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Proterozoic Orogens of India: A critical window to Gondwana by **T.R.K.Chetty,** CSIR-NGRI, Hyderabad- 500 007, pp- 1 to 405, Elsevier publication, ISBN; 978-0-12-804441-4: **Book Review** by **P.R.Reddy.**

Conflicting theories and opinions do exist in any science. They are more in earth science, as it is not an exact science like Physics and Chemistry. Because of such controversies many a time researchers spend considerable time in projecting their theories overlooking good content of other studies. To avoid such an attitude it is essential to integrate various inputs and come out with a theory or model that is in general nearer to reality. Presence of mineral grains of particular texture in a rock strata and absence of such a texture in the adjacent rocks of similar composition and structure excites an experienced field geologist and encourages him to explicitly study the two types of rock assemblages starting from the field and extending in to a well equipped lab to build structural and evolutionary models that can provide meaningful answers to some of the interpretational ambiguities existing for decades. Dr.T.R.K.Chetty is one such field geologist who has succeeded in opening new avenues and thereby provided a unique opportunity to understand the cross section of the well exposed and thoroughly studied part of the Earth`s crust and the varied processes of continental collision, using a wealth of data and information from other branches of earth science in better deciphering the data generated by him through concerted efforts in the field. In his seminal and authoritative overview of the latest information on the Proterozoic Orogens of India he has succeeded to a significant extent in explaining vividly the pulses of reworking processes and their impact on magmatism, metamorphism, and deformational history of Proterozoic orogens, specifically regarding supercontinental formation. In presenting the varied types of interpretations and hypotheses by well known geologists on structural architecture, crustal blocks , shear zone systems, magmatism, metamorphism, geochemical and isotopic signatures, mineralization, and temporally and spatially varying tectonic models that exhibit unique variations not only laterally but also vertically of all the Proterozoic orogens of India, Dr.Chetty to a significant extent succeeded in narrowing down the ambiguities. While discussing various reworking processes he has utilised useful inputs, with an open mind, from geophysics, geochemistry and geochronology there by enhanced the quality of his presentations through valuable illustrations reflecting not only the field based rich data sets but also very useful multi structural integrated data sets. It is good to find in the Preface Dr.Chetty giving due importance to recent, especially the refinements of many geological, geochemical, geochronological, and geophysical studies role in uncovering many new facets of the geology of the Proterozoic orogens of India along with some proposed new lines of thinking of traditional concepts, which were previously developed but were lacking a substantial amount of information that we now have today. Dr.Chetty in a way by stating so has encouraged close co-ordination of scientists belonging to different branches of earth science. According to me it is an apt approach to arrive at a better understanding of the Proterozoic orogens evolution. In the present synthesis Dr.Chetty correctly laid much stress on the large volume of the recently obtained field based multiscale data analysed properly through laboratory studies to clarify and address some of the earlier concepts to resolve many unknown controversies. In a way this approach has stressed the necessity to get proper data from the field, by planning in advance in selecting the main objective of acquiring such data instead of aimlessly collecting broad range of data sets that have no specific importance to a select study. When such randomly acquired data sets are processed using commercial software and routine lab studies one could succeed only in producing graphically colourful evolutionary models that can only add to the confusion instead of providing solutions to existing controversies. Publication of such models projecting them as cutting edge scientific research output negates growth of well articulated scientific research. From the details given in his book Dr.Chetty ,while covering various aspects of an important segment of Proterozoic orogens of India, without hesitation brought out limitations of some of his studies in providing unequivocally apt solutions to some of the still existing controversies .In his own words Dr.Chetty mentioned that the wisdom gained through three decades of field based experience , in conjunction with the enormous wealth of literature he has made an attempt to present an unprejudiced view with an open mind without fear or compulsion. In this context the statement made by Ian Fitzsimons in the "Foreword" is interesting and supports the significant initiatives made by Dr.Chetty. He has mentioned "While it had long been recognized that Precambrian basement rocks of India comprised a series of orogenic belts that wrap around granite-dominated cratons, a paucity of robust isotopic data meant that many of these rocks were still attributed an Archean age simply on account of their crystalline nature, making it difficult to integrate their histories with any certainty to those established for other continents. This situation has improved markedly in recent years as modern geochronological techniques have been applied to Indian outcrops at a ever-accelerating rate, and India`s basement orogens are now known to preserve Proterozoic tectonic events that correlate closely with the assembly of supercontinents." Dr.Chetty, aptly coupled geochronological data with structural, petrological, geochemical and geophysical data to produce exciting new models for the evolution of Proterozoic India and its tectonic and palaeographic relationships.

To properly exhibit uniqueness of different Proterozoic orogens, Dr.Chetty aptly sub divided his book into 6 chapters covering details on 1) Orogens, 2) The Southern Granulite Terrane, 3) The Eastern Ghats Mobile Belt, 4) The Central Indian Tectonic Zone,5) The Aravalli-Delhi Orogenic Belt and 6) The Gonndwana Correlations. Even though I carried out useful long range seismic refraction and deep reflection profiling studies and learnt many aspects of integrated geophysical and geological studies and published useful articles I have found it really difficult to objectively review Dr.Chetty`s excellent presentation that contains number of subsections in each chapter covering almost all the facets of Proterozoic orogens of India. I do hope that my effort to bring out some important details through this review will motivate young researchers in following the footsteps of Dr.Chetty in making their research initiatives meaningful and lasting for decades.

In the **first chapter** Dr.Chetty covered various facets of Orogens and highlighted their importance in deciphering the origin and evolution of specific crustal segments. The Proterozoic Orogens of India (POI) are defined by curvilinear, high-grade granulite-gneiss belts encompassing the entire Indian continent from Kanyakumari in the south to New Delhi in the north. The POI comprise a sinuous chain of four major orogens from south to north in a counter clockwise direction that include: the Southern Granulite Terrane (SGT), the Eastern Ghats Mobile Belt (EGMB), the Central Indian Tectonic Zone (CITZ), and the Aravalli-Delhi Orogenic Belt (ADOB). The SGT occurs at the southern margin of the Dharwar craton and the EGMB is situated along the east coast wrapping around Dharwar and Bastar cratons. The CITZ in central India is sandwiched between Bundelkhand craton to the north and the Bastar and Singhbhum cratons to the south, while the ADOB occurs to the west of Bundelkhand craton and extends up to the Himalayan orogenic belt in the north. These orogens are also described as fold-thrust belts. Details given in this chapter aptly introduce the focal theme of the book and explain in detail definition of Orogen and its classification. The orogens can broadly be grouped into collisional and accretional types . Accretionary orogenic systems (also described as "Pacific-type" or "Cordillera-type") are formed through on-going plate convergence during the period of supercontinent breakup and continental dispersal. Collisional orogenic systems (Himalayan-type) are generated when the ocean is closed during continental assembly and the formation of supercontinents. Collisional orogenic systems may be superimposed on accretionary systems, which can be described as subduction-to-collision orogenesis. Under General Characteristics subsection Dr.Chetty exposed the reader to various characteristics. Orogeny includes a collage of processes, such as: (1) magmatism, which generates continental crust; (2) rejuvenation and recrystallization by metamorphism where in the metamorphic belts occupy the orogenic core; (3) deformation to produce major structures of orogenic belts; and (4) sedimentation where the mountain-building activity takes place through the transportation of large volumes of sedimentary material. He has also detailed the importance of Plate Tectonics. It has been well established that the development of orogens involves plate tectonics through a variety of associated processes like subduction zones after the consumption of oceanic crust producing volcanoes and build island arcs magmatism. The other important associated processes include magmatism, metamorphism, crustal melting, and crustal thickening. However, these are dependent on the strength and rheology of the continental lithosphere and their change in their properties during orogenesis. Under the subsection Proterozoic orogens of India(POI) Dr.Chetty focused on the importance of POI. The Precambrian Indian shield is a mosaic of Archean cratons and Proterozoic orogens. There are four major cratons, which are characterized by Archean low grade granite greenstone sequences. The cratons are surrounded and separated by the Proterozoic orogens. The interface between cratons and orogens is marked by crustal-scale ductile shear zones. The Proterozoic period spans nearly 2 billion years, which can be divided into three eras: Palaeoproterozoic (2500 to 1600 Ma); Mesoproterozoic (1600 to 1000 Ma); and Neoproterozoic (1000 to 540 Ma). The Proterozoic is considered to be important because of great crustal stabilization marked by the development of global scale orogens. He has covered under the subsection "Terminology of Important Geologic Units" suture zones, shear zones, sheath folds, duplex structures etc.

In the **second chapter** SGT is covered. The SGT has been one of the most intensely studied orogens in the last two decades by several national and international groups encompassing all aspects of geology and geophysics. Innumerable publications have brought out large volumes of data with several modern concepts and innovative ideas but with variable and contradicting interpretations. However, many of the controversial topics remain debatable even today, despite the accumulation of significant amount of geological, geochemical, geochronological, and geophysical data. The plethora of contrasting interpretations and the evolution and subdivision of crustal blocks within the SGT are a direct consequence of limited field observations, lack of field and structurally constrained geochronological data, and limitations of accessibility due to high elevation and dense vegetation. The east-west trending tectonic features and associated structural fabrics broadly characterize the SGT. However, there are distinct variations in different segments as well as within the shear zones, as succinctly presented by active and passive seismic investigations. Composite long range seismic refraction and deep reflection profiling studies have brought out varied structures in different crustal blocks divided by number of regionally extending shear zones, such as Mettur shearzone, Palghat-Cauvery shear zone and Achankovil shearzone. The seismic investigations have also brought out bivergent reflectivity pattern, which Dr.Chetty and Dr.Bhaskar Rao named as a flower structure from their detailed investigations. Presence of a low velocity layer in middle and lower crust has been interpreted by well known geologists as a zone containing fluids. According to Dr.Chetty, based on the recent developments and significant advances, the SGT can be divided into five distinct crustal/tectonic units based on lithological assemblages, structural styles, geochronological characteristics, and geophysical signatures. From north to south, they are: (1) Northern Granulite Block (NGB), (2) Cauvery suture/shear zone (CSZ), (3) Madurai Granulite Block (MGB), (4) Achankovil suture/ shear zone (AKSZ), and (5) Trivandrum Granulite Block (TGB). A comprehensive foliation trajectory map of the SGT is presented in the book. Apart from the crustal-scale shear zones, the map shows well defined foliation trajectories defining broad fold forms, variable trends and geometries at different places pointing to the existence of a mosaic of different tectonic blocks within the SGT. A composite schematic tectonic model envisages an early rifting stage with the development of the Mozambique Ocean, followed by the southward subduction of the oceanic plate. The tectonic history of the SGT reveals a progressive sequence from Pacific-type to collision-type orogeny, which finally gave rise to a Himalayan-type Cambrian orogeny with characteristic magmatic, metasomatic, and metamorphic factories operating in subduction and collision setting. Dr.Chetty quoting some significant studies by internationally reputed geologists stated that the evolution of the SGT involves accretion processes of island arc magmatic suites, thrust stacking with duplex structures, and deformed sheath fold geometries, granitic emplacements, and obduction of ophiolite complexes: a complete range of processes like transpression associated with extrusion and exhumation, typical of modern orogenic belts. According to Dr.Chety the SGT could be a classic representative of ancient subduction factory that witnessed large-scale collision related to Gondwana amalgamation.

In the **third chapter** EGMB is covered. Dr.Chetty covered this Proterozoic orogenic belt extensively and gathered a huge wealth of data and addressed various important aspects with an amount of authority. He has done a great service by covering in detail the significant studies carried out by luminaries like Narayan Swamy, Leelanandam, Ramakrishnan, Raith and many others. The Eastern Ghats Mobile Belt (EGMB), a Mesoproterozoic collisional orogen, occurs along the east coast of India with a strike length of over 900 km and a width varying from 50 km in the south to a maximum of 300 km in the north .The margins of the EGMB are characterized by lithospheric shear zones at the contact with the Archean cratons of Dharwar and Bastar in the west and the Singhbhum craton in the north. Tectonic Synthesis of EGMB must have witnessed several deformational and metamorphic events (as detailed by many researchers), but three events are considered as the most significant. The earliest deformational event that could be recognized is the development of the compositional fabric or the gneissic banding, which can be related to a 2.8 Ga deformational event during the Neoarchean. This event must have been associated with northwest directed thrusting generating NE-SW trending fabrics with gentle to moderate dips at the western margin juxtaposing the Bastar craton and ENE-WSW fabrics at the northern margin juxtaposing the Singhbhum craton. The event is also marked by northwest-verging thrusts, giving rise to large-scale recumbent fold structures and other flat lying fabrics associated with crustal thickening and granulite facies metamorphism during 3000 to 2600 Ma. This is consistent with the existence of several thrust zones that were demarcated all over the EGMB. The other most significant thermal event recognized in the evolution of the EGMB is the Grenvillian orogenic event (1100 to 800 Ma), which was marked by the development of shear zones and associated metamorphism and migmatization. Dextral transpressional kinematics and intense strain partitioning during Grenvillian orogenic event period seem to be the dominant tectonic scenario continued until the end of the Neoproterozoic up to 500 Ma. This deformational event was related to the Mesoproterozoic oblique convergence between the Indian shield and the East Antarctica, broadly coinciding with the formation of the Rodinia supercontinent The other major event was the thrusting between 540 and 500 Ma, which was post tectonic to folding and granulite metamorphism of the cover rocks.. However,according to Dr.Chetty, the ages and the nature of deformational history with respect to the events is still a matter of debate, for instance, the time of thrusting and whether it is synchronous or post tectonic with the granulite facies metamorphism. Dr.Chetty believes that future research can resolve these critical and controversial issues in complex terranes like the EGMB. The Pan-African event, recorded around 500 Ma, could possibly represent a third deformation event, most probably restricted to shear zones.

In the **Fourth chapter** the Central Indian Tectonic Zone (CITZ) is covered. It is a conspicuous zone of deformation in central India that extends from the west coast up to Meghalaya plateau in the east. The CITZ, also regarded as Satpura Mobile Belt, merges with the Aravalli-Delhi orogen in the west, while it swerves around the nucleus of Singhbhum craton (SC) and joins the Eastern Ghats Mobile belt in the east. It extends for about 1500 km with a width of about 180 km and divides the Indian subcontinent into two distinct crustal provinces: the Bundelkhand craton (BKC) surrounded by Vindhyan sediments to the north, and the Deccan province constituting Bastar, Singhbhum, and Dharwar cratons to the south. The entire tectonic zone has been studied by number of geologists, geochemists and geophysicists. The structural architecture of the CITZ, compiled from the available literature together with the newly interpreted shear zone systems, shows a set of crustal-scale ENE-WSW trending shear zones throughout the entire stretch. The NSL constitutes two bounding shear zones namely, the Son-Narmada-North Shear Zone (SNNSZ) and the SNSSZ. All the shear zones divide the CITZ into distinct geological terranes with contrasting geologic histories. The western extensions seem to be extending westward up to the Arabian Sea, where it merges with NE-SW trending Aravalli-Delhi orogenic belt. It is speculated that both of them may coincide with the East African orogen. Several contrasting tectonic models were proposed with wide variation on many critical issues like the polarity of subduction, timing of collision, and location of suture zone, etc., but the basic commonality was the recognition of an ancient plate tectonic regime involved in the tectonic evolution of the CITZ. Coincident seismic refraction and deep reflection results have clearly demarcated location of CIS and presence of two distinct crustal blocks on either side of CIS, with opposite dipping reflection horizons. These inputs and wealth of geological data resolved reasonably some of the controversies. According to Dr.Chetty the geological characteristics and lithological sequences within the CITZ are typical of ancient subduction-accretion - collision tectonic models. Since CITZ bifurcates Indian continent in to two distinct blocks studies and significantly different theories have surfaced from time to time , as suggested by many earth scientists including Dr.Chetty, concerted efforts need to be continued to resolve many controversies.

In the **Fifth chapter** Aravalli-Delhi Orogenic Belt is detailed. The Aravalli-Delhi Orogenic Belt (ADOB) is a prominent physiographic unit, located in the northwestern part of the Indian shield. The ADOB trends NNE-SSW and is a collage of two variably metamorphosed volcano-sedimentary belts, which are described as the Paleoproterozic Aravalli Fold Belt (AFB) and the Mesoproterozoic Delhi Fold Belt (DFB). The basement of these fold belts is considered to be the Banded Gneissic Complex (BGC), a heterogeneous Archean terrain. The current status of our knowledge on the crustal evolution of the ADOB originated from numerous structural, petrological, geochemical, and geochronological investigations by scores of workers. Understood from a modern perspective, the ADOB can be described as a mosaic of juxtaposed geological terranes within a reworked Archean basement complex based on the lithological assemblages and structural architecture. For the sake of brevity and clarity, the ADOB can be divided and described in terms of major terranes separated by crustal scale shear zones. A multidisciplinary approach involving all geological and geophysical studies along a NW-SE trending geotransect was attempted across the ADOB, under Deep Continental studies project of DST, covering the adjacent terranes. Geophysical data, in particular deep seismic reflection data, provide useful information in evaluating crustal architecture and mantle dynamics and have been recently employed in many studies in conjunction with the surface geological features to understand subduction-accretion-collision history in the Precambrian terranes. The reflectivity pattern along the seismic profile from Nagaur to Jhalawar varies all along the N-J transect. The seismic reflection data was interpreted and modeled in terms of geological associations and plate tectonic controlled interactions in a broader framework of westward subduction. In contrast to the westward subduction described above, eastward subduction of the oceanic lithosphere under the continental margin of Mewar craton with the trench being located at the western boundary of SDT was also proposed recently by active seismic experts, utilising seismic reflection based crustal model. The model also successfully resolves the ambiguity by correlating the Marwar Terrane with the Rodinia assembly rather than later Pan-African orogeny located further west. The seismic images reveal possible subduction-collisional event in the form of SE-dipping reflection fabric throughout the Marwar terrane over which the 750 Ma Malani Igneous Suite (MIS) is emplaced. Recent studies of geology, geophysics and geochronology led the researchers to understand the evolution of the ADOB by involving the plate tectonic processes. It is now almost established that the ADOB was subjected to subduction-accretion-collisional processes like any other orogenic belt all over the globe. However, within the plate tectonic scenarios, conflicting opinions exist about the polarity of subduction. In summary, geological and geophysical studies established that the Plate tectonic processes were responsible for the evolution of Paleoproterozoic ADOB through an accretionary process of island arcs during subduction and/or by collision involving the Bundelkhand craton in the east and the Marwar terrane in the west. Individual terranes are recognized by differences in their seismic reflectivity characteristics and some of the crustal-scale shear zones may represent sutures that are characterized by various mineralized zones. The lithologic association and their nature of distribution are in accordance with a Paleoproterozoic Pacific-type orogeny in the Aravalli region with a westward subduction of the Archean cratonic margin and development of a wide accretionary belt, imbricated ocean plate stratigraphy including ophiolites and the extrusion of a high-grade regional metamorphic belt at the orogenic core following the final collision. The available geochronological data reinforces the suggestion that the tectonic history of the Banded Gneissic Complex (BGC-II) is distinct from that of BGC-I; the former is dominated by the Paleoproterozoic and Neoproterozoic intrusive and metamorphic events, and the latter appears to be entirely Archean. This needs to be further resolved. Dr.Chetty explicitly brought into focus the importance of this orogenic belt, by extensively quoting the significant studies carried out not only by eminent geologists but also by a highly talented team of geophysicists.

In the **last chapter** Gondwana Correlations have been discussed**.** This chapter deals with the brief description of the supercontinents with reference to their assembly- breakup history cycles and orogens of Gondwana supercontinent. Emphasis has been laid on the correlations and extensions of the shear zone network and suture zones associated with the Proterozoic orogens of India (POI) among different fragments of the Gondwana supercontinent. This is further substantiated with the help of the recent geochronological data that helped in understanding the assembly and breakup through different stages of Rodinia and Gondwana. The POI, representing a critical part of Gondwana orogenic systems, delineate and juxtapose different Archean cratons of India (Dharwar, Bastar, Sighbhum, and Bundelkhand). These orogens, being in the central part of the Gondwana supercontinent, play a crucial role in the enhanced understanding of the reconstruction models of supercontinents such as Columbia, Rodinia, and Gondwana. The POI have attracted global attention in recent years for the reconstruction models related to timing and tectonics of the breakup and amalgamation of constituent fragments of Rodinia and Gondwana. The structural and metamorphic characteristics of POI, in general, are highly varied and they exhibit a wide range of styles, magnitudes, and peak temperatures. There is no unique set of characteristics that defines these orogens, and their first-order structural framework and development appears to be comparable to those of orogens formed in the Phanerozoic. The episodic character of orogenies since late-Archean times has led to speculations that Phanerozoic-style plate tectonics can be applied to the Proterozoic, and that continental land masses have periodically assembled and dispersed since the Paleoproterozoic as a result of plate convergence and separation. These speculations have provided a major stimulus to the reconstruction of ancient supercontinents, including Meso-, to Neoproterozoic Rodinia, Neoproterozoic Pannotia/ Gondwana, and Paleozoic Pange that led to the emergence of global-scale collisional orogenies. The available geological and geophysical information from the Paleoproterozoic orogens of India, described in previous chapters, provide important clues on the broad architecture of these orogens and the subduction polarity. The POI are characterized by subduction-accretion and collision. Structurally, the orogens are generally composed of imbricated crustal terranes or nappes translated along low, to moderately dipping shear zones, and include the flow of middle or lower crust within nappe-or crustal-scale channels through meling. The crustal-scale shear zone structures associated with the POI can be extended to other adjacent continents, now-dispersed segments of the Gondwana landmass. Their linkage will provide a fresh basis for reconstructing the processes of supercontinent assemblage and breakup. It is well established that Mesoproterozoic rifting at the cratonic margins and subsequent crustal evolution along the Proterozoic orogens in the Indian shield can be correlated to plate tectonic processes linked to the assembly and breakup of supercontinents of Columbia, Rodinia, and Gondwana.

After going through this excellent book by Dr.Chetty I felt happy that earth science research would continue to flourish due to the concerted efforts made by learned scientists like Dr.T.R.K.Chetty, a good friend of mine. This book will be useful both as a text book and as a reference book for students, young researchers. It can also motivate senior researchers to continue their research activities, inspite of age related limitations, as earth science research alone can bail us out from the present chaotic and deteorating nature of our environment. I conclude my review by congratulating Dr.T.R.K.Chetty for bringing out such an important publication by toiling night and day during the last three years. Since the quality of the book is exceptionally high a few minor typographic errors, present in the later part of the book may be corrected. Also, where ever possible the details given in figure captions are made more legible and formatted uniformly.

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