6. Vijaya Kumar, K. and Ratnakar, J., *J. Geol. Soc. India*, 1995, 46, 245–254.
7. Babu, E. V. S. S. K., Unpublished Ph D thesis, University of Cambridge, UK, 1996.
8. Gribble, C. D. and O'Hara, M. J., *Nature*, 1967, 214, 1198–1201.
9. Presnall, D. C., Dixon, S. A., Dixon, J. B., O'Donnell, T. H., Brenner, N. L., Schrock, R. L. and Dycus, D. W., *Contrib. Mineral. Petrol.*, 1978, 66, 203–220.
10. Elthon, D., *Geochim. Cosmochim. Acta*, 1984, 48, 753–768.

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Proterozoic intracratonic Godavari rift development at right angle to the Eastern Ghat Mobile Belt: An example for collision-induced rifting in SE India

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Genetic relationship is indicated between two spatially related geological terrains with contrasting tectonic styles, namely the NE-SW trending Eastern Ghat Mobile Belt (EGMB) and NW-SE oriented Godavari rift (GR). The late Archaean pelite dominated Eastern Ghat sedimentary terrain was subjected to major reworking events around 3.0 Ga, 2.6 Ga, 2.0 Ga, 1.5 Ga, 1.0 Ga and 0.5 Ga. Along GR development of extensional basins, viz. Pakhal (Middle Proterozoic) and Sullavai (Late Proterozoic) was induced by 1.5 Ga and 1.0 Ga reworking events respectively in the EGMB. A sag/protorift formed along the tectonic join between the Dharwar and Bhandara cratonic blocks, in response to 1.5 Ga event in EGMB, paved way for the initiation of the Middle Proterozoic Pakhal sedimentary basin. Evolution of this basin into Late Proterozoic Sullavai sedimentary rift basin is perhaps triggered by an extensive tectonothermal rejuvenation associated with 1.0 Ga reworking event in the EGMB.

THE Proterozoic sedimentary basins of the Godavari valley include Pakhal (Middle Proterozoic) and Sullavai (Late Proterozoic). Stratigraphic record and structural framework of these basins embody testimony to a rare Precambrian rift-related sedimentary basin development at right angle to the growing curvilinear Eastern Ghat Mobile Belt (EGMB). Geology of the Godavari valley and its environs was first worked out by William King[1]. Subsequently, a host of workers have attempted to refine stratigraphy, sedimentation and tectonics[2–6] of the area. Nevertheless, understanding of the origin and initial phase of basin development along the Godavari valley continued to be in its infancy. The present study underscores the importance of the EGMB reworking events in inducing the Precambrian extensional sedimentary basin development of the intracratonic Godavari rift (GR).

An outline of geological framework and chronology of major tectonic events in the GR and EGMB are shown in Figure 1 and Table 1 respectively.

Along the southeastern margin of the Indian Peninsula, the NNE-SSW to NE-SW oriented curvilinear EGMB extends over a length of 700 km with a maximum width of about 200 km in the north and tapering end in the south (Figure 1). Major lithounits in the EGMB are classified according to their parentage into Khondalite (sedimentary) suite, Charnockite (igneous) suite and migmatites. Besides, there are several igneous intrusives, viz. anorthosites, nepheline syenites and chromite-bearing layered complexes[7,8]. There is a lateral zoning in the distribution of rock units in the EGMB – charnockites being predominant in the west followed by khondalites in the centre and migmatites in the east[9].

Along the western margin of the EGMB the charnockites show lithological gradation with the Peninsular gneiss, granites and amphibolites of the shield area[10]. This gradational zone is usually referred to as the Eastern Ghat Front marked by ductile shearing, metasomatism and igneous activity[11]. The gradation zone between EGMB and the Dharwar Craton is also referred to as 'Marginal Zone' which is characterized by the presence of garnetiferous gneiss and its granitic protoliths (± garnet) with enclaves of two pyroxene granulites and arrested charnockites[12]. Supracrustals of Khammam schist belt, anorthosites and amphibolite intrusives are located in this zone.

Lithounits of the EGMB were subjected to polyphase deformation and metamorphism. Although the age of folding could not be established on a regional scale with a great deal of accuracy, in Chilka lake area, the NE-SW set of folds and the coaxial refolded folds (F1) were formed during 3.0 Ga and 2.6 Ga tectonic events respectively. Formation of E-W oriented cross folds with westerly plunge was linked to 1.5 Ga tectonic event[13]. Besides folding, a major phase of granulite metamorphism is also associated with the 1.5 Ga and 1.0 Ga events[14].

Localized bodies of anorthosites, alkaline rocks,

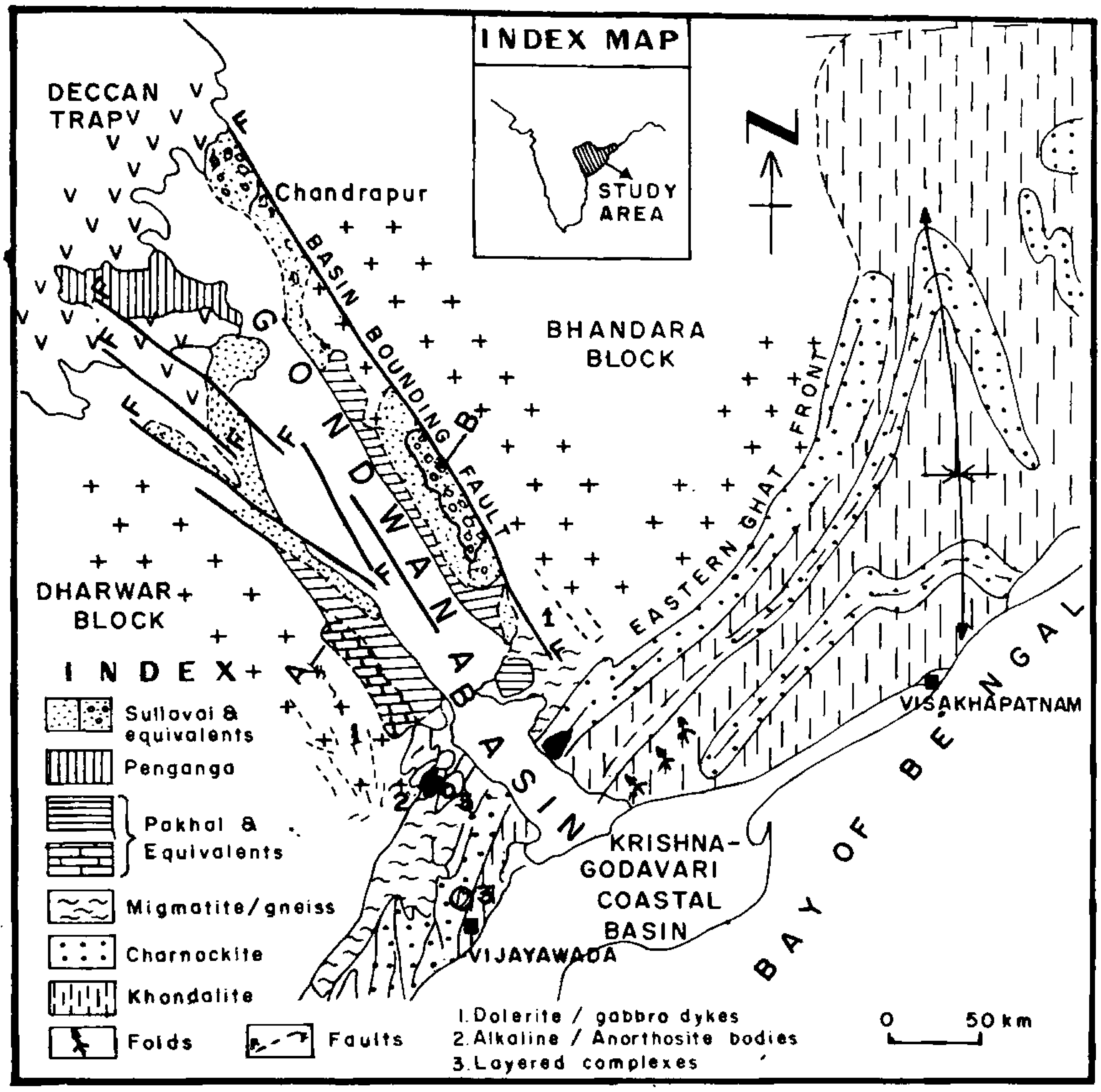


Figure 1. An outline geological map showing the spatial relationship between the Godavari rift (GR) and the Eastern Ghat Mobile Belt (EGMB). GR is located at the tectonic join between the Dharwar and Bhandara blocks. (Geology of the GR is after Rao[6] and Raman[5]; geology of EGMB is after Narayanaswami[8].) Cross symbols in Dharwar and Bhandara blocks indicate granitic basement.

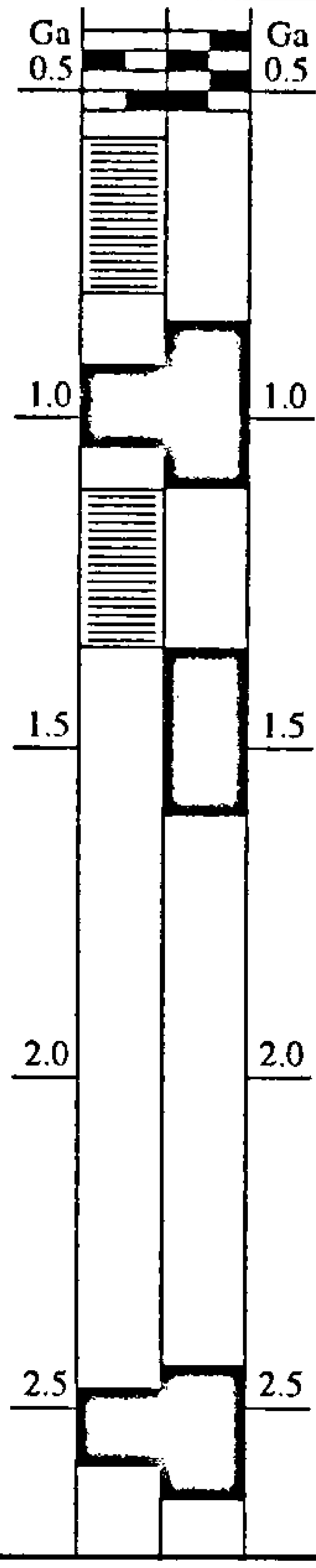
gabbros and chromite-bearing ultramafic rocks occur all along the EGMB. The gravity field over the EGMB is positive and highs are associated with the basic charnockite intrusives as well as gabbro-anorthosite masses and gravity lows are linked to acid charnockite intrusives[15]. Bouger gravity profile across the western margin of the EGMB compares well with the profile across the Grenville front[16].

Situated at the tectonic join between two cratonic blocks, i.e. Dharwar and Bhandara, the 400 km long, 2–80 km wide GR valley exposes a 10 km thick lithic fill deposited between Middle Proterozoic and Cretaceous period. The Middle and Late Proterozoic sediments belong to Pakhal Supergroup and Sullavai Group respectively, whereas the Late Carboniferous to Cretaceous sediments are known as the 'Gondwana'. A narrow constriction at Mailaram divides the GR into two segments – the northern Godavari sub-basin and the southern Kothagudem and Chintalapudi sub-basins. The latter two sub-basins expose only the Gondwana sequence, whereas the former contains both the Proterozoic and the Gondwana sediments. A schematic geological cross-section across the Godavari sub-basin is presented in Figure 2. From SW to NE, it includes basement (granites, gneisses, granulites and basic intrusives viz. dolerite, gabbro and lamproite dykes) → Pakhal → Sullavai → Gondwana ← Usur, Albaka ← Pakhal (Tippapuram, Cherla) ← Basement (granite, gneiss and granulites).

Along the southwestern margin, the Proterozoic sediments unconformably overlie the basement, whereas in the northeast the contact is marked by a prominent fault. The Proterozoic sequence is classified into Pakhal Supergroup, Penganga and Sullavai Groups[6]. The Gondwana tract divides the Proterozoic basin into two belts – western and eastern whose simplified stratigraphic succession and lithologies are shown in Figure 3.

The Pakhal Supergroup is made of conglomerate, quartzite/sandstone, shale, chert and dolomite. In the northwest of the Godavari Valley, limestone, arkose and shale constitute the Penganga Group. In the western

Table 1. Correlation between major reworking events in Eastern Ghat Mobile Belt (EGMB)* and coeval geological events in Godavari rift (GR) and its environs



GR and environs	Ga	EGMB
	0.5	
Sullavai sedimentation		Syn to post tectonic alkaline/anorthosite intrusives (localized)
Metamorphism of Pakhal sediments		Extensive tectonothermal rejuvenation folding, metamorphism and granitization
	1.0	
Deposition of Pakhal sediments in protorift/sag		
		Intrusion of syn to post orogenic alkaline/anorthosite bodies
	1.5	
		Major folding, regional metamorphism, granitization
Granitization and crustal growth in Dharwar and Bhandara cratonic blocks mafic dyke activity		Tectonothermal rejuvenation granitization
	2.0	
Granulite formation along the tectonic join between cratonic blocks		
		Major folding, regional metamorphism, granitization. Tholeiitic magmatism in marginal zone
	2.5	

*After Paul and Sarkar[31] and Sarvothaman[34] and GSI[28].

belt, the Pakhals are subdivided into Mallampalli and Mulug Groups. In the eastern belt, only the stratigraphic equivalent of Mulug Group is represented by a succession of Cherla, Somandevara and Tippapuram formations. Sedimentary sequence in the Pakhal Supergroup consists of broad fining upward cyclic sequence represented by interbands of conglomerate/glauconitic sandstone/sandstone (arkose), quartz arenite and ferruginous sandstone in the lower part, dolomite and shale in the upper part (Figure 3). Glauconite from the Pakhal sediments is dated to be 1330 ± 37 Ma (ref. 17). A detailed study of stromatolites from the Mallampalli Group indicated a Middle Proterozoic age[18]. The Pakhal sedimentation commenced in a marine environment. Sedimentological attributes indicate the interaction of near shore and off shore environments. Provenance for the Pakhal sediments is identified to be Archaean–Proterozic basement of the adjacent cratonic blocks[6] (Figure 5 *a*).

An angular unconformity marks the contact between the Middle and Late Proterozoic in the Godavari Valley. In the western belt, the Late Proterozoic sequence is represented by Sullavai Group consisting of variable proportions of sandstone, arkose, conglomerate, glauconitic sandstone and shale. Sandstone is characterized by red-white banding, and tabular/trough type crossbedding. In the southwest near Chelvai, the palaeocurrent is unimodal towards WNW and is interpreted to have been deposited in a complex of beaches swept by WNW long shore drift[19]. Conglomerate contains pebbles, cobbles and boulders of quartzite, sandstone, vein quartz and granite derived from the basement and the older sediments located in the west and southwest. In Ramagundam area palaeo-current is towards NE, E and SE; and SW near Mancherial. Alluvial fan/braided stream depositional settings existed during the Sullavai sedimentation along the western margin of the basin[20]. In the eastern belt, the Usur Group includes Lower Nambi Breccia, Middle Doli Sandstone and Upper Delam Sandstone and show the evidence for fault-controlled sedimentation in the form of breccias and conglomerates. Detailed lithofacies

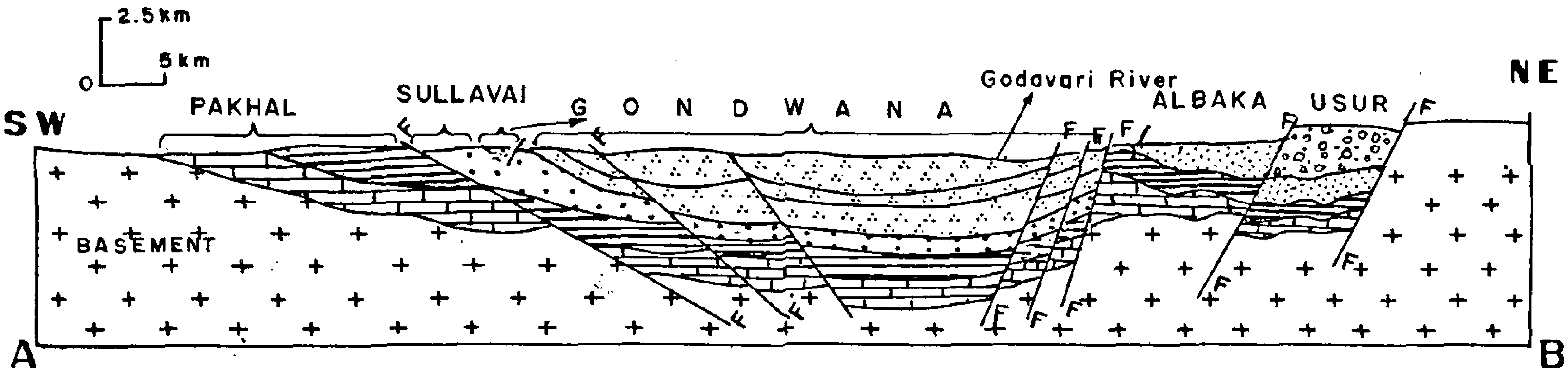


Figure 2. Schematic geological cross section across the GR. Section line is marked in Figure 1. Index to symbols same as in Figure 1. Eastern margin is fault-bounded whereas the western margin between Pakhal and the basement is unconformable.

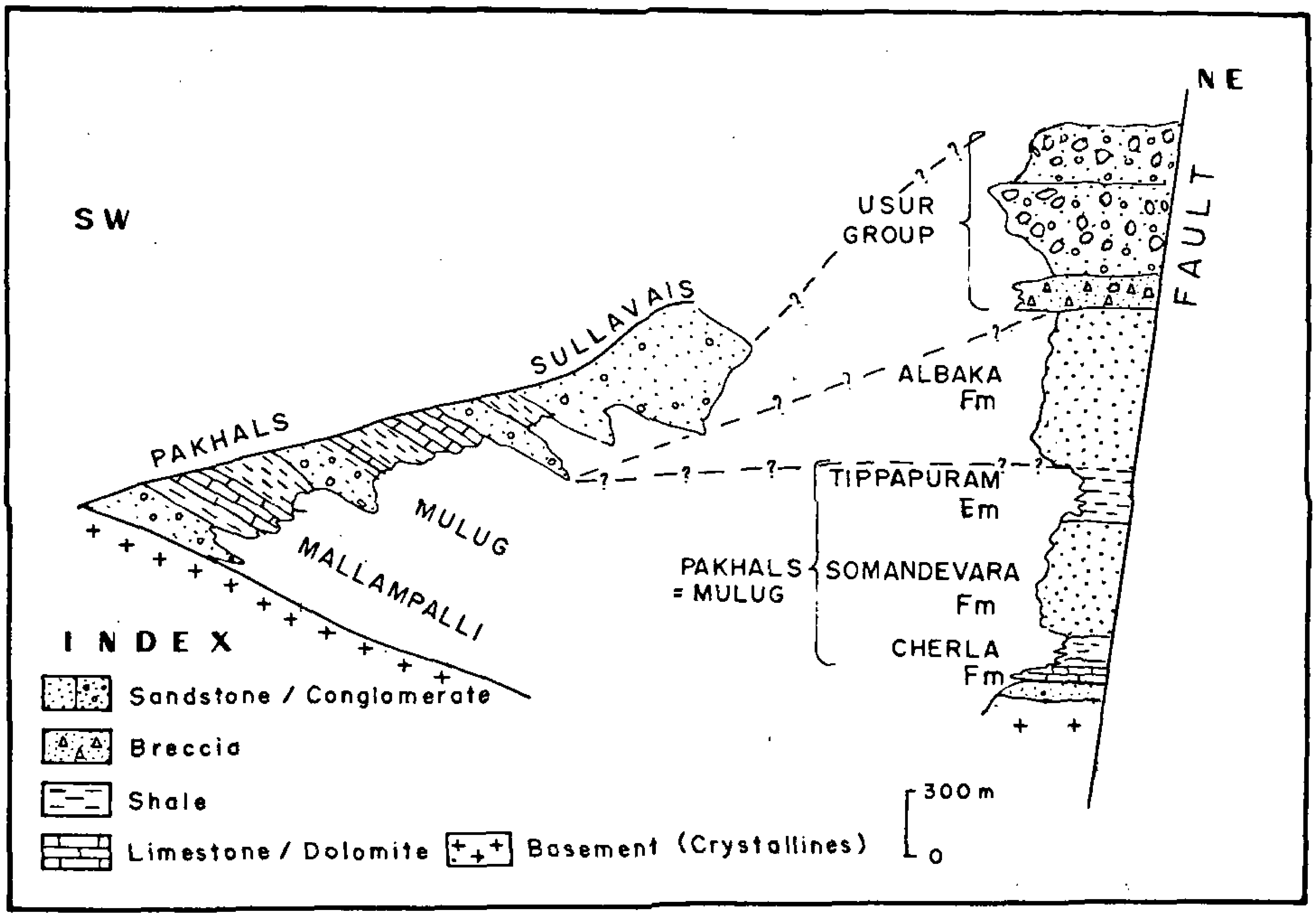


Figure 3. Disposition of sedimentary lithoassemblages along the northeastern and southwestern margins.

analysis revealed an alluvial fan-fluvial environment for the deposition of Usur Group[21]. Palaeocurrent and petrographic studies revealed that, besides cratonic blocks on either side of the GR, EGMB also contributed detritus to the Late Proterozoic sedimentary basins of the Godavari Valley (Rao and Rao (1970) cf. Rao, K. S. *et al.* 1979)[22].

Sediments of the Sullavai Group and equivalents were relatively undeformed and unmetamorphosed whereas those of the Pakhal Supergroup were structurally deformed and metamorphosed. South of Pakhal lake, the sediments are folded into a series of antiforms and synforms plunging NNW and NE. At places, sediments are cross folded on E-W axis. However, the intensity of metamorphism increases towards southeast and also from west to east. In the northwestern part, the effect of metamorphism on Pakhal sediments is feeble. But south of Pakhal lake, shales are converted into slates and phyllites, and further southeast to staurolite–almandine sub-facies of the amphibolite facies of metamorphism. Thermal metamorphic effects are also common as indicated by the development of staurolite and andalusite in pelites, tremolite and actinolite in marbles[6,23].

Rift/extensional sedimentary basins striking at right angles to the orogenic belts are conspicuous for their contrasting styles of tectonic development. Although these types of features have been recognized worldwide, their genetic relationships could not be explained perhaps owing to a general belief that the orogenesis (folding) and taphrogenesis (rifting) are two contrasting tectonic processes. With the advent of plate tectonic theory, several authors tried to explain the genetic relationship between the Phanerozoic rift valleys and orogenic belts in terms of triple junction models[24], or collision-induced rifting[25]. Not much information is available on the Precambrian examples of orogeny-related rifting other than Keweenawan rift and Grenville orogeny[26]. Information available on the sedimentary basin development in Keweenawan rift is meagre as it is filled mainly with the volcanics. It is proposed that the GR and the EGMB may serve as an example for Precambrian collision-induced sedimentary rift basin development.

Available geological and geochronological data[27,28] show that the Late Archaean to Early Proterozoic period (~ 3.0 Ga to 1.5 Ga) is marked by granitization crustal growth and stabilization of cratonic blocks in the south-eastern part of the Indian shield. The Karimnagar and Bhopalpatnam granulites and associated metasediments fringing the GR are believed to have been formed as a part of ancient orogenic belt that remained as a zone of weakness in between the Dharwar and Bhandara Cratonic blocks[29].

On the other hand, protoliths of khondalite and associated metasediments of the EGMB are believed to have been deposited in an Archaean geosyncline[8] or platform[30]. This terrain was subjected to major reworking events around 3.0 Ga, 2.6 Ga, 2.0 Ga, 1.5 Ga and 0.5 Ga (ref. 31). A continent–continent collision tectonics operated during the evolution of EGMB[32] and compression was from southeast[33]. The formation of Eastern Ghat front/marginal zone is attributed mainly to the ~ 1.5 Ga reworking events or younger[11]. Besides deformation of Khammam schist belt metasediments, the emplacement of Fe-tholeiite melts (represented by amphibolites) is linked to ~ 2.6 Ga (ref. 34) event. The Karimnagar granulites are believed to have been formed during ~ 2.6 Ga events, but the nature and origin of these granulite terrains is distinct from the granulites of the EGMB[35]. Stabilization of cratonic blocks in shield area was more or less complete by ~ 1.5 Ga. But weak zones in between two stabilized cratonic blocks responded immediately to ~ 1.5 Ga or younger reworking events in the EGMB. The cratonic blocks supplied detritus to the Pakhal sedimentary basin.

The 1.5 Ga reworking event is followed by the

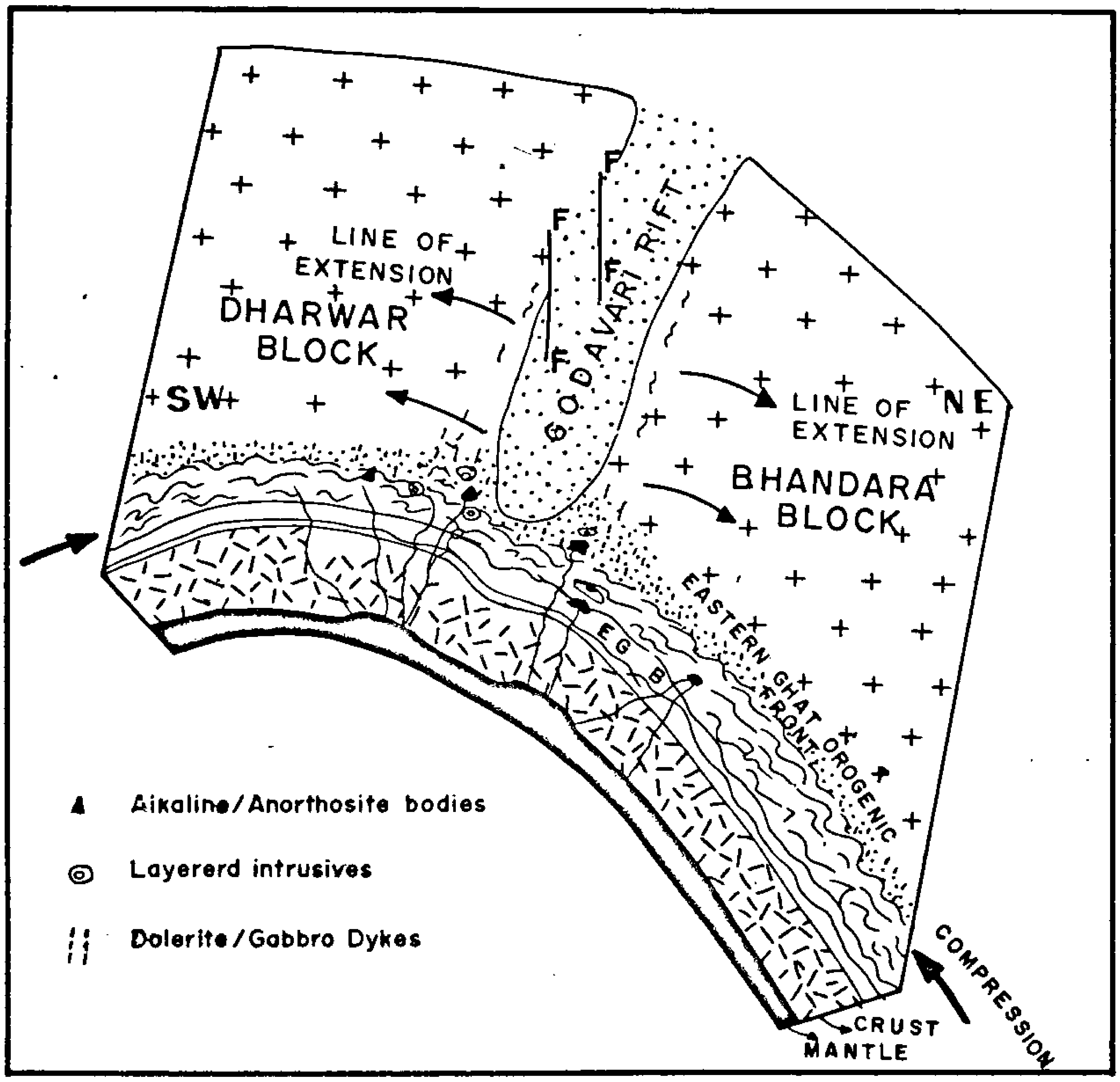


Figure 4. Block diagram indicating the genetic relationships between the EGMB and the GR. Subsequent to 1.5 Ga event sag/protorift formed along the tectonic join between the Dharwar and Bhandara blocks marks the immediate origin of the Middle Proterozoic Pakhal basin.

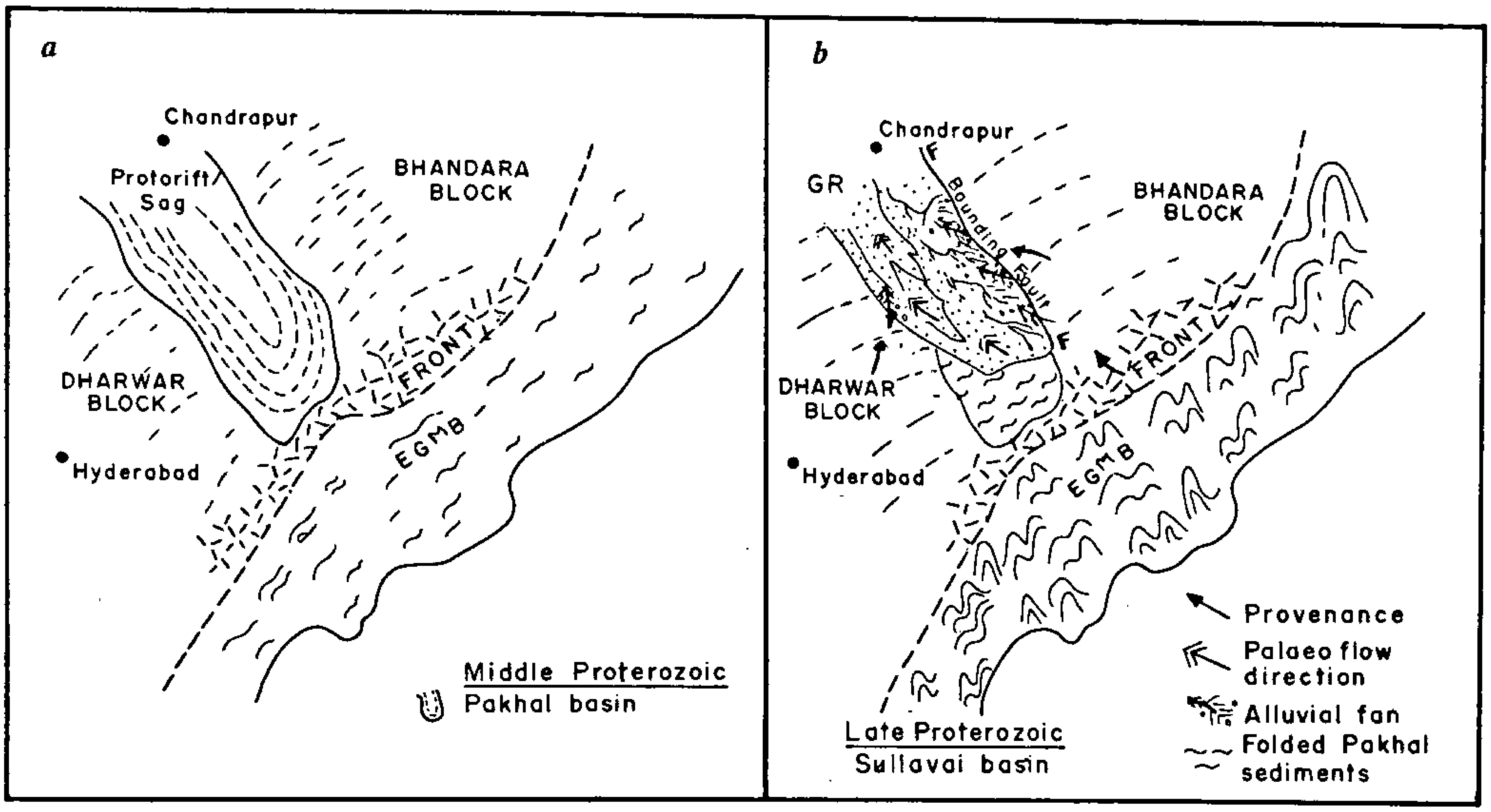


Figure 5. Sketch showing the palaeogeography of GR and its surroundings during (*a*) Middle Proterozoic (Pakhal) and (*b*) Late Proterozoic (Sullavai).

emplacement of alkali plutons and anorthosite complexes (Chilka Lake[13] ~ 1400 Ma, Kunavaram[36] ~ 1245 Ma). These igneous bodies are believed to be the manifestations of the mantle magmatism that triggered the extension in the upper crust. Besides, the crustal extension immediately following the continental collision (compression) is regarded as a fundamental process[37]. A narrow mountain belt with vertical strain is developed in the collision zone (EGMB), while in the adjacent shield area, convergent strain is accommodated by pushing aside the cratonic blocks (Figure 4). Horizontal strain is oriented in NE-SW and the corresponding NW-trending sag/protorift formed along the tectonic join between the Dharwar and the Bhandara cratonic blocks became the site for the deposition of quartzite–carbonate–argillite assemblage of the Pakhal Supergroup (Figure 5). Accumulation of over a thousand metre thick fine-grained sediments (Pakhals) along the Godavari valley was controlled by the subsidence along a sag or protorift (Figure 5 *a*). Basin subsidence is aided by the thermal events which result in the initial uplift of the lithosphere and subsequent cooling. In addition, the basin subsidence is also facilitated by the invasion of dense basic or ultrabasic intrusives[38] or due to metamorphism to granulite or eclogite facies in the lower crust[39]. There is evidence for this type of thermal events in EGMB during 1.5 Ga and 1.0 Ga reworking events in the form of tectonic deformations and increased charnockitization.

During the 1.0 Ga orogenic event in the EGMB, the Pakhal sediments were subdued to deeper crustal levels and were metamorphosed. This is supported by the fact that the metamorphism and folding of Pakhal sediments is limited to the southeastern part, i.e. in the vicinity of EGMB and the same sediments in the same basin away towards northwest are less affected. Depth to detachment controlling the deformation of the basin fill is estimated at 10 km (ref. 40). Extensive tectonothermal rejuvenation with fracturing and transcurrent shearing, migmatization and charnockitization are associated with 1.0 Ga orogenic event in the EGMB. This event is followed by another pulse of alkaline magmatism around 850 Ma. The Late Proterozoic rift basin is mainly filled with coarse-grained sandstones and conglomerates (Sullavais), sandstones, conglomerates and breccias (Usurs) (Figure 5 *b*) derived from the basement (shoulders) located in the west and east respectively. Development of the coarsening up alluvial sequences along the eastern margin fault points to its tectonically active nature. By Late Proterozoic, the EGMB became a positive area and supplied detritus to the Proterozoic basin along with the cratonic blocks bordering the GR[22]. Therefore, it is now suggested that origin and initial phase of the GR development is linked to the Proterozoic reworking events in the EGMB, thereby setting an example to the collision-induced rift development at right angles to the growing curvilinear EGMB in the Indian shield.

1. King, W., *Geol. Surv. India Mem.*, 1881, pp. 1–263.
2. Sarma, S. R. and Appavdhanulu, K., *J. Decc. Geol. Min. Soc.*, 1963, **3**, 80–87.
3. Basumallick, S., *Q. J. Geol. Min. Met. Soc. India*, 1967, **39**, 115–127.
4. Chaudhuri, A. K., *J. Geol. Soc. India*, 1985, **26**, 301–304.
5. Raman, R., *Geol. Surv. India. Misc. Publn.*, 1975, **23**, 165–175.

6. Rao, T. S., *Geol. Soc. India Memoir*, 1987, **6**, 161–187.
7. Fermor, L. L., *Geol. Surv. India Memoir*, 1936, **70**, 182.
8. Narayanaswami, S., *Geol. Surv. India Misc. Pub.*, 1975, **23**, 1–16.
9. Ramakrishnan, M., Nanda, J. K. and Augastine, P. F., Proceedings of the Workshop on Eastern Ghats Mobile Belt (Abstracts), 1994, pp. 15–16.
10. Crookshank, H., *Geol. Surv. India Rec.*, 1938, **73**, 398–434.
11. Rogers, J. J. W., *J. Geol.*, 1986, **94**, 129–143.
12. Sarvothaman, H., *Indian Min.*, 1995, **49**, 177–186.
13. Sarkar, A. N., Bhanumati, L. and Balasubrahmanyam, M. N., *Lithos*, 1981, **14**, 93–111.
14. Paul, D. K., Ray Burman, N. J., Mc Naughton, Fletchar, P. J., Potts, Ramakrishnan, M. and Augastine, P. F., *J. Geol.*, 1990, **98**, 253–263.
15. Subrahmanyam, C. and Verma, R. K., *Tectonophysics*, 1985, **84**, 225–245.
16. Subrahmanyam, C., *Geol. Soc. India Memoir*, 1983, **4**, 553–570.
17. Vinagradov, A., Tugarivov, A., Zhykow, C., Stapnikova, N., Bibikova, E. and Khordo, K., 22nd International Geol. Congress Report, 1964, vol. 10, pp. 553–567.
18. Chaudhuri, A., *Palaeogeogr. Palaeoclimatol. Palaeoenviron.*, 1970, **7**, 309–340.
19. Reddi, P. H. and Kumar, D. V. S. N. B., *Indian J. Earth Sci.*, 1993, **20**, 7–16.
20. Chakraborty, T., *Indian J. Geol.*, 1994, **66**, 124–147.
21. Rao, K. S., *Geol. Soc. India Mem.*, 1987, **6**, 161–187.
22. Rao, K. S., Rao, T. S., Subba Raju, M., Khan, M. M. A. and Silekar, B. S., Proceedings of Fourth International Gondwana Symposium, Calcutta, Today & Tomorrow Publ., New Delhi, 1979, vol. II, pp. 889–900.
23. RamaMohan Rao, T., *West Commemoration Volume*, 1970, 225–235.
24. Burke, K. and Dewey, J. F., *J. Geol.*, 1973, **81**, 406–433.
25. Illies, J. H., *Geol. Rundschau*, 1975, **64**, 677–699.
26. Gordon, M. B. and Hempton, M. R., *Tectonophysics*, 1986, **127**, 1–5.
27. Divakara Rao, V. and Rama Rao, P., *Precambr. Res.*, 1982, **16**, 257–271.
28. *Isotopic Age Map of Peninsular India*, 1989, GSI.
29. Rajesham, T., Bhaskar Rao, Y. J. and Murti, K. S., *J. Geol. Soc. India*, 1993, **41**, 51–59.
30. Shackleton, R. M., *The Early History of the Earth* (ed. Windley, B. F.), Wiley Interscience, 1976, pp. 317–321.
31. Paul, D. K. and Amitabha Sarkar, Proceedings of the Workshop Eastern Ghat Mobile Belt (Abstracts), 1994, pp. 50–51.
32. Naqvi, S. M. and Rogers, J. J. W., *Precambrian Geology of India*, Oxford University Press, New York, 1987, pp. 102–119.
33. Chetty, T. R. K. and Murthy, D. S. N., *Terra Nova*, 1994, **6**, 72–81.
34. Sarvothaman, H., *Geol. Surv. India Spl. Publ.*, 1996, **40**, 43–58.
35. Ramakrishnan, M., *Geol. Surv. India Spl. Publ.*, 1990, **28**, 44–66.
36. Clark, G. S. and Subba Rao, K. V., *Can. J. Earth Sci.*, 1971, **8**, 1597–1602.
37. Strachan, R. A., *Geology*, 1995, **22**, 913–916.
38. Beloussov, V. V., *J. Geophys. Res.*, 1960, **65**, 4127–4146.
39. Falvey, D. A., *Aust. Pet. Expl. Assoc. J.*, 1974, **14**, 95–106.
40. Saha, D., *Indian Min.*, 1992, **46**, 259–270.

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Age and formation of oyster beds of Muthukadu tidal flat zone, Chennai, Tamil Nadu

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The formation of alternate oyster beds with intervening tidal clay units indicates fluctuation in the sea level as consequent to Mid Holocene to terminal Pleistocene neotectonism. This inference is based on the new radio carbon ages of the study area presented for the first time.

ASSEMBLANCE of bivalve and univalve molluscs occurs due to eustatic, shoreline and sea level changes[1]. They are signatures of former sea level positions. ^{14}C dating of these shells and the organic carbon-rich clay occurring along the inland tidal flat zones can be used to determine their age of formation.

A study was carried out to understand sea level changes and sedimentological pattern in the tidal flat occurring along the Muthukadu tidal flat zone, 37 km south of Chennai. The study was focused on the geomorphology, ^{14}C dating of oyster beds and organic carbon-rich tidal clays. The area was mapped using satellite data IRS-1A LISS II and ground checked for the various geomorphic units (Figure 1). Stratigraphic sequences of oyster beds occur along the east coast of Chennai between Muthukadu (12°50′N, 80°15′E) and Mamallapuram (12°35′N, 80°19′14″E) forming a part of the tidal flat zone (Figure 1). Presently, the oyster beds are largely exploited for lime-burning by the local fishing community. The study area receives both summer and winter rains, the latter being dominant during October to December receiving an average annual rainfall of 1200 mm yr^{-1}. The area experiences a subtropical climate with mean annual average temperature of 28°C to 30°C.

Four major zones within the tidal flat were recognized: a) outer sand flat merging with the beach dune complex and rock exposures, b) middle sand flat, c) sandy to silty inner flats (mixed flats of Reineck and Singh[2]) and, d) salt marsh. The salt marsh is separated from the inner flat by a narrow spit built of shell and shell debris. Grain size decreases slightly from the outer flat zone to the inner flat although this trend is interrupted by coarse-grained samples from the tidal channel. The channel is also characterized by relatively poor sediment sorting. The poor sorting of the innermost sample is due to input of coarser sand and shelly debris from the adjacent spits. Spit's variation in carbonate percentage is largely a function of shell content. Shell content is typically high in the tidal channel and near the spit, largely represented by lamellibranchs and gastropods.

The outer sandy flat and the beach dune complex are