1991) discuss models for the formation of passive continental margins. Compressive deformation probably began when this attenuated continental margin became involved in accretionary tectonics, probably as a result of the onset of subduction, i.e. transformation of a passive into an active margin. The time of this tectonic inversion is not known but may have been several tens of millions of years or several hundred million years after rifting began.

The tectonic evolution of stable continental margins transformed into active margins when

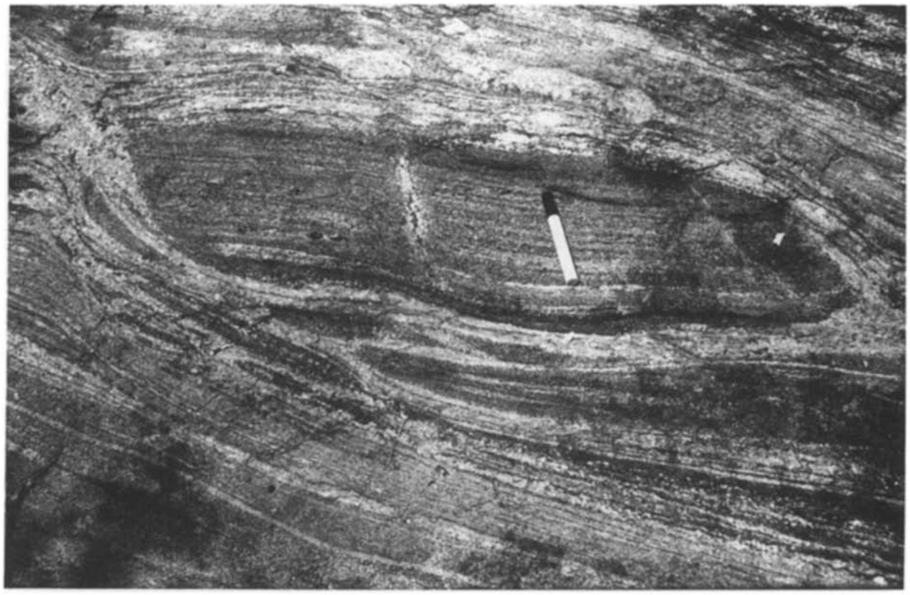

Fig. 8. Boudin of banded gneiss showing early fabric, surrounded by gneiss with younger compositional layering. The structure seen below the boudin may be an early isoclinal fold. Same locality as Figs. 6 and 7.

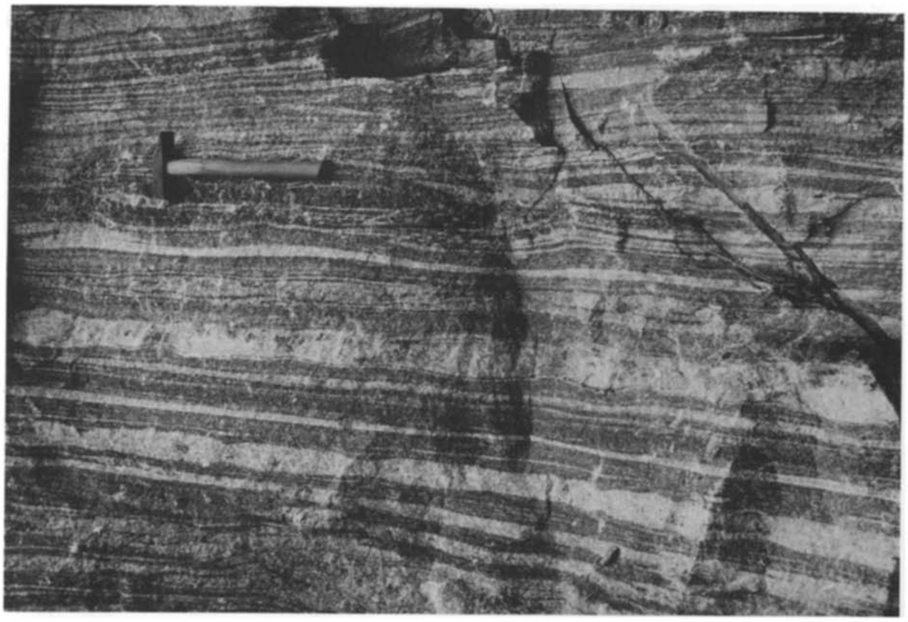

Fig. 9. Regularly layered gneiss ("straight gneiss") consisting of trondhjemitic and leucogranitic to pegmatitic components. The leucogranite originally intruded the trondhjemite, and the two components were brought into parallelism by progressive high-strain deformation. Kadugannawa Complex, quarry near Hirassagala, about 5 km SW of Kandy.

ern Grenville Province in Canada where they are part of thrust sheets and were named "straight gneiss" (Davidson, 1984; Hanmer, 1988). Many of the rock types interpreted as occurring in ductile shear zones in the Grenville Province and illustrated by Davidson

(1984) and Hanmer (1988), are identical in appearance to gneisses found in the HC and WC of Sri Lanka and attest to the high strains experienced by these rocks.

(3) Early structures are also preserved in low strain areas of the Kadugannawa Complex (Fig. 1), which become overprinted by, and transposed to, younger foliations near the contact with the Highland Complex (Kriegsman, 1994). Sheath folds in the zone of transposition and asymmetric foliation boudinage in the underlying Highland Complex attest to a significant component of simple shear (Kriegsman, 1994).

Transposition of structures can also be seen at several localities in banded granitoid gneisses. One such case is illustrated in Fig. 10 where ductile shearing has obliterated an early compositional layering, itself the result of severe flattening, giving rise to a new foliation. Myers (1978) has described and illustrated the progressive deformation of granitoid complexes in West Greenland into layered quartzofeldspathic gneisses, and these rocks look identical to the gneisses in Sri Lanka as exemplified by Figs. 9 and 10.

In the western part of the high-grade terrain, the Wanni Complex, where *P–T* conditions suggest somewhat higher crustal levels (Schumacher et al., 1990), transposition of early structures is generally less severe (Kriegsman, 1991). The relationship between five different phases of gabbroic to granitoid intrusions and their deformation is particularly well preserved in a quarry near Galla Paula, a small village some 13 km SW of Dambulla (Fig. 1), where the relative deformational sequence can be reconstructed. At least two foliations are preserved, and the older of these is developed in a dark grey biotite–hornblende gneiss (deformed metagabbro) with a $^{207}Pb/^{206}Pb$ single zircon evaporation age of 791 ± 7 Ma. The foliated metagabbro is cut by a younger granodiorite with a $^{207}Pb/^{206}Pb$ age of 773 ± 5 Ma. The younger foliation postdates a light grey, leucocratic granite cutting both the deformed gabbro and granodiorite and with a $^{207}Pb/^{206}Pb$ age of 557 ± 9 Ma (A. Kröner and P. Jae-

Fig. 10. Transposition of early compositional layering resulting from high-strain deformation as shown in Fig. 9 (bottom) within younger ductile shear zone (top). Same locality as Fig. 9.

subduction begins, is reasonably well understood from deep-sea drilling and detailed work in fold and thrust belts such as the Canadian Cordillera. Von Huene (1991) and Moore et al. (1991) have recently summarized and illustrated the structural evolution of accretionary complexes and showed that detachment surfaces, ramps and bedding-parallel thrusts develop early in the structural history of such terrains and lead to significant disturbance (i.e. thickening) of the original stratigraphy with repetition of many lithologies as a result of thrusting. Blome and Nestell (1991) have described a sedimentary mélange from a forearc basin in Oregon, USA, that was previously interpreted as a coherent succession. Excellent examples for structures in fold and thrust belts are provided by seismic data and drill holes from the Front Range of the Rocky Mountains W of Calgary, Canada, where Fox (1959) described numerous thrusts and ramps cutting bedding at a slight angle and considerably modifying the original stratigraphy (Fig. 12). Similar structures are known from the Cordillera farther N in the Skeena fold belt (Evenchick, 1991) and upper crustal fold belts evolving from passive margins elsewhere in the world.

All these structures have disturbed the original stratigraphy, often leading to tectonic duplication or even triplication of specific horizons in thrust belts. We envisage that this process has also taken place in the supracrustal rocks of the Highland Complex, and that many of the numerous quartzite and marble horizons now seen may originate from only a small number of beds in the original sequence. Fig. 13, modified from illustrations of Bradley and Kidd (1991) for the evolution of a collisional foredeep during the early Taconic orogeny, portrays this situation and shows the evolution of a passive margin sequence into an allochthonous thrust belt during progressive collision. If granitoid rocks intruded prior to or during this thrusting, as seems likely, these probably acquired a first non-penetrative foliation during this event and became tectonic wedges within the supracrustal rocks. This "tectonostratigraphy" was further modified when compressional deformation and metamorphism increased during transport of the entire package into lower crustal levels where

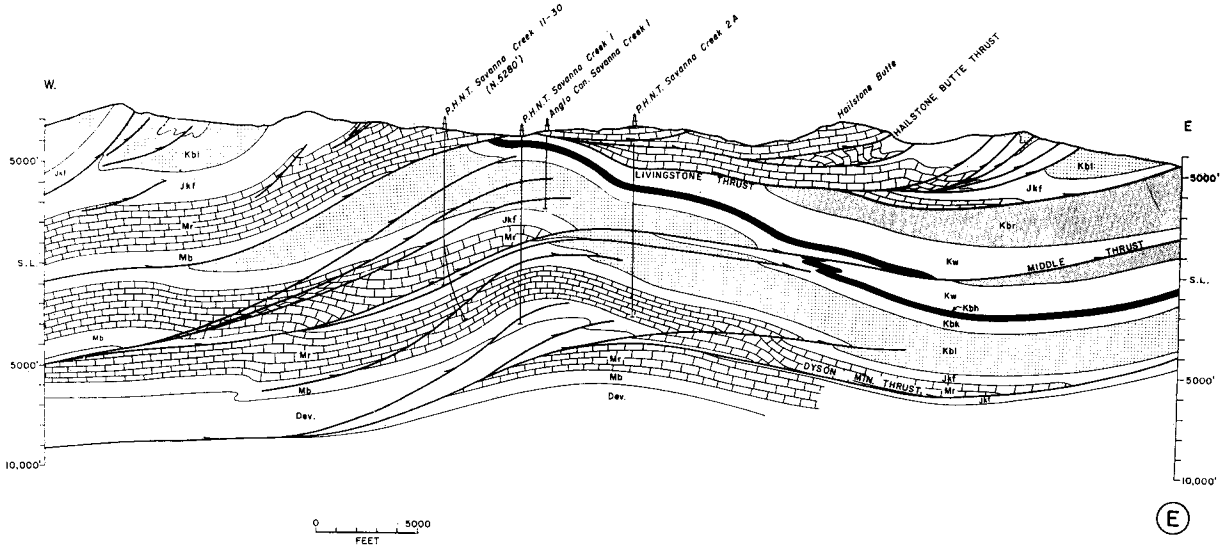

Fig. 12. Schematic cross-section through Plateau Mountain Anticline in Savanna Creek gas field, Front Range, Rocky Mountains, Canada, showing imbricate and folded thrust disrupting original stratigraphy. From Fox (1959).

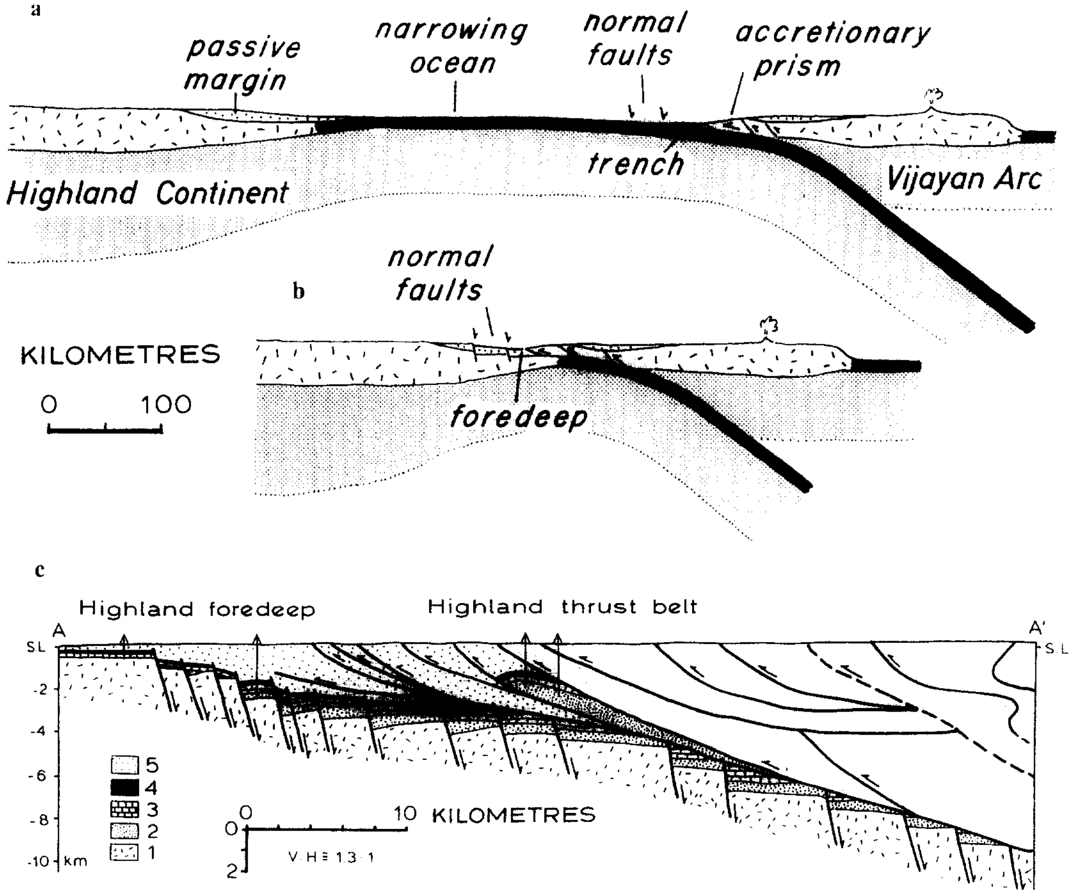

Fig. 13. (a and b) Speculative plate tectonic model for evolution of supracrustal rocks of the Highland Complex when they were still at high crustal levels, involving passive margin-arc collision. (a) Passive margin passed through regime of normal faulting as it approached the trench. Random dashes, pre-Highland continental crust; black, oceanic crust; grey, mantle lithosphere. (b) Schematic cross-section of suggested Highland collisional foredeep, showing structural regimes in the early stages of plate convergence. Note tectonic disruption of original stratigraphy in evolving Highland thrust belt. *1* = pre-Highland Archaean to Palaeoproterozoic basement, now detached. *2–5* = primary lithostratigraphic units of rift and passive margin sequence. Adapted from Bradley and Kidd (1991) from a model for Taconic orogeny.

ductile deformation began to predominate and where flat thrusts and ramp surfaces (with respect to original bedding) were rotated into parallelism with the dominant shear planes. The older discontinuities thus became obliterated, leaving a tectonic sequence of greatly thickened supracrustal rocks and intrusives, all tectonically interleaved and subsequently severely flattened during high-grade metamorphism.

At some later time, this flattened package was tectonically emplaced over the adjacent Vijayan Complex (see also Kleinschrodt, 1994). Remnants of the allochthonous thrust belt are now preserved as klippen in SSE Sri Lanka (Silva et al., 1981; see Fig. 1), and we speculate that the entire HC was detached from its basement during this process of thrusting, since pre-HC rocks have so far not been recognized. Fig. 12 does not serve as a model for final collisional tectonics bringing the Highland and Vijayan Complexes into thrust contact but is meant to illustrate the early tectonic evolution of the two approaching plate margins.

High-grade tectonic sequences as found in Sri

Lanka dominate many Precambrian terrains now interpreted as remnants of collisional belts as in the Grenville and other high-grade mobile belts of North America (Hoffman, 1989), West Greenland, Western and central Australia, South Africa and Antarctica (Windley and Tarney, 1986; Myers and Kröner, 1994). Colliston et al. (1991) have even recognized lozenge-shaped suspect terranes in a domain of granulite-facies assemblages in the Namaqua mobile belt of South Africa with lithologies and structures remarkably similar to those in Sri Lanka. The existence of a terrane boundary within the Sri Lankan granulite facies domain is also postulated by Kriegsman (1994).

It is highly unlikely that such a structural development took place synchronously over the entire high-grade terrain of Sri Lanka since stresses are not homogeneously distributed over large volumes of crust. However, it is evident from field relations that most of the ductile deformation took place after intrusion of relatively late granitoids such as at Kurunegala (771 ± 14 Ma, Baur et al., 1991) and when the rocks were already at reasonably deep crustal levels. There is thus a time span of more than 1000 Ma between deposition and ductile deformation to account for early, upper crustal, deformation in the Sri Lankan rocks.

5. Discussion

In contrast to what we propose here, Voll and Kleinschrodt (1991a, b) suggested that S_t in the Highland Complex represents original sedimentary bedding in the supracrustal rocks. The persistence of compositionally distinct bands such as biotite-rich and biotite-poor layers, several cm thick, in quartzo-feldspathic gneisses has been cited by these authors as evidence for a sedimentary origin for such rocks. They equate these layers with original sedimentary beds. However, most of the quartzo-feldspathic gneisses contain no detrital heavy minerals but, instead, carry near-idiomorphic long prismatic zircons typical of granitic rocks (Poldervaart, 1956). Some of these banded granitoid gneisses have been dated radiometrically and provide evidence for isotopically homogeneous zircon populations as expected in most igneous rocks (Kröner et al., 1987; Hölzl et al., 1991, 1994).

Other arguments put forward by Voll and Kleinschrodt (1991a) to support their hypothesis are (1) the persistence of individual layers such as metaquartzite and/or marble over distances up to several tens of kilometres, and (2) the recognition of a certain "stratigraphy" within late-generation major folds over considerable distances where "stratigraphy" in both limbs is claimed to match. Several objections can be raised against their interpretation. First, it is extremely difficult to match stratigraphy in highly deformed terrains unless unequivocal marker beds are present. The outcrop density in the Sri Lanka basement is far from continuous, making interpretation based on the comparison of transects a necessity. Hence, correlation of similarly looking "beds" carries a significant amount of uncertainty. Second, the combination of very high strain and relatively poor outcrop density render it likely that large-scale fold noses may be missed. For example, the various marble beds used by Voll and Kleinschrodt (1991a) are lithologically indistinguishable and could just as well represent one original unit. Third, the contacts between most lithologies in the HC are hardly visible due to weathering and poor outcrop conditions. They cannot be traced for any distance although some layers persist for tens of kilometres. Finally, extreme stretching in a subhorizontal direction highly increases the lateral extent of both supracrustal units and intrusive granitoid bodies. Hence, beds may locally even persist over longer distances than in the original sedimentary environment.

Granitoids and metabasites with contacts now parallel to compositional layering in the adjacent rocks have been interpreted by Voll and Kleinschrodt (1991a, b) as sills, which were intruded into an undeformed flat-lying sedimentary succession. These igneous events are considered to be the cause of extensive crustal thickening. Granulite metamorphism about 550–620 Ma ago would eventually have resulted in thorough recrystallization of the entire package, accompanied by severe flattening, largely by pure shear, reducing the layers to between 1/15th and 1/20th of their original thickness and not significantly disturbing the original stratigraphic sequence (Voll and Kleinschrodt, 1991a, p. 24). However, since the present minimum thickness (across layering) of the Highland and Wanni Complex rocks, as deduced from structural and petrologic data, is at least 15 km (Schumacher et al., 1990; Voll and Kleinschrodt, 1991a), the original thickness, before flattening, must therefore have been in the order of 150–300 km, clearly an implausible figure. In addition, this model does not explain in which tectonic environment the voluminous granitoids were formed and intruded and how the rocks were transported into the lower crust prior to, or during, granulite metamorphism.

In line with previously published hypotheses (Kröner, 1986, 1991; Kehelpannala, 1991; Kröner et al., 1991; Kriegsman, 1991, 1994) we have tried to demonstrate that the Sri Lankan granulites have evolved along essentially similar lines as those in other Precambrian granulite terrains (e.g. Enderby Land, Antarctica, James and Black, 1981; West Greenland, Bridgwater et al., 1974; Grenville and Pikwitonei belts of Canada, Hoffman, 1989; Namaqua–Natal belt of South Africa, Colliston et al., 1991). In our view the original stratigraphy of the supracrustal succession(s) has been destroyed by thrusting, early isoclinal folding and complete transposition of primary structures. The intrusive rocks were largely emplaced as pre- to syntectonic sheets, often discordant to pre-existing structures, and all original contacts were brought into parallelism due to high strain during non-coaxial deformation. The presently observed compositional layering is considered to result from these processes, which have been discussed in detail by Myers (1978), James and Black (1981), Van der Molen (1985), and Passchier et al. (1990). It is therefore contended that early tectonic processes predating the compositional layering now seen have substantially modified the original supracrustal sequence(s) and were also responsible for considerable tectonic thickening. This deformation, accompanied by increasing grades of metamorphism, probably took place during the passage of both supracrustal and igneous rocks to lower crustal levels and culminated in the development of the pervasive layering S_t just prior to, and during, the granulite-grade regional metamorphic event some 600 Ma ago.

The present dispute on the origin and evolution of the Sri Lankan gneisses is analogous to a controversy in the Grenville Province of Canada. Here, Lumbers (1978, 1982) interpreted a heterogeneous unit of gneissic rocks in the Central Gneiss Belt as a coarse clastic sedimentary sequence with preserved bedding, while Davidson (1986) has shown these rocks to be severely transposed with no stratigraphy preserved. The interlayered nature of high-grade pelitic metasediments and marble tectonites with sheet- or lens-shaped metaplutonic gneiss units "point to derivation of this package through some form of crustal imbrication involving deep-seated, relatively low-angle thrusting" (Davidson, 1986, p. 67).

6. Conclusions

Interpretation of the granulite-grade and partly retrograded layered succession of para- and orthogneisses in the HC as a tectonostratigraphic unit with no preserved primary stratigraphy is in line with the composition, structure and evolution of other Precambrian granulite terrains documented in the literature. We explain the present structural thickness of about 15 km by tectonic stacking during the early history of the Complex (between ~1800 and ~670 Ma ago) when the original

Highland succession evolved from a rift basin into a foredeep and then into a fold-and-thrust belt prior to severe flattening and transport into the lower crust during the final stages of collision some 550–620 Ma ago. Granitoid rocks were emplaced into the supracrustal sequence at various stages of the tectonic evolution, and the original intrusive contacts were obscured during progressive non-coaxial ductile deformation. The abundant basic dykes seen in the Highland Complex were probably emplaced as a dyke swarm during an extensional phase, perhaps when the rift basin evolved into a foredeep (Bradley and Kidd, 1991), and were then disrupted, deformed, flattened and rotated so that their intrusive contacts were destroyed.

Evidence for structures predating the presently observed layering of the Highland gneisses is seen in rootless isoclinal folds, boudins and in deformed pre-granulite metamorphic minerals preserved in garnet porphyroblasts.

The evolution of the HC suggested here is similar to that in other Precambrian granulite complexes in which evidence for the early structural development is better preserved. We caution against the use of lithostratigraphic principles in severely deformed high-grade assemblages since this may not only conceal the true structural complexity experienced by the rocks, but may also inhibit the recognition of differences in structural evolution, a key to the identification of different tectonic domains or "terranes" in areas underlain by high-grade rocks.

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