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THE INDIAN PENINSULAR MOVEMENTS, WESTERN GHAT FORMATION AND THEIR GEOMORPHIC REPERCUSSIONS
A Geographical Overview

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ABSTRACT : Recent interpretations of the palaeomagnetic and geophysical data has led to better revelation of the palaeogeography of the Gondwanic India and the seismotectonic environment of the present Indian Penisula. In view of these interpretations an attempt has been made here to review the major findings regarding the Indian Peninsular movement, the Western Ghat formation and their geomorphic repercussions, with a special reference to Maharashtra and Goa. Further, an attempt has also been made to highlight the present tectonic status of the Peninsular India, in the light of recent geological, geophysical and seismological studies.

Introduction

The indian peninsula has been a target of favourite attraction of many earth scientist, especially of the geologists and the geophysists, for over a century Large number of studies have facilitated in the reconstruction of the palaeogeography of the Indian Peninsula. In the present account an attempt has been made to make a co-ordinated review and highlight the major findings, together with an appraisal of the geomorphic repercussions of the related events and the geomorphic evolution of the landscape. In view of the scope of the subject only major findings, related to Maharashtra and Goa, have been emphasized and discussed here.

The Gondwanic India and the Drift

The reconstruction of the Gondwanaland, by many geologists and geophysists has brought in evidence for the existence of the Gondwanic India (as termed by Crawford, 1971) along with Africa, Madagascar, Antartica and Australia, near the ancient South Pole, during the early Mesozoic era. What was the nature and the geographical position of the Gondwanic India during the Paleozoic was not fully established till recently. However, the recent reconstruction of the Palaeocontinents for the late Cambrian period (about 500 Myrs) has revealed that the Gondwanic India along with Australia, occupied a location to the north-west of Africa in the Southern Hemisphere (Burrett, 1982) and not to the south-east of Africa, as we know, since late Mesozoic. The reconstruction is based on the palaeomagnetic data, using smallest subdivision of the geological time.

The movement of the Gondwanic India is supposed to have been initiated sometimes during late-Mesozoic (Sychanthavong and Merh, 1977). Since then the movement is belived to have continued till the terminal phase of Cenozoic, when the Gondwanic India came to occupy its present location. Irving (1977) on the basis of his extensive studies, has expressed the opinion that the

Gondwanic India, along with the adjacent Plates started its northward drift in the beginning of the the Tertiary.

Palaeomagnetic studies carried out by Klootwijk (1975) have indicated that the Indian subcontinent has rotated in a counterclockwise direction by about 80° since the late Permian times (about 200 Myrs). This observation reflects that the orientation of the Gondwanic India during the early Mesozoic era, was very much different from the present.

The direction of the movement has been found to be predominently NNE throughout the drift. Palaeomagnetic studies have demonstrated that the rate of the drift has been varying and heterogeneous during the movement, and has been the order of 6.0 cm/year during the Tertiary period (Meher Homji, 1977). Recent geophysical studies have indicated that the rate of movement has varied between 3.5 and 5.5 cm/year during the recent times, (Sychanthavong and Merh, 1977). The Tertiary and the post-Tertiary figures suggest that the rate of movement has reduced. This obviously can be ascribed to the opposing force of the Asian Plate, subsequent to the collision. The collision of the Gondwanic India with the Asian Plate has been adduced to have occurred during Eocene- Oligocene period (40 Myrs ago) according to Molnar and Chen (1978). It can be therefore, concluded that during the last 40 Myrs or so the Gondwanic India has been experiencing a decrease in its velocity.

The Drift and the Major Geological and Geomorphic Events

During the drift of the Gondwanic India several major and minor events must have taken place. The imprints of these events are seen in the form of the Deccan Traps, the Western Ghat Scarp, the West Coast and perhaps in the polycyclic nature of the Peninsular landscape.

a) The Deccan Trap Extrusion

This major geological event is believed to have taken place during the drift, when the Gondwanic India was far south of the present geographical position. Measurements of K/Ar whole age of Deccan Trap have indicated that the Traps are of post-late Cretaceous period. Recent palaeomagnetic date has given an age of 60 – 65 Myrs ago, when the Traps could have been entirely extruded (Molnar and Francheteau, 1975). The same data base has yielded an age of ⩾ 61.5 Myrs for the Mahableshwar lava, which presently occur at an alititude of more than 1400 m ASL.

The probable focus of the eruption was located near Bombay, according to De Souza and Sadashivaiah (1968). Evidences like, thick lava sequence exceeding 3000 m, concentration of positive gravity anomalies near Bombay and extensive tuffs in the Bassein area lend support to this hypothesis. Furthermore, the spread and the concentration of the lava was probably more towards the west of the 'eruptive focus' rather than towards its east. The maximum thickness of lava sequence nearly 18 km (18000 m) in the down faulted Gulf of Cambay region (Majumar and Ahmed, 1980), support the above argument.

The activity of Trap extrusion, which was spread over a significant geological time (5 Myrs) was not a continuous one. The presence of intertrappean beds clearly suggest intermittent extrusion activity. Neverthless, the intervals were not long and the eruptions took place in quick succession (Karmarkar, 1978).

During the eruptions, it has been deduced, that the earth's magnetic field underwent reversal. And therefore, the Traps are palaeomagnetically classified in to two group- (i) Lower Traps (reversed) and (ii) Upper Traps (normal),according to Athavale et. al.(1972). The demarcation line identified by the investigators runs along an altitude of 600 ± 60 m ASL.

The age of the Deccan Trap extrusion manifests that the activity took place when the Gondwanic India was still in the South-

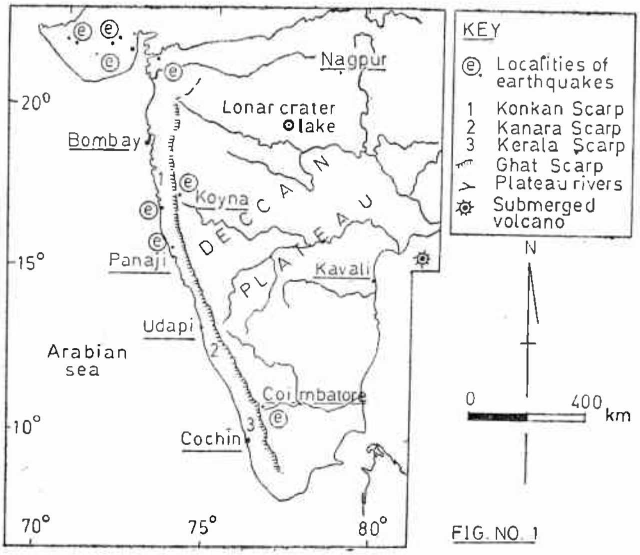

FIG. NO. 1

ern Hemisphere and was centred approximately over 30°S, as depicted on the palaeogeographical maps prepared by Klootwijk and Peirce (1979).

b) The Western Ghat Scarp Formation

This geotectonic feature, running almost parallel to the coast line for a length of several hundred km, has attracted the attention of many scholars. De Souza and Sadashivaiah (1968) have classified the Western Ghat Scarp into three types viz. (i) the Konkan Scarp, (ii) the Kanara Scarp and (iii) the Kerala Scarp, on the basis of the morphological characterstics (Fig. 1). The authors have associated the three types of the Scarps to differential dislocations along possible fractures or faults. The writers, on the basis of the number of embayments in the Ghat zone and the frequency of river captures, have expressed the view that the Western Ghat Scarp to the south of Goa is more mature topographically and may thus be older than the Konkan Scarp. Although the observation is apparently true, it does not fit in the model of Western Ghat Scarp developement, because then one has to imagine that the Scarp developed in parts. This of course is difficult to accept, cosidering the straightness of the Scarp line.

The Western Ghat Scarp, as a whole, was initially believed to be a dead cliff. It was opinioned that the cliff has receded in course of time to its present location. Nevertheless this hypothesis has long been refuted. Now faulting is adduced as the reason of the formation of the Ghat Scarp. The following evidences are some of the significant evidences lending support to the latter concept.

(i) The Scarp line, on LANDSAT imageries, reveal that it cuts across the Deccan Trap and the Archean-Dharwarian terrain without much longitudinal deviation. Considering the lithological variation, it is difficult to accept that a cliff can recede in a more or less straight line, irrespective of the lithological resistence to erosion and weathering.

(ii) The Bouguer map of gravity anomalies for the Peninsula depict a concentration of negative anomalies along a line close to the West Coast. The line coincides with the Western Ghats (Radhakrishnan, 1967). Profiles drawn elsewhere, from the

West Coast to the East Coast of India, from the Bouguer Gravity map, exhibit a distinct depression in the Scarp Zone. The gravity lows according to Majumdar and Ahmed (1980) are probably related to deep crustal faults.

(iii) Geophysical study based on Deep Seismic Sounding (DSS) along a profile from Kavali (A. P.) to Udapi (Karwar) (Fig. 1) has displayed the presence of a major fault or thrust in the Western Ghat zone (Roy Chowdhury, et. al., 1981). The fault or thrust penetrates deep into the crust and reaches the Moho discontinuity at a depth of about 35 km. A similar crustal study by DSS from the West Coast via Koyna indicates that a deep fault exists in the Ghat zone (Kaila, et, al., 1981). The fault reaches a depth of more than 40 km and has offset the Moho discontinuity. The deep fault at Koyna is aligned NNW-SSW with a down throw towards the west (Majumdar and Ahmed, 1980).

(iv) Some of the east flowing rivers like, Kukadi, Pushpawati, Indrayani etc of the Trap country exhibit beheaded nature of the source region. It is difficult to visualize that these rivers had achieved senility, right up to their source in recent geological past. The possibility becomes further remote considering the gradient of the rivers, which are very low. And so only faulting can explain the mature forms, in the source region of the rivers. Recently, however, many geologists have expressed doubts about the validity of the argument, because of many unexplainable problems.

(v) Deccan Traps exposed at Bombay at the sea level, are found to be normally magnetised. The fact that the normally polarised rocks are present at an altitude of more than 600 m in the Scarp sequence suggests that the great Scarp is a fault, with the downthrow on the western side (Athavale et. al., 1972).

(vi) The Panvel flexure, the N–S faults east of the Bombay High, along with other faults and fractures, do not suggest an evolutionary history of the West Coast and Western Ghat Scarp, but a diastrophic one.

Age

The exact period of the Scarp formation is still an unsolved problem. However, the dates of the Traps imply that the faulting must have taken place in the post-Eocene period. Krishnan(1956), Poscoe (1964), Wadia (1966), Radhakrishnan (1967) and others are of the opinion that the Ghats evolved some where between lower Miocene and Pliocene. The age of the Scarp formation suggested by these scholars seems to be plausible, as the period follows the collision of the Gondwanic India and the Asian Plate (about 40 Myrs ago). It is possible that the Ghat faulting must have taken place due to an indirect effect, in response to the Collision. Whatever the cause of the origin it is for certain that the Ghats evolved in stages. Meher Homji (1977) has referred that the Ghats achieved their full height during Pliocene. This observation is of great geomorphic significance, considering the repercussions of the discontinous evolution.

Comments

In the above reconstruction of the palaeography of the Peninsular India, there are many missing links and complications ln the chain of events. For instance, the nature of the relationship between the drift and the Deccan Trap extrusion has not been understood properly. Secondly, what was the tectonic status of the Gondwanic India during the post–Trap extrusion and pre-faulting period is still unknown. Thirdly, recent studies have failed to explain, as to why only a part of the Peninsula got faulted and dislocated when many deep faults exist in other parts of the Peninsula.

Furthermore, it is felt necessary to state here, that in spite of the numerous evidences, geologists are not fully convinced that the Western Ghat Scarp is a fault. However, it is felt by many geologists that the studies being carried out in the

Table I

Era/Epoch	Events	References
1. Pliocene	Complete rise of the Western Ghats	Meher Homji (1977)
2. Early Miocene -Pliocene	Faulting and the rise of the Western Ghats in stages	Krishnan (1956) Poscoe (1964) Wadia (1966)
3. Eocene-Oligocene (about 40 Myrs)	Collision of Gondwanic India with the Asian Plate	Molnar and Chen (1978) Klootwijk and Perice (1979)
4. Early Eocene (60–65 Myrs)	Deccan Trap extrusion in quick successions	Molnar and Franche-teau (1975)
5. Early Tertiary Late Mesozoic (?)	Initiation of the northward movement of Gondwanic Indi	Irving (1977)
6. Early Paleozoic (Late Cambrian about 500 Myrs)	Location of Gondwanic India to the NW of Africa in the Southern Hemisphere.	Burrett (1982)

Arabian sea will be very useful in this respect.

In view of the various recent findings and interpretations a summary of the geological events can be reconstructed in the following manner :

The Geomorphic Repercussions of the Peninsular Movement and the Western Ghat Formation

The drift and the Western Ghat formations seem to have vitally determined and governed the nature and the form of the gemorphic processes. An attempt has been made here to evaluate it.

(a) Erosional Surfaces of the Deccan Plateau

Normally, the triggering of a new erosional cycle is associated with the climatic changes, beside sea level (base level)changes. Usually, the major changes in climate are ascribed to the global changes in climatic conditions, in response to glaciation and deglaciation. However, in the context of the Gondwanic India it seems that the peninsula must experience variation in climatic parameters as a result of change in the latitude during the movement. The palaeolatitudinal positions during the Plate journey, therefore, must have determined the nature of climate, aside global climatic variations. The proposed hypothesis is likely to be incorrect, if the palaeo-equator would have occupied a totally different latitudinal position, than the present equator (thermal).

Palaeomagnetic evidences have established that Nagpur, was 7° N of the equator. during the Miocene epoch (Meher Homji, 1977). This fact reflects that a large part of the Gondwanic India was under the regime of equatorial warm and wet climate. In the periods following and preceding this epoch, the climate must have been drier relatively. The drier climate can be explained by the location of the Gondwanic India in the Tropics. These climatic changes from dry to wet and then from wet to dry and other changes at various stages of the movement must have accelerated and decelerated the geomorphological process. New cycles must have been triggered in various basins of the Peninsula, and at other periods (relative dry) the rivers must have experienced a reduction in the discharge and subsequently in the erosional and the transportational capacities.

Moreover, taking into account the rate of the movement (6.0 cm/year) during the Tertiary it seems that it would have taken more than fifteen millions years for any part of the Peninsula to pass the equatorial wet and warm zone. The period appears sufficient to start a new cycle and to lead it to a relatively advanced stage. Hence, it is likely that some of the older (High level) erosional surfaces of the Deccan Plateau (not the coastal) that we observe today must have evolved in response to the " palaeo-latitudinal climates ".

Furthermore, considering the gradient of the east flowing rivers it is difficult to perceive, that these rivers have carved broad valleys, with the relative relief exceeding 600 m in the source region. Therefore, it appears more probable, that these rivers, despite low channel gradient, gained sufficient erosional power in the equatorial zone, with an increase in runoff and discharge.

Against these views, it is possible that tectonic uplift during the drift might have been responsible for some of the Tertiary erosional surfaces. due to ' block rejuvenation'. Investigation at Aurangabad, has demonstrated that the place has been uplifted by about 325 m during the post-Trap extrusion period (Athavale, et. al., 1972). Considering more or less a similar rise in other parts, there is every possibility that rejuvenation and subsequent development of surfaces must have taken place in many river basins of the Trap country.

The problem becomes further complicated, especially in non-Trap areas, because it is highly probable that the presently existing valleys have their origin in the Mesozoic or the Paleozoic era, as in the case of the Godavari valley. The Godavari valley is a well recognized garben structure and is believed to have evolved towards the close of Paleozoic era (Majumdar and Ahmed, 1980).

Thus, although the possibility of the impact of the palaeolatitudinal climate on the origin of the erosional surfaces cannot be ruled out completely, it is difficult to step up with a definite and convincing relationship.

(b) The Palaeoplains of the West Coast

The palaeoplains (small riverine plains) of the coastal lowland occurring above 300 m ASL, are probably associated with the discontinuous activity of the Western Ghat formation and subsidence of the coastal lowland. It can be postulated that the palaeoplains developed when the Ghat formation stopped for a short period (on the geological scale). These periods of no-rise were the phases when the vertical erosion was exceeded and overcome by the process of lateral erosion and valley widening. This, tentative hypothesis appears to account for high level surfaces of the coastal lowland, when one cannot perceive, such high corresponding base levels (sea level).

It can be argued that these palaeoplains are possibly the residual forms of the Plateau-surfaces, which had developed during the pre-faulting period. Nevertheless, considering the high energy environment of the coastal strip, it seems, that there is little possibility that such, dispositioned surfaces could have survived.

(c) Bauxites of the Peninsula

During the course of the movement of the Gondwanic India, as mentioned earlier, the plate must have passed through the equatorial region or the doldrums. This phase of warm and wet climate with more than eight months of wet season (extrapolated) must have affected the weathering processes also. The climate must have been conducive for deep weathering and for large scale leaching, and therefore for the genesis of laterites and bauxites. Bardossy (1981) in his study of the bauxite formation in the context of the continental drift has attempted to establish that the bauxites of the Peninsula had formed long before the Indian Plate reached its present location. Although the age and the location of the Peninsula, as observed by him does not match and agree with the recent observations, the major thesis of the bauxite formation remains unchanged. Hence, the hypothesis mentioned here is substantiated by the views of Bardossy.

Furthermore, considering the time of more than fifteen million years for any point to cross the equatorial warm and humid zone, it appears that the time span must have been sufficient for the genesis of thick laterites and bauxites. Schellmann (1982) believes that in order to devlop a metre of bauxites with Al_2O_3 exceeding 50 per cent a period of more than 1.2 Myrs is required. Thus, the proposed hypothesis seems to be plausible. Further it seems more likely that the induration and the consequent formation of the bauxites must have taken place after the Gondwanic India crossed the equatorial zone and entered a zone with longer dry periods and lesser wet months.

Comments

The views expressed here although unsupported by strong evidences, do not seem to be totally incorrect aud wrong. Future studies in this respect will be undoubtedly useful.

The Present Tectonic Status of the Indian Peninsula

The present tectonic environment of the Indian Peninsula is perhaps related to the Plate movement and to the pre-existing fractures and faults, developed during the drift. Hence, their spatial distribution is of great geomorphic importance, for the present morphology, at least locally, is dependent upon the same. In this context, the understanding of the location of such areas becomes essential and therefore have been dealt with, in the present account.

During the recent geological past it is possible that tectonic movements must have occurred. According to Poscoe (1964) the uplift along the West Coast during the Holocene is probably menifest in the raised beaches or ' littoral concrete '. Similarly, cymatogenic movements have been perceived by some geomorphologists to explain the high relief in the central part of the coastal lowland of Goa and Maharashtra (Dikshit, personal communication).

Presently, although the Indian Peninsula has been widely accepted as one of the most stable landmasses, there are many evidences and events which suggest against the traditional view. Some of these events and evidences are cited below :

(i) Volcanic Activity

The Deccan Traps and the Lonar Crater lake (Fig. 1) are the only evidences of volcanic activity on the Peninsular India. However, two cases have been cited in the recent times to suggest post-Trap activity. The first case is that of a volcanic activity in the Bay of Bengal in the year 1756, (Grady, 1971). The volcanic island which subsequenently evolved, was several km across, and is believed to have disappeared later. Recent investigation has confirmed the presence of a submerged volcano off Yanam (Fig. 1) in the Bay of Bengal (Grady, 1971). More recent studies in the Ghat region, to the east of Bombay have indicated the presence of lava flows of post-Deccan Trap age. These flows are believed to be suggestive of volcanic activity during the Pleistocene too (Guzder, 1980).

(ii) Hot Springs

About 33 hot springs occur in Konkan (Majumdar and Ahmed, 1980) in a more or less straight line. The spring line is parallel to the Scarp line and runs for over 300 km. The thermal springs according to Sychanthvong and Merh (1977) probably represent the initial stage of ' hot spot mantle upwelling' along the fractures. The concentration of the thermal springs in the Deccan Trap region, probably suggests a relation between the two. However, this association does not account for the presence a thermal spring in south Kanara. Therefore it appears that the thermal springs of the Konkan have a relation with deep fractures that cut across the crystalline basement. Similar views have been expressed by some geophysicists in case of the hot springs in the Godavari valley.

(iii) Seismicity

Historic and recent seismic activities along the western part and other parts of the Peninsula, have established that the Deccan Peninsula is not a very stable block, and that the Western Ghat, in parts, is prone to tectonic disturbances. Numerous earthquakes in Saurashtra in last 300 yrs, the earthquakes of Coimbatore in 1900, Ratnagiri in 1962, Sawantwadi in 1968 and the quakes of Koyna since 1967, besides the seismic activity in other parts of the Peninsula have indicated that the Indian Peninsula is not a stable block.

Gupta and Rastogi (1974) on the basis of their of their observations from the year 1969 to 1973 have established that there is a definite enhancement in the seismic activity at Koyna, associated with the reservoir level. This fact probably reflects that the Scarp zone is, in parts, tectonically unstable and weak. The earthquake of Coimbatore, has been ascribed to dislocation along a fault, parrllel to the Coast (Brahma and Kanugo, 1976) due to tectonic instability. Other good number of seismic activities in Andhra Pradesh and other parts, have totally terminated the traditional belief of the seismic nature of the Peninsular India.

(iv) West Coast Tectonic Movements

Guzder (1980) citing evidences given elsewhere, has shown that the rise in the sea level along the West coast of India, differs substantially (Table II) from Saurashtra to the Kerala coast, due to tectonic movements.

Table II

Locality	period	rise in sea level in m/ century
Bhavnagar	1937–1955	1.75
Bombay	1878–1958	0·15
Cochin	1939–1958	0.45

(after Guzder 1980)

The heterogeneous nature of the sea level rise suggests that probably the Saurashtra coast is subsiding at a faster rate than the Kerala coast, due to tectonic movements. While the Bombay coast is exhibiting a low rate of submergence.

Comments

According to some geologists the seismicity and the tectonic movements along the Western part of the Peninsula are related to the frequent reactivation of the pre-existing fractures. These fractures had possily developed during the movement of the Gondwanic India (Sychanthavong and Merh, 1977). Contrary to these views, Sunder Kumar (1975) has attributed the present tectonic status of the West coast to the interaction between the underthrusting Indian Ocean floor and the Indian subcontinent.

The Geomorphic Repercussions

In the context of the above observations it is difficult to assess and appraise the geomorphic effects of the tectonic disturbances and movements in the studied area due to the pausity of geomorphic data. Nevertheless, the after effects of the earthquakes have appeared in recent literature and are being mentioned here. Gupte (1968) has reported that minor changes have taken place in the environs of Koyna after the earthquake. Investigation has brought to light, that the quake caused rapid mass movement in the form of rock falls and detachment of soil material from the upper hillslopes. Cracks 20–30 m long were also observed. According to Gupte (1968) the post-earthquake period also witnessed local subsidence and a shift in the ground water table. Guzder (1980) has reported a change in the watertable as far as Malvan due to the Koyna earthquake. At Sawantwadi, occurrence of a fault was noticed after the earthquake of 1968 (Sunder Kumar, 1975).

In view of these occurrences it can be perceived that similar changes, leading to local changes in the morphology and drainage must have occurred in other areas of the Peninsula. An attempt therefore, to identify these changes will undoubtedly be beneficial in the geomorphological context.

Review

The Gondwanic India that started its northward drift in the early Tertiary period has experienced many geological and geomorphic changes during its long journey. These events are represented in the form of the present West Coast, the Western Ghat Scarp, the Deccan Traps and perhaps also in the erosional surfaces of the Deccan Plateau, palaeoplains of the coastal lowland and the bauxites of the Peninsula. The Indian Peninsula is still active and tectonically disturbed, this is menifest in the seismic activity, besides the occurrence of thermal springs and the heterogeneous sea level rise along the West coast. The geomorphic repercussions of the palaeo-events are apparent, but what are the repercussions of the present activeness of the Plate is not yet understood and established properly. Therefore, future geological and geophysical studies in this respect would be both academically and economically vital.

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