REVIEW*

THE TECTONIC MAP OF INDIA. Published by the Oil & Natural Gas Commission in co-operation with the United Nations Development Programme.

Professor L. Rama Rao has asked me to add to the discussion of the Tectonic map of India published by the O.N.G.C., Dehra Dun, in 1968 on the scale of 1 : 2 million. It will be recalled that Dr. B. P. Radhakrishna has already very ably reviewed this map in 1971. In agreeing to the request I should point out that I left the Geological Survey of India in 1953, 19 years ago, and that my subsequent nine visits to India, Nepal, Ceylon and West Pakistan were all of short duration and concerned solely with applied geology. I must inevitably therefore be out of touch with much recent work which has been done on the sub-continent by the Geological Survey of India, State Surveys, Oil and Natural Gas Commission and in increasing amount by flourishing University departments.

It is proposed to discuss a few points on a regional basis, selecting those features of the map for review which are of personal idiosyncratic interest, and must consequently result in the overweighting of certain problems.

The map under discussion was published in 1968 by the O.N.G.C. in collaboration with the U.N.D.P., with an editorial board of 7 Indian and 5 Soviet members. There is no reference whatever on the map, and only one indication in the accompanying brochure, that the present Tectonic map is really a second edition of one which was prepared by the Geological Survey of India and published in 1963. Between the issue of the two maps was issued from Moscow the Tectonic map of Eurasia on the scale of 1 : 5 million (1966).

At the outset it should be stated that the map is an impressive compilation, which is particularly valuable in connection with the sedimentary areas that have been investigated by geophysical methods and exploratory drilling in the search for oil and natural gas. Important information is thus now available about the Cauvery and Godavari deltas, the Bengal basin, Brahmaputra and Gangetic plains, Gujarat and Rajasthan, of which little was previously known. The more problematical concepts of the map concern the remaining 2 million square kilometres of the Indian peninsula.

South India: Without a detailed experience of the geology of South India it may be presumptious to attempt any discussion of the pre-Cambrian formations, but a few comments are possibly justified. It was Fermor (1936, p. 42) who first divided the Archaeans into Charnockitic and non-Charnockitic provinces, with a curved line running west of the Eastern Ghats to near Madras, and then cutting across the peninsula to meet the west coast north of Mangalore. That line does indeed appear to mark the north and west limit of the Charnockitic area and would need little modification now notwithstanding the far more detailed representation of S. Narayanaswami (1966, p. 86, and Fig. 2 under M. S. Krishnan in the same volume). In these maps there are four belts of Charnockite folded within Peninsular Gneiss over a

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* The first review of the O.N.G.C. 'Tectonic Map of India' by Dr. B. P. Radhakrishna was published in our Journal—Vol. 12, No. 1, March 1971, pp. 94-97. The present review by Dr. J. B. Auden has been received in response to the Editor's Note appearing at the end of the first Review referred to above.—*Editor.*

north-south distance of 500 km between latitudes $8\frac{3}{4}°$ and $12\frac{1}{2}°$, and the whole region south of Bangalore would appear to have essentially similar characteristics.

The 1963 Tectonic map of India (G.S.I.) did not follow Fermor and differentiate between the two provinces. It shows only 3 major outcrops of Charnockite, two in the Ootacamund-Salem area, and one, covering 1400 km², to the south east of Lake Periyar. On the other hand the 1968 Tectonic map of India (O.N.G.C.) indicates a major deep fault which separates areas of Dharwar folding from those associated with the Eastern Ghats. This deep fault cuts right across the Charnockite and Peninsular Gneiss belts, separating the Ootacamund-Salem outcrops from three belts of Narayanaswami south of latitude 11°. It corresponds to the deep fault given in the 1966 Soviet Tectonic map of Eurasia, which separates the Saamide area from the Karelide area, although there is a divergene of 40 km near Salem between the faults of the 1966 and 1968 maps.

A. R. Crawford (1969) has carried out important investigations on Rb-Sr dating scattered over 400,000 km² of South India. For Charnockites he finds ages varying from more than 3000 m.y. to 1300 m.y. and the Mysore gneiss is determined to be 2585 m.y. His age determinations, over such a great area, do not confirm the existence of marked provinces, and he doubts the validity of extending the Eastern Ghats province across South India to Kerala. The same conclusion is evident from Pichamuthu's review of the geochronology (1971).

It would appear that the assumption of a deep fault cutting across the peninsula from Vellore to Coimbatore may have arisen from the disposition of Bouguer gravity anomalies, which were discussed by Qureshi (1964, p. 678). The inferred fault lies between a NE-SW axis of gravity high (Qureshi NE-11-H) which passes through Calicut, Ootacamund and Kolar, and a parallel axis of gravity low (NE-14-L) which lies 60-100 km further south. Towards Orissa, however, this postulated deep fault has the gravity high on the south-east side, at Vizakhapatnam, and the gravity low on the north-west side in the Bastar depression, between which the gravity gradient is 0.7 mgals/km, but in a reversed direction to that in the Coimbatore area.

The O.N.G.C. map also has a NW-SE deep fault extending 1000 km from the Cauvery delta to Belgaum, which follows closely the two gravity axes of Qureshi NW-18-L and NW-21-L, and cuts across the Dharwar and Eastern Ghat provinces of the map. This fault, if extrapolated, would pass close to the Koyna dam, and its existence might be considered to be confirmed by the seismic instability which has recently been associated with Koyna. Fault-plane solutions undertaken by Tandon (1968), Lee and Rayleigh (1969) and Gorbonova, Kondorskaya and Landyreva (1970) would favour a deep fault aligned NNE-SSW as being responsible for the main shock at Koyna ($M = 6.3$); and the coincidence between the seismicity at Koyna and the NW-SE deep fault postulated by the O.N.G.C. on the basis of Bouguer anomalies may be accidental.

The relationship between gravity anomalies and crustal structure is often very deceptive. For example, the NE-SW gravity high between Madhupur and Calcutta, 300 km in length, bears no relation whatever to the thickness of the Mesozoic and Tertiary cover in the Bengal basin. At Madhupur, with a Bouguer anomaly of −15 mgals, the top of the Eocene is at a depth of about 4700 m. Near Bogra, 57 km to the WNW, with an anomaly of −35 mgals, the top of the Eocene is only at 1750 m depth. The pronounced gravity low of −130 mgals which is 200 km WNW of Bangalore is located entirely within Dharwar metamorphics, while its apparent twin of −100 mgals north-west of Madras is related to the Cuddapah sedimentary basin.

Three years after the publication of the O.N.G.C. map, Grady (1971) has indicated the existence of several geometrically straight deep main faults in South India, orientated NE-SW. The Attur fault extends for 380 km, passing through coordinates 12°N : 79°E, and is located 30–120 km distant to the south-east from the O.N.G.C. main fault. Grady's faults, based largely on photo-geology, are evidently shallower than those suggested in the 1968 Tectonic map, which are assumed to be delineated by geophysical evidence.

Aside from the deep crustal faults, the O.N.G.C. map has demarcated a series of straight faults in South India forming a box pattern and striking westwards to the Laccadive and Amindivi islands. These faults are evidently the interpretation of Eremenko, but his pattern is quite at variance with the triangular fault system that was postulated by I. E. Gubin (1969, Fig. 17, p. 45) on the basis geomorphology and seismicity. The present writer pointed out the discrepancies between the Eremenko and Gubin fault alignments (1969, para. 5.5.2 and map 5). With the latest suggestions of Grady, there now exist three quite different interpretations of deep and shallow fault structure in South India, aside from the faults which have been suggested by actual field work on the ground (Narayanaswami in Krishnan, 1964, Fig. 2). The straight rectilinear and triangular patterns would appear to be suspiciously geometrical and untied to rigorous work in the field. A communication just received (January 1972) from the Geological Survey of India indicates that there is now considerable scepticism about the existence of some of the geometric faults of the 1968 Tectonic map, and in their extensions to the islands off the west coast of India.

So far as field work and isotope dating have gone, there would appear to be doubt about the validity of the Vellore-Coimbatore deep fault, at least in its indicated role as a line separating quite distinct geological provinces in the uppermost 10 km of the lithosphere. Indeed, on geological grounds Fermor's primary line, which passes 90 km north of Salem, would be preferable as a boundary between contrasted petrological regions, although the interpretation of this boundary in terms of three-dimensional relationships between the two provinces must also raise difficulties.

Narmada-Son Lineament: The O.N.G.C. map shows a major deep-seated fault along the Narmada-Son zone extending 1,800 km from Saurashtra to Bengal. The importance of the Narmada-Son Lineament was emphasised by the writer 23 years ago (1949a, pp. 333,340) and recently by G. C. Chaterji and P. K. Ghosh (1970, plate 2). Nowhere is this zone more implicit than along the line of small basement inliers which crop out over a distance of 250 km along the south side of the Narmada between Hoshangabad and Jabalpur, the significance of which escaped recognition in the 1963 Tectonic Map. A related important and parallel fault system is present along the Tapi valley, being evident at the small basement inlier near Salbardi village (21°25½′ : 78°01′) and further west.

The present writer considers, however, that the eastern extension of the deep fault as shown on the O.N.G.C. map is less acceptable. The two curves of the s-bend at Umaria, with radii of curvature of 12 km, are surely too sharp for such a deep structure. Still further east the fracture is shown as passing far south of the Son valley and as skirting along the northern edges of the Damodar valley coalfields, finally ending orthogonally against the West Bengal shelf some 80 km north-west of Burdwan. The majority of the Damodar coalfields are only faulted on their south flanks in a manner recognised by the 1966 Soviet Tectonic map of Eurasia. To the north of the Damodar valley occur outliers of Lower Gondwana rocks covering a basement area of 4,000 km² between Giridih and the Santal Parganas, and excluding the Rajmahal outcrops. These outliers point to a once continuous spread of Lower Gondwanas right across the postulated deep fault, which would separate identical crustal blocks with a similar structural and sedimentation history. Moreover, the Bouguer anomaly isogals at the western edge of the Bengal basin run north-south between Burdwan, Bolpur and Nalhati and show no deflection by the postulated deep fault.

In the writer's opinion the Narmada-Son fault system lies within the Son valley, and possibly forms the north-west side of the concealed Monghyr-Saharsa ridge below the Gangetic alluvium.

The hypothetical nature of the Son fault system as shown in the O.N.G.C. map may be compared with that which is given in the 1966 Soviet Tectonic map of Eurasia. This lies 50 km north of the O.N.G.C. deep fault, as far east as 84°E longitude, east of which by inference it bends northward towards Patna.

There are sometimes sound geophysical reasons for postulating a deep crustal fault, such as the Turanian fault designated by Ishutin (1971) which extends for 1,000 km from south-west of the Aral Sea to near Birjand in east-central Iran, and runs at depth across the surface folds of the Mashhad area. This fault has been delineated by deep-seismic sounding, and separates crustal blocks of different natural seismic characteristics. Unless there are sound geophysical reasons, either deep-seismic sounding, or aeromagnetic, for placing the eastern half of the Narmada-Son lineament to the south of the Son, as shown in the O.N.G.C. map, I would suggest that its delineation is suspect, since it runs contrary to existing geological knowledge.

Bundelkhand: The O.N.G.C. map shows a series of NW–SE lineations across the Bandelkhand massif. The most striking feature of this granite massif is, however, the presence of a system of NE–SW quartz reefs which are not represented on the map. These reefs are up to 100 km in length and the average spacing across the granite outcrop covering 40,000 km² is about 10 km. They must represent an important structural phase within the granite after its intrusion.

The floor of the Gangetic basin and the Rajmahal gap: Of great interest in the map is the E.N.E. concealed Faizabad extension of the Bandelkhand massif towards the Kali Gandaki section of the Nepal Himalaya, over which the Vindhyans of the great Vindhyan syneclise have been removed by erosion. Parallel to the Faizabad ridge are the Monghyr-Saharsa ridge and the Rangpur ridge of Bangla Desh. Indeed, the grain of the Basement and Vindhyan formations under the Gangetic downwarp is most mainfest in the 1968 Tectonic map, which includes the important NE–SW fault extending between Arrah, Muzaffapur and Sitamarhi. The north-eastern end of this fault is close to the epicentre of the 1934 Bihar-Nepal earthquake ($M = 8.3$), but the disposition of the isoseismals of that earthquake points to a WNW–ESE fault failure, related to the Gangetic downwarp which cuts right across the peninsular grain. That parts of the peninsular-Himalaya possessed the NE–SW grain was suggested by the writer in 1935 (1935, p. 154) but the most conspicuous development of the Aravalli strike was found later in Simla Slates along the Nayar river between Marora and the Ganga (30° : 78°38′).

The existence of the Malda-Dinajpur ridge, which appears to serve as a concealed connection between the edge of the Satpura basement of the Rajmahal hills and the

Shillong plateau, raises the question of the 250-km eastward migration of the Shillong-Mikir massif which has been postulated by P. Evans to have taken place along the Dauki fault since the Mio-Pliocene (1964). If the whole of the Shillong-Mikir basement has moved 250 km to the east during the approximately 10 million years from its original connection with the northern end of the Rajmahal hills, it would be necessary to assume a style of plate tectonics involving a considerable thickness of the lithosphere travelling over an oceanic crust. Such a movement of the basement would offset also the carapace of Gondwana and later sediments. In the gap left by the eastward migrating massif there should be no sediments earlier than Mio-Pliocene since the gap did not exist before then, and all sediments earlier than Neogene which had been deposited before the formation of the gap would have been carried eastwards with the massif. The gap itself should probably consist of oceanic crust.

Data are scarce regarding the sub-alluvial formations of the Garo-Rajmahal gap and the Gangetic basin, but certain facts are available.

1. At coordinates 25°N : 89°E the Eocene limestone is proved by geophysical studies to be present at a depth of only 700 m., and it is understood that the Eocene is at a depth of only 180 m 80 km to the WSW, near the crest of the concealed ridge.
2. At Kuchma (24°42′ : 89°17′) on the south-east flank of the ridge the Lower Gondwana, Cretaceous and Paleogene succession is more than 1,400 m in thickness.
3. In an exploratory well 40 km north-east of Purnea 1,622 m Gondwanas are present above the basement (Metre, 1968, p. 46). This is on the north-west flank of the ridge.
4. At Singrimari (25°45′ : 89°57′) on the west side of the Garo hills, Lower Gondwanas dip westwards under alluvium and rest on basement. The Mesozoic and Tertiary sediments swing round the basement at Nokrek hill (1411 m 25°28′ : 90°20′) with quaquaversal dips.

The lack of Paleogene and older sediments over parts of the ridge can of course be explained by thinning and overlap towards the shelf, as is well established nearer Burdwan. Some 520 m of Cretaceous and Eocene sediments die out within 20 km WNW of Galsi, while 270 m of Eocene limestone thin to 4 m within a distance of 60 km. The presence of Lower Gondwanas at Purnea, Rajmahal, Kuchma, Singrimari, and in the Darjeeling foothills, points however to a fairly general spread of this formation, although made intermittent by late-Gondwana faulting and erosion. That the ridge exists, and consists of lithosphere rather than oceanic crust, is evident because normal basement is at a depth of only 294 m 40 km south-west of Dinajpur.

Consequently an alternative to the hypothesis of P. Evans may exist; for the Rajmahal gap may have been formed by differential vertical movements between the Shillong-Mikir massif and the once continuous Malda-Dinajpur ridge. Moreover, the disposition of the Cretaceous, Paleogene, and Neogene sediments round the west end of the Garo hills is suggestive of an upwarped massif involving its carapace with centrifugal dips, rather than of a trailer of sediments behind an eastward advancing leviathan.

These are just tentative suggestions. The hypothesis of P. Evans certainly explains many features which otherwise appear to be anomalous.

Centres of ancient volcanic effusions: The only centres of ancient volcanic effusions which are figured on the map are those of Barren and Narcondam islands.

It is a pity that the important centres of plutonic eruption associated with the Deccan volcanic episode, are not also shown. The five plutonic centres of Saurashtra were indicated by Fedden in 1884, and by the writer (1949 b, plate 7), that of Chomardi-Chogat (21°49′ : 71°53′) being the least well known. It must have covered an area of 35 km² before erosion into isolated remnants and was found in 1950 to have layered gabbros as well as micrograthe.

East of the Cambay graben is the plutonic mass of Phenai Mata (22°08′ : 73°52′) covering 11 km², with layered gabbros which have recently been described by Sukheswala and Sethna (1969), and the economically very important centre of explosion eruption and hydrothermal volcanic mineralisation of Amba Donga (21°59′ : 74°04′) where 4.7 million tonnes of fluorspar have been proved by the Geological Survey of India as replacement deposits in Bagh limestones, calc sandstones and explosion breccia (1967-1968).

These centres all lie on the north side of the Narmada fault system, although another centre exists on the south side of the fault around Kalivada village (21°40′ : 73°18′).

Further, the Narmada-Tapti dyke swarm, 100 km in width and over 220 km in length, with dykes up to 100 m in width, is orientated ENE–WSW along the Narmada alignment and is clearly a feature of tectonic interest which deserves emphasis in a tectonic map. The Saurashtra radial dyke system and peripheral swarms evidently have some connection with the Kathiawar plutonic masses, while the Konkan dyke network is evidently related to the Panvel flexure.

Cambay Graben: The map brings out with great clarity the extraordinary feature of the Cambay Graben, which has also been figured by Metre (1968, fig. 5). The accumulation of 5,000 m of Tertiary sediments above the Deccan volcanics, within a graben which is only 90 km wide at its southern end, is an event of great geological interest. The extension of this graben which is favoured by the O.N.G.C. is to the Sanchor depression and northwards to Jaisalmer. It may be wondered, however, if the Cambay Graben may instead continue to the Shahgarh depression (27° : 70°), passing west of Barmer. It would of course be limited on the west side by the Nagar Pakar massif. In the NW-SE Quetta-Sibi re-entrant there is a somewhat similar feature where 7,000 m of Oligocene-Pliocene sediments accumulated, with exceptionally rapid increase in formation thickness towards the axis of the trough. It is suggested that there may have been a connection between the Cambay and Sibi troughs, passing through the Shahgarh depression.

J. B. AUDEN

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N. B. *The National Institute of Sciences of India is now termed the Indian National Science Academy, but the above references are all to publications of the original Institute, before its change of designation.*