

## Archaean crustal thickness of greenstone granite belts of South India

C S PICHAMUTHU, R SRINIVASAN, FAREEDUDDIN and APPAJI AMRIT BHASKER

Department of Mines and Geology, Bangalore 560 001, India

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**Abstract.** Archaean crustal thickness for the Dharwar craton is estimated using potash index and Rb-Sr crustal thickness grid. The volcanics of the Dharwar greenstone belts appear to have evolved in a less than 20 km thick crust. Whereas the tonalite-trondhjemite pebbles of the Dharwar conglomerates ( $3250 \pm 150$  m.y.) were derived from gneisses that evolved in a crust less than 20 km thick, the bulk of the peninsular gneisses and associated granitoids were emplaced in a crust 25 to 35 km thick. The 2000 m.y. old Closepet granite suite was emplaced in a crust thicker than 30 km. It is deduced that the continental crust in the region thickened from 15 to 35 km during a span of about 1000 m.y. between  $3250 \pm 150$  to 2000 m.y. ago. Calculations show that Archaean geothermal gradients in Dharwar craton were three to four times steeper when compared to the present  $10.5^\circ\text{C}/\text{km}$ . The thin crust and the steep geothermal gradients are reflected by the emplacement of high magnesia basalts, layered igneous complexes and the strong iron enrichment trend shown by Dharwar metavolcanics.

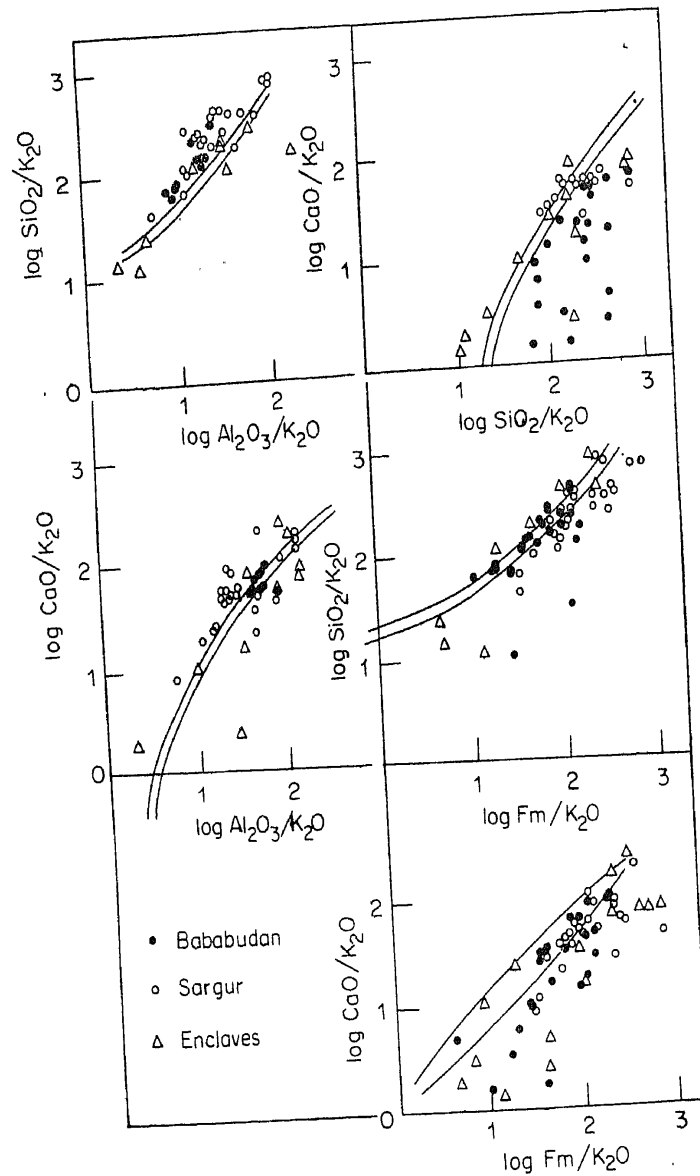
**Keywords.** Archaean ; greenstone belts ; crustal thickness ; tectonic environments ; geothermal gradients.

### 1. Introduction

Crustal thickness has a bearing on the contemporary geothermal gradient which influences the geotectonic evolution of any terrain. Direct estimation of crustal thickness is possible for the present day crust using seismic methods. Estimation of crustal thickness during Archaean times has to be carried out by indirect methods such as (1) measuring exposed stratigraphic succession, (2) study of *P-T* of the metamorphic mineral assemblages, and (3) by geochemical polarity indices related to crustal thickness (Condie 1973). Condie (1973) proposed potash index and Rb-Sr crustal thickness grid for estimating the crustal thickness.

In using the geochemical parameters it is necessary to ascertain that the abundance and ratios of the said alkali elements reflect the original composition and they are unaffected by later metasomatism. Critical selection of geochemical

data is, therefore, necessary. The LMPR (Log Molecular Proportion Ratio) diagrams proposed by Beswick and Soucie (1978) provide criteria for filtering useful geochemical data. Based on such reliable geochemical data, the Archaean crustal thickness of the South Indian Shield has been estimated and the tectonic environments are interpreted in the light of the contemporary crustal thickness.



**Figure 1.** LMPR diagram after Beswick and Soucie (1978) showing the fields occupied by unmetasomatised samples of basic igneous rocks from different tectonic regimes of the oceanic domain. The plots of mafic enclaves in gneisses, amphibolites of Sargur, and metavolcanics of Bababudan show a wide scatter outside these fields indicating that their original composition has been largely modified.

2. LMPR test of geochemical data

The greenstone belts of South India are represented and well studied in Karnataka. There are over 350 chemical analyses of metabasic igneous rocks of the schist belts of Karnataka (Geochemistry Group NGRI 1977; Ananta Iyer and Narayanan Kutty 1978; Bhasker Rao and Naqvi 1978; Janardhan *et al* 1978; Naqvi *et al* 1978; unpublished data of the present authors). LMPR plots for these metabasic igneous rocks are given in figures 1 and 2, from which the following observations can be made:

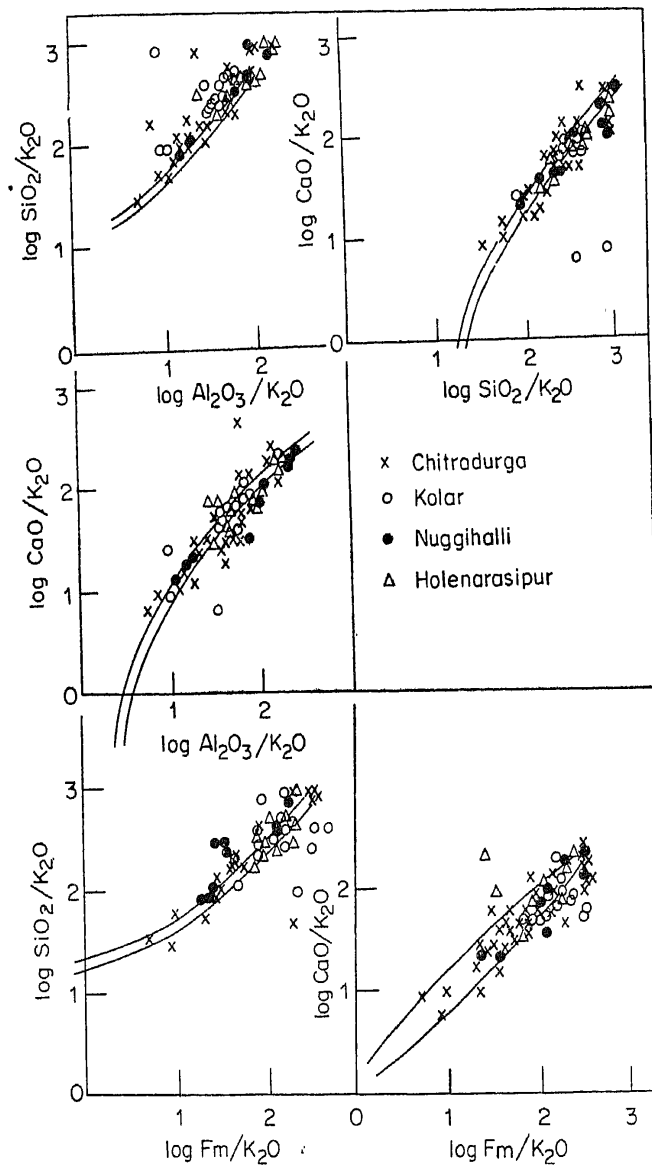


Figure 2. LMPR diagram for metamorphosed mafic rocks of Holenarasipur, Nuggihalli, Kolar, and Chitradurga greenstone belts, indicating that they have preserved their original compositions.

- (i) Amphibolite inclusions in the gneisses show a wide scatter, and therefore, their original composition has been modified.
- (ii) Amphibolites of the Sargur schist complex that have been considered as representing either root zones of the Dharwar schist belts or as rocks older than Dharwar are also modified.
- (iii) The metabasalts of the Bababudan subgroup have been affected by metasomatism.
- (iv) The mafic rocks of Holenarasipur and Nuggihalli schist belts have retained the original composition without much modification.
- (v) The metabasalts of the Chitradurga subgroup of the Chitradurga schist belt and the amphibolites of the Kolar schist belt have retained their original chemistry.

From the above, it can be seen that the geochemical data for Nuggihalli, Holenarasipur, Kolar and Chitradurga greenstone belts are useful for geochemical modelling studies. Therefore, the data pertaining to these belts are used in the present paper for estimating the Archaean crustal thickness of the greenstone belt terrain.

The granitoids belonging to the peninsular gneiss suite constitute a major part of the Archaean complex of South India. Members having basement relation to the Dharwar schist belts and those showing intrusive relation into the Dharwars have been recognised. Both ortho- and para-gneisses are noticed (Divakara Rao *et al* 1974; Saha 1978; Jayaram 1980). The detailed work by Jayaram (1980) on the granitoids of Karnataka shows that the orthogneisses have a typical calc-alkaline trend.

Comparable and divergent slopes between greenstones and granitoids in the potash index diagram and also comparable crustal thickness values from the *K*-index and Rb-Sr crustal thickness grid were used by Condie (1973, 1976) to distinguish granitoids that represent plutonic representatives of the acid volcanics of greenstone belts from those which evolved independently of greenstone belt volcanism. Such an attempt in the Dharwar craton holds the possibility for recognising the different episodes of granitoid emplacement during the course of evolution and thickening of the continental crust.

### 3. Thickness of the crust of the greenstone belt terrain

*K*-index and Rb-Sr plots for the metavolcanics of the Dharwar greenstone belts are given in figures 3 and 4, respectively. The crustal thickness *C* is given in table 1.

It has been proposed that the greenstone belts in Karnataka belong to an older and younger suite (Srinivasan and Sreenivas 1972; Naqvi 1976; Swaminath *et al* 1976; Radhakrishna and Vasudev 1977). The Holenarasipur and Nuggihalli schist belts are considered to be representative of the older greenstone belts and the Chitradurga schist belt of a younger greenstone belt. There is some difference of opinion as to whether the Kolar greenstone belt represents the older or younger greenstone belt (Radhakrishna and Vasudev 1977).

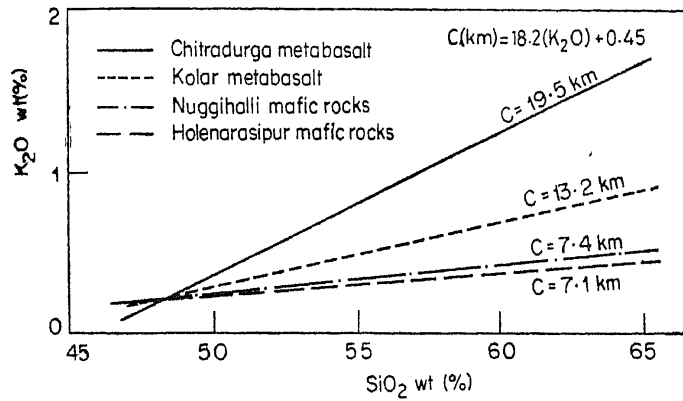


Figure 3. Crustal thickness (C) estimate from SiO<sub>2</sub>-K<sub>2</sub>O (K-index) diagram after Condie (1976) for some greenstone belts of Karnataka. Each line in the diagram represents the best fit for the data of that belt. Note that greenstone belts evolved in a crust less than 20 km thick and the older greenstone belts (Holenarasipur and Nuggihalli) evolved in a thinner crust than younger (Kolar and Chitradurga) ones.

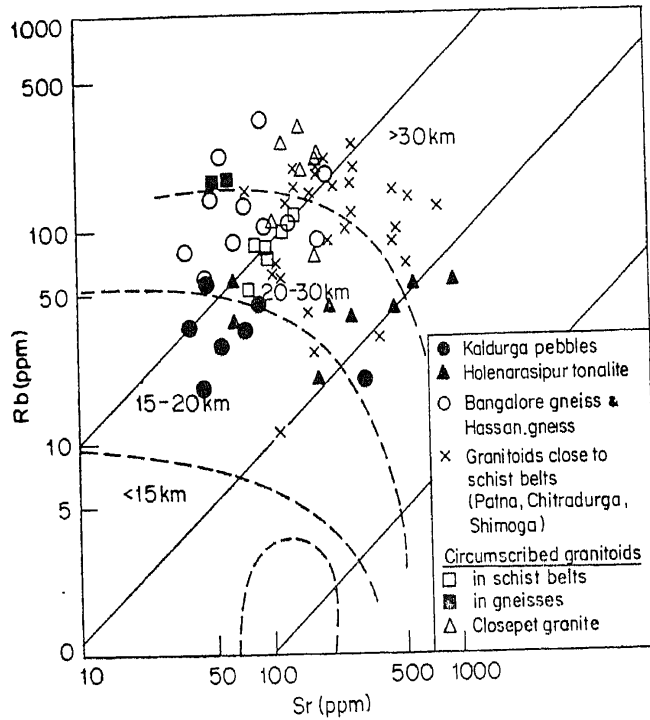


Figure 4. Plot of Rb-Sr for the greenstone belts of Karnataka in the Rb-Sr crustal thickness grid after Condie (1976) showing that the greenstone belts of Karnataka evolved in a crust less than 20 km thick.

Table 1. Archaean crustal thickness by geochemical polarity indices for the Dharwar craton.

	Crustal thickness based on <i>K</i> -index in km.	Crustal thickness by Rb-Sr crustal thickness grid in km
<b>Greenstone belt terrain</b>		
Holenarasipur belt	7.10	16.00
Nuggihalli belt	7.40	15-16
Kolar belt	13.19	15.00
Chitaldurg belt	19.50	16-21
<b>Gneiss-granitoid terrain</b>		
Tonalite pebbles in Kaldurga conglomerate	12.10	15-20
Tonalites, Holenarasipur	12.10	18-22
Tarikere Valley gneiss	39.00	-
Peninsular gneiss, Hassan	30.00	28-32
Bangalore	39.40	28-32
Circumscribed granitoids in schist belts	-	30
Circumscribed granitoids in gneisses	66.00(?)	30-35

It can be seen from the data presented in this paper based on *K*-index that the Holenarasipur and Nuggihalli schist belts evolved in a crust less than 10 km thick. The Kolar greenstone belt appears to have developed on a somewhat thickened crust approximately 13 km thick. The younger greenstone belt represented by the Chitradurga greenstone belt appears to have developed on a thicker crust ( $\approx 20$  km). Plots on Rb-Sr grid indicate that the greenstone belts evolved on a thinner crust, less than 20 km thick.

#### 4. Archaean crustal thickness for the gneissic terrain

*K*-index and Rb-Sr plots for the granitoids of Karnataka are given in figures 5 and 6, and the thickness values are given in table 1. It is seen that the  $3250 \pm 150$  m.y. old tonalite pebbles of the Kaldurga conglomerate (Venkatasubramanian and Narayanaswamy 1974) and the  $3358 \pm 66$  m.y. tonalites and trondhjemites of the Holenarasipur region (Beckinsale *et al* 1980) have *K*-index values characteristic of granitoids emplaced in a crust less than 15 km thick. The Rb-Sr ratio for these indicates that they were emplaced in a crust 15-20 km thick; this corresponds to the thickness indicated by the volcanics of the younger greenstone belts, such as those of Kolar and Chitradurga.

A comparison of the slopes for the tonalite pebbles of Kaldurga and the Tarikere valley gneisses in the *K*-index diagram shows that the valley gneisses evolved in a much thicker crust, greater than 30 km thick. This implies that the Tarikere valley gneisses did not constitute the provenance rocks for the pebbles in the Kaldurga conglomerate. A majority of the peninsular gneiss compositions indicate a crustal thickness of 20 to 30 km. Circumscribed gneissic granitoids occurring within the greenstone belts and those that border the greenstone belts were emplaced in a crust about 28-32 km thick. Circumscribed gneissic granites in the gneissic

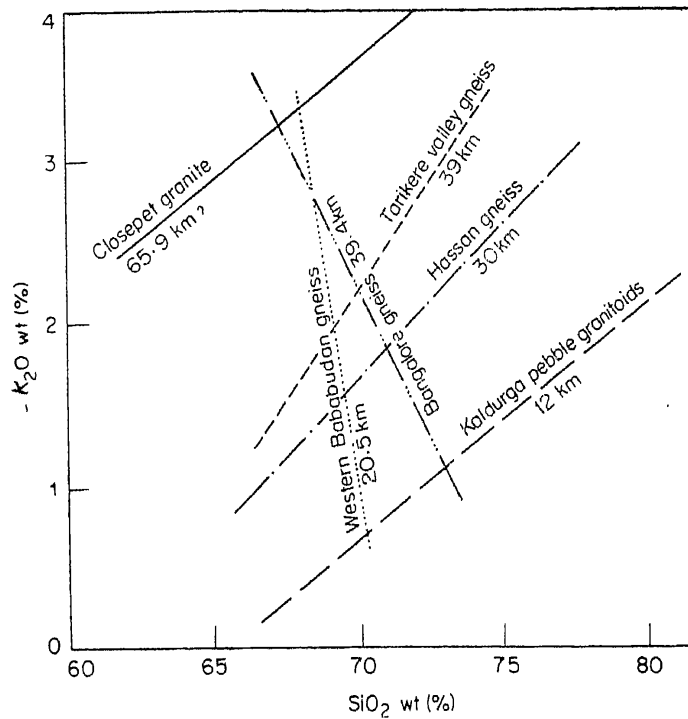


Figure 5. K-index plots for crustal thickness estimation of gneissic terrain. The older tonalites represented by pebbles evolved in a thinner crust, while majority of the members of the peninsular gneisses evolved when the crust had been thickened to more than 25 km. Closepet granite was emplaced in a much more thickened crust.

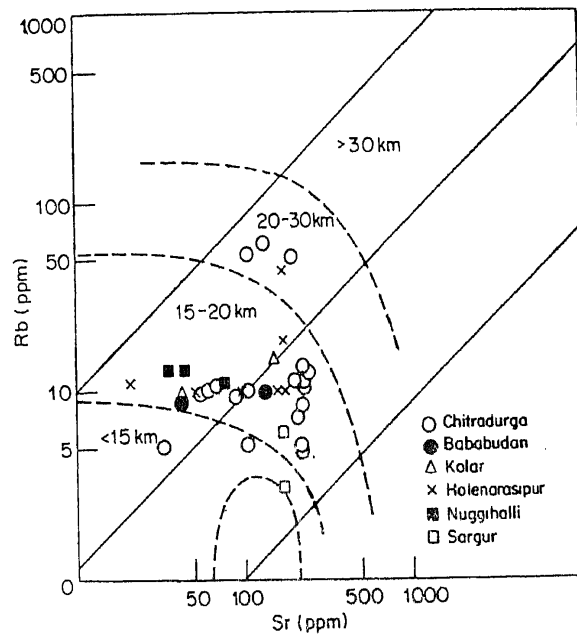


Figure 6. Rb-Sr plot for the peninsular gneisses and the Closepet granite of Karnataka. Note that majority of the gneisses were emplaced when the crust was more than 25 km thickness, whereas the older tonalites evolved in a crust less than 20 km thick, a thickness corresponding to that of the crust at the time of evolution of younger greenstone belts.

terrain, such as Arasikere granite, were emplaced in a crust about 30 km thick. The Closepet granite suite was emplaced in a crust about 30 to 35 km thick.

The observed patterns indicate that prior to the development of the younger greenstone belts, the crust was thinner than 20 km, and that much of the granitic matter was emplaced subsequent to the greenstone belt evolution. It is interesting to note from the *K*-index plots of gneisses and greenstones that some of the granitoids such as tonalites in the Holenarasipur belt and the pebble gneisses, have a slope comparable to that of the greenstone belt volcanics. These probably represent the plutonic equivalents of greenstone belt volcanism. However, the majority of the granitoids constituting the peninsular gneiss have slopes different from the greenstone belt volcanics. This suggests that most of the granitoids are unrelated to the greenstone belt volcanism.

It can thus be deduced that :

- (i) The older greenstone belts were emplaced in a crust 10-12 km thick.
- (ii) A first phase of tonalite emplacement was probably responsible for the thickening of the crust to 15-17 km.
- (iii) The younger greenstone belts developed on a 15 to 22 km thick crust.
- (iv) The majority of the granitoids constituting the peninsular gneiss terrain were developed in a crust 20 to 35 km thick and this major event has generally obliterated evidences of the precursor gneisses.
- (v) The Closepet granites were emplaced in a crust about 30-35 km thick.

##### 5. Influence of crustal thickness on the geotectonic evolution of the terrain

It has been shown by Bridgwater and Windley (1973), and Windley (1973) that the nature of magmatic activity and the trend of magmatic differentiation are strongly influenced by the thickness of the contemporary crust. A thin crust promotes the rise of magma to higher levels allowing only limited and relatively rapid differentiation into stratiform complexes. Evidences for this are noticed in the Holenarasipur and Nuggihalli greenstone belts (Naqvi 1976; Lakshmi pathi 1978; Vasudev and Srinivasan 1979). Such stratiform complexes are not noticed in the Kolar and Chitradurga greenstone belts, implying that these younger greenstone belts developed on a comparatively thickened crust. Whereas the platform-mobile zone distinction is characteristic of the younger greenstone belts (Srinivasan and Sreenivas 1972, 1975), such a distinction is not evident in the older greenstone belts of Holenarasipur and Nuggihalli. The latter appear to have evolved in a permobile regime (Naqvi 1976).

The similarity of the geosynclinal volcanic rocks and the continental margin volcanics is well-known, and plate tectonic models of geosynclines have been proposed (Dickinson 1971). It has been shown by Sreenivas and Srinivasan (1974) and Ananta Iyer and Vasudev (1979), that the volcanic rocks of the younger greenstone belts have continental margin affinity; the amphibolites of the Kolar greenstone belt have MBB characteristics, and the Chitradurga greenstones island arc volcanic characteristics. These observations show that the platform-mobile



zone distinction appeared on the crust in this part of the Precambrian shield, when the crust had thickened to more than 15 km, and that a permobile tectonic regime on a thin crust prevailed earlier. It has been shown by Fyfe (1976) that kyanites found along the western margin of the Chitradurga belt (around Ghatitihosahalli) have andalusite cores indicating that the kyanites are secondary after andalusite. This evidence, therefore, supports the view that an early low pressure metamorphism characterizes this Archaean terrain as elsewhere in the world. Such low pressure metamorphism is a reflection of steep geothermal gradients in a thin crust.

The thickness of the South Indian crust has been estimated to be about 36 km thick by deep seismic sounding (Kaila *et al* 1979). The geothermal gradient is found to indicate a temperature of 400°C at the crust-upper mantle interface (Gupta *et al* 1979). This would account for a rise of temperature of about 11°C/km. It has been estimated that the high-grade mineral assemblages noticed in the early greenstone belts are characteristic of a temperature of 650°C. If the corresponding crustal thickness was about 15 km, it could be deduced that around 3300 m.y. ago, the geothermal gradient was about four times steeper in South India.

The thickness of the crust 2000 m.y. ago when the Closepet granites were emplaced (Venkatasubramanian *et al* 1971) being in the range of 35 km, and the estimated crustal thickness prior to 3300 m.y. ago being in the range of 7 km would suggest a crustal thickening rate of about 1 km every 70 m.y. in the Archaean-Early Proterozoic time as evidenced from the geochemical data of the South Indian shield. It is also evident that almost the present thickness of the crust had developed 2000 m.y. ago.

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