

From the Roots to the Roof of a Granite: the Closepet Granite of South India

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INTRODUCTION

The formation and evolution of granitic provinces and batholiths are being increasingly studied, because of their importance for crustal evolution. These areas generally consist in several contemporaneous intrusions displaying common or similar geochemical and petrological features that are interpreted as cogenetic (e.g. Cobbing and Pitcher, 1972; Barnes et al., 1986). However, both geochemical and mineralogical compositions generally vary over a narrow range, from granodiorite to granite or trondhjemite. As the more mafic and less differentiated terms are lacking, reliable petrogenetic interpretation is difficult to constrain. In spite of these difficulties, granite petrogenesis is classically interpreted in terms of restite unmixing, fractional crystallization or magma mixing and mingling. Petrogenesis is deduced from indirect clues, such as enclave composition, trace element or isotope behaviour, and sometimes geophysical data. Interpretations generally infer the existence of magmatic reservoir in deep crustal levels, where most petrogenetic processes are supposed to operate. This magma chamber is supposedly linked to the superficial intrusions through a complex of dykes (Bussell, 1985; Barnes et al., 1986; Hecht et al., 1997). Unfortunately, few such magma chambers are known, and until now, only rare descriptions of both the deep magma chamber and the associated superficial intrusion in the same place do exist (D'Lemos et al., 1992; Sawyer, 1998).

The Dharwar craton in South India, displays a tilted section through an Archaean continental crust (Rollinson et al., 1981; Raase et al., 1986). It is intruded by several

elongated bodies of granite. Among them, the Closepet Granite extends over 400 km long, from deep crustal levels in the south to shallow levels in the north. It is made of several coalescent intrusions or feeding centres, sharing the same origin and emplacement mechanism. However, no significant contact or discontinuity can be observed on the field, and consequently it is difficult to distinguish each individual pluton. Thus, the continuous observation of all structural levels from the deep crust (granulite facies) to the upper levels (greenschist facies) offers an unique opportunity to reconstruct the anatomy of a granitic intrusion, from the root zones, through the magma chamber to the superficial intrusions. This crustal section also allows an investigation of the relationships between the different components of a granitic body.

For the last 10 years, the Closepet Granite has been the target of joint Franco-Indian investigations (Jayananda and Mahabaleswar, 1991; Jayananda et al., 1995; Moyen, 2000; Moyen et al., 1997, 2001a, 2001b, 2002). These investigations have been carried using a combination of field work, structural analysis (remote sensing, anisotropy of magnetic susceptibility), on one hand (Jayananda and Mahabaleswar, 1991; Moyen, 2000; Moyen et al., 2001b, 2002); and petrology and geochemistry, on the other hand (Jayananda et al., 1995; Moyen, 2000; Moyen et al., 1997, 2001a). Detailed results of the investigations are published elsewhere. The aim of this paper is to propose a synthesis of the data obtained on the formation and emplacement history of the Closepet Granite, with an emphasis placed on field data. Because of the unique opportunity given by the Closepet Granite to study in the same place all components of a granitic body, this also allows to discuss

contrasted granite emplacement modes at different crustal levels.

GEOLOGICAL SETTING

Like most Archaean domains, the Dharwar craton consists of three main units (Condie, 1994; Chadwick et al., 2000):

1) A TTG gneissic basement: the Peninsular Gneisses, the age of which ranges from 3.3 to 2.7 Ga (Taylor et al., 1984; Peucat et al., 1995).

2) Two sets of volcano-sedimentary greenstone belts, unconformably overlying the Peninsular Gneisses, which are dated at 3.5-3.0 Ga for the older set: the Sargur Supergroup (Nutman et al., 1992; Peucat et al., 1995) and 3.0 - 2.7 Ga for the younger one: the Dharwar Supergroup (Taylor et al., 1984; Anil Kumar et al., 1996; Nutman et al., 1996).

3) Late, K-rich granitic intrusions - among which the Closepet Granite is the most prominent- forming north-south elongated bodies (Drury and Holt, 1980), dated between 2.5 and 2.6 Ga (2.51 - 2.53 Ga for the southern Closepet Granite) (Friend and Nutman, 1991; Krogstad et al., 1991; Jayananda et al., 1995). They constitute the latest Archaean event in the Dharwar craton. It has been recently recognized that the Late Archaean granites represent a large part of the eastern Dharwar Craton -actually, true Peninsular Gneisses appear to be very uncommon in this area. This lead Chadwick et al. (2000) to collectively refer to all the Late Archaean granites in the eastern Dharwar Craton as "Dharwar Batholith". While this term does clearly emphasize the importance of Late Archaean granites in eastern Dharwar, it should not obscure the fact that this "batholith" is made of several, mapable granitic bodies with distinct petrological or geochemical characteristics. The Closepet

Granite is one of these bodies, and can be independantly studied.

Late Archaean metamorphism was associated with transcurrent deformation (Bouhallier et al., 1995). Metamorphic grade reaches granulite facies in the South (Fig. 1), and this metamorphism induced partial melting of the Peninsular Gneisses (Newton, 1990). Metamorphism and deformation are synchronous with the emplacement of the late granites (Drury and Holt, 1980; Jayananda and Mahabaleswar, 1991), which were emplaced perpendicular to the metamorphic isograds, along major shear zones.

A CRUSTAL CROSS-SECTION IN THE ARCHAEOAN CRUST

It has long been demonstrated (e.g. Rollinson et al., 1981) that the Dharwar craton represents a cross section of Late Archaean crust. The deeper levels are located in the south, whereas the top of the crust outcrops in the north. This conclusion is based on a set of geological evidences:

1) Metamorphism provides the strongest evidences. The metamorphic peak conditions progressively evolve (Fig. 1) from low grade greenschist facies (3.5 Kbar, 500°C) in the north, to granulites (6-7 Kbar, 700°C) in the south. When dated (Peucat et al., 1993), metamorphism always gives ages around 2.5 Ga, demonstrating that all P-T data refer to the same event, synchronous with granite emplacement. Thus, it can be assumed that metamorphic data summarized in Fig. 1 provide minimum estimate of the P-T conditions in the Archaean crust at the time of the Closepet batholith emplacement.

2) The field relationships between Closepet Granite and the surrounding basement provide additional evidence: in the south, the Peninsular Gneisses underwent

intensive migmatization, and the Closepet batholith displays transitional contacts with the migmatitic gneisses (Friend, 1984; Newton, 1990). On the other hand, to the north, the same granite shows sharp, intrusive contacts with unmigmatized gneisses (Chadwick et al., 1996).

3) In addition, the strain pattern has been mapped in greenstone belts at various structural levels in the Western Dharwar craton (Bouhallier et al., 1995; Chardon et al., 1996). The tectonic features observed in the south are interpreted as being the deeper part of structures whose shallower levels are exposed to the north.

THE CLOSEPET GRANITE

The Closepet Granite has long been recognized as a unique magmatic body (Drury and Holt, 1980). However, most work was focussed on its southernmost part, near the amphibolite-granulite transition (Friend, 1984; Allen et al., 1986; Jayananda et al., 1995, among others) and less work has been performed on its central and northern parts (Chadwick et al., 1996).

Based on field data (Fig. 1), we propose to distinguish the following zones in the Closepet Granite, following the terminology of Moyen et al. (2002):

Root zone

The root zone extends from the Cauvery river in the south to 13°N. In this zone, the Closepet Granite is mainly (> 80% volume) made of coarse grained porphyritic monzogranite, with subordinate clinopyroxene-bearing monzonite as large (1-100 m), rounded or elongate bodies, and pink or grey anatectic granites grading to gneisses through a thick (10 km) zone of intense migmatization, located near the

granite-basement contact (Fig. 2). Jayananda et al. (1995) and Moyen et al. (1997) described several evidences of mixing and mingling between all these components, demonstrating these magmas to be coeval. A striking feature of this zone is its heterogeneity : in addition to the diversity of magmatic facies, the granite also contains feldspar accumulations, decimetric microgranular enclaves, metric to decametric basement xenoliths, decimetric angular cumulate enclaves and biotite schlieren. All these elements are aligned and draw a strong magmatic foliation, which is interpreted by Jayananda and Mahabaleswar (1991) and Moyen et al. (in press) as syntectonic and contemporaneous with the granite emplacement.

Based on geochemical modelling, Moyen et al., (1997; 2001a) proposed the following petrogenetical model: (i) a mantle-derived, mafic magma intruded the gneissic crust and induced its partial melting; (ii) The mafic liquid underwent a small (5-10 %) amount of fractional crystallization; (iii) Both mantle-derived and crustal magmas mixed together, thus accounting for the main chemical and petrological features of the Closepet Granite. This zone is the deepest level where the granite can be observed, and is considered to be the root of the granite, where large scale interaction between the mantle derived magma and the lower crust took place.

Transfer zone

This zone extends from 13°N until the town of Kalyandurga (Fig. 1). Here too, the granite is a porphyritic monzogranite associated with pink and grey equigranular granites at its periphery. Again, the equigranular granites grade to the Peninsular Gneisses via a migmatitic zone, slightly narrower than in the root zone (5 km). But here, the monzogranite is less deformed (no

solid-state deformation) and bears few or no enclave, except in narrow, enclave-rich channels, several hundred metres wide (fig. 3). The enclaves are: (1) granulite-facies metapelites; (2) amphibole cumulates with adcumulate texture; (3) microgranular mafic enclaves (representing weakly differentiated magmas), showing evidence of mechanical mixing with the surrounding monzogranite; (4) K-feldspar accumulations. All these enclaves are similar to the rocks found in deeper levels (i.e. the root zone). The enclave-rich channels are affected by a syn-magmatic shear deformation, which has been still locally active when the monzogranite cooled to a sub-solid state (Moyen et al., 2002). The close association between enclave concentration and high-strain zones is evidenced on the map Fig.4.

This demonstrates that, in the transfer zone, magma ascent was concentrated in some restricted zones. These channels were then able to carry more efficiently denser enclaves from the bottom. Latter on, they preferentially localized the deformation, leading to the development of these high-strain, enclave-rich channels.

In spite of the heterogeneity, the same porphyritic monzogranite is found in both the root and the transfer zones, without any contact or interruption. This physical continuity demonstrates that (at least in this part) the Closepet granite emplaced as a unique, well-identified magmatic suite rather than as a tract of individual, unrelated plutons, as sometimes assumed (Chadwick et al., 1996).

Intrusion zone

North of the transfer zone is found a 10 km-wide zone with no or few outcrops of granites, that has been described as a “magmatic gap” (Moyen, 2000). The

intrusion zone extends north of the gap, from Rayadurga to the Proterozoic cover or the Deccan Traps (15°30N, Fig. 1). In this zone, the granite consists of small (10 to 50 km long) elliptical intrusions. The contact with the Peninsular Gneisses is sharp with no migmatization near the contacts. Each individual intrusion is granitic in composition and is petrographically and geochemically similar to the more differentiated facies from the root and transfer zones (Fig. 5): the mafic (clinopyroxene monzonite) and intermediate (porphyritic monzogranite) facies are missing. The texture of the granites in these intrusions is medium grained and equigranular, with very scarce weakly porphyritic facies. In addition, the intrusions contain very few enclave or schlieren, except in some kilometre-size zones (e.g. immediately north of the “gap”, close to Rayadurga: Fig. 6). These areas probably correspond to feeder zones of the intrusions, were enclave-rich magma rising from below filled the granitic plutons. The granites are generally isotropic with no evidences of magmatic deformation; however, the intrusions have an elliptic shape, with longer axis parallel to the regional foliation. Anisotropy of Magnetic Susceptibility (AMS) was used to determine a “magnetic foliation” and “magnetic lineation” in the otherwise isotropic granites of the northern intrusion; Bouchez (1997, 2000) showed that AMS allows to reliably characterise the fabric of granitic rocks, even when no mesoscopic fabric is seen on the field. AMS study (Moyen et al., 2002) in one of the intrusions (the Hampi Granite) showed that the magnetic foliation in this intrusion is vertical, parallel to the long axis of the intrusion, and is associated with an horizontal lineation (Fig. 7). These structures show that the superficial intrusions emplaced in the same transcurrent tectonic setting as

the main mass (root + transfer zone) of the Closepet granite.

In spite of these differences, these intrusions belong to the Closepet batholith: (i) on the field, they are located in the prolongation and continuity of the root and transfer zones (Fig 1): the map pattern of the Closepet Granite bends parallel to the regional trend of foliation (Drury et al., 1984); (ii) their age (2.57 Ga; Nutman et al., 1996) is similar to those obtained in the southern part with different geochronological methods (2.51 to 2.53 Ga ; Jayananda et al., 1995 and Friend and Nutman, 1991); (iii) the mineralogical and chemical compositions, including the differentiation trends for both major and trace elements (Fig. 5), of this granite are the same as those of the differentiated facies from the root zone (*see below*). As the three zones belong to the same magmatic history, the significance of the magmatic gap must be addressed.

PHYSICAL CONTINUITY THROUGH THE GAP

The geological map of the "magmatic gap", between Kalyandurg and Rayadurga (Fig. 8) shows the following features from south to north :

(I) To the south, the main mass of the Closepet granite (transfer zone) is prolonged by apophyses of porphyritic monzogranite within the Peninsular Gneisses. This part of the gap is also characterised by the abundance of 10 to 50 m wide dykes of pink and grey heterogeneous equigranular granites, intrusive into the basement gneisses.

(II) In the middle of the gap, the porphyritic monzogranite is not exposed. It only remains as a network of heterogeneous dykes of either grey or pink granite in Peninsular Gneisses.

(III) Close to Rayadurga, greyish granite becomes prominent. It consists in an enclave and schlieren-rich granite that rapidly (few hundred metres) and progressively grades to an homogeneous granite with very scarce surmicaceous enclaves and schlieren. The enclaves in turn completely disappear few hundred metres further north in the intrusion zone (Fig. 8).

These observations show that the root-transfer zone is linked to the intrusion zone by a network of granitic dykes; both zones are actually physically connected. This again demonstrates that the whole Closepet Granite is indeed a single magmatic object. The gap only corresponds to a drastic change in emplacement mode and granite-basement relationships.

GEOCHEMICAL ARGUMENTS

In the intrusion zone, granites are homogeneous in both mineralogy and geochemistry (see Harker plots, Fig. 5) : all are differentiated, but silica content varies only in a small range ($\text{SiO}_2 = 68-75\%$). The compatible element contents are low in the northern granites, and incompatible elements contents are high. This characteristic, which is frequent in granitic suites, makes the geochemical interpretation difficult, because few evidences of the early petrogenetic processes are left. As a physical link has been established between northern and southern Closepet, a comparison between both parts is allowed. Major and trace element analysis have been published elsewhere (Oak, 1990; Jayananda et al, 1995; Moyen, 2000; Moyen et al., 2001a). In Harker's plots (Fig. 4) for major and trace elements, the compositions of the granites from the intrusion zone overdraw the trends of the southern Closepet batholith.

Isotopic analysis for Sr and Nd have been done on all zones of the Closepet granite (Tab. 1). Samples from the root zone were analyzed by Jayananda et al. (1995); samples from the transfer zone, gap and intrusion zone have been analyzed in Laboratoire Magmas et Volcans at Clermont-Ferrand University, France in 1999; the analytical procedure is described elsewhere (Moyen, 2000). Major and trace element analysis for these samples are found in Moyen (2000).

Sr and Nd isotopic ratios are classically displayed as “initial ratios”, i.e. the isotopic ratio that existed at the time of the rock formation. Additionally, for Nd isotopic ratio, an “ $\epsilon_{Nd}(T)$ ” is calculated; $\epsilon_{Nd}(T)$ corresponds to 10 000 times the difference between the initial $^{143}\text{Nd}/^{144}\text{Nd}$ ratio, and the $^{143}\text{Nd}/^{144}\text{Nd}$ ratio of the mantle at the time of rock formation.

An $\epsilon_{Nd}(T)$ vs. $I_{Sr}(T)$ plot allows to represent graphically both values. In such a diagram, mantle-derived rocks plot in the “mantle array” in the upper-left quadrant; old crustal rocks are in the lower-right quadrant. Hybrid rocks will, of course, plot along a mixing line (generally an hyperbola) in between. This is the case for most samples analyzed in the Closepet Granite, except for two of them (BH 335 and BH 342). Both samples have impossibly low Sr isotopic ratios (lower than the depleted mantle), that point to latter disturbance of the isotopic system. Moyen (2000) proposed that this disturbance has been caused by lower Proterozoic hydrothermal events, synchronous with the formation of Cuddapah basin or granulite facies metamorphism in the south of the Indian Peninsula.

Using this diagrams for Closepet Granite samples (Fig. 9) shows that samples from the transfer, gap and intrusion zones fall in the same area as the samples in the root zone (except for the two samples with impossibly low $^{87}\text{Sr}/^{86}\text{Sr}$) suggesting that the isotopic

signatures of the upper zones are generated by the same processes that operated in the root zone, which again points to the genetic links between all zones of the Closepet batholith.

This leads to two important conclusions: (1) Such a geochemical and isotopic similarity is not accidental or fortuitous, and demonstrates the identity between both parts of the Closepet batholith. (2) In the northern part, trends are restricted to the more evolved and differentiated rocks of the suite. They are the same as for the evolved facies in the south, and consequently they can be considered as generated through the same mechanisms. As the trends are more complete in the south, they provide better constrains for the petrogenetic interpretation, and they have been interpreted (Jayananda et al., 1995; Moyen et al., 1997) as mainly due to magma mixing (*see above*). Thus north of the gap, the trends have also been interpreted in term of magmatic mixing.

MEANING OF THE GAP

The so-called “gap” appears to be a major feature in the Closepet Granite. While the granites north and south of it are chemically identical, corresponding to emplacement of the same magmas, the textures in both sides are extremely different. To the south, granites are heterogeneous, enclave-rich and deformed, while in the north, they are homogeneous, enclave-poor and apparently undeformed. The gap appears to correspond to a dramatical change in emplacement modes.

Based on the previous arguments, we propose the following interpretation (Fig. 10): at 2.5 Ga, mantle-derived magmas intruded the crust and interacted with it as described above and evolved within the deep crust (southern Closepet) (Jayananda et al.,

1995; Moyen et al., 1997, 2001a). This part operated as a large magma chamber (although it is unlikely, for mechanical reasons, that the whole root zone was liquid at the same time), giving rise to a large petrographic diversity (from monzonites to granites). Because of the magmatic processes operating, the root zone is also rich in all kinds of inclusions: K-feldspar accumulation, schlieren, restitic enclaves, microgranular mafic enclaves, xenoliths, etc. In the prominent phenocryst-rich monzogranite, both the crystal and the inclusion load is high, resulting in highly viscous magmas. In contrast, the anatectic magmas at the margins of the massif are more differentiated and phenocryst-poor, with few inclusions; consequently their viscosity was comparatively low.

Ascent of these magmas through the crust happened in different ways: mass movement for the porphyritic monzogranite in the center, dykes and sheets of anatectic facies in the periphery. North of the gap, however, granitic magmas are emplaced as small plutons filled by narrow feeder zones: the gap actually corresponds to an abrupt change in emplacement modes.

The ascent of the deep-generated magmas has been stopped at the gap level. As discussed by Moyen et al. (2001b), the most likely cause is a change in basement's rheology. Since no difference in lithology is observed, and since this occurred at a depth around 10 km, it is proposed that this level corresponded to a place where a transient brittle behaviour in the crust resulted from the magmatic overpressure, driven by magma squeezing at a deeper level (Williams et al., 1995), thus resulting in a change in emplacement modes, from ductile to locally brittle conditions (Moyen et al. 2002). Such an interpretation is also supported by the contrasting granite-basement relationships: south of the gap, the

basement is migmatized and injected, whereas sharp intrusive contacts are observed in the north.

At the gap level, all high density and highly viscous materials (less differentiated and/or rich in solid load) were stopped and remained in deeper levels. The upward movement of the magma continued only through a network of dykes, allowing only low-viscosity materials to transit through the narrow dykes. These low viscosity materials were the differentiated, enclave- and phenocryst-poor, magmas. They ascended into the upper crust where they filled large pockets constituting typical plutons. Studies of similar clusters of intrusions suggest that the opening of such pockets in upper crustal levels is deformation-controlled (Lagarde et al., 1990; Vigneresse, 1995), which explains the elliptical, elongated shape of the northern intrusions. In this aspect, the gap has operated as a filter, allowing only the less viscous material to move upwards.

CONCLUSION

The Closepet granite appears to be an excellent case-study, showing all parts of a typical granitic body: (1) the roots, where magma is generated, interacts with the basement and evolves; (2) the magma chamber and transfer zone, where magma moves upwards; (3) the intrusions with feeder dykes. This makes the Closepet Granite an outstanding "natural laboratory" to study magmatic processes operating in a granitic body. It's also a unique example where the hypothesis on formation and evolution of granitic intrusions can be tested directly on the field, rather than through indirect methods.

Some problems, however, remain to be assessed regarding the origin of the Closepet Granite. One is the problem of the size: even if the processes operating are the same all

along the Closepet Granite, such a huge body probably needs several feeding zones, or even a continuous band of magma input zones, even if the subsequent evolution is similar all along the granite. A second question is the unique nature of the Closepet granite within the Dharwar craton: even if granitic bodies are common in the area (Drury and Holt, 1980; Krogstad et al., 1991; Chadwick et al., 1996), none of them reaches the same size, nor displays the same degree of crust-mantle interaction. The source of both the large quantity of observed magma, and the considerable amount of heat needed remains unknown. This calls for further investigations on the geodynamical setting and evolution of the Late Archaean Dharwar Craton.

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Figure captions

Fig. 1. Geological map of the Closepet batholith. Metamorphic conditions (Moyen et al., 2002) are shown. Ramanagaram was formerly known as “Closepet”. Locations of sites referred to in this work (field photograph or isotopic analysis - see Table 1) are shown (the common prefix “BH” is omitted).

Fig. 2. Synthetic, schematic cross-section in the root zone of the Closepet granite, showing the relationships between the different facies and the deformation. This synthetic section is drawn from serried sections at different latitudes, from Cauvery river (12°10') to Magadi (13°00'). No vertical scale; this drawing is only intended as a graphical description of the geologic relationships.

Fig. 3. (a) Schematic cross-section of the Closepet Granite at the latitude of Pavagada (14°N). No vertical scale, same comment as figure 2. The Closepet Granite is mainly made of a weakly porphyritic granite with occasional C/S fabric or shear zone, but in one area located close to the eastern boundary of the Closepet Granite, a high-strain zone is rich in enclaves of all kinds, originating in the deeper crustal levels. (b) Slightly porphyritic, homogeneous granite (BH 271, 20 km west of Pavagada). (c) C/S fabric (BH 100, Pavagada quarry). (d) enclave-rich corridor (BH 100, Pavagada quarry, looking north). Scale bar is 10 cm in (b) and (c), and 1m in (d). (b) and (c) are pictures of a horizontal plane.

Fig.4. Map of the Closepet Granite transfer zone, showing the relationship between the shear zones (from Moyen et al., 2002) and the basement and microgranular enclaves (mapped by Oak, 1990). Geological contours from Moyen et al., 2002.

Fig. 5. Harker's plots for selected major and trace elements. Although some scatter of data is observed for mobile elements (K_2O), the following features are observed:

(1) good linear correlations for both trace and major elements, that have been interpreted by Moyen et al. (2001a) in term of magmas mixing (see discussion in text).

(2) superposition of the trends on both sides of the gap, emphasising the similarity of both groups of rocks and pointing to a common origin and evolution.

Fig.6. Map of the southernmost of the superficial intrusion, with localisation of basement enclaves (Oak, 1990). The enclaves are located (1) close to the contacts, (2) near Rayadurga at the boundary with the gap, and (3) in specific zones within the intrusion that are interpreted as feeder zones.

Fig. 7. AMS foliations (a) and lineations (b) in the Hampi intrusion. Tunghabhadra river is represented by the SSW-NNE heavy line; Hampi intrusion is dark grey, whereas the surrounding, slightly porphyritic pink granite is in light grey (Moyen et al., 2002).

Fig. 8. Geological map of the gap in Rayadurga - Kalyandurga area. Numbers refer to photographs on the right, showing the progressive transition from the "feeder dykes" to the homogeneous intrusion of Rayadurga. Parts I, II, III are described in text.

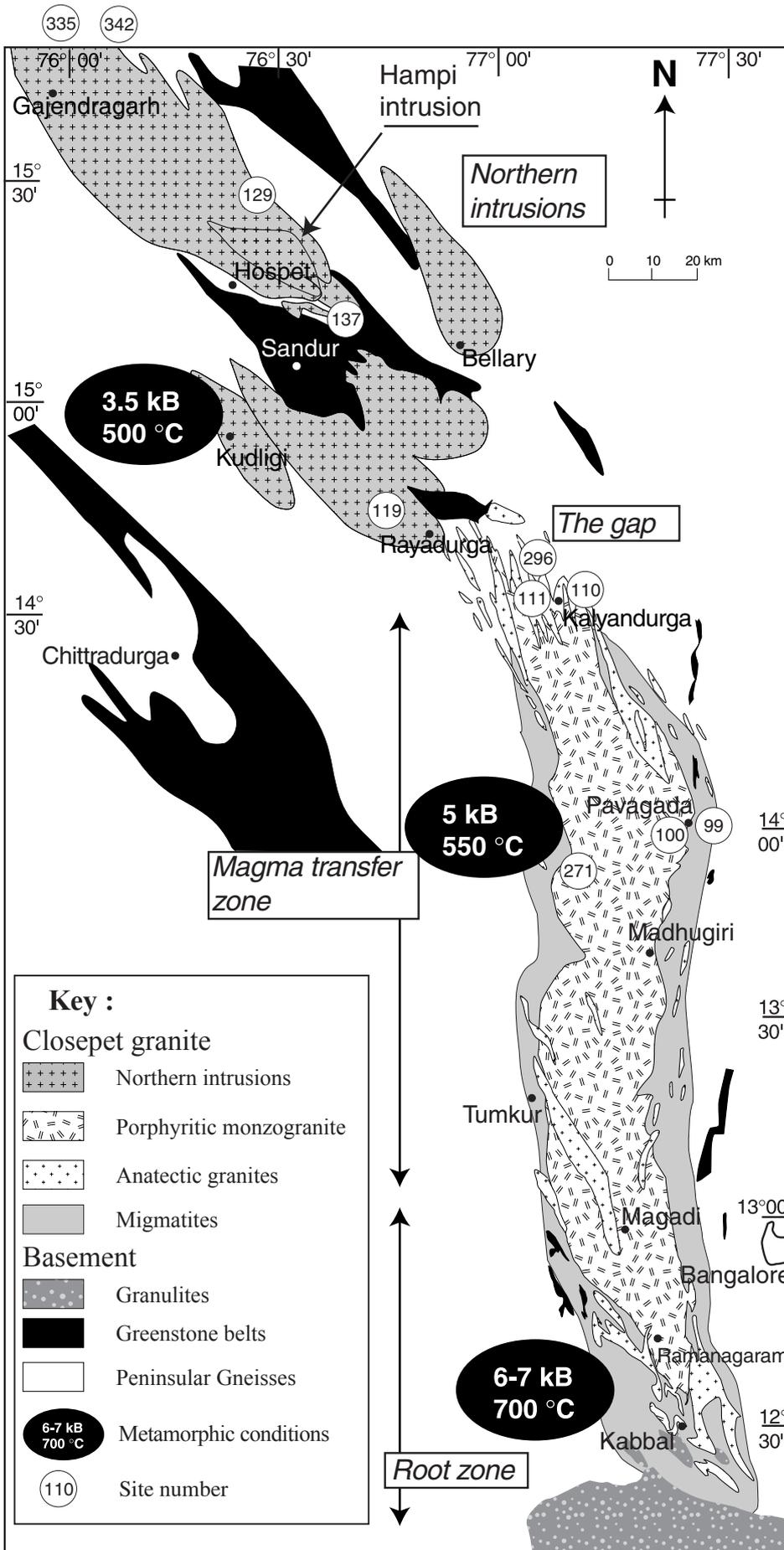
R: Rayadurga; K: Kalyandurga.

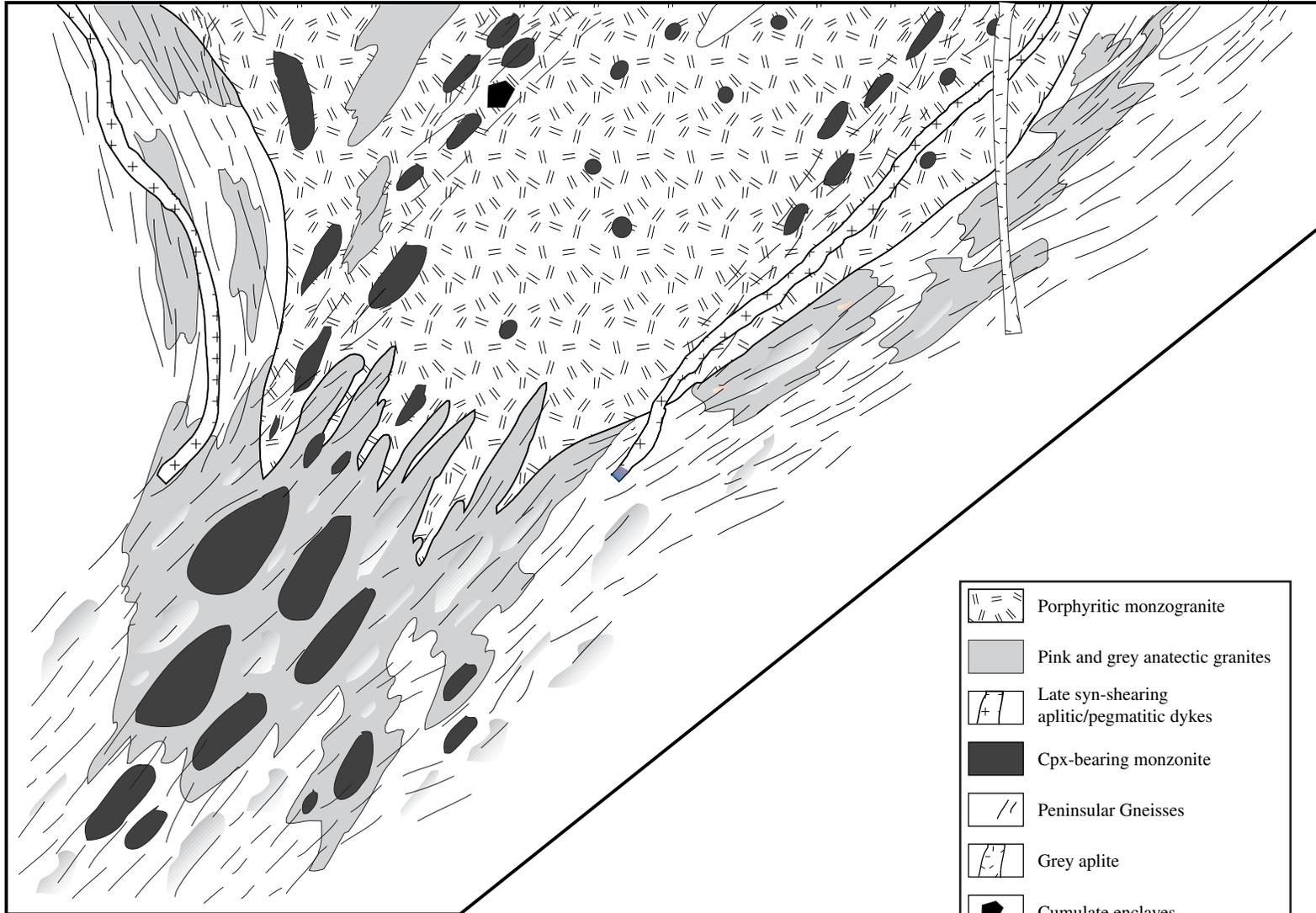
Fig.9. isotopic diagram I_{Sr} vs. ϵ_{Nd} for samples in the transfer zone (square), gap (triangles) and northern intrusions (circles) zones. The fields for the root zone and for the Peninsular Gneisses (and anatectic granites) have also been drawn. (Jayananda et al., 1995). Comments in text.

Fig. 10. 3D drawings, showing the emplacement history of the Closepet Granite as deduced from the present study. (1) Mafic, mantle derived magmas intruding the crust induce melting of the gneisses. (2) Both magmas mix, generating the porphyritic monzogranite. Since this occurs syntectonically, a vertical foliation develops. (3) Intersitial liquids are expelled to the top and fill pockets that will form the northern intrusions. Enclaves from the root zone rise in the main shear zones (4) The deformation is still active while the granite cools and solidifies.

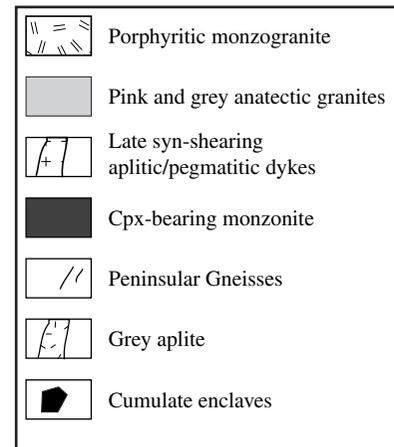
Table caption:

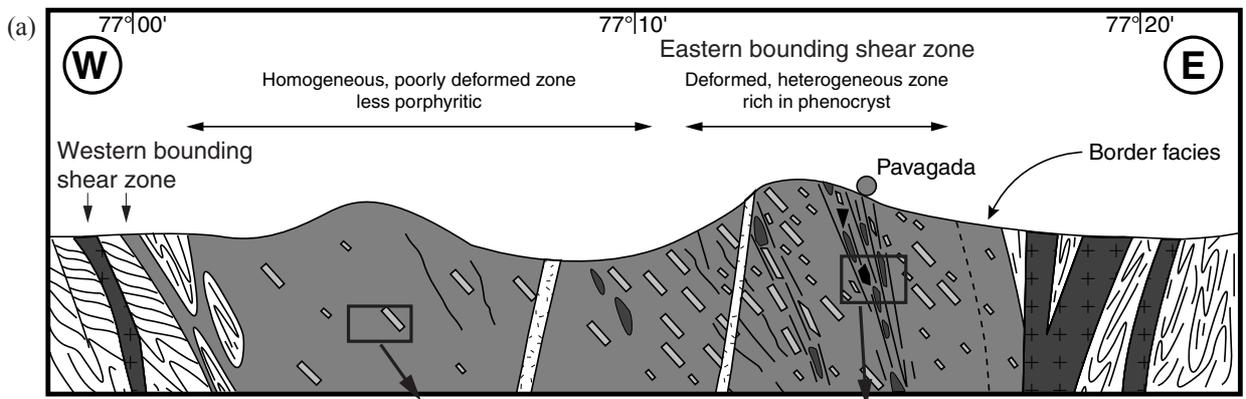
Table 1. Isotopic analysis for samples of the Closepet Granite. Sample location in Fig. 1: numbers in the form BH296a, b, c, refer to different samples picked in the same site (in this case site BH 296).



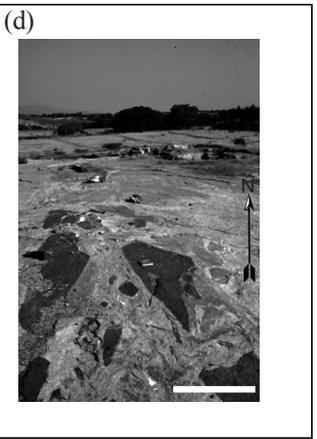
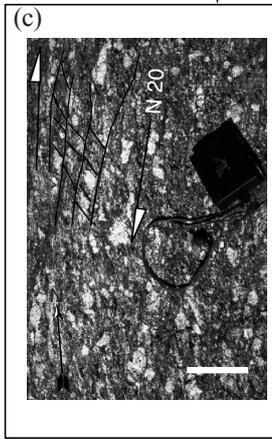
W**E**13° N
(Magadi)12°30
(Kabbal)12°10
(Cauvery river)

2 km

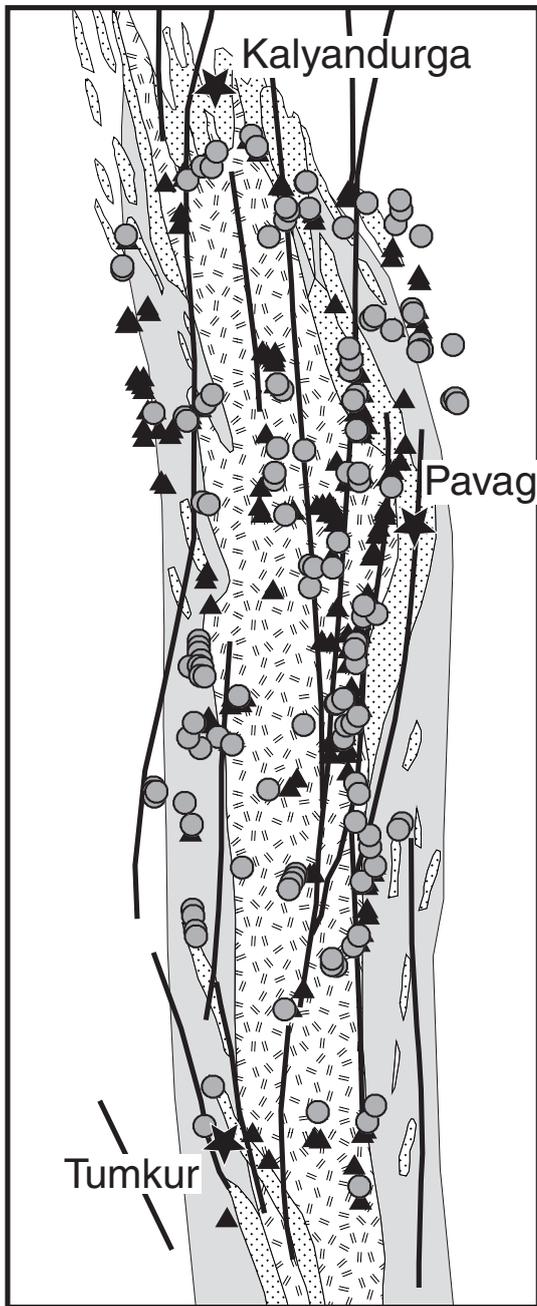
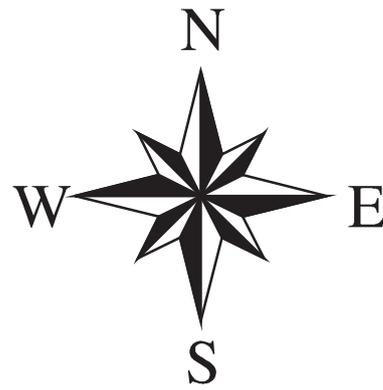




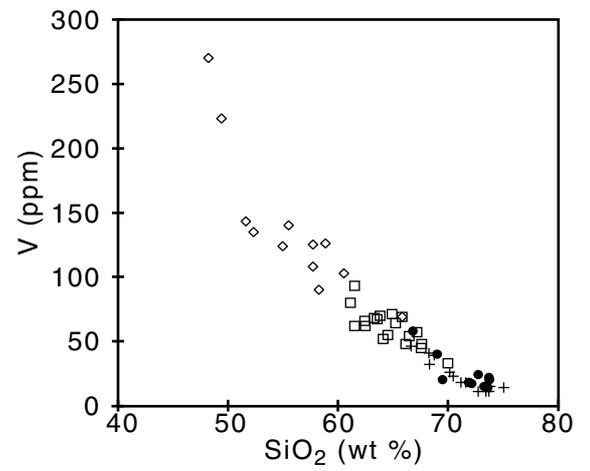
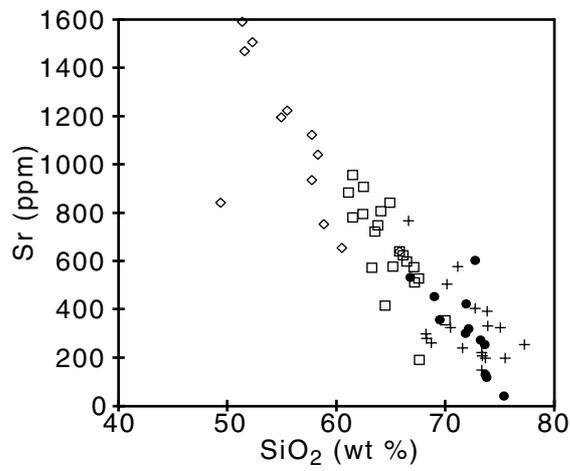
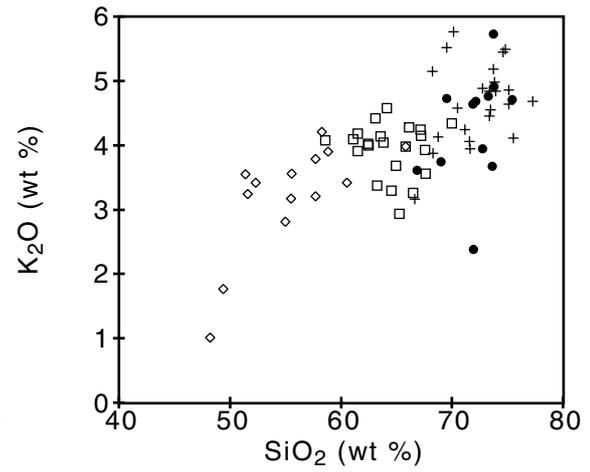
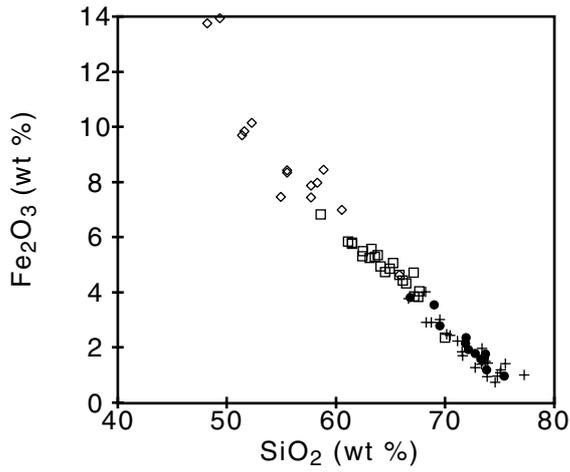
- Gneissic basement
- Porphyritic granite
- Pink granite
- Cpx-bearing monzonite
- Cumulate
- Schlieren
- Grey aplite



20 0 20 40 Kilometres

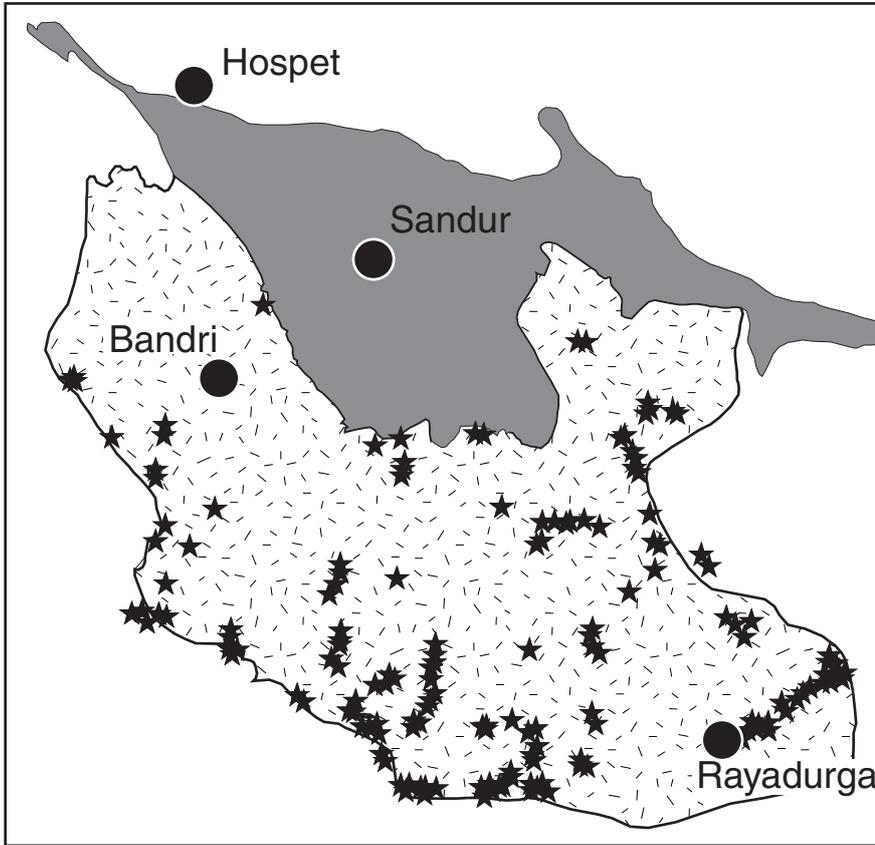


-  Shear zone
-  Porphyritic monzogranite
-  Anatectic granites
-  Migmatites
-  Peninsular gneisses
- Enclaves:**
 -  Gneissic xenolith
 -  Comagmatic dioritic enclave

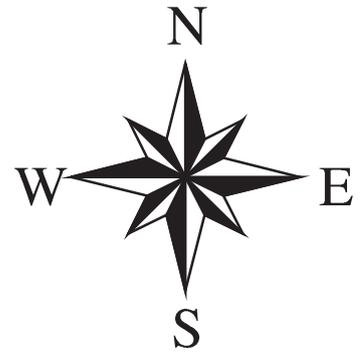


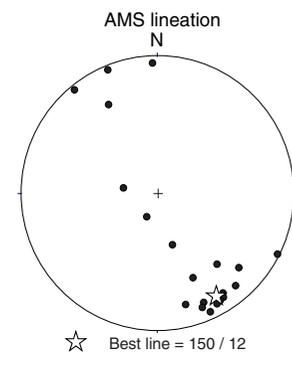
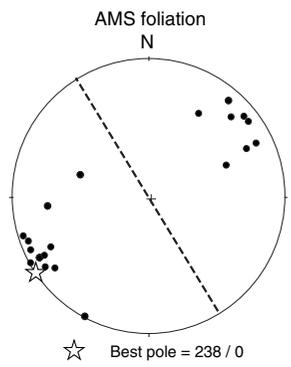
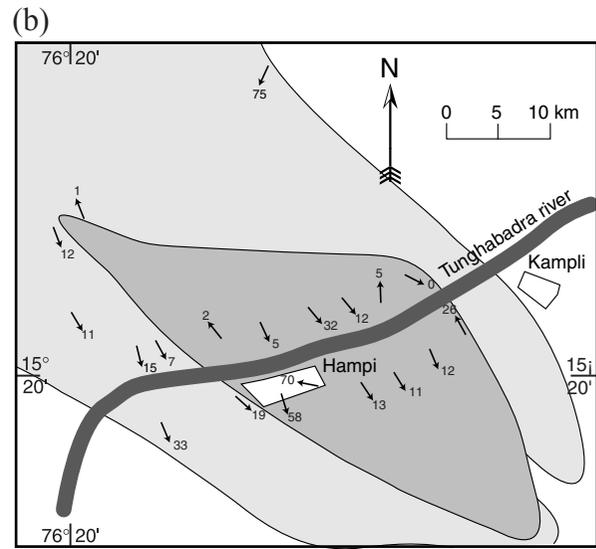
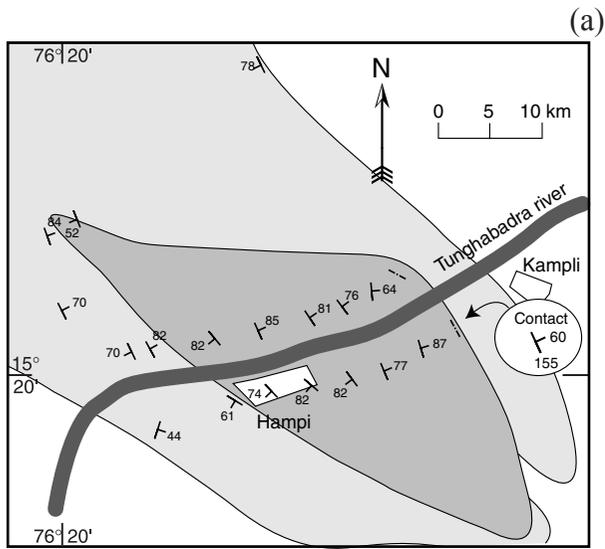
<u>South of the Gap :</u>	<u>North of the Gap :</u>
◇ Cpx-bearing monzonite	● Various granites
□ Porphyritic monzogranite	
+ Anatectic facies	

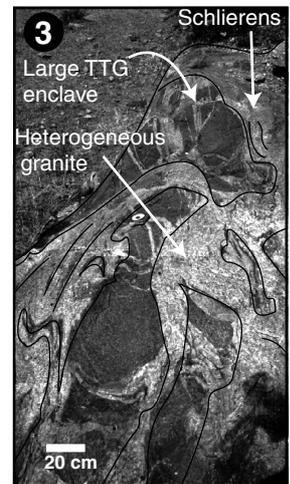
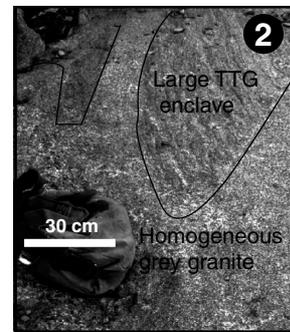
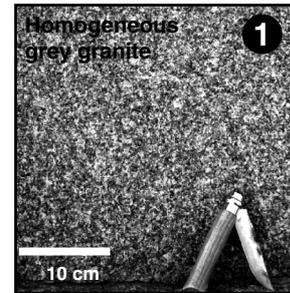
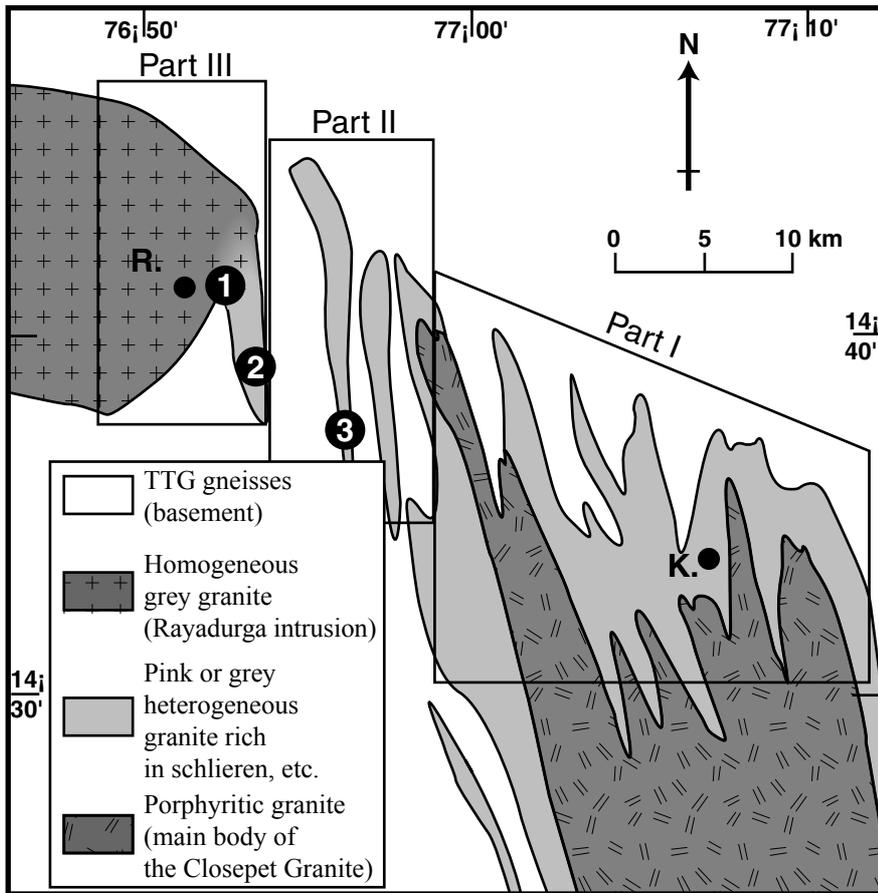
20 0 20 40 Kilometres

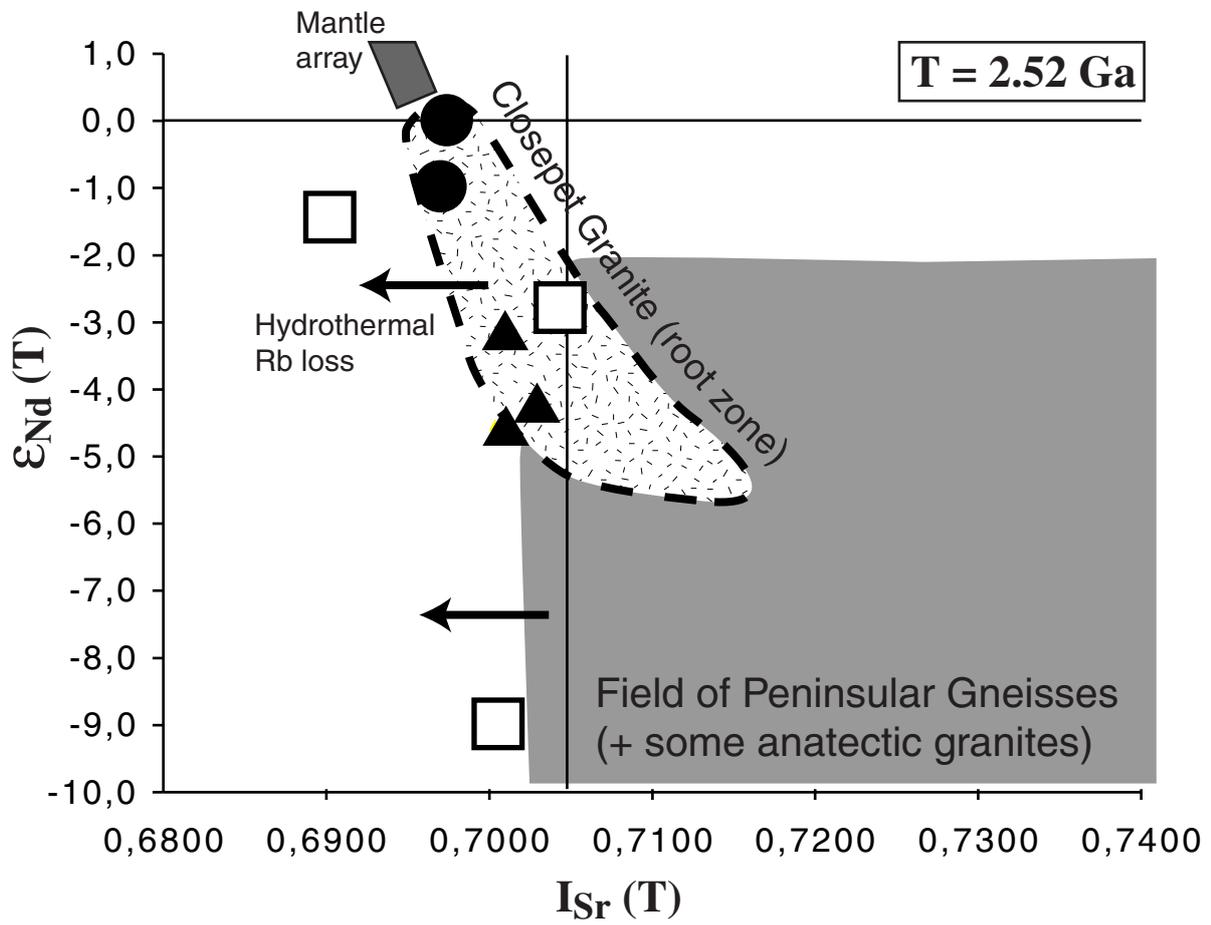


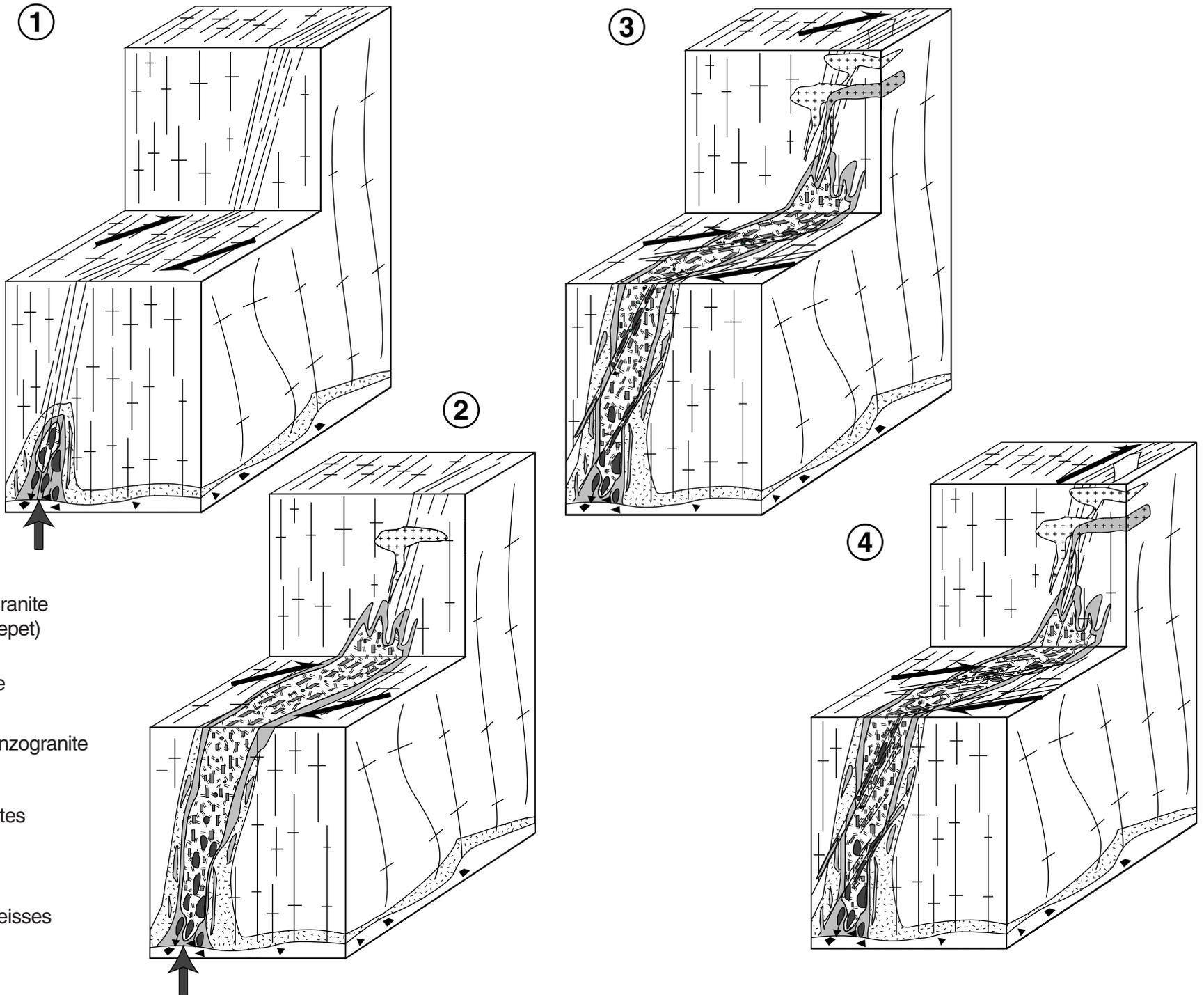
- ★ Basement enclave
- Sandur Schist Belt
- ▨ Granite
- Peninsular Gneisses

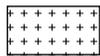
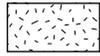
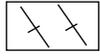










-  Equigranular granite (northern Closepet)
-  Cpx-monzonite
-  Porphyritic monzogranite
-  Pink & grey anatectic granites
-  Migmatites
-  Peninsular Gneisses

Sample	Rb (ppm)	Sr (ppm)	87Rb/86Sr	87Sr/86Sr	error	$I_0(T)$	Sm(ppm)	Nd(ppm)	147Sm/144Nd	143Nd/144Nd	error	(e)	(T)	T_{DM} (Ga)	
<u>Transfer zone</u>															
	<i>ICP-MS data</i>		<i>Ratio calculated from ICP-MS data</i>												
BH99	291	510	1,65	0,7645	12	0,7043			0,0971	0,510857	8	-34,78	-2,7	2,977	
BH110b	64	153	1,21	0,7346	13	0,6905	5,1	16,5	0,1874	0,512409	8	-4,51	-1,5	4,244	
BH111	141	287	1,42	0,7523	10	0,7006	5,9	45,2	0,0793	0,510244	9	-46,74	-9,0	3,270	
<u>"The Gap"</u>															
BH296a	73	594	0,36	0,7133	11	0,7004	7,1	40,9	0,1053	0,510901	9	-33,92	-4,5	3,140	
BH296b	173	463	1,08	0,7403	10	0,7010	13,8	76,4	0,1093	0,511038	9	-31,25	-3,2	3,064	
BH296c	175	496	1,02	0,7400	11	0,7028	12,0	91,9	0,0792	0,510481	8	-42,12	-4,3	3,003	
<u>Northern intrusions</u>															
BH335	214	203	3,05	0,8080	11	0,6969	3,3	20,8	0,0947	0,510906	7	-33,82	-1,0	2,856	
BH342	156	243	1,86	0,7652	7	0,6976	4,4	35,1	0,0748	0,510634	8	-39,13	0,1	2,746	
BH119		130		0,9207	10		9,4	57,2	0,0996	0,510882	9	-34,29	-3,1	3,009	
BH129a		253		0,7501	11		3,5	20,3	0,1041	0,510836	11	-35,19	-5,4	3,195	
BH137a		453		0,7407	10		7,3	49,2	0,0893	0,510783	9	-36,22	-1,7	2,882	

Abstract : The Dharwar craton exposes a natural cross-section of the continental crust. This crust has been intruded during the Late Archaean by large volumes of granites. One of these is the Closepet Granite, which outcrops at structural levels from deep (corresponding to paleopressures of 7-8 Kbar) to shallow (2-3 Kbar) crust. This cross-section allows the study of all components of this granite: the root zone, displaying strong crust-mantle interaction, resulting in highly heterogeneous, enclave-rich monzonitic to granitic magmas; the transfer zone, with inferred upward movement of these magmas; and a rheological interface in the shallow crust at which ascent of the magmas was arrested. At this level, only the less viscous (differentiated and enclave-free) magmas were able to rise through a network of dykes and fill small pockets, forming typical, elliptic granitic intrusions (the “intrusion zone”).