EVOLUTION OF THE LANDSCAPE AROUND SAGAR, MADHYA PRADESH

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The landscape around Sagar presents some very ancient Vindhyan landforms, mixed up with much younger Deccan Trap landforms; these have had different geomorphic histories. All the Vindhyan landforms are palaeogeomorphic features, little modified after their exhumation from beneath the Deccan Traps.

The denudation chronology has been deciphered on the basis of the results of (*a*) geomorphological mapping; (*b*) generalized topographic contours; altimetric frequency analysis; (*c*) superimposed topographic profiles; (*d*) geological cross sections; (*e*) longitudinal, cross and spur profiles; and (*f*) field studies. On the strength of cumulative evidence, the following erosion surfaces have been established : (1) The Rewa Surface (2050′—1900′)*, (2) The Infra-Trappean Surface (1700′ — 1400′), (3 and 4) the Post-Deccan Trap Surfaces I and II, and (5) the Quaternary Surface. The landscape is thus a multicyclic and compound one.

The climates during the operation of these erosion cycles were humid for the first and arid for the rest. The hillslopes have evolved mostly by parallel retreat and the surfaces, by pediplanation. The courses of the major present-day rivers have been superposed on the Vindhyans. In this superposition, they have been guided, at places, by the courses of the ancient rivers, some of which were structure controlled.

INTRODUCTION

Sagar (23°50′ : 78°45′) is a divisional town in Madhya Pradesh, located nearly at the centre of India, less than ½° north of the Tropic of Cancer. This paper relates to a 1400 sq. km. tract around Sagar in which the author had carried out detailed geomorphological investigations on the scale of 1″ to 1 mile. This area is covered by the whole of two Survey of India topographical maps Nos. 55 I/9 and I/13 and lies between N. latitudes 23°45′ and 24°00′ and E. longitudes 78°30′ and 79°00′.

Physiography : The country around Sagar presents two major zones of hills and ridges, about 2 km across, trending NE-SW and mutually parallel, to the north and south of the township (Fig. 1). The two zones are loosely connected by a third zone of isolated hills, trending north-south. The only major outlet among the hills is the valley-plain of the Bankri stream to the NE. A crescentic row of low hills has facilitated the formation of a lovely lake in the southern half of the township. There are valley-plains farther east, west and NW.

Climate : A tropical monsoonic climate prevails in this part of the country, which can be described as sub-tropical, winter-dry and summer-hot. The rainfall is 125.66 cm at an average, obtained from July to October every year.

*All the elevations mentioned are above the Mean Sea Level.

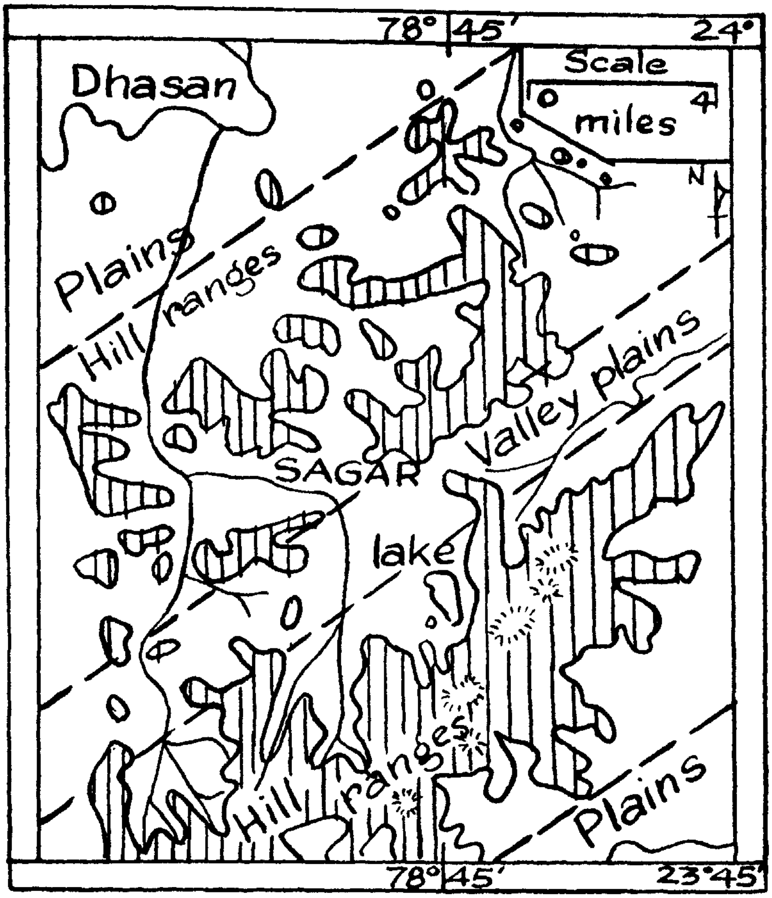

FIG. 1. A generalized physiographic map of the area around Sagar.

Geology : The area offers a simple, yet interesting, geology; there are at present only two major rock formations, viz., the pre-Cambrian Vindhyan quartzites and the early-Tertiary Deccan Trap basalts, the latter with a few bands of limestone between some of the flows.

Landforms : The landforms seen in the country around Sagar have been grouped by the author and described (Subramanyan 1973, 1975) under the Vindhyan Land System and the Deccan Trap Land System. The former occupies 148 sq. km. and contains the following land units : plateau top, ridge top, hill top, lag gravel surface, scarp, debris slope, pediment, amphitheatrical valleyhead, river valley, stream valley, water gap, wind gap, tors, hills sticking to basalts, residual hills, rockslide form and spring-sapped recess. The Deccan Trap Land System occupies 1252 sq. km. and exhibits the following land units :

Duricrust; plateau top; ridge top; hill top; plateau, ridge and hill slopes; foot-hill slope; spur slope; mesa; conical hill; plain; river valley; stream valley; limestone prominence; and 'lapies'.

Previous work : Prof. W. D. West was the first to have studied the geomorphology of the area around Sagar; in his joint-paper with Choubey (1964) he has dealt with the superimposition of the drainage on the Vindhyans and the pediplanation of the Deccan Traps.

EVOLUTION OF LANDFORMS

The establishment of the denudation chronology, i.e., the history of evolution of Landforms, has been one of the aims of the author's investigations of the study-area. While attempting the same, the author takes full cognisance of Thompson's (1941) warning that the interpretation of the geomorphic history is largely a matter of consideration of the balance of probabilities and conclusions must change as new facts become available or new meaning is given to old facts.

The landscape around Sagar presents some very ancient landforms, viz., the Vindhyan landforms that were sculptured during the Palaeozoic and Mesozoic eras. These ancient landforms are seen mixed up with the Deccan Trap landforms which must have started appearing in the early part of the Tertiary era. Even though both these systems of landforms are undergoing the same cycle of erosion at present, they have indeed had different histories. Therefore it is appropriate to treat the antiquarian Vindhyan forms separately as palaeogeomorphic features before dealing with the Deccan Trap landforms.

Palaeogeomorphology : Palaeogeomorphology deals with ancient landforms. Martin (1968, p. 804) considers only the buried ("fossil") landforms as palaeogeomorphic, whereas Thornbury (1969, p. 511) treats the buried, relict and exhumed forms as palaeogeomorphic in character. The Vindhyan landscape of the study-area is mostly palaeogeomorphic, from considerations of its age, causative processes and climate. Only about 10 per cent of the original Vindhyan landscape has been exhumed in the study-area and the rest of it still lies buried beneath the Deccan Trap basalts. No part of this ancient Vindhyan landscape has escaped burial by the lava flows, for, the Deccan Traps are still to be seen upto an elevation of 2107′ (642.21 m), while the Vindhyans are seen only upto 2050′ (625 m) in the study-area; further, the Deccan Traps are also seen all around. Therefore, none of the Vindhyan forms are relict features in the study-area.

Thornbury (1969, p. 512) considers even the volcanic landforms of the Deccan (wherein lies the area of investigation) as palaeogeomorphic forms of the relict type on the ground that the process responsible for them, viz., regional volcanism, is no more operative today. However, it is the opinion of the author that only the Vindhyan landforms deserve to be treated as palaeogeomorphic in view of their antiquity, whereas the Deccan Trap landforms, being very much younger, can only be considered *old* and not *ancient.*

Palaeogeomorphic forms : All the Vindhyan landforms mentioned earlier are palaeogeomorphic forms, little modified after their exhumation. Some of them, like the amphitheatrical valleyheads and the many gaps seen in the Vindhyan topography, give significant clues to the positions and directions of the palaeodrainage courses. The author's reconstruction of the palaeodrainage of the Sagar area (Subramanyan 1972) shows that the ancient river courses were about the same as the courses of the present-day rivers. It is to be noted that about 90 per cent of

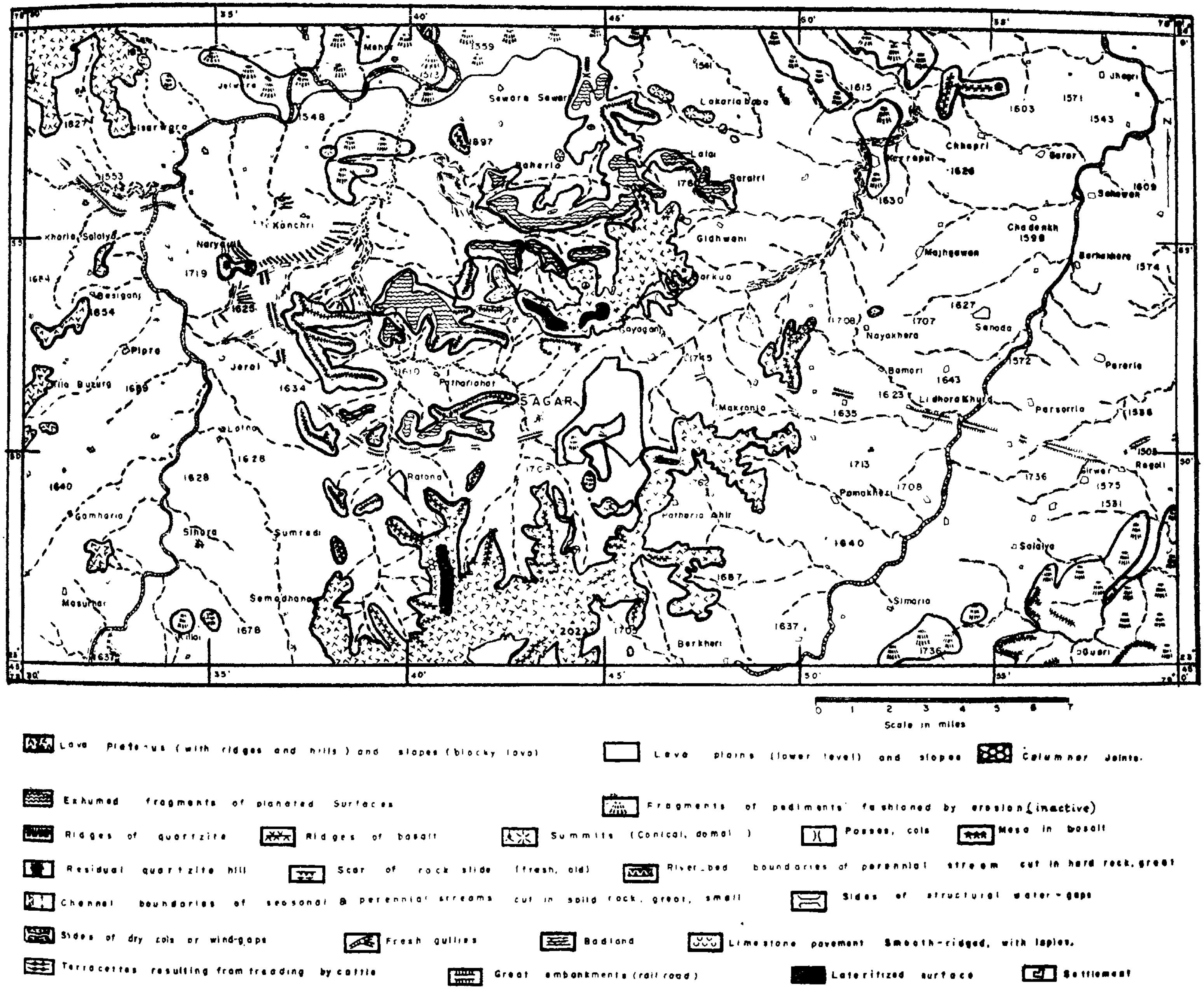

FIG. 2. Geomorphological map of the area around Sagar.

the study-area is occupied by the Deccan Trap basalts; therefore it is very likely that many other palaeodrainage features, like ancient channel deposits, are still lying buried beneath the lavas.

Climate during their evolution : After the Vindhyans were uplifted to form a landmass, there was a long period of time—from pre-Cambrian to Upper Cretaceous —during which they were subjected to denudation. Prior to the advent of the Deccan Trap lavas, parts of the Vindhyans were block-faulted, giving rise to inland lakes. Sedimentation took place in these lakes, resulting in the formation of coal-bearing sedimentaries—the Gondwanas. The coal seams present in these beds indicate the luxuriant growth of vegetation during the Gondwana times. Even within this period, this part of the country witnessed climatic vicissitudes: the Talchir boulder bed indicates a period of glaciation while the Barren Measures suggest a return to aridity.

When the Gondwanas were uplifted to form a landmass, erosion set in again, producing lakes and rivers. Sedimentation in these led to the formation of the Lameta sedimentary beds (which contain fossil remnants of the Dinosaurs near Jabalpur). The Deccan Trap lavas then welled forth and buried most of the landforms developed on these formations.

This brief account of the geomorphic and stratigraphic events goes to show that when the Vindhyan landmass was undergoing erosion, the climatic conditions might have varied appreciably in time and space. The tremendous heat which the lavas brought with them, must have dried up the water bodies completely and transformed the climate into a hot and dry one.

Denudation Chronology

(I) Background : Anyone who attempts at recognizing the 'erosion surfaces' as a first step towards building up the denudation chronology today, finds himself in a veritable quandary. Geomorphic thinking on their connotation has meandered back and forth in the past forty-seven years (since Wooldridge 1928), that Meyerhoff's observations of 1940, quoted here, are as valid now as they were then : *"If, in presenting my views, I sound a little confused, you may assume that I am very much confused; and I believe that the status of geomorphic thinking, particularly, geomorphic thinking on the evolution of erosion surfaces, is as badly confused as I."*

An erosion surface literally means any surface that has undergone (and is undergoing) erosion; this obviously excludes all depositional surfaces. If used only in this sense, it will liberally include all surfaces produced by erosion. But, in its conventional usage, the term has a certain conservatism tagged on to it and denotes only such flat (or nearly so) surfaces as or at or near the end of the cycle of erosion. Small (1970, p. 263) makes out a case for abandoning this term 'erosion surface' and recommends using 'planation surface' instead. Brown (1968) had in fact suggested the same earlier. But this does not seem to the author to resolve the confusion altogether because, 'planation' had been used by Gilbert (1877, p. 126-127) to include deposition of alluvium also in its purview. Therefore, the author has preferred to use the term 'surface' only, using appropriate prefixes, e.g., "Rewa Surface".

Also, there is no unanimity with regard to the reliability of the various methods in vogue to study the erosion surfaces. At one extreme is Rich (1938) who questions the validity of almost all the criteria conventionally used to recognize erosion surfaces. He lashes out at those who conjure up multiple erosion surfaces at very close intervals, firmly holding that it is not theoretically conceivable to have more than one or two such surfaces in any region. While, at the other extreme, we have Brown (1952) who recognizes as many as nine erosion surfaces within a vertical range of 1500′, using a large number of morphometric techniques. A study of the available literature on the erosion surfaces by a number of American and British geomorphologists reveals that, except Rich (1938) and Ashley (1935), the rest have employed a good number of conventional methods and recognized a number of erosion surfaces. As terrestrial history has witnessed epeirogeny, orogeny and eustatism (diastrophic and glacial) besides possible cymatogeny, there must have been a number of interruptions to the cycles of erosion, resulting in as many surfaces.

There still remains the problem of interpreting the surfaces, once they are established. This is an equally confounding problem because, these surfaces may be peneplains (Davis 1909), pediplains (King 1950), 'endrumpf' (Penck 1924, *Trans.* Penck 1953), 'panfans' (Lawson 1915), 'pan plains' (Crickmay 1933), 'etchplains' (Wayland 1934), 'marine plains' (Barrell 1920), 'cryoplains', 'stripped' or 'structural' plains or 'karst plains'. The author attempts to interpret his results with an awareness of these possibilities.

(II) Methods employed

(*a*) *Geomorphological map :* A geomorphological map was prepared (Fig. 2) with the geological, morphological, morphometric and morphochronological data collected in the field. In preparing this, the colours, shades, signs and symbols proposed by the International Geographical Union (1968) were used. This geomorphological map of the study-area presents the different landforms in the following groups on a genetic basis :—

(*i*) *Endogenous Landforms :*

Landforms of volcanic origin

Depositional landforms

1. Lava plateaus (with ridges and hills) and slopes.
2. Lava plains (lower level) and slopes.

(*ii*) *Exogenous Landforms :*

Denudational landforms

Destructional landforms

Remnants of late mature relief, unrejuvenated

1. Fragments of planated surfaces now exhumed from beneath the insoluble cap-rock.
2. Fragments of pediments fashioned by erosion.
3. Hard rock ridges (of quartzites).
4. Residuals of quartzites.
5. Summits, small and large.
6. Structural water-gaps.
7. Dry wind gaps.

(*b*) *Generalized contours :* In order to reconstruct the topography that must have existed prior to their dissection by the recent streams, every alternate contour, i.e., at intervals of 100′, was generalized by eliminating the smaller valleys that are present along these contours. Such generalized contours are shown in Fig. 3.

(*c*) *Altimetric frequency :* An altimetric analysis was carried out on the two topographical maps of the study-area (Nos. 55 I/9 and I/13). Thompson's (1941) method of finding out the frequency of the summits and their areas with reference to elevation was used. For this purpose, the quadrangles measuring 5′ latitude and 5′ longitude, which are marked on the base maps of the area, were utilized. In each such quadrangle, the total number of summits, represented by closed contours for every 50′ of altitude, were counted and tabulated. In addition, the areas of such summits were also measured planimetrically. These data were then plotted on the same graph, keeping the altitude on the ordinate and the frequency of the summits and their areas on the abscissa. The data for the Vindhyans and the Deccan Traps were plotted separately (Figs. 4 and 5).

(*d*) *Superimposed topographic profiles :* Eleven topographical maps of the areas all around the study-area were used and topographic profiles were constructed on one and the same graph paper in a superimposed manner at 5′ intervals along the latitudes (Fig. 6). A similar north-south series of profiles were also drawn superimposed one upon the other along 5′ longitudes separately (Fig. 7).

(*e*) *Geological cross-sections :* Apart from the geological cross-sections that were constructed for understanding the geological structure, two more sections were drawn across the Vindhyan hills alone (Fig. 8). All these sections were used for making out the erosion surfaces.

(*f*) *Longitudinal, cross and spur profiles :* Longitudinal profiles were drawn along the streams and rivers of the study-area and were analysed for the presence of genuine knick-points (Fig. 9). In addition, profiles were drawn across valleys and also along some spur-slopes (Fig. 10).

(*g*) *Field methods :* The accordance of the summits in the scenery around Sagaı was carefully studied with reference to the rock types and altitude. The existence of topographic flats on the tops of hills and at the foot of the hills was also noted. The altitudinal distribution of the lateritic caps and lag gravels was also studied (Figs. 11, 12, and 13).

(*III*) *Results obtained :* The results obtained by the application of the methods detailed above are given in Table I.

Discussion

(*a*) *The Vindhyan (Pre-Deccan Trap) erosion cycles*

The maximum elevation on top of the Vindhyan landforms in the study-area is 2050′ (625 m) on the ridge to the south of the Jarara village (23°51′ : 78°37′). Their minimum elevation is 1500′ (458 m) along the Dhasan river to the NE of the Mehar village (23°59′45″ : 78°39′30″) and also along the Gadheri stream which flows in the southeastern corner of the study-area. The relief in the Vindhyan terrain is thus 550′ (167.5 m).

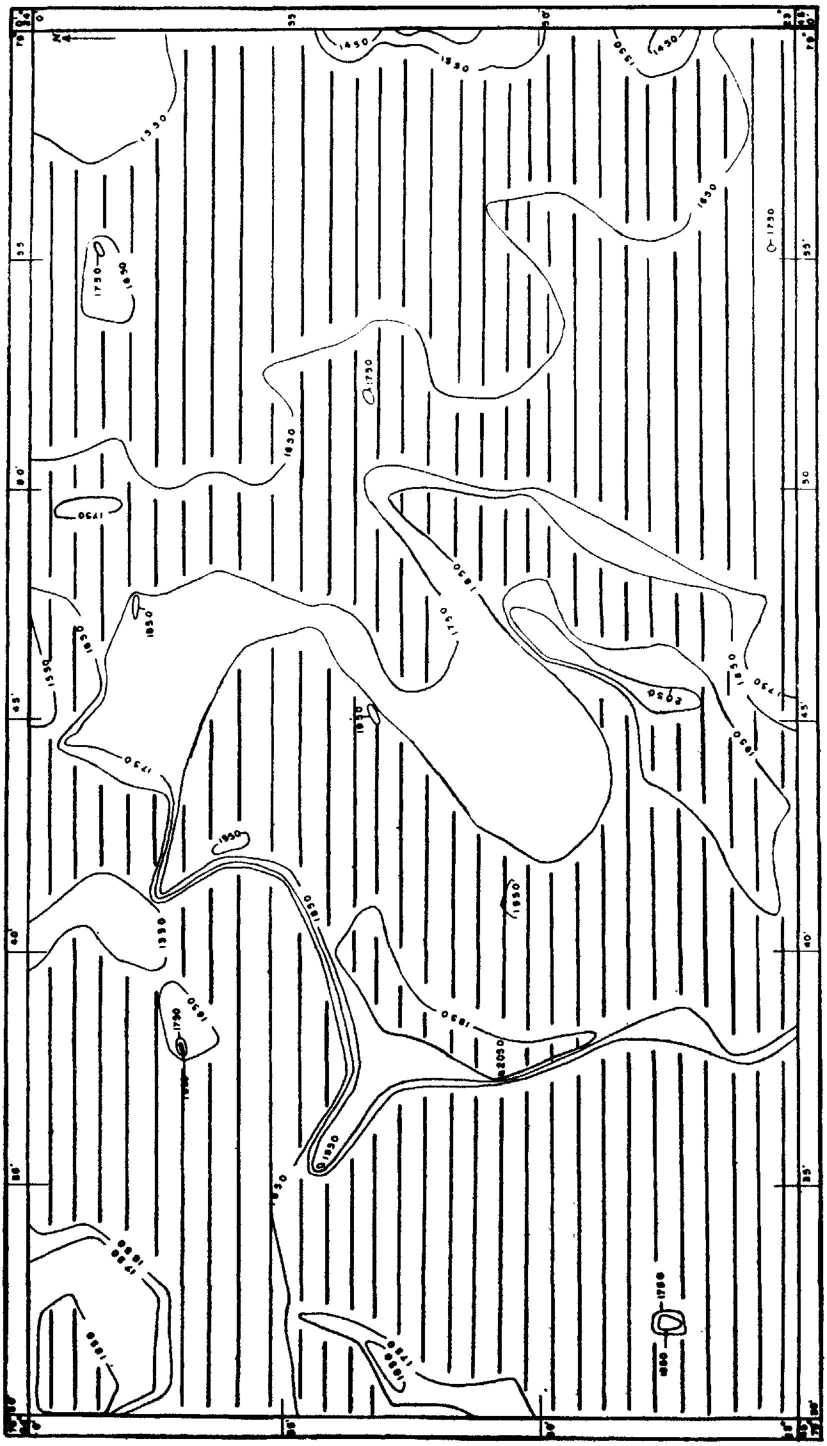

FIG. 3. Generalized Contour map of the area around Sagar.

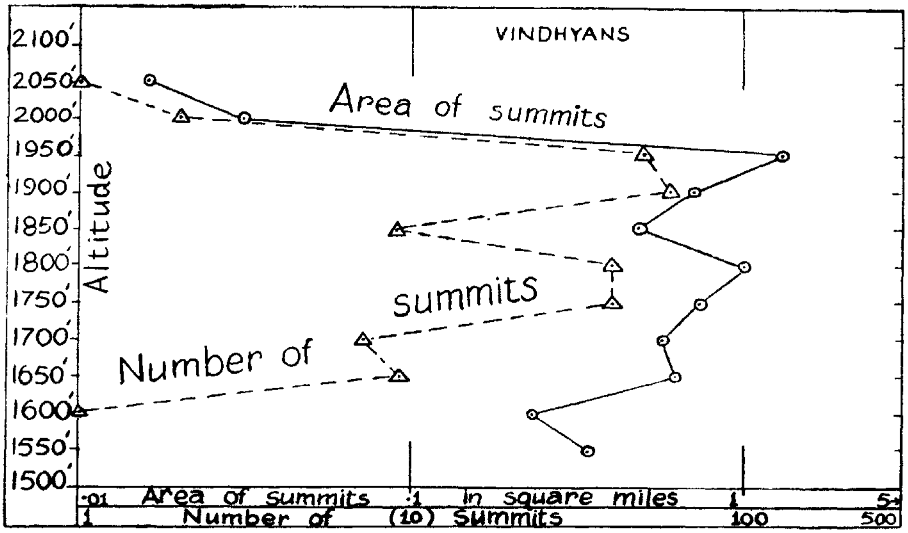

FIG 4. Altimetric Frequency diagram for the Vindhyans of the area around Sagar.

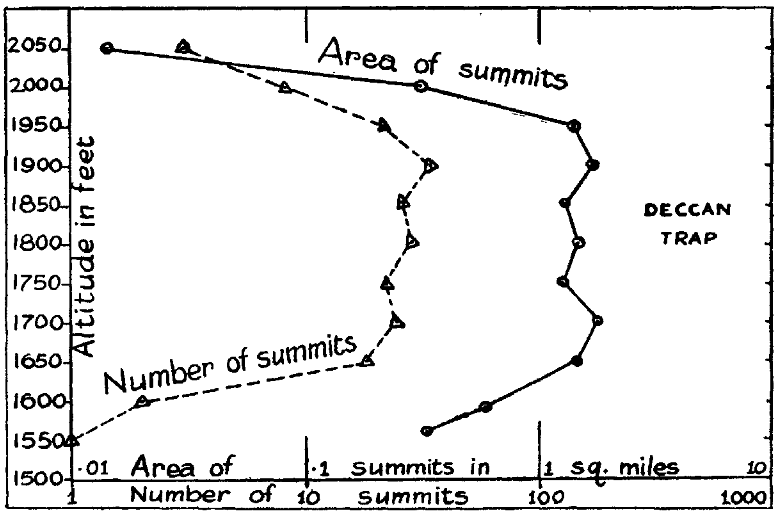

FIG. 5. Altimetric Frequency diagram for the Deccan Traps of the area around Sagar.

The Vindhyan ridges which occur to the west and NW of Sagar produce an even skyline that runs between 1950′ (594 m) and 1900′ (about 580 m; Fig. 12). It is at this level that a pronounced convex break of slope is observed on the Vindhyan hills. The geological cross-sections, the altimetric frequency curves, the super-imposed profiles, the valley cross profiles, the generalized contours and the morphological map show that the accordance of summit levels observed in the field does not appear to be illusory, but is real.

This level, which, more precisely, is between 2050′ and 1900′, is therefore a palaeo-geomorphic surface developed on the Vindhyans after they were uplifted to form a

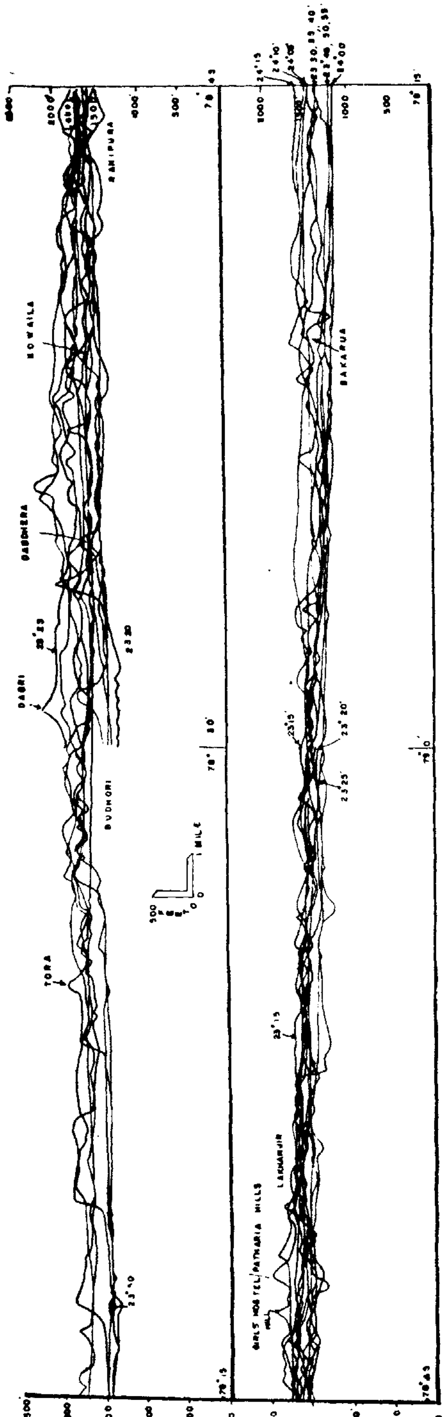

FIG. 6. Superimposed Topographic Profiles (East-West series).

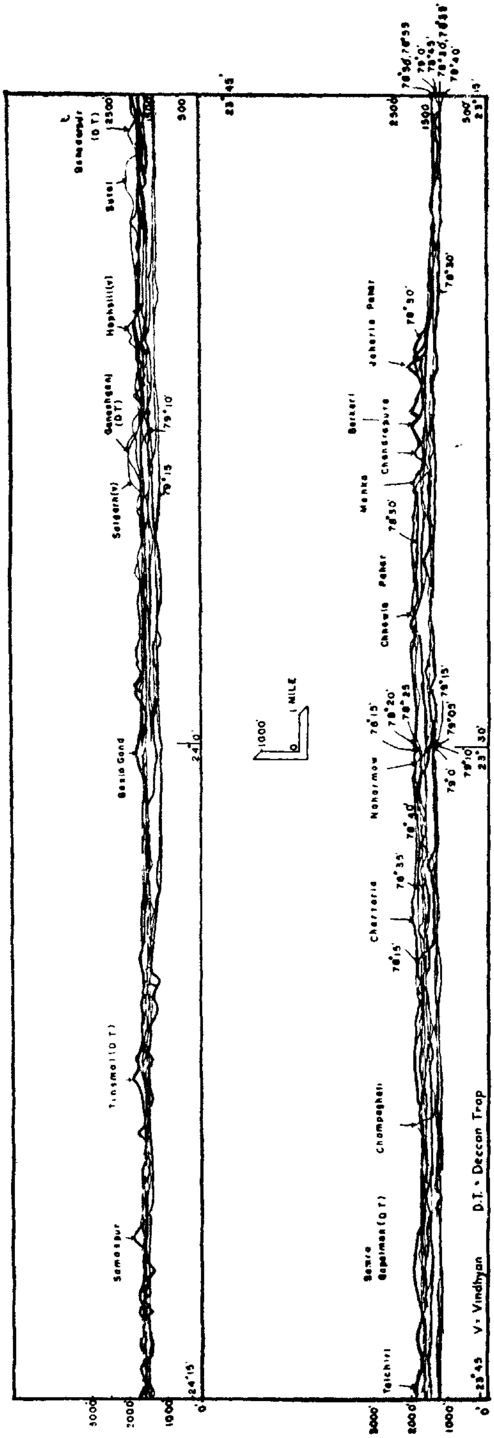

FIG. 7. Superimposed Topographic Profiles (North-South series).

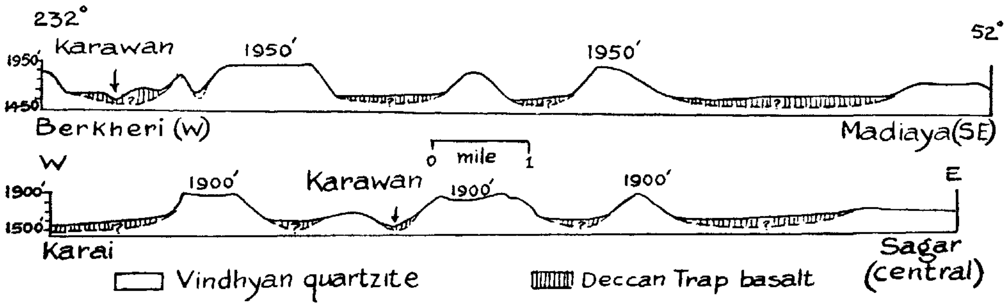

FIG. 8. Geological Sections across the Sagar area.

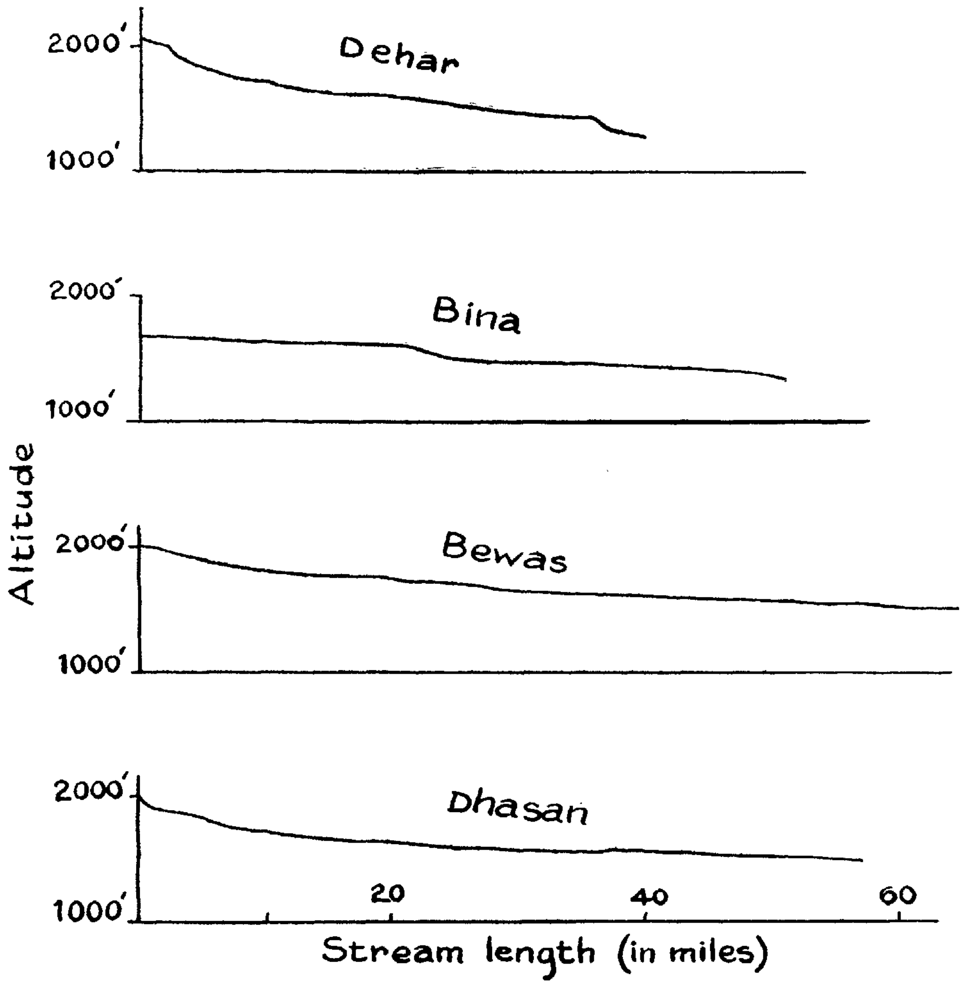

FIG. 9. Longitudinal Stream Profiles.

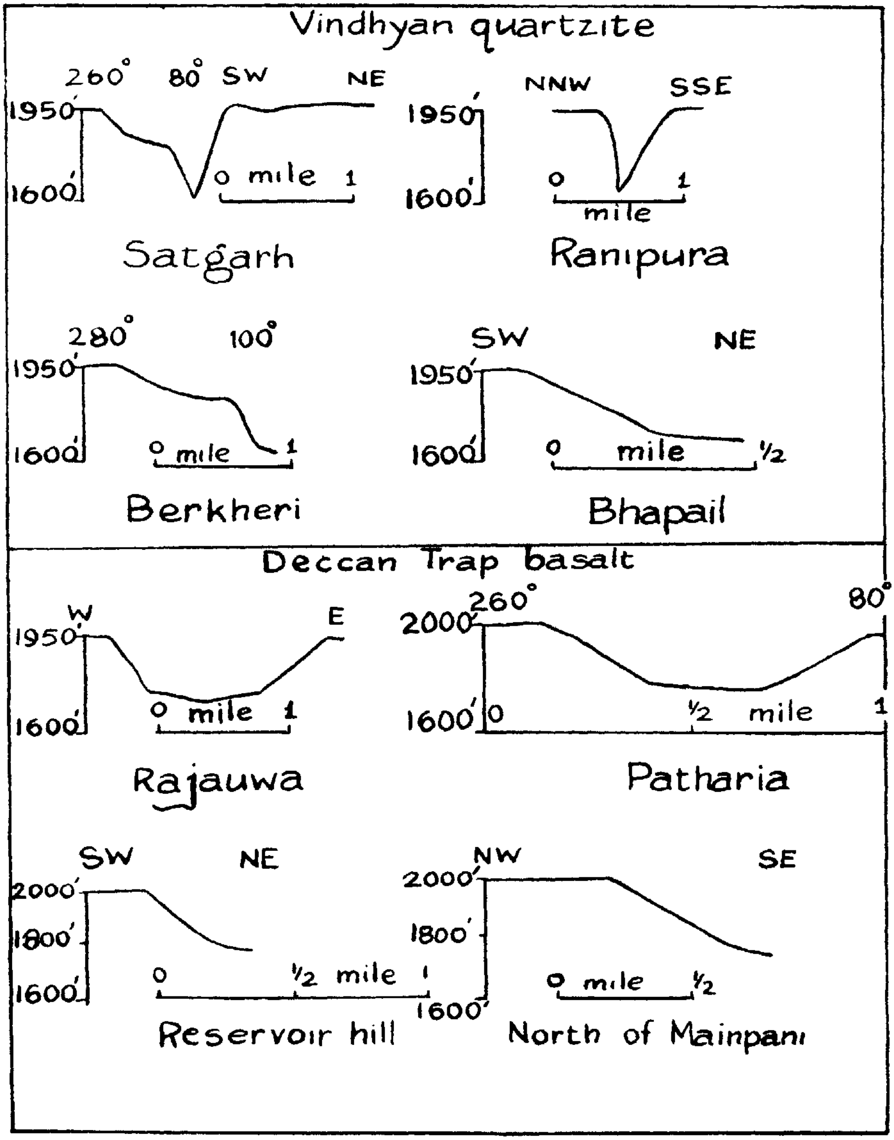

FIG. 10. Valley cross-profiles and spur profiles.

landmass and represents more or less the completion of a cycle of erosion. This conclusion is reached keeping in mind the enormous time interval between the uplift of the Vindhyans (pre-Cambrian) and the onset of the eruption of the Deccan Trap volcanics (late Cretaceous). Linton (1957, p. 58) has in fact shown that peneplanation may be completed in areas of modest elevation in less than 10 million years. If this be true, then, the Vindhyans might have undergone a few cycles of erosion : how many, it is difficult to say, because, the evidence of an earlier cycle might have been completely obliterated by the succeeding cycle and much of the Vindhyan topography

FIGS. 11–13. 11. A view looking north from the Saugar University of the Deccan Trap plateau showing an even skyline at 1900′. 12. A view looking WNW from the Saugar University of the landscape showing an accordance of summit levels on the Vindhyan ridges at 1900′–1950′. 13. A view looking SW from the Saugar University showing the even skyline produced by the Deccan Trap plateau at 1950′.

TABLE I

Results of the Erosion Surface Studies

No.	Method	Results
1.	Geomorphological map	(*i*) Shows fragments of planated surfaces now exhumed at elevations varying from 2050′ to 1900′. (*ii*) Shows fragments of Vindhyan pediments at elevations varying from 1600′ to 1500′. (*iii*) Shows extensive lava plateaus at elevations varying from 1950′ to 1900′. (*iv*) Shows extensive lava plains at elevations varying from 1650′ to 1450′.
2.	Generalized contours	(*i*) Show a flat at 1950′ + (*ii*) Show many extensive flats between 1850′ and 1950′. (*iii*) Show flats extensively between 1650′ and 1750′. (*iv*) Show flats between 1650′ and 1550′.
3.	Altimetric analysis	The altimetric frequency shows peaks for the number of summits as well as their areas between 1950′ and 1900′ for the Vindhyans and 2100′ and 1900′ for the Deccan Traps.
4.	Superimposed profiles	Show accordance of summit levels between 2000′ and 1900′ and 1600′ and 1500′.
5.	Geological cross-sections	The topographic profiles show (*i*) Accordance of ridge levels between 1950′ and 1900′; (*ii*) The contact between the Vindhyan and the Deccan Traps between 1600′ and 1500′; (*iii*) Accordance of plateau and summit levels between 1950′ and 1900′, and (*iv*) Flats between 1650′ and 1450′.
6.	Longitudinal, cross and spur profiles	Show breaks of slope between 2000′ and 1950′.
7.	Field methods	(*i*) An accordance of summits seen in the skyline between 2000′ and 1900′ for both the Vindhyans and the Deccan Traps. (*ii*) Pedimented surfaces in the Vindhyans seen between 1600′ and 1500′. (*iii*) Extensive lava plains seen between 1650′ and 1450′. (*iv*) Laterites observed from 2100′ to 1900′. (*v*) Sharp breaks of slope between the upper levels and the slopes and between the slopes and the lower levels. (*vi*) Lag gravels observed on the Vindhyans between 1700′ and 1520′.

in the study-area still lies buried beneath the lavas. This surface is herein called the "Rewa Surface" (2050′–1900′), because this surface has been formed on the Upper Rewa quartzites in the study-area. It has survived only on the summits of the ridges.

Geyl (1961, p. 388) has stated that the convex break of slope between the flatter part of one erosion surface and the marginal slope of the next lower surface is the main criterion for the recognition of erosion surfaces on contoured maps. This Rewa

Surface has such a break of slope which is observed clearly in the field and also in the morphological map. This surface further confirms Geyl's (*op. cit.*) findings that stepped erosion surface to perhaps 2000′ and over, may be a worldwide feature in stable regions since the study-area forms a part of the stable Peninsular India. In the absence of reliable evidences like terrace deposits, it has not been possible to date the pre-Deccan Trap Rewa Surface. Such evidences, even if they were present, might have been removed by subsequent erosion and later, by the moving lava flows themselves.

The Vindhyan scenery around Sagar shows steep slopes with valleys having heights varying between 300′ and 400′ (91.44 m and 121.72 m) and also pedimented surfaces at a lower elevation, i.e., 1500′—1600′ (457.2 m–487.68 m), in addition to the plateau and ridge levels. The total relief is of the order of 550′ (167.64 m) and the interfluves are mostly sharp-crested, narrow ridges. Lag gravels are present on the pediments and there are two isolated residuals. All these features suggest that the Rewa Surface was uplifted and dissected by a later cycle of erosion into a series of landforms that are observed in the landscape at present. This cycle had been abruptly terminated by the eruptions of the lavas at a time when it had progressed to maturity at higher elevations and produced a nearly level surface at lower elevations.

The Deccan Trap basalts are seen resting on the Vindhyan rocks at an elevation of 1700′ (518.16 m) in the locality near Richhora village (23°54′30″ : 78°45′20″). The basalt flow is exposed at about 1400′ (427.72 m) in the locality near the village Pararia (23°52′ : 78°58′). The Geological Survey of India drilled two vertical bore holes, one on the Reservoir Hill (23°49′45″ : 78°46′30″) and the other at the village Sidgawan (23°53′ : 78°50′15″) in 1972-73. The basement Vindhyan rocks were struck in these holes at 1720′ (524.25 m) and 1570′ (457.53 m) respectively. The lag gravels are found at an elevation of 1520′ (463.29 m) in the Mehar locality. In the geological cross-sections, the contact between the Vindhyans and the Deccan Traps keeps to elevations between 1500′ and 1600′.

The data given above indicate that the surface produced by the second cycle of erosion has an elevation range between 1700′ and 1400′. It is worked out into small hummocks with gentle slopes of 3° and is observed to continue up to the base of the residuals as pediments. This is herein called the "Infra-Trappean Surface (1700′–1400′)" and can be assigned a late-Cretaceous age on the basis of the Deccan Traps. It represents a lowering of the Rewa Surface by 350′ to 550′ (106.66 m to 167.64 m).

(*i*) *The nature of the Vindhyan cycles :* There are indications that, during the operation of the first cycle of erosion on the Vindhyans, the climate might have been humid as mentioned earlier. The Rewa Surface may therefore be called a peneplain. The presence of features of the palaeodrainage, like the amphitheatrical valley-heads, gaps among ridges etc., suggests fluvial action by big meandering rivers, landslides and spring-sapping. It is inferred from this that humid conditions continued during the operation of most of the second cycle of erosion on the Vindhyans. But, just before the interruption of this cycle by the eruption of the lavas, conditions must have become very hot and dry on account of the increase in the geothermal gradient toward the surface brought about by the heat of the lavas. As a consequence, parts of the Vindhyan surface might have got heated differentially, giving rise to low and high pressure belts in the atmosphere, resulting in high velocity winds. The facetting, pitting and coating of the desert varnish observed on the pebbles of the lag gravels and the pediments themselves may be attributed to aeolian action in an arid environment. It is interesting to note in this connection that Mathur (1972) has recorded evidence of wind action in the form of isolated stacks and pedestal rocks in the Bhander sandstone around Bhopal. Therefore it is inferred that the second cycle was probably a pediplanation cycle and the surface produced may be called a pediplain, which represents coalesced pediments.

(*ii*) *The order of evolution of the Vindhyan forms :* After the Rewa Surface was uplifted above the sea level and gently tilted, drainage lines must have got initiated and in due course, elongated and elaborated. The valleys must have been deepened and widened by the rivers. Headward and sideward erosion of some of these valleys must have taken place through spring-sapping and landslides. Amphitheatrical valley-heads must have formed in this manner. The other stream valleys must have produced deep dents along the margins of the interfluve ridges. The scarps must have retreated from the river banks differentially, more where the rock formations were thin-bedded, jointed and cross-bedded, thus producing marked concavities. The rivers must have been meandering freely by now, and might have also aided in the formation of the concavities. More and more of the interfluve areas must have been consumed by the retreat of the scarps brought about by the undercutting action (lateral planation) of the rivers and mass movements. As a consequence, the pediments formed must have extended to areas far away from the rivers. These must have coalesced to produce the pediplain. Some of the hills must have escaped erosional lowering to be retained as residuals. Lag gravels must have formed by wind action on the pedimented surface.

The initial Rewa Surface is still held up on tops of the plateaus, ridges and hills in the study-area. This clearly shows that the second cycle did not reach beyond maturity in the hilly tracts.

(*b*) *The Trappean Surfaces*

The Deccan Trap lavas welled out from long fissures intermittently and piled in the form of flows one after another on the late-Cretaceous Surface in the study-area. The maximum elevation at which the lavas are seen at present in the area is 2107′ (642.21 m). To the NE of Sagar, the basalts are seen at an elevation of 2141′ (652.58 m) at the peak of the Tinsmall hill which is located 40 km away. There are a number of peaks in the study-area which reach just above 2000′. Extensive plateaus are also present with their tops between 1950′ and 1900′. A huge thickness of laterite is found toward the top of the Tinsmall hill; according to West and Choubey (1964, p. 47), this thickness is 180′ (54.86 m). The peak of another hill near the village Dewalchori (23°44′ : 78°33′30″) about 20 km SW of Sagar is also lateritized for the top 6 metres and lateritization is evident right down to 1900′ at a few other places in the area. When this lateritization is considered along with the presence of an even skyline between 1900′ and 1950′, the development of the first post-Deccan Trap Surface between 2140′ (652.28 m) and 1900′ can be readily visualized (Figs. 11, 13).

This surface, which is very much younger than the Vindhyan surfaces, incidentally coincides with the Rewa Surface at about the same elevation and thus makes the evenness of the skyline even more spectacular. The morphological map, altimetric frequency curves, generalized contours, longitudinal profiles and the superimposed profiles prepared for the study-area reveal this surface clearly. This surface is herein called the "post-Deccan Trap Surface-I (2140′–1900′)".

Apart from surviving at the peaks of conical and dome-shaped hills, this surface is preserved on top of a few extensive, linear plateaus. Otherwise, this surface has been dissected into a landscape that appears to have reached the mature stage. This is evidenced not only from the minimal interfluve areas and extensive plains but more significantly from the hypsometric integrals of 0.36 and 0.40 obtained for the Karawan and Bankri stream basins respectively (Subramanyan 1974). Therefore it would seem that a much younger cycle has been responsible for dissecting the earlier surface, presumably after uplift, into extensive flats from 1450′ to 1650′ above which the remnants of the earlier surface rise as plateaus and conical hills. Such a rejuvenation might have been brought about by the unloading of a huge thickness of the lavas by erosion. This surface is herein called the "post-Deccan Trap Surface II (1650′–1450′)". It has been responsible for the resurrection of the two pre-Deccan Trap surfaces partly. The generalized contours, the profiles and the morphological map also provide evidence for the existence of this surface.

Apart from these, it is to be expected that a quaternary cycle is operating at the lower reaches of the big rivers of the region, working their way up the valleys. There is however, no clear evidence of this in the study-area. Perhaps its operation is seen in the headward migration of the knick-point at the waterfall near Rahatgarh, 40 km west of Sagar.

(*i*) *Nature of the cycles :* The post-Deccan Trap cycles I and II must have operated during the early and middle Tertiary times and the climate during the whole of the Tertiary was supposed to be warm and arid according to Schwarzbach (1963). From the nature of the remnants of the first cycle surviving on hill and plateau tops, it is not possible to infer anything more on the nature of the landscape cycle than the possibility that it might not have been very different from what followed, with the same rock and the same climate.

The second cycle, however, has produced a variety of landforms from which the process responsible can be understood. There are conical and dome-shaped hills and peaks, small mesas, flat-topped plateaus, ridges, hills and platforms, constant hill slopes, and extensive lowland plains apart from valleys of all sorts. The most striking features of this scenery are the horizontality of the resulting skyline (which persists for long distances), the terraced nature of the hill slopes and the remarkable constancy of the slope angle in the individual segments. These slopes pass downwards into featureless plains with a noticeable piedmont angle.

Looking at all these, the conclusion seems inevitable that the landscape cycle that had produced these forms was a pediplanation cycle. The main reason for concluding so is the hill slope which maintains its angle everywhere at 16° to 17°. This can be explained by suggesting that the slopes have been retreating parallel to themselves away from the main rivers in the Penckian fashion, without loss in their angles. The conical hills must have resulted due to the meeting of two slopes retreating in opposite directions and the lowland plains must have been produced by the coalescence of pediments.

In this connection, it is necessary to mention King's (1963) conception of a pediplanation cycle which he developed for the South African scenery, under semi-arid climate with periodic or episodic rainfall. In youth, consequent and insequent streams corrode vertically the initial surface producing ravines, gorges and steep-sided valleys. The insequent streams then multiply, increasing the dissection and with it, also the relief. The valleys continue to open out, as their sides flatten under weathering, until a relatively stable angle is achieved. Subsequently the valley sides retreat as hill slopes at nearly constant declivity, away from the rivers and streams, leaving behind them a pediment which extends to the margin of the river.

King (*op. cit.*) further states that in maturity, with continued scarp retreat, the pediments extend away from the rivers with an attendant shrinkage of the hill areas; more of the country becomes levelled down until the plain areas exceed or equal the residual hills. At lower levels, the pediments coalesce to form a pediplain, and undergo intermittent remodelling. Opposite scarps meet and the hills get lowered thereby. The mesas and conical hills are intermediate steps in this process. A levelled landscape of low relief and of multiconcave form, which is called the pediplain, results. In old age, the divides get rounded and the hill slopes become convexo-concave; rivers flow sluggishly in broad flood-plains.

A similar pediplanation cycle appears to have been responsible for the Deccan Trap scenery in the area under discussion. It has also periodic rainfalls and longer dry periods. The cycle appears to have reached maturity at higher elevations, while it has reached the ultimate stage at lower elevations. However, a significant difference in its operation needs to be pointed out. The hill slopes, instead of retreating as a single unit, retreat in two or three segments at different rates. This is due to the differences in the resistance offered by some of the flows to erosion, the harder of which hold up flat platforms on their tops. The horizontality of the flows aids such a development. Consequently, a stepped appearance is imparted to the slopes (Fig. 14).

The scarp retreat is brought about by the action of many turbulent rills and gullies that cut into the scarps which are seen in action during the rainy season. The pediments, as per King (1949, 1953) are shaped by the laminar, non-erosive flow of the run-off water which ensues from the break in the slope at the foot of the hills, i.e., the 'piedmont knick-point'. However, it must be pointed out that the basaltic pediments occurring in the study-area, are not so conspicuous as the Vindhyan pediments. Further, the break of slope at the foot of the hills is not so sharp. This is possibly because the basalt is much less resistant than the quartzites. Usually the vesicular tops of the lava flows, which are easily erodible, mark the positions of such knick-points. They also do not appear to be smooth, stable landform features (as they are generally undulating grounds) permitting huge volumes of sheet-flood waters to pass over them without any damage to themselves. Rather, they are cut by a number of rills and stream channels and are undergoing considerable weathering and erosion. Therefore, the piedmont knick-point would seem to be due to the change from the unconcentrated rainwash on the scarps to more efficient flow of ephemeral streams in definite channels on the pediment. Bryan (1940) had also proposed a similar origin for the pediments.

(*ii*) *Regional conclusions of other workers :* Erosion surfaces develop over larger regions and therefore it is deemed necessary to mention the conclusions of

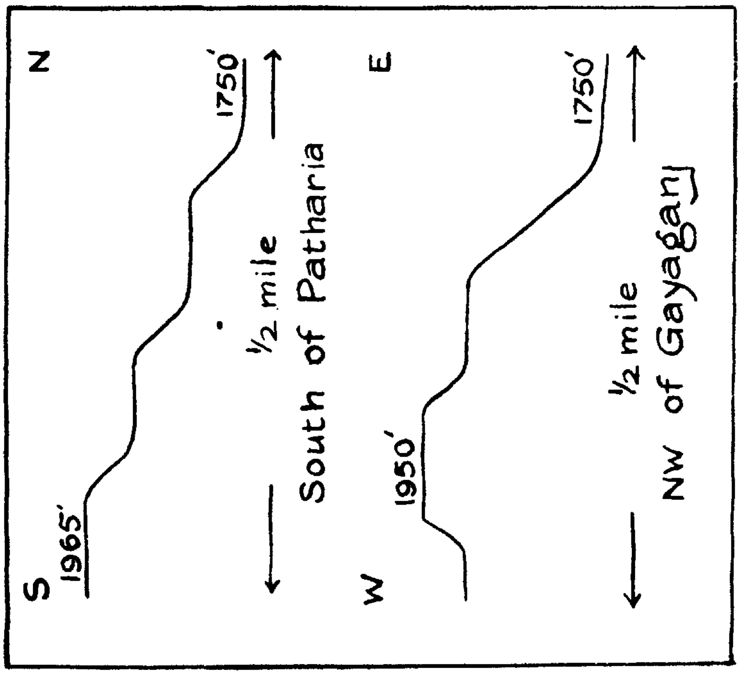

FIG. 14. Stepped Deccan Trap Slopes.

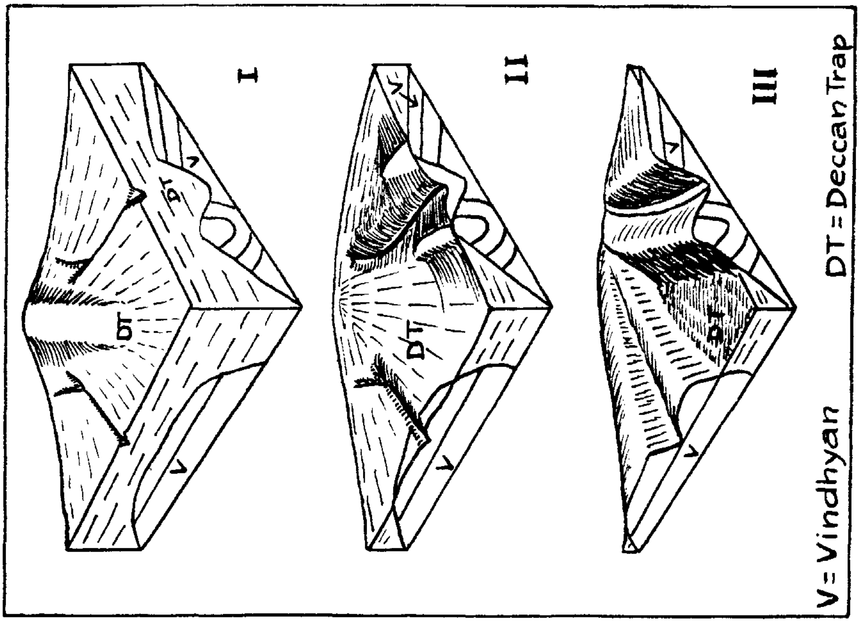

FIG. 15. Stages in the superposition of the younger Deccan Trap drainage on the Vindhyans.

other workers on the erosion surfaces in different areas of Central India. These are given along with the author's for comparison in Table 2. As will be seen from this Table, there is good agreement between the author's conclusions and those of Dixey (1970) in relation to the first three surfaces. Dixey's fourth surface—the 'Jabalpur Surface'—also appears to be a southerly continuation of the author's post-Deccan Trap Surface II.

(*iii*) *The evolution of the hill-slopes :* Pediplanation, brought about by the parallel retreat of the slopes, has so far been shown to have run most of the erosion cycles made out in the study-area; an analysis of the development of the various slope elements reveals the following.

With reference to the slope elements formed on the Vindhyan quartzites before the advent of the Deccan Trap lavas, the crest appears to have been perfected by rainwash, mechanical weathering and incision by widely-spaced streams. The scarp or free face must have been produced by rock-slides and incision by streams. The debris slope was obviously formed by the accumulation of the falling debris and it might have been acted on by rainwash and rill action. The pediment must have been shaped by sheet-flood action and deposition of alluvium.

As for the Deccan Trap slope elements, the crest appears to have been formed by rainwash, chemical weathering and sheet-erosion. The debris slope is formed by the accumulation of the rolled boulders and shaped by closely-spaced streams. The pediments are formed by rill action and alluviation.

TABLE II

Erosion surfaces proposed by other workers in the region

Choubey (1966, 1967, 1969) Katangi area	Rai (1969) Sonar-Bearma Basin	Dixey (1970) Madhya Pradesh	Pandey (1972) Sleemanabad	Subramanyan (1973) Sagar area
1. Cretaceous Peneplain–1950′	1. Exhumed Vindhyan Surface and the Late Eocene Surface–1900′.	1. The Bhander Surface of post-Gondwana (Jurassic) age—2300′–1950′.		1. The Rewa Surface—2050′–1900′.
2. Sub-basaltic pre-Deccan Trap Erosion Surface 1750′–1450′ ? 1450′–1200′ ? 1450′–1400′ ?	2. Middle Miocene Surface—1750′–1450′. 3. Pleistocene Surface—1300′–1200′	2. The sub-Trap Surface (late Cretaceous) 3. The early post-Trap Surface—2100′ ?		2. The Infra-Trappean Surface—1700′–1400′. 3. The post-Deccan Trap Surface-I 2140′–1900′
3. Modern valley cycle (coicnident with the second surface)	4. Pleistocene–Recent Surface 1000′	4. The Jabalpur Surface–1325′–900′	1. The Jabalpur Surface—1350′–1100′.	4. The post-Deccan Trap Surface II—1650′–1450′
		5. The Marble rocks valley Surface 6. The Quaternary Surface(s).		5. The Quaternary Surface

(*iv*) *The evolution of the drainage :* After the eruptions of the Deccan Trap volcanics had ceased, a few major consequent streams must have developed on the initial surface of the lavas, guided probably by the general dip of the lava flows. In the absence of any controlling structures in the nearly horizontal lavas, the drainage development subsequently must have been largely through a multitude of insequent streams branching dendritically. The fluvial cycle probably ran its whole course and brought the country to the base level as mentioned earlier.

With the progress of erosion of the lava flows, the country to the north of the Narmada river was probably warped up along an east-west axis, on account of the unloading of the lavas, thereby giving the country gradients to the north and south. A new drainage developed over these slopes in much the same manner as described before. As the cycle progressed, more and more of the lava materials got removed, so much so that the underlying Vindhyans got exposed to view once more at places. This exhumation must have taken place within a short time after the commencement of this cycle of erosion, because, the difference between the highest elevation reached on the Vindhyans in the study-area, namely, 2050′ and the maximum elevation reached on the Deccan Traps, namely, 2140′, is only 90′ (27.43 m). The drainage lines must have been confronted by these newly-emerged, hard, quartzite ridges here and there. The smaller among the streams must have adapted themselves to the changed environment by avoiding the quartzites and flowing over the relatively soft basalts. The bigger rivers must have tried to keep to their original courses over the Vindhyan quartzites also and got superposed over these harder and older rocks (Fig. 15). The stream that flows to the west of the village Pagara and the one flowing to the west of the village Richhora are adapted streams in the study-area, besides a few others. The Karawan stream in the study-area and the Bina river in the area around Rahatgarh are superposed rivers.

Closer studies of the manner of superposition of the Karawan and the Bina have revealed new facts. The Karawan flows through three gaps in the Vindhyan quartzites located near Bhapail (23°48′30″ : 78°38′15″), Ratona railway station (23°50′ : 78°40′) and Satgarh (23°53′ : 78°39′). From the enormous sizes of these gaps and the other gaps present in the study-area, it was concluded (Subramanyan 1972) that all these gaps were palaeogeomorphic features, incised by the pre-Deccan Trap rivers. Therefore the Karawan and the other streams of the area, during their superposition on the Vindhyans, have guided their courses through these already-existing gaps (valleys); thus they cross from one Deccan Trap valley to the other. This (utilisation of the old valleys) in itself is an adaptation and the process of superposition, in its puritanic sense, does not include any such adaptation. Nevertheless, the fact remains that the present drainage is a palimpsest drainage, the streams flowing, at least in part, along the reexposed valleys of the ancient streams.

The same is true of the Bina river also, which falls spectacularly into a gorge in the hard Vindhyan quartzites, 60 metres deep, 80 metres wide and 3 km long. It has been shown (Subramanyan & Das 1970) that this gorge is an old, pre-Deccan Trap feature.

Still more significant is the author's finding on the relation of the superposed Bina river to the underlying structures which goes to prove that the conventionally stipulated transverse relation of the superposed rivers to the underlying structures is not always required, much depending on the conditions obtaining during superposition. "And especially where there is no uplift facilitating a faster down-cutting, the stream may have ample opportunities to explore, locate and flow along paths of least resistance, like the already-formed valleys" (Subramanyan 1973). It is therefore concluded that the present drainage of the study-area has evolved mostly by a judiciously guided superposition and partly by adaptation. The former adds an altogether new dimension to the process of superposition of rivers on exhumed structures as it is conventionally understood.

(*v*) *The evolution of the Deccan Trap forms :* From the uplifted or upwarped basaltic surface, the first forms to appear on account of stream dissection were the stream valleys. The valley side-slopes retreated thereafter, maintaining their declivity and as a result the plateaus, the ridges, the hills and the pediments were produced with increasing rate of retreat. Steps got formed on the slopes due to the different rates at which the slopes retreated because of the differences in the ease with which the retreat could progress in the differrent flows. Table-topped hills (mesas) and conical hills resulted wherever two slopes retreating in opposite directions came closer or actually met. In the assemblage of the Deccan Trap landforms seen today, the plateaus must be regarded as the oldest and the pedimented surfaces, i.e., the plains, the youngest.

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