Tectonic episodes in the basement of KG Basin as deduced from Geochronological studies

Piyush Gupta*, S S Rathore, A N Sarkar
KDM Institute of Petroleum Exploration, ONGC, Dehradun

piyush@ongc.co.in

Keywords

KG Basin, Basement rocks, Rb-Sr/ Sm-Nd ages, Tectonic episodes

Summary

This paper presents new geochronological findings based on Rb-Sr and Sm-Nd dating of igneous and metamorphic basement encountered in Krishna-Godavari Basin, East Coast of India. In KG Basin, emplacement ages of ~1900 Ma for charnockites and khondalites have been obtained, whereas emplacement ages of ~1400 Ma have been obtained for alkaline intrusives. In addition, later stage metamorphic ages of ~1100 Ma and ~500 Ma have also been obtained from the basement of KG Basin. The ~1.9 Ga ages in the EGB establishes a new upper age constraint for charnockites and khondalites in the basement of KG Basin and suggest towards a possible Paleoproterozoic connection of South Indian Cratons with North China Craton, based on similar ages reported from the latter. The ~1.4 Ga ages of alkaline magmatism and subsequent metamorphism during two high grade tectonothermal events correlated to Grenvillian orogeny at ~1.0-1.1 Ga and Pan-African orogeny at ~0.5-0.6 Ga calculated from studied wells attempts to delineate the tectonic-tectonothermal episodes for the crustal evolution of EGB during Mesoproterozoic-Neoproterozoic times, which suggests rifting of Southern India-Antarctica during Columbia break up and opening of an oceanic basin, subsequent alkaline magmatism and closing of rift during Rodinia assembly. The study further suggests the assembly of Gondwana through Pan-African orogeny in Neoproterozoic-early Palaeozoic times in the basement of KG Basin.

Geological Framework

The Krishna-Godavari Basin is a pericratonic basin, located in the Eastern coastal margin of the Indian shield. The basin having NE-SW alignment extends over an area of 15,000 sq.km onland and about 25,000 sq. km offshore up to 1000 m isobaths and covers mostly the coastal tract of Andhra Pradesh from Vishakhapatnam in the north to Ongole in the south. The basin originated in Jurassic times due to extensional tectonics and has evolved in two phases – rift phase and drift phase (Rangaraju and Rao, 1986). The rift processes resulted in northeast-trending faulted horsts and grabens, which were filled with Mesozoic sediments.

The Precambrian igneous and metamorphic complex forms the basement of this basin, which comprises of rocks belonging to the adjacent Eastern Ghats Belt (EGB). The EGB is a NE-SW trending arcuate Precambrian fold belt of high-grade metamorphic rocks, extending over a length of ~600 km along the east coast of India from north of Cuttack in Orissa to Nellore in Andhra Pradesh. The belt has a maximum width of 100 km in the northern part and less than 20 km in the south where it is concealed under the Phanerozoic cover. (Sharma, 2009)
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The EGB represents a granulite terrain widely considered to have formed during orogenic collisions between India and Antarctica (Mezger and Cosca, 1999). The belt has a polychronous evolutionary history (Mezger and Cosca, 1999; Rickers et al., 2001; Upadhyay et al., 2006; Simmat and Raith, 2008) and is dominated by a sedimentary succession hosting intrusives of charnockites, enderbites, basic granulites, massif anorthosites, megacrystic granitoids and alkaline rocks, all metamorphosed at granulite-facies condition.

Due to lack of basement rock outcrop and thick Phanerozoic cover, the geochronological data in the KG Basement i.e. Eastern part of the EGB remains unscathed scanty. In this paper, we attempt to resolve the geochronological constraints of the Eastern part of EGB encountered in the basement of KG Basin and establish a genetic linkage of the crustal domain with the rest of Eastern Ghats Belt, through Rb–Sr and Sm–Nd dating of Precambrian basement encountered in the drilled core samples of onshore wells.

Methodology

The basement samples from 05 onshore wells i.e. Draksharama–A, Endamuru–A, Kaza–B, Lamellapadu–A and Mandapeta–A were taken up for the study (Fig. 1).

For Rb-Sr and Sm-Nd isotopic analysis, about 100 mg powder sample was digested in a mixture of acids as per the procedure detailed above. The Rb-Sr and Sm-Nd mixed spike were added to the sample prior to the dissolution to ensure complete mixing. The Rb, Sr, Sm and Nd elements were separated using ion-exchange chromatography as per the in-house established procedure (Rathore et al., 2010).

The isotopic analyses (Rb, Sr, Sm and Nd) were carried out on Thermal Ionization Mass Spectrometer (TIMS) as per in-house procedure (Rathore et al., 2010). The measured Sr and Nd isotopic ratios were normalized to the values of 0.1194 (\(^{86}\text{Sr}/^{88}\text{Sr}\)) and 0.7219 (\(^{146}\text{Nd}/^{144}\text{Nd}\)), respectively. During the analyses, the reference standards i.e. SRM-987 for Sr and JNDi for Nd were analysed to monitor the stability and accuracy of the measurements.

Results

The petrographic study indicates varied lithology for the basement samples. The basement encountered in well Draksharama–A appears to be hypersthene andesite with the lower part being gabbro, whereas that in well Endamuru–A were identified as hypersthene bearing granulites. The metamorphic basements from Kaza structure (wells Kaza–B and Kaza–C) represent schists and gneisses, being quartz biotite schist and garnet biotite gneiss, respectively. The basement from well Lamellapadu–A and that from well Mandapeta–A represent the most interesting lithologies, being charnockite and khondalite, respectively. The results of Rb–Sr and Sm–Nd whole-rock and minerals geochronology have been summarized in Table 1. A representative isochron of obtained ages from well Lamellapadu–A is presented in Fig. 2 for reference.

Discussion

The Eastern Ghats Belt (EGB) of peninsular India represents a granulite terrain widely considered to have formed during orogenic collisions between eastern India and East Antarctica (Mezger and Cosca, 1999). Some workers (Rogers and Santosh, 2002; Zhao et al., 2004;) have also suggested that the composite Mesoarchaean Dharwar-Bastar and Singhbhum craton probably was a part of supercontinent Columbia wherein the Dharwar craton was continuous with the North China craton based on similar formation ages of Neoarchaean crust (tonalite-tronjhemite-granodiorite) followed by high-
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grade metamorphism within a short span of ~50 Ma at ~2.5 Ga. Nevertheless, the EGB has a polychronous evolutionary history (Mezger and Cosca, 1999; Rickers et al., 2001; Upadhayay et al., 2006; Upadhyay, 2008) and is dominated by a sedimentary succession hosting intrusives of charnockites, enderbites, basic granulites, massif anorthosites, megacrystic granitoids and alkaline rocks all metamorphosed at granulite-facies condition. In the present study, Precambrian basement from five wells of KG Onshore has been taken for Geochronological studies through Rb-Sr and Sm-Nd dating.

Table 1: Summary of obtained ages from the studied samples of wells from KG Basin and their interpretations:

<table>
<thead>
<tr>
<th>Sl No</th>
<th>Well</th>
<th>Structure</th>
<th>Core Depth (m)</th>
<th>Lithology</th>
<th>Crystallization ages obtained (Ma)</th>
<th>Metamorphic ages obtained (Ma)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Draksharama-A</td>
<td>Draksharama High</td>
<td>3142.00-3145.00m</td>
<td>Hypersthene andesite/gabbro</td>
<td>1424±57 (Rb-Sr)</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>Endamuru-A</td>
<td>East Godavari Sub Basin</td>
<td>2183.48-2185.78m</td>
<td>Hypersthene Granulite</td>
<td>1357±45 (Sm-Nd)</td>
<td>1100±31 (Rb-Sr WR); 557±24 (Rb-Sr WR+ minerals)</td>
</tr>
<tr>
<td>3</td>
<td>Kaza-B</td>
<td>Kaza High</td>
<td>2142.50-2145.00m</td>
<td>Quartz Biotite Schist</td>
<td>-</td>
<td>499±18 Ma (Rb-Sr WR)</td>
</tr>
<tr>
<td>4</td>
<td>Kaza-C</td>
<td>Kaza High</td>
<td>2160.00-2161.50m</td>
<td>Garnet Biotite Schist</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>5</td>
<td>Lamellapadu-A</td>
<td>Krishna Low</td>
<td>1590.00-1592.00m</td>
<td>Charnockite</td>
<td>1902±32 (Sm-Nd)</td>
<td>579±14 (Rb-Sr WR)</td>
</tr>
<tr>
<td>6</td>
<td>Mandapeta-A</td>
<td>Kavitam-Mandapeta Low</td>
<td>4286.00-4289.60m</td>
<td>Khondalite</td>
<td>1963±17 (Sm-Nd)</td>
<td>1033±22 (Rb-Sr WR)</td>
</tr>
</tbody>
</table>

The studied wells are located toward the eastern extremity of the Krishna Province and Eastern Ghat Province, and hence are highly important in establishing the geochronological constraints in the area covered by alluvium, in terms of alkaline emplacements related to Mesoproterozoic rifting of Columbia Supercontinent as well as the Paleoproterozoic to Neoproterozoic metamorphism and their connection with the orogens responsible for the assembly of Columbia, Rodinia and Gondwana in the Eastern Ghats Belt. The calculated ages from the studied wells along with other reported ages in the EGB has been summarized in Fig. 3.

Formation of Khondalitic and charnockitic basements: The Eastern Ghats belt comprises of massif-type charnockite as a major component in the regional granulite terrain, and there is unambiguous evidence of the different generation of charnockites. Archaean charnockites (~3.0-2.9 Ga) have been described from northern margin against Singhbhum craton and western margin against Bastar craton (Rickers et al., 2001; Kovach et al., 2001), followed by a reported charnockite magmatism at ~1.7-1.6 Ga (Kovach et al., 2001; Dobmeier et al., 2006; Bhattacharya et al., 2014), and at ~1.0-0.9 Ga, as part of the Grenvillian orogeny (Aftalion et al., 1988; Bhattacharya et al., 2014).
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In the present study, charnockite samples were encountered in the basement of drilled well Lamellapadu-A, located towards the east in the Ongole Domain (Fig. 3). The Sm-Nd whole-rock isochron age of these charnockite samples are determined to be 1902±32 Ma, indicating it to be the oldest charnockite body reported from the Ongole domain. The new age (~1.9 Ga) would constrain the upper limit of charnockite magmatism in the Southern EGB to be ~1.9 Ga, previously established as 1.7-1.6 Ga (Kovach et al., 2001; Dobmeier et al., 2006; Bhattacharya et al., 2014).

On similar lines, Upadhyay et al. (2006) reported khondalites in the EGB from Late Archaean/early Proterozoic–Mesoproterozoic provenances. Bhattacharya et al. (2013) reported several U-Pb and Pb-Pb ages of zircons from khondalites and other metapelites from north and central part of EGB, in which older detrital components define age peaks of 2499 Ma, 2470 Ma and 2340 Ma, with metamorphic overprinting during the Mesoproterozoic.

The present study reports a mid-Palaeoproterozoic protolith age for the khondalitic basement in the Eastern Ghats province through the Sm-Nd whole-rock isochron age of 1963±17 Ma encountered in garnet-sillimanite-gneissic core samples of well Mandapeta-A (Fig. 3).

Charnockites and Khondalites of similar ages have also been reported in the North China Craton (NCC), from the Inner Mongolia Suture Zone (IMSZ) and the Trans-North China Orogen (TNCO) (ChunYan et al., 2007; Santosh et al., 2013). Zircons in the charnockites from the southern margin of Khondalite Belt fringing the UHT granulites in the IMSZ have been dated to be of 1932±24 Ma, whereas those from the charnockites to the western periphery of the TNCO have been dated to be 1.95-1.86 Ga. These charnockites have been associated with the UHT
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metamorphism in the IMSZ, dated to be ~1.9 Ga and ~1.92 Ga. These reported ages in corollary to the age of charnockites and khondalites from EGB could also be an indicative of a crustal configuration in which the Dharwar Craton was continuous with the North China Craton, as suggested by workers like Zhao et al. (2003), Pirajno et al. (2005) and Ravikant (2010) (Fig. 4).

Mesoproterozoic rifting at the cratonic margin and subsequent crustal evolution in the basement of KG Basin in EGB may be correlated to plate tectonic processes linked to the assembly and fragmentation of supercontinents in the past:

**Tectonic-Tectonothermal episodes in the basement of KG Basin and links to Paleo-supercontinents- Pre-Rodinian Assembly:**

The idea of a pre-Rodinian supercontinent was first postulated by Hoffman (1989) who furnished evidences that such a continent could have assembled in the period 2.0-1.8 Ga, which was later named Columbia by Rogers and Santosh (2002).

Though the detailed reconstruction of Columbia still remains a challenge, there is unequivocal evidence that the Mesoproterozoic Geology in many parts of the world is characterized by widespread continental rifting (1.5-1.2 Ga) and anorogenic magmatism possibly related to the breakup of a supercontinent (Upadhyay, 2008 and references therein). The opening of a Mesoproterozoic (~1.5-1.3 Ga) NE-SW trending rift at craton margin in southeastern India and the development of the Godavari-Pranhita rift as its likely aulocogen is similar to the 1.5-1.2 Ga ages of continental rifts associated with the final breakup of Columbia.

The ages obtained in the present study from wells Endamuru-A and Draksharama-A (1357±45 Ma and 1424±57 Ma, respectively) are consistent with the timing of alkaline magmatism associated with the Mesoproterozoic rifting in the KG Basin/EGB (1.5-1.3 Ga) (Fig. 5) and are correlatable with earlier reported ages (Mezger and Cosca, 1999; Upadhyay et al., 2006) from Khariar, Kunavaram, Elchuru, Jojuru and Uppalapadu alkaline complexes spanning the entire length of the craton-EGB contact.

The **EGP in Rodinia-Corollary of a Wilson Cycle:**
Zhao et al. (2004) suggested that the final breakup of Columbia at about 1.3-1.2 Ga was immediately followed by the assembly of the supercontinent Rodinia along globally distributed Grenvillian orogens at ~1.0 Ga. The opening of the Mesoproterozoic rift between India and East Antarctica subsequent to the breakup of Columbia may have formed a large oceanic basin between the two where the sedimentary sequences of the EGP were deposited (Fig. 5).

This was followed by the inversion of the rift basin as a result of the collision between proto India and East Antarctica during the assembly of Rodinia. The collision formed the Grenvillian EGP-Rayner complex orogen where the EGP sediments and the rocks of the Rayner complex were deformed, metamorphosed and migmatized at granulite-facies condition (Upadhyay, 2008) (Fig. 5). The Mesoproterozoic rifting and the Grenvillian basin closure may thus represent a Wilson cycle (i.e. the

![Fig. 5: Tectonic-tectonothermal events identified from the basement of KG Basin/EGB based on obtained ages](image-url)
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opening and closure of an ocean) related to the breakup of Columbia and the assembly of Rodinia.

The present study reports similar ages of metamorphism from the EGP, viz, 1100±31 Ma from well Endamuru-A and 1033±22 Ma from well Mandapeta-A, which are consistent with the age of high-grade granulite facies metamorphism during the Grenvillian event in Southeastern India and East Antarctica (Fig. 5).

**Pan-African deformation and metamorphism of alkaline complexes: Gondwana Assembly:** As a result of Pan-African tectonic movements during the assembly of Gondwana, the Grenvillian granulites of EGP were thrust westward over the Indian craton. The alkaline complexes and the other craton margin rocks were deformed and metamorphosed to amphibolite-facies condition during this event (Fig. 5).

New age data have suggested that high-grade metamorphism in some areas of East Antarctica and elsewhere in Gondwanaland is of late Neoproterozoic to Cambrian in age (Upadhyay, 2008). Since the EGB was juxtaposed against east Antarctica during Gondwana assembly, it must have been affected by Neoproterozoic-Cambrian events. Pan-African ages in the EGB rocks have been reported by different workers (Kovach et al., 1997; Mezger and Cosca, 1999; Simmat and Raith, 1998; Upadhyay, 2008 and references therein). Present study also reports several Pan-African ages in the studied core samples from wells Endamuru-A (557±24 Ma), Lamellapadu-A (579±14 Ma) and Kaza-B (499±18 Ma), indicating that the Pan-African thermal imprint has affected the basement of KG Basin as well, concealed under the phanerozoic cover, yet played an important part in the basement configuration during westward thrusting and deformation of EGP rocks during the Gondwana assembly.

**Conclusions**

In the present study, Precambrian basement from five wells of KG Onshore was attempted for Geochronological studies through Rb-Sr and Sm-Nd dating, which provided following important geochronological constraints in the area covered by alluvium, in terms of tectonic and tectonothermal episodes in the basement of KG Basin and by analogy, the Eastern Ghats Belt:

1. The 1902±32 Ma age of the charnockitic basement from well Lamellapadu-A and 1963±17 Ma age of the khondalitic basement from well Mandapeta-A, can be correlated with contemporaneous charnockite and khondalite emplacements in the Inner Mongolian Suture Zone (IMSZ) and the Trans-North China Orogen (TNCO), in the North China craton, which has been proposed to be the part of a supercontinent along with south Indian Cratons prior to 1.9 Ga.

2. Mesoproterozoic emplacement ages, 1424±57 Ma and 1357±45 Ma obtained from the basements of wells Draksharama-A and Endamuru-A, respectively, represent the timing of alkaline magmatism during 1.5–1.2 Ga in the EGB/KG basin, subsequent to the rifting of Southern India–Antarctica during the Mesoproterozoic.

3. Later stage metamorphic imprint ages determined from the basement of KG Basin, around ~1100 Ma from wells Endamuru-A and Mandapeta-A, and of around ~500 Ma from wells Lamellapadu-A, Endamuru-A and Kaza-B, represents closing of the oceanic basin during amalgamation of south India–Antarctica due to Rodinia assembly (Grenvillian tectonothermal event, ~1.1–1.0 Ga), and Gondwana assembly during Pan-African event (~0.6–0.5 Ga), respectively.

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