STRATIGRAPHY OF NORTH-WESTERN INDIA AND ITS CORRELATION WITH THAT OF INDUS BASIN, PAKISTAN, MALAGASY AND SOUTH AFRICA*

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ABSTRACT

In north-western India, Cambrian sediments—Marwar Supergroup, were laid down in the Marwar Basin ; they are correlatable to Saline Series, Salt Range, and are unknown in Gujarat. They were followed by glaciation and marine incursion during the Permian. Continental and marine sedimentation in Jurassic and Cretaceous alternated in Rajasthan Shelf, Kutch Basin, and parts of Saurashtra, while Deccan Trap volcanism enveloped Kutch and Saurashtra, Gujarat. Paleocene and Eocene were deposited in the Jaisalmer Basin, and other basins of Rajasthan, and upto Pliocene in Gujarat ; the sequence is correlatable to that of the Indus Basin.The sedimentation was tectonically controlled, the basinal architecture having developed along a NNE-SSW trending graben. The Meso-Cenozoic basinal framework was evolved on NNW-SEE trending grabens. The Cambay graben extended north-northwestwards, being co-extensive with Barmer Basin and the Shahgarh depression ; the tectonic set up was related to Deccan Trap volcanism. The stratigraphic sequence of rock formations in north-western India and the Indus Basin is closely comparable and indicative of these rock formations being part of one large and deep basin. It is correlatable to that of Malagasy and South Africa, that represent drifted segments of Gondwanaland. An identity in their Pre-Cretaceous geological history is inferred.

INTRODUCTION

Several assemblies have been proposed for the reconstruction of Gondwanaland comprising India, Africa, South America, Australia, and Malagasy. The island of Malagasy has been placed between the west coast of India and east coast of Africa (KING, 1950, SMITH & HALLAM, 1970; FISHER *et al.*, 1971; MCKENZIE & SCLATER, 1971), or the eastern coast of India and Antarctica (CAREY, 1954), or between the eastern coast of Africa and southern coast of Australia (AHMAD, 1961). The palaeoposition of Malagasy has been considered adjacent to east Africa off the coast of modern Somalia, Kenya, and Tanzania (DU TOIT, 1937; SMITH & HALLAM, 1970; MCELHINNY, 1979); adjacent to Mozambique in the coastal embayment in south-east Africa(WEGENER, 1929; FLORES, 1970). Stratigraphic sequences of Malagasy, South Africa, north-western India, and Indus Basin, that once formed part of the Gondwanaland, are compared and correlated to draw an inference (PAREEK, 1980). All these continents witnessed Palaeozoic, Mesozoic, and Tertiary sedimentation, and their stratigraphy is likely to bring out points of comparison.

Data on Malagasy (BESAIRIE, 1946, 1953, 1972, 1973; FURON, 1961), South Africa (FURON, 1961; MARTIN, 1961, 1964, 1968; BIGARELLA, 1970; HAUGHTON, 1970), Indus Basin (WILLIAMS, 1959; GANSSER, 1964), and Porwar region (GILL, 1952 a, b) is existing, while that on the north-western India is being built up. The north-western India comprises the states of Rajasthan and Gujarat (Fig. 2) traversed diagonally by

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the Aravalli mountain-range, through the middle. The region, west of the range, presents the Palaeozoic, Mesozoic, and Tertiary sequence of rock formations (PAREEK, 1981).

NORTH-WESTERN INDIA

RAJASTHAN

The Aravalli mountain-range has NE-SW regional trend for 2,400 km, from Delhi to Champaner, at the head of Gulf of Cambay, continuing southwards into the Laccadives (KRISHNAN, 1961, p. 4, 5). The eastern margin is faulted—the Great Boundary Fault running from SW to NE for 400 km. This range must have been similar to the present day Himalaya, during the post-Delhi and early Vindhyan period (GANSSER, 1964, pp. 16, 17), acting as a barrier for Trans-Aravalli sedimentation. The Aravalli and Delhi foldings of Archaean (Proterozoic age) formed the basement of the Western Indian platform (SASTRI & DUTTA, 1972, p. 371).

A shallow ridge postulated to be burried underneath the alluvial cover protruded northwards as Delhi-Sargodha ridge, extending to the east of Salt Range even beyond Sargodha, and northwards as Delhi-Harwar ridge. The existence of a ridge at shallow depths, underneath the alluvium cover, where it was expected, could not be indicated by refraction seismic survey along these cross sections (SIMHA & BOSE, 1963); "a sort of hump over the crystallines possibly occurs much farther to the south, at a fairly large depth", running along Tosham-Sirsa-Chautala, the crest plunging northwest.

The area being essentially covered by the Thar desert, the data has to be evaluated on subsurface information, and the tectonic pattern revealed appears in Figure 1 (after GHOSH, 1952; PODDAR, 1964; CHANDRA & CHOWDHARY, 1969; SASTRI & DUTTA, 1972; RAGHAVENDRA RAO, 1972; DAS GUPTA, 1975; ROY, 1977; PAREEK, 1981, 1981a). These ultimately led to the concept of basin evolution. The tectonic structures are delineated in NE-SE and NNE-SSW trends, extending into the Arabian Sea, and are traversed by another NW-SE fault which extends into north-western Rajasthan (Fig. 1). The NNE-SSW trending fault systems extend from east of Barmer to near Ganganagar, west of Jalor to Jodhpur to Nagaur and possibly much beyond. They were possibly responsible for controlling the formation of fissures for erruption of Malani igneous suite of rocks (PAREEK, 1981). The Malani extrusion spread north-wards through Barmer-Jalor graben, and successive intrusive phase. The Malani igneous suite of rocks are not reported to occur north of the graben off NW-SE fault, and also beyond the southern boundary of Rajasthan, unless they are buried under the thick Deccan Trap cover. These tectonic structures are possibly related to the other segments of the Gondwanaland and would have been responsible for extrusion of similar felsic lava material.

Nagaur Basin

The post-Malani sedimentation, i.e. Marwar Supergroup, was confined to the Nagaur Basin (Fig. 2) of Marwar Basin (PAREEK, 1981a) and this basin seems to have been an extension of Upper Indus Basin. The sediments of the Nagaur Basin comprised a total thickness of 1,000 m, and classified into the Jodhpur, Bilara and Nagpur Groups (PAREEK & SINHA, 1978; PAREEK, 1981, 1981a). They exhibit flat to rolling dips towards north and north-west, being folded only locally. These rock formations have

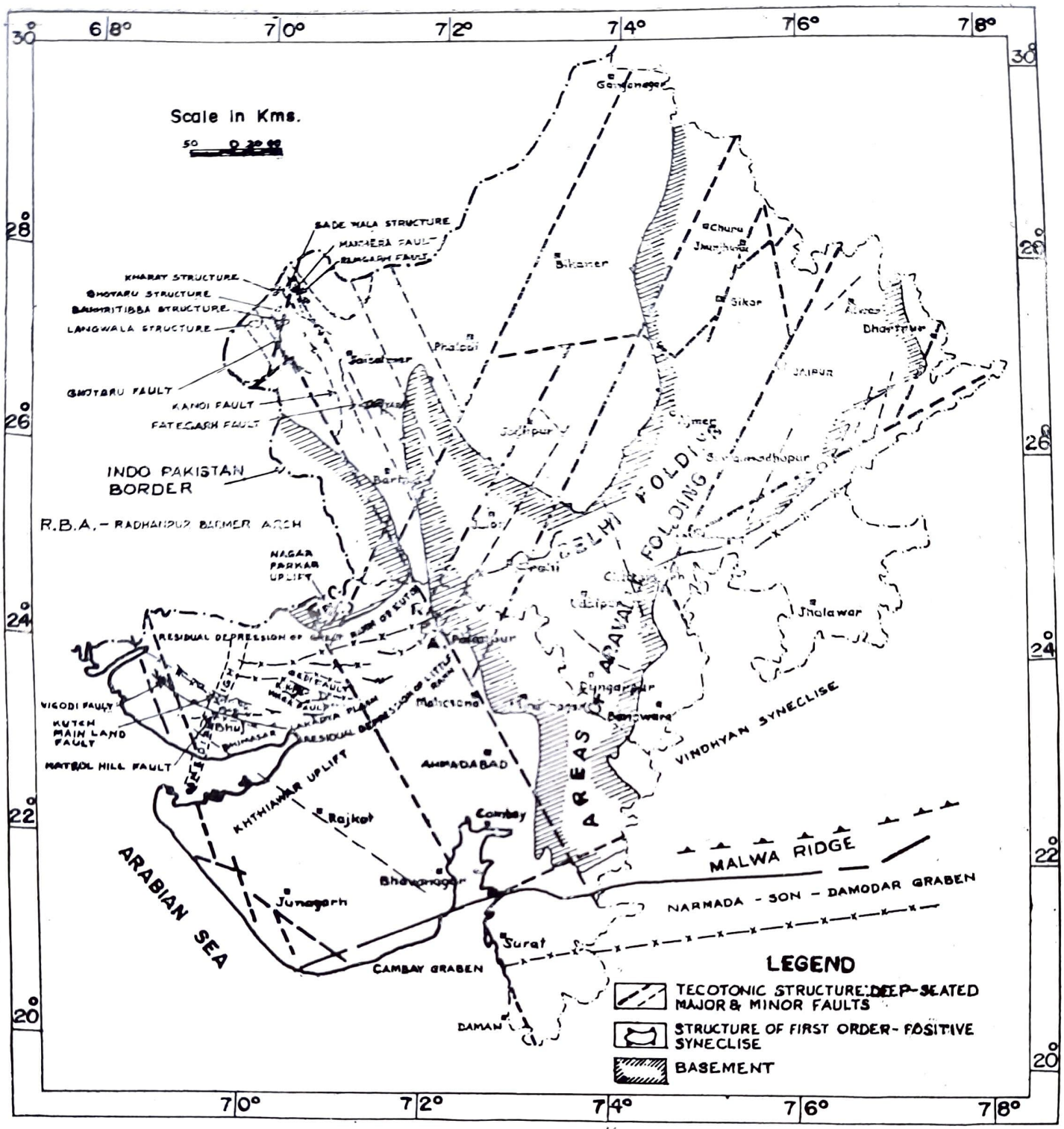


Fig. 1. Tectonic map of the North-Western India after Poddar (1964), Biswas and Deshpande (1970), Sastri and Dutta (1972), Das Gupta (1975), and Roy (1977).

lithological and stratigraphic similarity with those of the Salt Range and the basin can be postulated to have been extensive, deepening northwards, being bound southwards by the Jodhpur-Malani ridge (SIDDIQUIE, 1963).

The continuity of the basin is strengthened by the occurrence of a cap of Bap Boulder Bed over the Nagaur Group of rocks and by the overlying marine Badhaura Sandstone (Artinskian-Sakmarian); this marine sequence is traceable in the Salt Range also (Table 1). The subsurface data reveal that the Permian sediments are 255 m thick and are overlain by the non-marine Triassic sediments (TIKKU *et al.*, 1976).

Lathi Basin

Extensive erosion during the post-Permian period was followed by fluviatile sedimentation as the Lathi Sandstone (Liassic) which had the basin spread from near Pokaran in the east to Barmer in the south, and possibly into the Upper Indus Basin, due north and north-westwards. The thickness of the Lathi Sandstone could be as much as 600 m (pers. comm.—K. R. KARANTH).

Jaisalmer Basin

Towards the upper portion, the Lathi Sandstone has marine intercalations and develops an intertonguing contact with the marine Jaisalmer Limestone (Callovian). These calcareous beds are overlain by Baisakhi Shale (Kimmeridgian), and Bedesar Sandstone (Portlandian), occurring as repetitive bands in subsurface. Felspathic sandstones and quartzites of Pariwar Sandstone (Neocomian) overlie them. The Jaisalmer Basin was invaded by sea during the Aptian and records the Abur Limestone of restricted distribution (NARAYANAN, 1971; PAREEK, 1979, 1981a; PAREEK *et al.*, 1977).

The Mesozoic rock formations are overlain by the Sanu Sandstone (Paleocene), which is an arenaceous fluviatile sequence. The marine transgressions are represented by Khuiala Limestone (YPRESIAN), and Bandah Limestone (Lutetian). In subsurface, the Khuiala Limestone compares with Ghazij Shale and limestone and Dunghan Limestone and marly clay, and the Bandah Limestone also consists of two members (DAS GUPTA, 1975). The gap between the Habur and the Sanu is represented by Goru and Parh Formations (LUKOSE, 1974).

The stratigraphic columns from Jaisalmer (outcrop), Kharatar (wells), Mari (wells), and Sui (wells) and their correlation indicate marked increases in thickness of the sediments westwards. The sediments are 150 m thick in Jaisalmer and have thickened to 3,100 m; similar columns from Jaisalmer to Quetta indicate thickening from 300 m to 10,000 m (SASTRI & DUTTA, 1972, p. 374). It is, therefore, interpretable that the Jaisalmer Basin extended into the Lower Indus Basin and they now form part of one extensive basin.

The major structural features recorded in the Jaisalmer Basin are the SE-NW trending Jaisalmer-Mari arch extending as far as Quetta; Kishangarh shelf on its north-east, forming a gently sloping platform; and the Shahgarh depression on the south-west. The Jaisalmer-Mari arch is a large anticlinal uplift and its length is considerably greater than the width; it extends subsurface north-westwards. It lies *en echelon* with the Jacobabad High on its west, and Hyderabad High on its south in Pakistan (RAGHAVENDRA RAO, 1972). Subsurface structures delineated are Band Taba, Sadewala, Kharatar, Manhera Tibba, Ghotaru, Bakhri Tibba, Langwala, Vikhran Nai, Shumarwali Talai, Bhuana, and Lunar (DAS GUPTA, 1975, fig. 1). The basinal architecture is attributable to tectonic movements of Jurassic and post-Jurassic ages. Tectonic trough in E-W trend near Kolayat and Palana located the Palana embayment, which preserves a thick Tertiary sequence (Table 1). Similar trough is delineatable in subsurface near Ganganagar (PAREEK, 1981a).

Palana Embayment

The entire north-western Rajasthan was enveloped by Tertiary sedimentation of fresh water and marine derivations (JACOB & SASTRI, 1950; SAHNI *et al.*, 1974, 1975; SINGH, 1953, 1957, 1969). The sequence comprises Palana Shale, Marh Sandstone, and Jogira Fuller's Earth. The existence of the latter in parts of northern Rajasthan

(KHAN & TIWARI, 1973) and also its occurrence and that of nummulitic limestone revealed through borehole data in areas of Ganganagar district have proved that the Tertiary rock formations covered the entire north-western Rajasthan touching the Aravalli range (PAREEK, 1981a).

Barmer Basin

An elongated to oval-shaped remnant of 100 km extent in roughly N-S direction and 50 km width in E-W direction preserving the Tertiary rock formations exists north of Barmer (Fig. 2). The oldest Tertiary rock formation rests on the marine Fatehgarh Sandstone (Cretaceous) and comprise the Akli Bentonite (=Sanu =Palana), overlain by Mandai Sandstone (=Khuiala =Marh), and Kapurdi Fuller's Earth (= Bandah =Jogira). On the basis of fish remains, the Kapurdi Fuller's Earth has been assigned an early Eocene (Ypresian) age (SAHNI & CHOWDHURY, 1972). The Paleocene records igneous activity and is considered responsible for instability of the shelf (DAS GUPTA *et al.*, 1975).

The western Rajasthan, thus, presents stratigraphy of the Nagaur, Lathi, Jaisalmer, and Barmer basins and Palana embayment. It shows identity of lithological and palaeontological correlation with that of the Indus Basin which will be discussed subsequently.

GUJARAT

Kutch Shelf

Three major fault zones trending in NW-SE direction form post-Cretaceous grabens for sedimentation in Kutch (Fig. 1). The Kutch Mainland fault runs in WNW-ESE direction getting submerged below the cover westwards; Vigodi and Katrol hill Faults traverse the Mesozoic rock formations (BISWAS & DESHPANDE, 1970). The Nagar Parkar High, Median High, and Nagar Parkar-Khadir-Bhuj ridge form the main structural features (SASTRI & DUTTA, 1972). The Great Rann of Kutch depression, Island Belt High, Banni depression, Wagad High, and Mainland High represent the downthrown blocks form north to south tilted southwards. The south is bounded by Kathiawar Uplift and north by Radhanpur-Barmer arch. The Mesozoic rock formations form a domal structure and have undergone uplift, E-W faulting and domal flexures (BISWAS & DESHPANDE, 1970). The first fault line is parallel to Pachham, Khadir, and Bela islands; the second to the southern boundary of eastern Kutch extending through Banni; and the third and fourth lines are along the northern borders of the mainland as the hill range south of Bhuj (PODDAR, 1964).

In Kutch, the rocks are exposed as domes in the central part and are capped in the coastal part by the Deccan Trap. The Tertiary rock formations overlie the trap in the coastal plains. The Mesozoic sediments directly overlie a crystalline Precambrian basement (BISWAS & DESHPANDE, 1968). Palaeontologically, they are classified into Patcham, Chari, Dhosa Oolite, Katrol, and Umia (RAJNATH, 1932). The lithological rock units evolved are Jhurio, Jhumara, Jhuran, and Bhuj (BISWAS & DESHPANDE, 1970; PATIL, 1975). They are compared in table 1.

Saurashtra Shelf

Saurashtra represents rectangular faulted mainland, the boundary representing fractured zones along the sea coast (Fig. 2). A concealed ENE-WSW fault forms

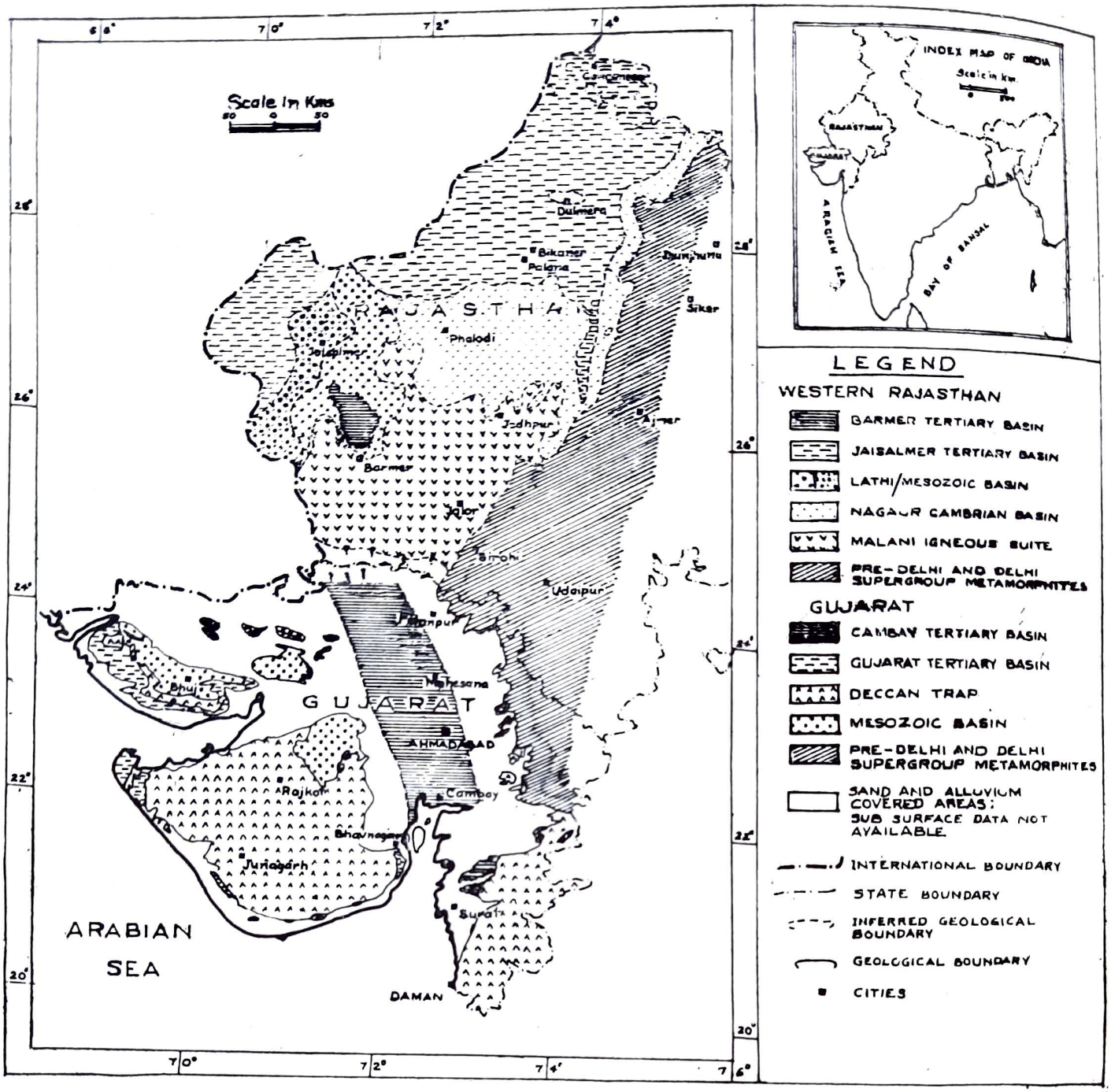


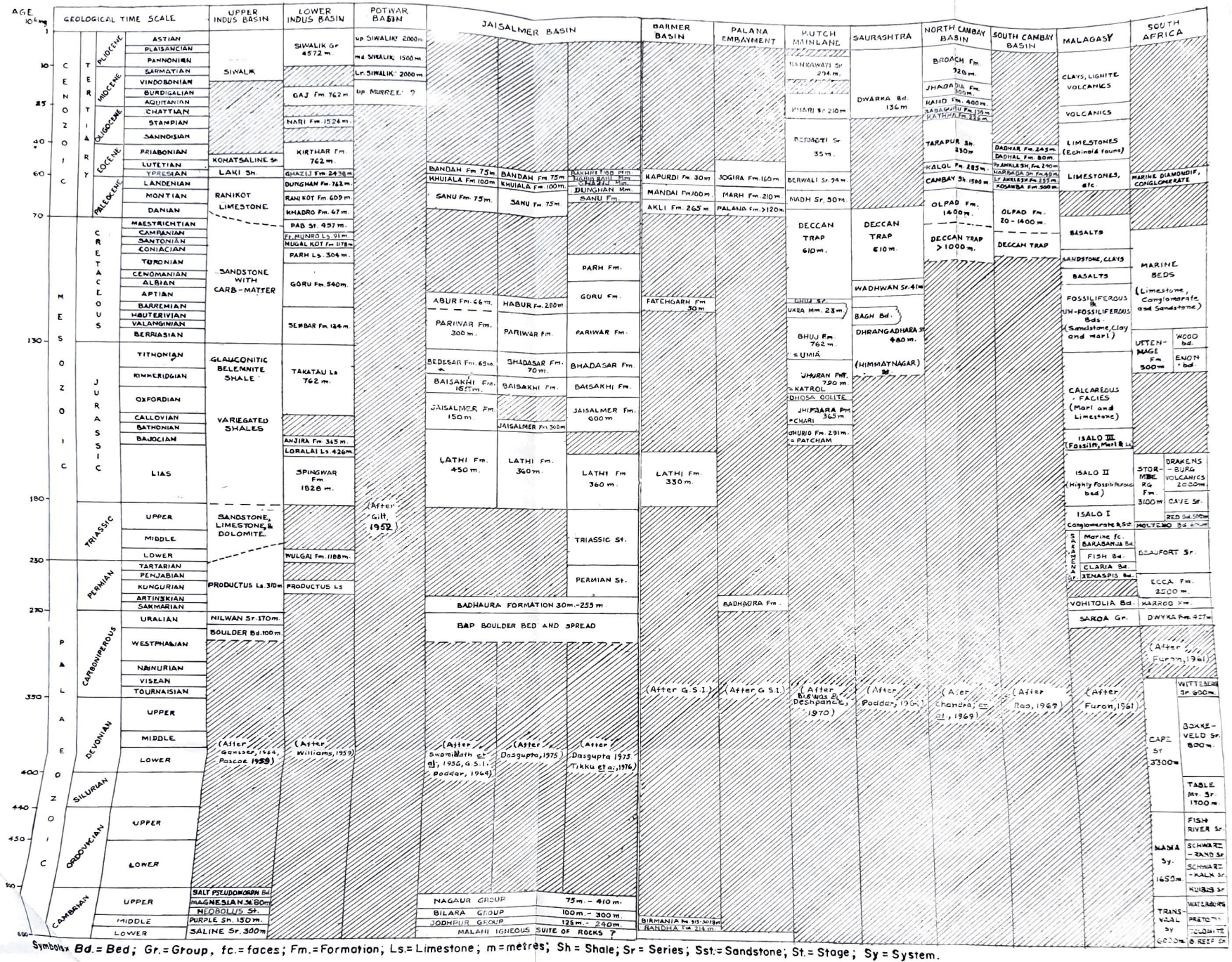
Fig. 2. Geological map of basin-wise sedimentaries of North-Western India—after Geological Survey of India (1962) and Pareek (1981a, 1981b).

the northern coast, straight coast line fault appears as the south-western edge, the southern coast line being the extension of Narbada geofracture, and the eastern margin by the Cambay basin zone of faulting (PODDAR, 1964, p. 139). The plateau has been elevated, during recent times, as appears from the overlying relationship of the Porbandar Limestone and older formations. The Dwarka beds are 136 m thick in the type area (BAWEJA & PRASAD, 1967). The sequence appears in table 1.

Cambay Basin

The Cambay Basin referred to as graben or half-graben or both (RAJU, 1968) extends from north of Mehsana, near Tharad, for about 385 km southward into the Gulf of Cambay and beneath the Arabian sea. It is 190 km wide as seen in Broach district.

Table 1—Stratigraphic sequence of rock formations in Indus Basin, Potwar Basin, Pakistan; North-Western India, Malagasy and South Africa.



Northwards, it is co-extensive with Kutch, Sanchore and Barmer basins. On eastern and western sides it is flanked by Precambrian and Deccan trap, respectively. It is considered by SASTRI AND DUTTA (1972) as "a Meso-Cenozoic structure, representing the northernmost part of the extensive Meso-Cenozoic Kerala-Laccadive-Cambay graben. Thick, mostly Upper Cretaceous, Deccan Trap lava-flows form the tectonical basement of the graben and pre-trappean data are not known. The southern part of the Cambay graben between Narmada and Tapti rivers seems to be in the westerly continuation of Narmada-Son-Damodar graben. Further to the south, it merges with the Deccan syneclise".

The Cambay Basin, an intra-cratonic basin between the Saurashtra craton to its west and the Aravalli swell and Deccan shield on its east, is of post-Mesozoic age (CHANDRA & CHOWDHARY, 1969). According to GAMBHIR (1975), it forms part of the pericratonic depression off the west coast and came into existence during Deccan Trap volcanicity. The Trappean and post-Trappean periods formed two major stages in the basin evolution; the former had intense tectonic instability. The deep-seated faults of the west-coast fault-zone extended during this period into the basin, the Trappean tectonism intensity waning upwards in the Paleogene. KALININ (1964, p. 251) described it as being related to the Precambrian basement thrust, and has two staged structure; the Precambrian basement is overlain by Deccan Traps, in turn overlain by a sequence of Tertiary sediments; the Deccan Traps are cut by faults, forming a graben with step-like slopes and the block-movement controlled sedimentation and Tertiary folding. CHOWDHARY (1975, fig. 2, p. 93) considers the subsidence of the basin along the ancient tectonic trends resulting due to outpouring of colossal volumes of flood basalts, dike swarms and eruptic centres, the dike swarms being aligned ENE-WSW, parallel to the Satpura trend. Rifting began parallel to the dike swarms and the graben subsided along ancient tectonic trends.

CHOWDHARY (1975) considers that compressional forces were developed in the competent crust and were relieved by the uplift of faulted blocks in the sagging basin floor. The location of the Cambay Basin at the junction of three ancient Precambrian tectonic trends—the Aravalli-Delhi, Satpura, and Dharwar, was of significance in adjustment of the blocks. The significance is that possibly "rejuvenation along one of the three Precambrian trends led to *unstressing* of the fault horsts pounded by the remaining two ancient trends." Unstressed blocks then seem to have readjusted by vertical movements in response to other forces.

The stratigraphic sequence of rock formations appears in table 1. The generalised stratigraphic column down from Kirthar range to Kutch, Viramgam, Kalol, Cambay, and Ankleshwar indicates marked thinning from 8,000 m in Kirthar to 2,800 m in Kutch and 1,000 m in Viramgam. In Cambay Basin, 3,000 m of strata in Kalol is reduced in Cambay and finally to 1,800 m in Ankleshwar (SASTRI & DUTTA, 1972, p. 376). This data brings out northwards thickening of the beds. The deeper part of the basin is thus suggested in the Indus Basin.

The occurrence of Tertiary rocks resting over the Malani Rhyolite in Rajasthan gave a clue to their continuity into the Cambay Basin. In Serau well, 367 m thick sediments resting on granites were found and established the link between Barmer—Sanchor—Cambay Basins (ROY CHOWDHURY, MATHUR & MISRA, 1972). The general slope of the basin was towards the north, during Eocene, with a zone of highs along the Cambay—Kathna alignment (MATHUR *et al.*, 1966). The O. N. G. C. drill hole data indicates a thick pile of marine and fresh-water sediments on an uneven Deccan Trap floor, diminishing from 5,800 m near a major fault north of Narmada to 1,600 m near

Tharad. The continuity of the Cambay Basin north-north-westwards into Rajasthan is thus suggested by this data (Fig. 2), as also the slope of the basin is indicated to be originally northwards, till the Eocene and becoming southwards in post-Eocene times.

INDUS BASIN

The Indus Basin is subdivided into Upper and Lower, falling north and south, respectively, of 32° latitude. The Upper Indus Basin exposes the sequence of the Cambrian, Carboniferous to Permian, through Mesozoic to Tertiary, while the Lower Indus Basin has from Permian to Siwalik Group (Table 1). The Cretaceous-Tertiary stratigraphy of the Indus Basin forms the standard section with which the successions are correlated.

Upper Indus Basin

The Upper Indus Basin has the Salt Range which is over 200 km long located between the Rivers Jhelum and Indus, and the predominant strike direction is E-W. Its present geological knowledge is largely due to Gee (1945), Schindewolf & Seilacher (1955), Pascoe (1959) and Gansser (1964). The section exposed in its eastern part comprises Precambrian-Lower Cambrian sequence. The Saline Series (Precambrian-Cambrian) forms the oldest outcropping rock formation exposing over 500 m thick sediments comprising gypsum, salt-marls, and rock-salt. The Lower Cambrian sequence includes the Purple Sandstone of 150 m thickness that conformably overlie the gypsum bed comprising cross-bedded shaly sandstones, red-brown shales and purple quartz-sandstones. Grey to green pyritic clay shales, oolites and dolomitic bands containing trilobite fauna constitute the *Neobolus*-Shale, which are overlain by "Magnesian Sandstone"—a dolomite of 80 m thickness. Salt Pseudomorph Beds are unfossiliferous and consist of red to violet sandstones and shales rich in salt pseudomorphs.

Unconformably overlying the Lower Cambrian rock sequence is the Shahpur System subdivided into Nilawan Series comprising glacial Boulder Bed, *Conularia*-Bed, Speckled Sandstone and Lavender Clays; and *Productus*-Limestone Series; Talchir Boulder Bed containing sandy to argillaceous matrix with boulders and pebbles of Cambrian rocks and of granites and rhyolites, similar to the Malani igneous suite. The overlying sequence comprises Speckled Sandstone (Early Permian—Wensink, 1975b, p. 283), unfossiliferous Lavender Clay and *Productus*-Limestone. In the eastern Salt Range, marine Permian *Productus*-Limestone is missing, probably eroded away, while in the western Salt Range, they grade normally into marine Lower Triassic, comprising soft sandstone, sandy limestone with greenish clay nodules. The Upper Triassic comprises dolomites, and is overlain, unconformably, by shales with plant fossils and marine limestone—Upper Jurassic. Glauconite-bearing *Belemnite*-Shales conformably merge into the Cretaceous; the eastern Salt Range does not preserve the Cretaceous rocks.

The Tertiary rock formations comprise the Ranikot Limestone (Paleocene), which overlies the glacial tillite directly in the eastern Salt Range; Laki Shales and Limestones, and Kohat Saline Series (Kirthar). Upper Eocene and Oligocene are absent. The Murree Series (Miocene), followed by the Siwalik Series, appears north of the Salt Range in the Potwar Plateau.

Gansser (1964, p. 26) describes the Salt Range as a relatively simple structure and is "..essentially faulted and folded monocline, rising southwards with a marked scarp to the south and dipping gently into the Potwar Tertiary Basin... The southern scarp of the Salt Range is formed by steep southwards dipping faults which cut the

monocline into a system of large blocks". It, however, requires definite evidence to say that the Salt Range is a monocline.

Lower Indus Basin

The Lower Indus Basin comprises the folded belt, corresponding to the mountainous regions, being an area of uplift and tectonic activity, and the alluvial area of the Indus Valley (WILLIAMS, 1959). *Productus*-Limestone (Permian) forms the oldest sedimentary rock observed near Wulgai, overlain by Wulgai Formation (Triassic) comprising grey mudstone; and shale, bedded limestone and "slatey" shale at the top, of maximum thickness of 914 m. The Spingwar Formation (Liassic) comprises dark grey to black limestone and inter-bedded shale, exposed in the folded belt, having a maximum thickness of 1,828 m. The Sulaiman Limestone Group comprising Loralai Limestone (Liassic), Anjira Formation (Toarcian-Bajocian), and Takatu Limestone (Upper Jurassic) of a maximum thickness of 1,737 m. The Cretaceous System includes the Sembar Formation (Neocomian)—glauconitic-silty shale, siltstone and nodular limestone of 1,34 m; Goru Formation (Albian—Cenomanian)—limestone, alternating with shale in the upper part and constituting 540 m thickness; Parh Limestone (Senonian-Turonian) seldom over 305 m thick; Mughal Kot Formation (Maestrichtian) composed of calcareous mudstone being 1178 m thick; Ft. Munro Limestone Member (Maestrichtian) sandy in the upper part and being 100 m thick; and Pab Sandstone (Maestrichtian) comprising coarse quartzose to quartzitic sandstone with silty shale being 497 m thick in the type sections. Olive-coloured to yellow-brown sandstone and shale with limestone of 67 m thickness forming the *Cardita beaumonti* beds designated as Khadro Formation (Danian) separated the Pab Sandstone with the overlying Ranikot Formation (Lower Paleocene), comprising variegated sandstone and shale, locally containing thin seams of coal, and is barren of marine fauna. The overlying Tertiary formations include the Dunghan Formation (Paleocene) which is exclusively limestone, 367 m thick; Ghazij Formation (Lower Eocene) is olive shale with limestone, sandstone, and coal of 597 m thickness in the type section; Kirthar Formation (Middle Eocene to Lower Oligocene) is limestone of 570 m thickness in type section. The Nari Formation (Middle Oligocene)—brown sandstone with interbedded shale; Gaj Formation (Lower and Middle Miocene)—gypsiferous shale; and Siwalik Group (Plio-Pleistocene) are of thickness upto 1524 m, 762 m, and 4572 m, respectively. The deeper parts of the basin thus preserve as much as 11, 584 m thick Mesozoic and Cenozoic strata (WILLIAMS, 1959).

Potwar Plateau

The Potwar Plateau is located between the river Indus on the west and river Jhelum on the east; the Salt Range on the south, and the Hazara foothills on the north. It has a distinct tectonic set-up and stratigraphy (GILL, 1952); the tectonic structures being defined into three major zones of deformation that include a zone of open folding affected by fold-faulting, a fault zone with northerly heading reversed faults, and a zone of closely-spaced strike faults and severely compressed folds terminating at the main boundary fault (GILL, 1952a). The stratigraphic sequence is represented by the Murree (Miocene) of thickness 2,440 m -2,740 m, and Siwalik (Pliocene-Pleistocene) Series of upto 3,960 m making a maximum total of 9,448 m, the boundary between them being gradual. The Murree transgresses into Lower Eocene beds with gypsum and saline red beds, and they form 40 km wide band crossing the Jhelum thinning south-eastwards (GANSSER, 1964, p. 40). The Siwalik Series shows variation in facies and thickness in the region,

their thickness estimated in Soan Syncline being 3,722 m in the northern flank and 3,173 m in southern flank (GILL, 1951, Table II, p. 382). On the Jhamat fold, the Middle Siwalik is 1,981 m thick while at the eastern end of the Soan Syncline its total thickness is 1,737 m; these beds show thinning rapidly towards the line of the river Jhelum. In the Lower Siwalik, there is progressive thickening eastwards (GILL, 1952a).

MALAGASY

The island of Malagasy is a plateau inclined towards the Mozambique channel. Its eastern part is faulted and the basement is of Precambrian rock formations, having a regional strike of NNE-SSW. The western part exposes Mesozoic-Tertiary sequence of rock formations that show seaward dips (BESAIRIE, 1946, 1953). The rift —Mozambique Channel, appeared during the Permian and widened during Upper Permian and Jurassic; it remained connected with India till Aptian marine transgression when Malagasy and Africa drifted away as indicated by closely allied species of reptilian remains existing in the middle and upper Cretaceous on the east coast of Malagasy. India and Malagasy were connected until the middle Cretaceous (DU TOIT, 1937, p. 214).

Now there is strong evidence that Malagasy fitted along the south-eastern coast of South Africa, adjacent to Rhodesia and Kaapvaal (KRÖNER, 1977, fig. 1, p. 168). The pre-Mesozoic Gondwana palaeoposition (KING, 1973; TARLING, 1972; fig. 1, p. 92) includes this island to be a part of Precambrian evolution of Africa, in which the island existed as a "large Early Precambrian sialic crustal fragment in southern Africa which included most of South Africa, Southern South West Africa (Namibia), Rhodesia and Malagasy and for which the name Kalahari-Malagasy Protoshield is proposed" (KRÖNER, 1977, fig. 3, p. 171). There is evidence of southerly derivation of Malagasy (TARLING, 1972, p. 93). Thus, after this strong evidence, if it is considered that Kutch lay to the east of Malagasy, Ceylon must have been to the south of South Africa, which is a reconstruction not going to be subscribed by any one now. Malagasy lay south-east of South Africa and south-west of India, as per recent work (see fig. 1, p. 92 of TARLING, 1972).

The complete sequence of rock formations appears in table 1. The Karroo Supergroup of rocks are classified (BESAIRIE, 1972, 1973) into three following groups separated by unconformities :

Isalo Group	..	Middle Triassic to Middle Jurassic, comprises red sandstones, shales, and mudstones.
Sakamena Group	..	Upper Permian to Lower Triassic; lower are 2,500 m, middle 400 m, and upper 600 m thick.
Sakoa Group	..	Upper Carboniferous to Lower Permian; comprises tillites with shales 400 m thick (Sakoa I), Coal measures (II), and Lower Red Series (III) 1,400 m thick.

SOUTH AFRICA

In Africa, the oldest part of the Sahara Platform is located in the western Ahaggar. Early and middle Precambrian and late Precambrian provinces on both sides of the southern Atlantic were attempted by MARTIN (1961). The general pattern of the tectonic structures is considered to be suggestive of existence of a former link between Africa and South America (MARTIN, 1969, p. 70). The Palaeozoic basins were formed

as intercratonic basins by subsidence of the basement, and sequences from Cambro-Ordovician to Devonian were deposited in Ahggar area; the Cambro-Ordovician is divided into four formations of arkoses, conglomerates, cross-bedded sandstones, micaceous sandstones with organic structures (BIGARELLA, 1970). In the Cape Province, the Cape System consisting of sandstones, shales, and quartzites overlies older formations and overlain by Karroo System (DU TOIT, 1954). These sediments resemble those of central Sahara.

In Upper Paleozoic, MARTIN (1961, 1964) described several outcrops along the eastern border of Parana Basin concluding that the ice sheets came from east and southeast. In the northern part of the Karroo Basin ice movement was mainly from N and NE. The Permian sediments had no direct connections between Parana and Karroo basins, as suggested from cross-bedding measurements (BIGARELLA, 1970, p. 87).

Although sediments are preserved in areas of sub-equatorial Africa, the complete rock sequence is to be found in the Great Karroo Basin occupying a large area within the Cape Province and southern Transvaal. The Karroo System commences with glacial Dwyka Tillite and terminated by Drakensberg (Stormberg lavas, as detailed below; HAUGHTON, 1970) :

Stormberg Series	..	Drakensberg Volcanic Stage
		Cave Sandstone Stage
		Red Beds Stage
		Molteno Stage
Beaufort Series	..	Upper, Middle, and Lower stages
Ecca Series	..	Upper, Middle, and Lower stages
Dwyka Series	..	Upper Stage, and Tillite Stage

The Beaufort and Stormberg successions are dominantly reptilians; the plant remains are confined to the coal-bearing Ecca Series and Molteno Stage. The *Glossopteris* flora characterises from Dwyka to Middle Beaufort, and the upper part of Karroo succession is of *Dicroidium* flora. The Karroo sediments and lavas are practically undisturbed over most of the Great Karroo Basin, but subjected to folding in the south and the east (HAUGHTON, 1970). The stratigraphic sequence of the rock formations appears tabulated in table 1.

It may be mentioned here that in the north-western Africa, volcanic activity is represented by a series of rhyolites, tuffs, associated with final Precambrian movements. To what extent these Precambrian rhyolites and tuffs are comparable to those of the Malani igneous suite of Rajasthan is of interest in view of their similar age and nature. With the distances involved between north-western Africa and India, this similarity could just be accidential even though requiring closer examination.

STRATIGRAPHIC COMPARISONS

PRECAMBRIAN

The Malani Igneous suite of rocks is exposed in northern and western Rajasthan, and has not been recorded from Gujarat and the Indus basins. The Malani Rhyolite gave an ischron age of 745 ± 10 my (CRAWFORD & COMPSTON, 1970, p. 364) and is of Pre-Marwar Supergroup (Precambrian) age (PAREEK & SINHA, 1978, p. 18; PAREEK, 1981). Erupted through fissures, resulting from tectonic grabens they have not been

recorded from Malagasy but have been reported from north-western Africa. "At the western end of the Moroccan Anti-Atlas mountains, near Ifui, BOURCART (1936) has recorded a series of rhyolites covering the folded and eroded Precambrian, then an alternation of volcanic tuffs and dolomites and finally a last extrusion of rhyolite before the basal Georgian conglomerate. The same series has been noticed in other parts of Morocco by CHOUBERT AND NETTER and by MENCHIKOFF in the Qugarta Ranges a far away as Guinea. Thus, in a large part of north-western Africa the final Precambrian movements were accompanied by volcanic activity producing outpourings of rhyolite (FURON, 1961, p. 8). A tectonically-controlled volcanic activity of acidic composition thus prevailed in the Gondwanaland during the closing of Precambrian epoch.

LOWER PALAEOZOIC

The Marwar Supergroup is correlatable to the Jhelum Series of Upper Indus Basin. The Saline Series is correlatable to the Nagaur Sandstone, which has thick evaporite sequence with potash salts, polyhalite, recorded by G. S. I., after halite was first struck in a bore hole (SINHA *et al.*, 1973).

Cambrian beds are not recorded from Gujarat but occur in South Africa as the Transvaal System. The Black Reef Series is correlatable to the Jodhpur Group and the Dolomite Series comprising stromatolitic cherty dolomitic rocks to Bilara Group. The tillite of 20 m thickness could account for correlation with Khichan Conglomerate, forming the base of Nagaur Group. There is an interruption in sedimentary processes by the basic lavas forming the Pretoria Series.

The Ordovician, Silurian and Devonian sediments are recorded only from South Africa. The rock formations commence with a tillite bed and comprise an arenaceous and calcareous sequence of 5,050 m thickness containing well-preserved fossils. The top-most bed, the Witteberg Series, is described to present a transition from the Upper Devonian to Lower Carboniferous. The Ordovician, Silurian and Devonian rock formations are not present in the Indo-Pakistan subcontinent; this area might have been uplifted during the period.

UPPER PALAEOZOIC

Glaciation covered Gondwanaland left its mark as Bap Boulder Bed in Western Rajasthan (PAREEK & SINHA, 1978) and Talchir Boulder Bed in Salt Range (WENSINK, 1975a); there have Malani rhyolite and granite pebbles, cobbles and boulders. In Malagasy, Sakoa Group commences with a tillite bed of 150 m thickness, and is "similar to the Dwyka tillites in South Africa" (FURON, 1961, p. 356). The Dwyka Formation has a sequence of lower shales, tillite, and upper shales. The climatic zones are concluded (DU TOIT, 1948, p. 113-126; *In* AHMAD, 1961, p. 87) to be NE-SW in Africa, which coincides with the axis of ellipse drawn by AHMAD in fig. 3. The direction of the ice-movement is "from some where in the eastern part of Africa to Simla and the Salt Range" (p. 86). This line of movement is in agreement with Rajasthan also, since the rhyolite, granite, and syenite boulders were transported from western Rajasthan to Salt Range.

A shallow arm of the sea "extended in Permian times to Rewa in Central India from southern Rajputana through Cutch and Narbada valley" (KRISHNAN, 1961, p. 111). Marine Permians are found in Umaria area of Madhya Pradesh, Badhaura area in Western Rajasthan, and are not known from Gujarat; they have been described from the Indus Basin. The Umaria Marine Bed had a direct link to the south-east

(AHMAD, 1958), by way of an incursion from Australia; seaway to the west existed simultaneously and continued during the Permian and the subsequent Barakar drainage-system discharged in the west (AHMAD, 1970). The Badhaura Sandstone (Sakmarian-Artinskian) comprises bouldery sandstones, ferruginous fossiliferous sandstones, grits, and clays containing fossil wood, and a variety of marine fossils. The fossil assemblages in the descending order are (i) Linguilids and the plant remains in the ferruginous sandstone, (ii) mostly brachiopods in fine grained ferruginous sandstone, and (iii) pelecypods, gastropods, crinoids, and conularids in medium-grained ferruginous sandstones (DICKINS & SHAH, 1973). RANGA RAO *et al.* (1979) have recorded and described *Eurydesma* fossils from Bap Formation for the first time, and *Conularia* fauna from Badhaura Formation. A marine source from the south-east for the Mahendragarh and Umaria, opening westwards and connecting Badhaura and Indus Basin is thus re-affirmed as put forth by AHMAD (1970).

In Salt Range, "the Talchir are followed by a wide-spread marine invasion which, after a more detrital sedimentation giving such formations as the Speckled Sandstones and Lavender clays, culiminate in the well-known Permian *Productus* limestones" (GANSEER, 1964, p. 25).

In Malagasy, the tillites are overlain by Coal Beds, containing a flora characteristic of the South Ecca, Red Clays, and Vohitolia Marine Beds that are *Productus* and *Spirifer*-bearing limestones. They belong to Lower Permian *sensu lato* (FURON, 1961, p. 357). Marine and continental facies overlie the Sakoa Group, the latter passing laterally into marine facies. The Mozambique channel had appeared at this time and the rift valley widened till the Permian. A Jurassic derivation of the island from the Mozambique area has been evidenced (FLORES, 1970).

In South Africa, the Ecca Formation overlies the Dwyka, and comprises bluish shales, coal-bearing fossiliferous felspathic sand stones, and in its turn is overlain by bluish shales. The Lower Permian rocks exhibit considerable facies change. The Indo-Pakistan subcontinent, Malagasy, and South Africa uniformly witnessed marine transgression during the Lower Permian period, and the African shield area had fluviatile sedimentation with terrestrial vegetation.

TRIASSIC

The Mesozoic Era commenced with fluviatile Triassic sedimentation in the deeper parts of the Jaisalmer Basin in north-western India. No Triassic beds are reported from Gujarat, and may possibly be underlying the massive Deccan trap, not penetrated yet. Triassic beds are represented by Wulgai Formation containing *Ceratites* and *Halorites* in Lower Indus Basin, and dolomites, limestones, and clay nodules with *Ophiceras* fauna in the Upper Indus Basin.

Malagasy had marine facies developed as Sakamena Group, and Isalo Group, while South Africa had Beaufort Formation with distinctive reptile fauna subdivided into six zones. The end of Triassic was marked by large scale faulting and vulcanicity leading to emanation of basaltic flows. No such flows have been recorded in Indo-Pakistan continent, during this period Vulcanicity, representative of the Deccan Trap, thus seems to have commenced firstly from the southern continents, spreading southwards.

JURASSIC

The Mesozoic sedimentation in Rajasthan commenced with fluviatile sedimen-

tation (Lathi Sandstone) and the first marine transgression was recorded during Callovian (Jaisalmer Limestone). In Kutch, the entire Mesozoic sequence is of marine origin (RAJNATH, 1932); the marine transggession that invaded Kutch and Indus Basins, early Jurassic, did not reach Rajasthan earlier than Callovian. In Malagasy and Africa, biotic relationship is suggestive of free migration in Jurassic with difficulty of migration until completion of final separation in mid-Cretaceous (TARLING, 1972, p. 92).

Upper Jurassic forms a continuous and very fossiliferous succession with entire sequences represented. The beds of Kutch are folded which could have happened during Lower Eocene and may be related to Narbada geofracture zone. The Saurashtra beds commenced with Himmatnagar Sandstone/Dhrangadhara Sandstone. Jurassic fauna for some reason was very widespread.

The correlations drawn are deduced below, during the Jurassic period, for the rock formations in the different countries (see Table 1).

1. Lathi, Spingwar, Jhurio, Patcham, Stormberg Formations (Lower part), Isalo I, II Group.
2. Jaisalmer, Loralai, Variegated Shales, Anjira, Chari, Jhumara and Dhosa Oolite Formations, Isalo Group III.
3. Baisakhi-Bedesar, Anjira, Katrol, Jhuran, Glauconitic *Belemnite* Shales, Takatau, Calcareous Facies (Malagasy), Uitenhage Formation.
4. Parihar (=Pariwar), Umia, Bhuj Sandstones with carb. matter, Sembar, Dhrangadhara, Himmatnagar, Fossiliferous and unfossiliferous Beds (Malagasy), Uitenhage Formation (South Africa).

CRETACEOUS

Gujarat witnessed volcanic outpourings in Cretaceous, continuing till Paleocene. The extrusion of Deccan Trap was prolonged and the sequence of events imagined by AUDEN (1949, p. 149) is (a) eruption of the traps of Kutch and Kathiawar, (b) plutonic foci of Kathiawar, (c) subsidence in Kutch accompanied by Lower Eocene marine transgression, and (d) renewed lava eruption over main Deccan area.

Malagasy recorded large sheets of basalt during Campanian—Maestrichtian—Danian epoch, along its western faulted portion and in association with western sedimentaries, while South Africa recorded volcanic activity as diamond-bearing kimberlite pipes. The coastal South Africa had marine facies. Volcanicity thus commenced in the different assemblies of the Gondwanaland earlier to or concomitant with the drifting of the continents, and was restricted mainly and mostly to the coastal areas which once formed part of one continent. Western Rajasthan, Gujarat, and Indus Basins witnessed marine transgression recorded as Abur, Fatehgarh, Goru, and Ukra formations. Coastal deposits of marine transgressions are also recorded in Malagasy and Africa.

PALEOCENE

In Rajasthan, Paleocene is represented by Sanu (Jaisalmer Basin), Palana (Palana Embayment) and Akli (Barmer Basin) of continental deposition; in Gujarat by Mata-no-Madh (Kutch Shelf), Olpad and Vagadkhol (Cambay Basin; Southern Gujarat) Formations. Marine deposition took place in the Indus Basin which has Ranikot limestones. In Malagasy, Danian is composed of marine fossils, while in South Africa the beds pass directly into the Eocene.

Eocene

A widespread marine transgression marked the Eocene which has thick seams of lignite in Kutch and Cambay Basins and thin seam in Indus Basin. The deposits are mainly limestones with beds of arenaceous rocks. Khuiala Limestone is recorded in Western Rajasthan; Ghazij Formation in Lower Indus Basin; Laki Series in Upper Indus Basin; Berwali Series in Kutch; Cambay Black Shale, and Kosamba, Lower Ankleshwar Formations in Cambay Basin; Limestone facies in Malagasy; and Marine Diamondiferous conglomerate in South Africa.

The second marine transgression took place in Middle Eocene and the rock formations represented are Bandah Limestone (Rajasthan Shelf), Kirthar Series (Lower Indus Basin), Kohat Saline Series (Upper Indus Basin), and Berwali Series (Kutch Shelf). The *Kalol* Formation, Narbada Shale and Upper Ankleshwar Formation of Cambay Basin are their equivalents.

The Eocene marked the end of Tertiary sedimentation in Rajasthan.

Oligocene

The Bermoti Series (Kutch Shelf) is equivalent of Tarapur Shale, Dadhal and Dadhar formations (Cambay Basin) and correlatable to Nari Formation of Lower Indus Basin.

Miocene-Pliocene

The Khari and Kankawati Series of Kutch correlate with Kathna, Baba Guru, Kand, and Jhagadia Formations, and Broach Formation of Gujarat. In Saurashtra, the Dwarka Beds directly overlie the Deccan Trap. In Malagasy, this period was represented by volcanic activity, and associated with clays and lignite. In Indus Basin and Potwar region, Murree and Siwalik sedimentation progressed.

CONCLUSION

In north-western India, NNE-SSW trending tectonic structures controlled effusion of the Malani Igneous suite of rocks and formation of basinal architecture for deposition of the Marwar Supergroup (Cambrian). While Gujarat does not show any evidence of Cambrian deposition, Indus Basin (Salt Range) exhibits close correspondence.

Glaciation covered the Gondwanaland during late Palaeozoic period and is recorded as Bap Boulder Bed (Rajasthan Shelf), Talchir Boulder Bed (Indus Basin), Sakoa Tillite (Malagasy), and Dwyka Tillite (South Africa). This was followed by marine sedimentation evidenced by Badhaura Sandstone (Rajasthan Shelf), *Productus* Limestone (Indus Basin), Coal Beds (Malagasy), and fluviatile Ecca Series (South Africa).

Marine Triassic outcrops are not recorded from north-western India but occur in Indus Basin, and South Africa. This was followed by large scale volcanicity and, thus, the Deccan trap activity initially commenced from southwards. While Rajasthan shelf witnessed fluviatile sedimentation during Liassic, marine deposits occur in all other regions; correlations in the different rock formations exist.

During Cretaceous, volcanic outpourings reigned Gujarat, Malagasy, and South Africa, concomitant with drifting of continents, while Rajasthan, being away from the tectonic zone, escaped volcanicity, as also Indus Basin. Volcanicity thus comm-

enced with Drakensberg Volcanics in Africa and spread to north-western India, tectonically accelerated by drifting of the continents. Post-Cretaceous NW-SE grabens controlled futher Tertiary sedimentation in Rajasthan Shelf, Kutch Shelf and Cambay Basin in north-western India and these extended into the Indus Basin which form the standard Tertiary section.

The stratigraphic comparison indicates indentity of Mesozoic and Tertiary rock formations of Gujarat, Rajasthan, with those of the Upper Indus Basin. Identity exists between the pre-Cretaceous rock formations with those of South Africa. Malagasy shows identity in stratigraphy to that of South Africa.

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