

## THE PUNJAB PIEDMONT PEDIMENTS : A CLIMATO-GENETIC INTERPRETATION

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**ABSTRACT** : A striking series of small, undissected or partially dissected pediments are observed in the northern parts of the Siwalik Hills Piedmont stretching along the southern contact of the Siwalik Hills with the Punjab Plains. Their geomorphological interest is derived essentially from their distribution in a modified Cwg (Koppen) climatic zone characterised by an annual rainfall of about 750 to 1000 cms. and their geological recency. Field observations reveal that the pediments :

- ( a ) are bare rock surfaces with a thin veneer of slope-wash particles in transportation,
- ( b ) have a much smaller topographic gradient than the dip of the Siwalik formations, and
- ( c ) have been developed on the Siwalik formations, mainly the Upper Boulder Conglomerate.

Two field observations suggest that the pediments are Upper Pleistocene and Holocene and more likely late Upper Pleistocene and Holocene in age :

- ( a ) the dipping Siwalik beds were tilted in the Middle Pleistocene, and
- ( b ) the pediments are everywhere observed flanking the extended gullies and *choes* which originate much south of the main water-divide in the Siwalik Hills and are consequent upon the youngest south-facing hogbacks.

The pediments are no longer evolving or are extending into the hill slopes almost imperceptibly and, thus, are dead, relict features. It is proposed that they owe their origin to the retreat of the south-facing slopes of the Siwalik Hills, masswasting and slope wash, and marginally to stream lateral planation. Neotectonic movements of the Upper Pleistocene and Holocene have entrenched the flanking streams and thus, sustained and undissected or little dissected pediment surface. It is suggested that those pediments are not climatic analogues of those observed in the BS and BW climatic regions.

### INTRODUCTION

A fairly long and continuous distribution of pediments can be observed along the contact of the south-facing slopes of the Siwalik Hills and the Punjab Piedmont plain to the northwest and southeast of Chandigarh City. ( Figs. 1 and 2 ). The region of their occurrence has had experiences of marked climatic changes and tectonic events and is presently subject to the processes which operate in Cwg Koppen climatic conditions and occasional neotectonic movements. The origin, evolution, and properties of these pediments would be expected to differ from the classical pediments investigated in the arid and semi-arid regions which

have remained tectonically stable over a very long geological period. Although the Punjab Pediments are clearly homologous with those occurring along the Aravallis and the Western and Eastern Ghats they are not their analogues. This divergence results from the climatic character of the regions of their occurrence, through climato-genetic processes which have a definite beginning in a particular geological period. Climatic differences, lithologic contexts, tectonic conditions, historical periods of genesis, and topographic associations would distinguish the Punjab pediments from the other members of the generic group. There is ample evidence of distinctiveness in terms of form, extent, surface appearance, surficial material,

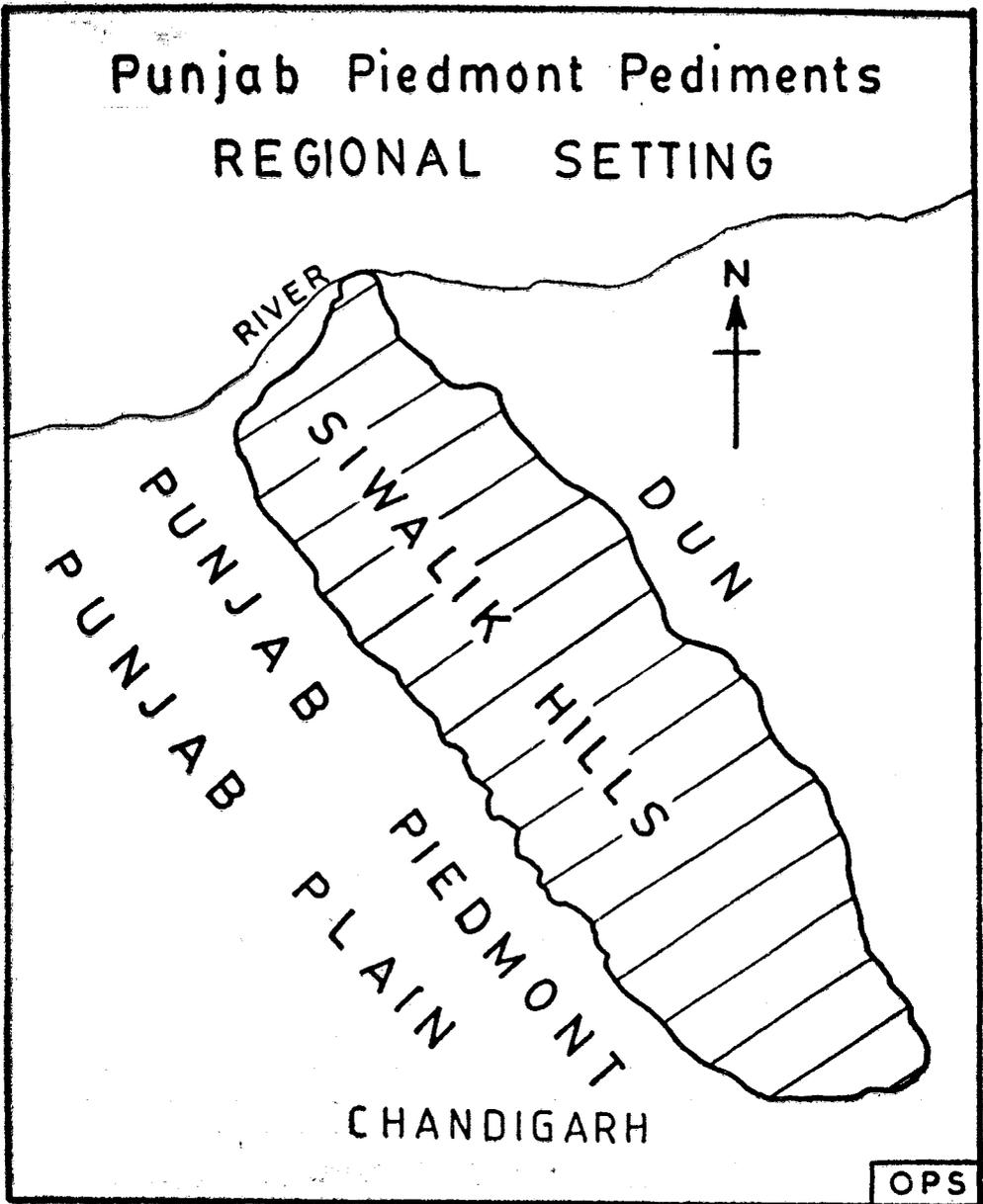


FIG. 1

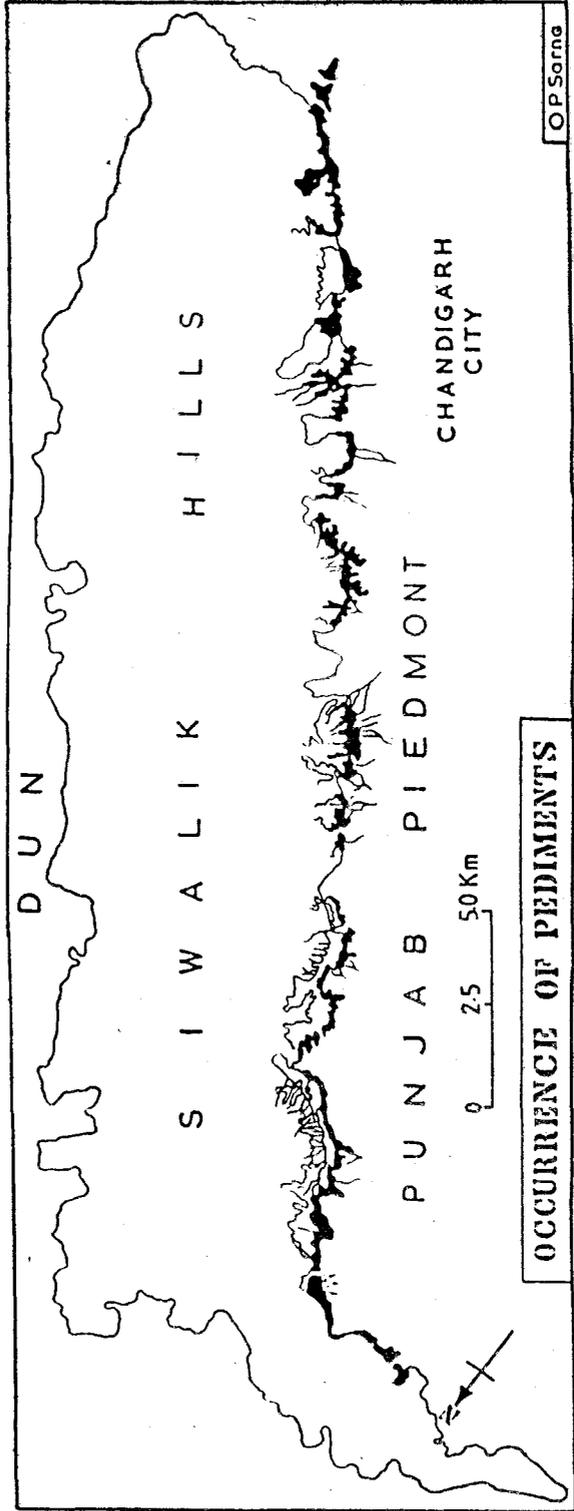


Fig. 2

and distribution. Finally, there remains an interesting question : are these pediments being formed presently, are they dead or active ?

### SIGNIFICANCE OF STUDY

Throughout the period they have been investigated, within and outside of India, the pediments occurring in the arid regions have received monopoly considerations. This fact is supported even by a miniscule segment of the continuously burgeoning geological and geomorphological literature bearing on this feature. (Blackwelder, 1931, pp. 442-450; Bradley, 1940, pp. 244-255; Bryan, 1932, pp. 128-129; Bryan, 1935, pp. 765-775; Bryan, 1935-1936, pp. 125-135; Bryan, 1940, pp. 254-268; Denny, 1967, pp. 81-105; Singh, 1977, pp. 6-7; Chatterji, et. al., 1978, pp. 214-215; Singh and Kaith, 1971, pp. 50-59; Kar, Singh, and Ghosh, 1977, pp. 16-20; Kar, Singh and Kaith, 1979, pp. 236-245; Kar, 1984, pp. 67-74; Kar, 1984, pp. 21-27; King, 1962, pp. 698-699; and Twidale, 1974; pp. 115-126). A study of the recent literature reveals that the geologists and geomorphologists are slowly becoming aware of the pediment occurrences in humid and cold environments. (Dury, 1972, pp. 139-152). It is, however, surprising that the Indian geomorphologists have, by and large, concerned themselves with the arid zone and peninsular pediments. What would attract the Indian geomorphologists to the pediments of the Punjab piedmont is their occurrence in a region that presently experiences Koppen's Cwg climatic type, which is essentially a modification of megathermal, monsoonal regime. These pediments, although not large enough to strike the eyes of the geomorphologists searching for spectacular features, would be interesting for their Cwg climatic associations.

The entire corpus of pediment literature published in India deals with the Rajasthan

and the Peninsular Regions which have either experienced phase of tectonic instability in the pre-Tertiary times or have remained stable subsequent to Pre-Cambrian up to the present times. These pediments, therefore, are genetically related to the progress of the pedimentation cycle. In complete contrast the Punjab pediments are developed in a zone that has been subjected to tectonic movements during the Quaternary and Holocene times and have also responded to neotectonic impulses even though the landscape expressions have been subdued. It would be interesting to examine the role, if any, of tectonic movements in the formation and development of the Punjab pediments. This becomes all the more necessary because of the already identified and mapped fault that runs along the foot of the south-west facing slopes of the Siwalik Hills either forming the break-of-slope at the head of the pediments or segmenting its surface.

Almost everywhere the classic pediments reported from different and distant parts of the world are described along with the central koppice, hill, monadnock, tor, or inselberg around which they form a skirting belt. Both in locational associations and genetic history the pediments are analysed in the context of the central positive relief axis. The Punjab piedmont pediments are distinguished by their location at the foot of the Siwalik Hills, both features occurring in linear belts paralleling each other. Unlike the tors or the central hills and the pediments which cannot be divorced from each other in the genetic sense those of the Punjab piedmont are genetically unrelated to the Siwalik Hills.

Almost nowhere in the piedmont-hill contact ribbon can one find the pediments flanking the *choes* (large, seasonal, ephemeral streams). Typically, the pediments are laterally disposed along the gullies and extended gullies, both originating on the immediate backing slope or on the dip-

slopes hidden behind the south-facing fore-slope scarps and terminating at the foot of the scarps or at distance of 150 to 200 metres from it. ( Fig. 2, Photos 1 and 2 ).

Finally, the Punjab pediments are made interesting by the absence of convex debris, and free face units of the classic L. C. King's model. ( King, 1957, pp. 81-102 ). The absence of these three essential components of the widely accepted King Model in relation to the pediments clearly illustrated in the field ( Photos 3, 4, and 5 ) will be discussed in the attributes and formation of the pediments.

### LOCATION ASPECTS

For any geomorphic feature, but more particularly that which is surrounded by features of larger dimensions, the two most meaningful locational attributes are site and situation. The Punjab piedmont pediments are much smaller than the piedmont plain in which they are embedded and the Siwalik Hills by which they are both flanked and dominated.

Typically the pediments are situated in the northern rim of the Punjab Plain Piedmont ( henceforth termed Punjab piedmont pediment or Punjab pediment ) tract that runs in the northwest-southeast direction paralleling the strike of the Upper Siwalik formations which comprise the Siwalik Hills and the direction of the layout of the latter. The tract is dissected intensely by streams of various sizes and types; extended gullies, and gullies of diverse dimensions, and thus displays a rolling appearance. The inter-stream tracts, generally narrow and steep, extend more or less orthogonally to the Siwalik Hills. ( Fig. 2 ). In the hillward ends of these long, rectangular tracts and at the break-of-slope where the gullies and extended gullies debouch modestly on the piedmont is observed a series of pediments forming a narrow belt running along the

foot of the south-facing hog-back ridge slopes and scarps.

Along the larger streams which originate deep within the Siwalik Hills and flow through the piedmont and beyond it one encounters *choe* terraces. ( Mukerji, 1976, pp. 1-19 ). The pediments almost nowhere occur along these streams but typically along small gullies and extended gullies, typically, consequent, which originate on the south-facing slopes or immediately behind them in the Siwalik Hills. The streams are typically shallow, about 1 to 1.5 metres deep, about 2 to 2.5 metres wide and 80 to 150 metres long. The gullies are much younger than the streams, probably younger than Holocene, and many of historic ages, about 2000 to 3000 years.

The pediments are sited on the Upper Conglomerate beds, mainly on a bed of clay intermixed with pebbles and cobbles and nodular concretions. The surface below the in-situ developed grus is hard. ( Photos 3, 6, and 7 ). Pediment sites are characteristically broken and bounded by gullies and extended gullies which are prominently shown in the middle portion as a narrow but perceptible linear depression. ( Photo 11 ). The distal parts of the pediment sites are terminated at places by a wall-like scarp cut by a transverse gully or by undulated ground of the piedmont. ( Photos 7 and 8 ). The original site rests on the steeply sloping beds the original configuration of which are still observed at the head of the pediment. ( Photos 3 and 5 ). This relation of the site and the higher bedrock remnants at its back is a crucial clue to the reconstruction of the phases of evolution and the processes of formation. Everywhere the sites are very well drained not only because of the steep dip and slope but also because of the high clay contents of the beds. Where incipient soil formation has started the sub-surface moisture extends up to a depth of only 10 to 15 cms as also indicated by the dark wet

colour. (Photo 6). Very frequently the site is completely dry and bare of incipient soil, grus, and grass cover. It is on these sites that we find the demonstration of the classic pediment-forming processes.

Finally the sites form a long, discontinuous, narrow strip in which the piedmont alluvium at places extends up to the hog-back slopes and at others these slopes drive the alluvium boundary back quite some distance from the Siwalik Hill slopes. The sites thus appear as protruding tongues separated by embayments of alluvium. These can be related mainly to the creation of noticeable terraces by the larger *choes* which jut out over a relatively large area from the points of stream debouchment. Thus, the sites of the pediments and the sites of the terraces are locationally completely segregated, suggesting the operation of two different sets of processes at the two different locales.

There is a commanding vista of the piedmont provided from the pediment related to the rather sudden elevation brought about by the steep slopes. (Photos 1, 4, and 9). Both pediment strips and piedmont zone are undulating, the rolling character being the product of a large number of streams of various types and size. The numerous fragments of topographic surface are aligned perpendicular to the Siwalik slopes.

### GEOLOGICAL FOUNDATION

Though pediment geomorphology, in its character and genesis, has been investigated very largely in terms of the climatic contexts and climatically generated epigenic processes the role of rock types and geological structure providing the initial setting in the evolution of pediment is far too significant to be ignored. It has already been established through research in different climatic regions and in widely separated areas endowed with very contrasting geological contexts and this

prompts a critical examination of the climatic contingency versus structural settings. (King, 1962, pp. 698-699).

Geologically, the pediments sit on the beds of the Upper Siwalik formation which are comprised of the Tatrot, Pinjor, and Boulder Conglomerate, the first one being the oldest. Most of the Siwalik Hills, above the topographical surface, however, is comprised of different beds and facies of the Pinjor formation. (Fig. 3). Since most of the pediments have developed on the surface of the Boulder Conglomerate beds it is these which concern us the most. There are almost no sites where the entire thickness of the Boulder Conglomerate is eroded or has disappeared from the surface through fault movements so as to expose the Pinjor and Tatrot beds to the immediate south of the south-flanking slopes of the Siwalik Hills and on which the pediments could have developed.

The Boulder Conglomerate formation, marking the end of the Siwalik deposition during the Middle Pleistocene, forms the uppermost member of the Upper Siwaliks. Stratigraphically the formation sits conformably over the Pinjors (Figs. 3 and 4). In age it belongs to Lower to Middle Pleistocene. (Gansser, 1964, p. 48). The beds of the Boulder Conglomerate are up to 150 metres thick and are comprised of subangular to subrounded granules and pebble-sized fragments derived from quartzites, sandstones, shales, limestones, cherts, slates, and schists. (Gill, 1985, p. 45) The fragments of sandstones constitute a higher proportion in the conglomerates of the Upper Siwaliks. Calcareous and ferruginous nodules occur inside the beds and on the surface.

Essentially the Boulder Conglomerate is comprised of sandstone and clay beds interstratified with conglomerates and often separated by thin pebble or gravel beds. Pink clay and grey and buff sandstones are

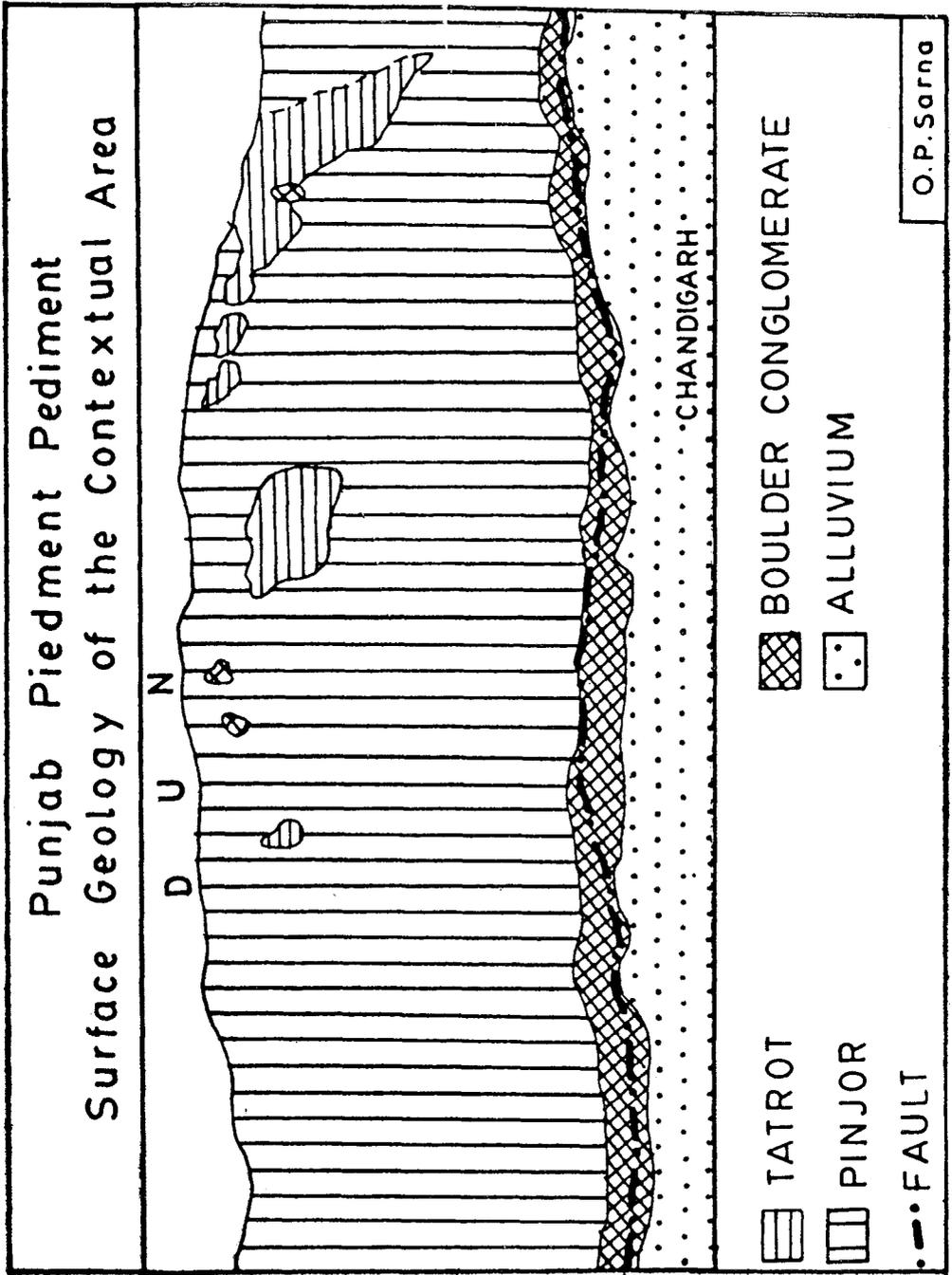


Fig. 3

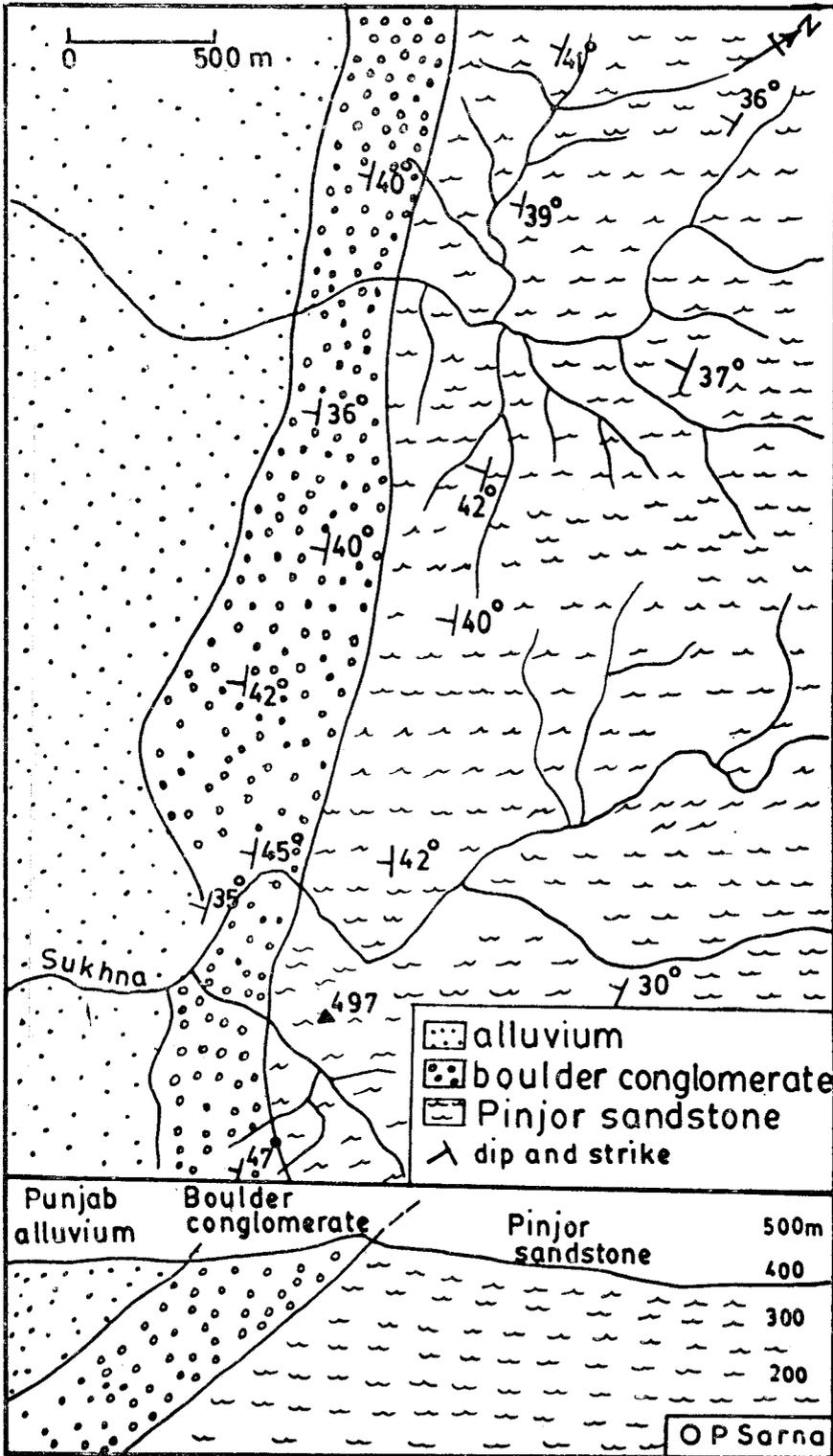


Fig. 4

highly characteristic of the Boulder Conglomerate beds. The beds are consolidated by the infiltration of the siliceous material. There is a preponderance of arenaceous fractions in the lithology. (Chaudhari, 1974, pp. 47-51) Hard bed rock appearing as eroded benches with a planar slope are prominent at some places while at other subdued concave slope covered with thin incipient soil can be observed. (Photos 2 and 5) Whether covered by soil or grus or not ferruginous matter and clay matrix serve as cementing material everywhere. (Gill, 1985, p. 50) Ferruginous cement forms about one fifth of the rock composition and hardens the exposed surface to reduced erosion.

The Siwalik Hills, as a structural form<sup>2</sup> consists mainly of open plunging anticlines. Hence, the axial sections of the Hills are gently dipping while the northern and southern flanks are steeper. The Boulder Conglomerate beds, on which the pediments have developed, constitute the southern flanks of the Hills, and extend as a narrow belt hugging the Pinjors which underlie them and the Punjab piedmont alluvium which overlies them. (Figs. 3 and 4)

The Boulder Conglomerate, sufficiently steep to have been eroded into hog-back ridges, dip towards the south and south-west, their dips ranging from lows of about  $10^{\circ}$  to highs of  $40^{\circ}$  to  $45^{\circ}$ . (Figs. 3 and Photo 1) Apart from the open and large anticlines and dips there are several local and regional faults, reversed and normal, which criss-cross the Siwalik Hills. The prominent ones among them extend near or along the peripheries of the Siwalik Hills. The long fault extending along the contact of the Punjab piedmont and the south-west facing slopes of the southern flanks of the Siwalik Hills is indicated by the narrowing of the surface exposures of the Boulder conglomerate beds all along the topographic contacts between the hills and the piedmont, the sharp break

in slope, the displacement of beds, and the occurrence of the Boulder Conglomerate outliers at some distance from the head of the pediment.

The surficial material, derived from the bedrocks and created by the epigenetic processes, occurs in various forms on the pediments. Bedrocks out cropping on the pediments is a rare occurrence. In patches one observes weathered mantle rock and at most places coarse young, immature, more endogenetic than exogenetic, soils. (Photo 2). The presence of soils covered by tufts of grass of long, capillary roots and species of *Acacia* suggest that the grus and the soil have taken time to develop but not long enough to become mature. After the formation of the pediment which succeeded faulting the terrain must have remained quite stable for a long time, a condition ideally suitable for the perpetuation of the pediments once they have been formed.

### CLIMATIC ATTRIBUTES

The regional climate of the piedmont site and situation is essentially of Cwg Koppen type but its characteristics are a variation, toward lesser rainfall, of the Koppen category. Easily the most significant climatic element involved in the genesis, evolution, and characteristics of the pediments in the region, as indeed everywhere else, is rainfall, its amount, periodicity of occurrence, fluctuation, and nature.

The average annual rainfall of the region is between 75 and 100 cms but partaking the Cwg rainfall pattern of the North-West India the total annual displays a large range of fluctuation. During 1886 and 1986 the maximum and the minimum of 143.75 cms. and 48.75 cms occurred in 1963 and 1883 respectively. This gives a range of 95.00 cms. The large fluctuations in the annual rainfall have been considered as one of the conductive attributes of climate in the

genesis of pediments. (Beaty, 1974, pp. 19-51; Chatterji, Singh, and Quereshi, 1978, pp. 211-224; Singh, 1972, pp. 121-130; and Kar, Singh, and Ghose, 1977, pp. 16-20)

The fluctuations over the years are equally well reflected in the monthly variations. In any typical year almost 70 to 80 per cent of the annual total falls during the four months of June through September, with the maximum of 50 per cent of the annual total always concentrated in June and July. If the sudden, large surface run-off creating the sheet flow is the most crucial determinant of the pediment forming process it is obvious that this process would operate with maximum effect during the months of monsoonal rainfall.

During the last hundred years the trend of the maximum concentration of rainfall during the monsoon months has been both consistent and persistent. Hence, the intensity of rainfall has always been the maximum during the summer monsoonal months. Within these months can also be observed the maximum concentration of the number of rainy days. In a normal climatic year of 40 to 50 rainy days as many as 24 to 27 are found during the summer monsoonal months. In the past the total rainfall in the wettest months has been as much as 175 cms out of the annual total of about 200 cms, thus accounting for 87 per cent. The largest rainfall of 24 hours also has occurred in these months. The intensity of rainfall

$$\left( I_R = \frac{\text{Rainfall}}{\text{days}} \times 100 \right)$$

in these months can rise to as high as 75 to 80 per cent.

It is during the summer monsoon months that one observes high intensity rainfall caused by thunderstorms, intense local convection, and thermodynamic advective-convective-orographic rainfall. Enormous

runoff forming sheetflows are the widespread results.

With the high intensity and high concentration of rainfall during the monsoon months the pediment forming processes attain their maximum power and effect. In the remaining months insitu weathering is more prominent, the role of which is only minimal and preparatory.

It is important to remember that the present climate is very different from that of the past. Immediately following the deposition of the Boulder Conglomerate and after the uplift of the Upper Siwalik beds the climate, for a long time, remained cold and dry. This condition persisted through the Mindel-Riss Interglacial. This cold and dry phase is indicated by a complete absence of fossils, red pigmentation, kaolinization and calcareous contents of the sediments. (Gaur and Chopra, 1984, pp. 353-355) The climate ameliorated substantially during the Riss-Wurm Interglacial and the later glacial phases. However, the drier periods continued during the Upper Pleistocene. (Zeuner, 1953, pp. 242-253) The typical monsoon established itself well after the disappearance of the low-level mountain glaciers, deep within the Holocene.

#### DIMENSIONAL ATTRIBUTES

The pediments occur in a narrow zone suggesting their relatively small size. Within this zone they do not form a continuous tract but appear as fragmented occurrences. (Fig. 2 and Photo 12) The fragmented nature is not only attributable to the traversing gullies and extended gullies but also to the tongues of exposures of the bedrocks, mainly the boulder units of the Boulder Conglomerate. At the points of debouchement of the major *choes* the pediments tend to disappear and be replaced by terraces. (Mukerji, 1976, pp. 1-19) The size and shape of the pediments and their extension

very largely depend upon the alignment of the gullies and the extended gullies and the appearance of the underlying Boulder Conglomerate beds and their dips.

The size, length, and width of the pediments vary considerably. In length the variations are from as low as 10 metres to the high of 150 metres or even more. Since the fault that traverses the Boulder Conglomerate has a sinuous alignment the length of the exposed bedrock varies considerably along with that of the pediments. Where the fault runs through at some distance from the break-of-slope a longer trajectory plane of the bedrock has outcropped and a longer pediment has developed. (Photos, 2, 7 and 10) It is suggested that the alignment of the downthrown blocks to the south of the fault has also resulted in the decline of their dips and hence increase in the length of particular slope segments developed on them. At some sites this has not happened and the exposed bedrock reveals a much shorter length. In the field one is struck by the repetitive occurrence of discordant relationship between the length of the exposed bedrock, the length of the pediment, and the transformed dip as a result of the changes in the disposition of the downthrown southern blocks along the fault. Nonetheless the length of the exposed rock and the length of the pediment seem to bear a harmonious relationship at most sites. In the field one also finds an interesting relationship between the direction of the hill-slope behind the pediment and the direction of the *choe* flow or gully flow with the length of the pediment. The gullies flow to the southwest, south, and southeast. The general slope of the Siwalik Hills southern flanks is toward the southwest. Hence the pediments associated with the gullies flowing to the southwest are longer as the gullies in conjunction with the topographical slopes flow over a longer distance. In contrast the gullies which flow toward the south and

southeast are discordant with the direction of the topographical slope and are shorter and hence the pediments associated with them are shorter. (Fig. 5). Thus, the pediments extending orthogonal to the grain of the Siwalik Hills are the longest and those emerging out at lesser angles are the shortest. The more acute is the angle of spread the shorter is the length. This relationship is essentially dependent on the physics of the river flow. The lower angle of emergence necessitates a longer path of the stream on the hill-slopes flowing over which the gully loses a large part of energy through friction and hence its eroding power down the slope and down the pediment zone is reduced. This reduction results in the shortening of the gully and the pediment alike.

Unlike the length of the pediment which is controlled by both the nature of the bedrock exposure and direction of gully flow the width is determined by the alignment and spacing of the gullies. The field observations clearly reveal that the pediments are wider near their head, the piedmont-hill-slope contact, than in their distal parts. The field observations suggest that the pediments generally are sited between the gullies, either convergent and confluent or parallel to each other below the distal part of the pediment. Where the confluence takes place very near the piedmont-hillslope contact the extension of the pediment below the confluence is almost entirely terminated at this point. The distance of the confluence of the adjacent, mainly first-order gullies is a crucial determinant of the variation of the width of the pediments. By the nature of the alignment of the gullies the width of the pediment varies in different parts, proximal, middle, and distal. In almost all the pediments the length is indicated by the major axis, more or less, extending through the central parts. Where the pediments are trapezoid in form the length is the same in all directions.

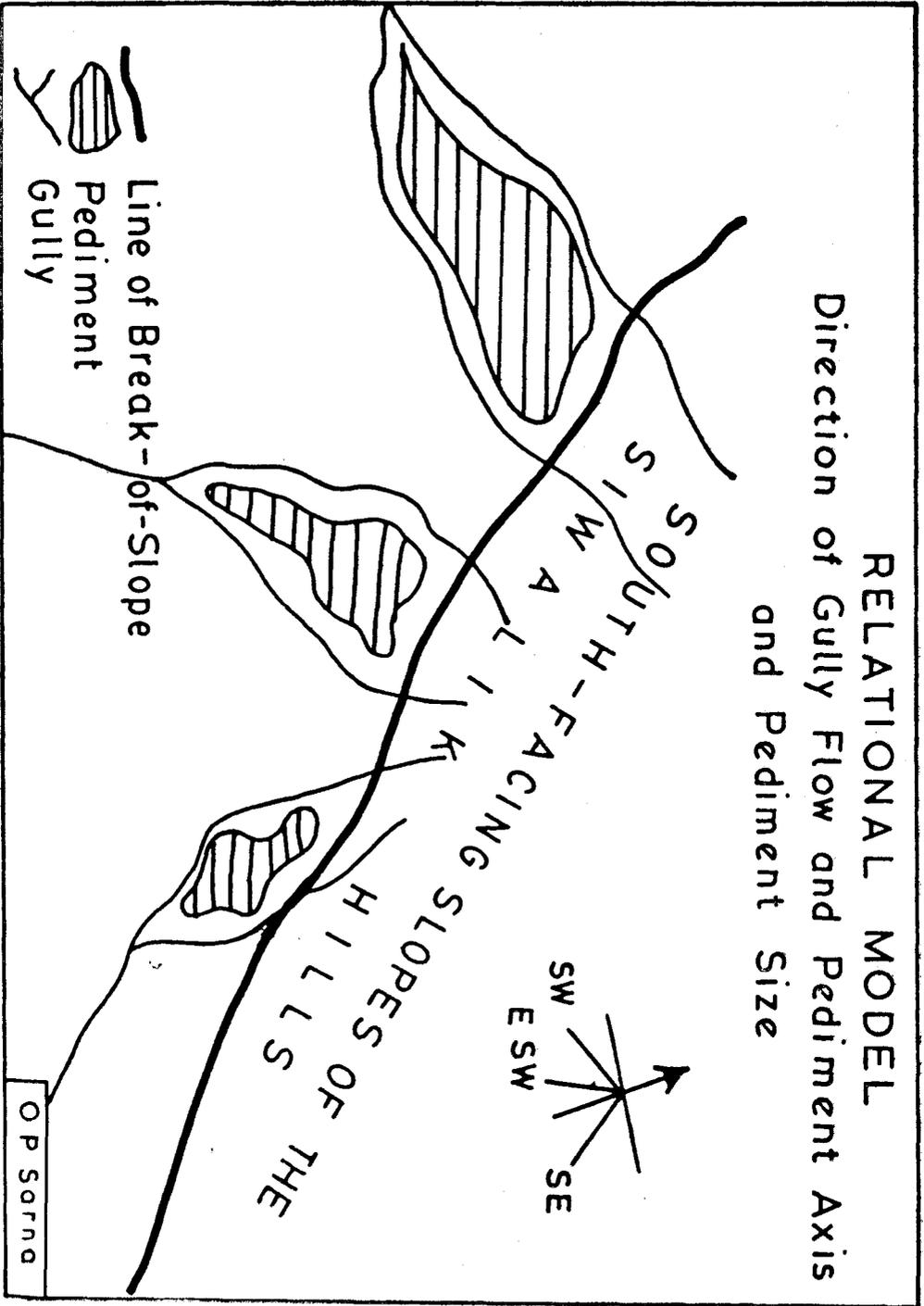


Fig. 5

The width and length relationship of the pediments appears to be inconsistent. In some of the large pediments both length and width are large while in others the pediment axis is short but their lateral extension is pronounced. While the length of the pediment from its head to terminal line remains fairly constant within a particular pediment the width at various points varies according to its shape. The width is influenced or determined by the spacing of the laterally flanking gullies, alignment of the bedrock exposures, the channel form of the streams (whether stable or shifting and straight, sinuous, or meandering), stream pattern, pattern of the angle of confluence and projections of the piedmont alluvium. By far the most important determinants are the spacing and pattern of the flank gullies. This simple relationship is repeatedly observed because the gullies hug closely the lateral edges of the pediments to which they are bound genetically. The pediments of the study area vary between less than 100 metres to more than 400 metres. Most pediments being ellipsoidal, semi-circular, and triangular have width of about 100 to 250 metres or so. In the strikingly rectangular pediments the width can range from 250 to 600 metres but these pediments are few in our region. It cannot always be observed presently but it can be argued that the lateral extension was effected by the lateral sweep of the overbank stream flow. In a miniature form it is observed in the region during the few hours or even less than an hour when the enormous discharge collected in the headward slopes as a result of thunder-showers seeks to flow out through the rather inadequate channels of the gullies and extended gullies. Splays then laterally sweep the bedrock surfaces.

There is a large diversity of shapes of the pediments that can be unmistakably observed in the field and in the aerial photographs (scale of 1 : 30,000) and also inferentially

on the toposheets (scale of 1 : 63,360 and 1 : 50,000). Some of the commonly observed shapes are radial (Photos 1 and 2), triangular with base along the slope-foot contact (Photos 5 and 9), trapezoid (Photo 7), spindle, semi-circular, narrow rectangular and ellipsoidal. (Photo 12) It is very difficult, if not altogether impossible, to generalise the shape geometry, quantitatively measure the shapes, and determine the explanatory variables controlling the shapes. However, it can be conjectured, although it does not appear to be obvious, that the alignment of the bedrock exposures, direction of flow of the gullies, ground plan of the gullies, geometrical design of the channels (straight, meandering, or sinuous), confluent or parallel stream patterns, and the angle of confluence of the confluent streams. All the determinants can be identified although their operation in the determining of shape cannot be fully observed or established in the field. Some are however quite clear. Trapezoid pediments occur between the parallel streams, a triangular with a base at the slope foot is found between two gullies having a low angle confluence and a semi-circular and an ellipsoidal occur between curvilinear alignments of confluent streams. The extension of the Boulder Conglomerate bedrock beyond the south-facing hillslopes of the Siwalik Hills is another important determinant of the pediment shape, the extension itself is contingent upon the initial erosion by adjacent gullies and extended gullies. It is in the interplay of random behaviour of the determinants that the explanations of the shapes are located. The randomness is very strikingly demonstrated in a variety of weird shapes of the pediments. (Fig. 2) At many places it is indeed difficult to distinguish the individual pediments and separate them one from the other. The jumbled combinations reveal a bewildering variety of shapes mainly related to the erosional configuration of the bedrock exposures and the complex pattern of stream

and gully integration. At places the complexity of shapes is further complicated by the hill-ward projections of piedmont alluvium. At places over considerable length the bedrocks have been very sharply cut and displaced vertically by a fault. (Photo 12) At these sites the pediments are invariably broad-based along the slope foot and backed by triangular faceted ridges—a direct evidence of a strong, linear fault. Structure here has played a role in determining the pediment site and shape. This finding in the field and in the aerial photographs fully supports the earlier findings and generalisations. (Twidale, 1967, pp. 393–411) Through its relationships with bedrock exposures and gullies the pediment shapes have some genetic implications as well.

Slope is easily the most important element in the morphological personality of pediment as it indeed is in the locationally and genetically associated alluvial fan. Lithology, surficial material, weathering, nature of runoff, climatic effects, and tectonics are associated with slopes of the pediments and alluvial fans. Geologists have often considered the pediments and alluvial fans either to contrast or to complement their property analyses. (Denny, 1967, pp. 81–105) Pediment, equally significantly, is one of the four integral elements of the classical hillside slopes and its evolution and extension are related to the retreat of the scarps into the hills and finally their reduction. It is clear therefore that the evolution and life history of a pediment has to be investigated along with the changes in the other three elements of the slope system.

The pediment surface morphology does reveal three parts, distinguishable in many pediments, proximal, middle and distal. In most of the members the first and the third are pronounced and easily identifiable because of their location, gradient, and surficial material.

The proximal segment of the pediments stretches from the hill-slope foot along the contact of the Punjab piedmont and the Siwalik Hills. It is characterised by slopes of  $7^{\circ}$  to  $10^{\circ}$  and at many places of up to  $18^{\circ}$  to  $25^{\circ}$ . At most places the proximal segment appears to have a subdued concave form but planar forms are also common. (Photos 2, 3, 4, 5, and 10) The bedrock scarp standing immediately behind the head of the pediment has a sharp junction with it at a fairly high angle of  $135^{\circ}$  to  $152^{\circ}$ . (Photos 2 and 3) Indeed the presence of this scarp and the high angle of junction immediately signify the presence of the pediment and the origin of its proximal segment. Typically the pediments have an inverted triangle slope which means therefore that we have a wide proximal segment but there are innumerable examples of radial plan proximal segments. Particularly where an extended gully jumps from the hillside slope on to the pediment and is fragmented into distributary gullies the radial plan of the proximal segment becomes strikingly pronounced. (Photos 2 and 7) In those pediments, and there are many examples of them, where scarp retreat is continuing albeit at a slow rate the proximal segment is live and active and is covered with a thin clay-dominant *grus* that does not remain lodged there for long. At other sites where the scarp is either stable or has become gentle the production and accumulation of *grus* brought down as colluvium are directly reduced and the proximal segment is practically bare. There is a definite relationship, although not quantitatively determined, between the debris size with the angle of slope on the one hand and distance from the head on the other. (Kar, et al. 1979, pp. 236–245) On the proximal segment the surficial material is fine clay and silt as here the angle of slope is the largest (also clay has a very large angle of repose), the locus is near the head, and the adjacent bedrock outcrop is the clay bed in the

Boulder Conglomerate Formation. Unlike the Rajasthan-Aravali pediments their analogues of the Punjab piedmont are not separated from the hillside slope by talus slope. (Kar, 1984, pp. 67-74) The absence of the talus slope revealing an abrupt junction of the pediment with the scarp has also been noted by earlier workers in their investigations of the pediments in the tropical savannas which are quite similar to the piedmont characteristics of the Study Area (Kesel, 1973, pp. 97-109) It is equally true that the proximal pediment represents more or less the original surface as contrasted with a surface of bedrock that has been exhumed from beneath a thick alluvial or colluvial cover. (Cooke and Mason, 1973, pp. 49-61)

In total contrast to the proximal segment can be observed the distal segment of the pediment. The distal segment, as the term indicates, is the lower part of the pediment beyond which stretches the alluvial piedmont. Although all the three pediment segments are slopes of transportation, in some measure or other, the distal segment displays a subtle positive balance in favour of debris supply as compared to debris removal. In these distal pediments can be observed a debris cover about 10 to 35 cms thick mainly comprised of coarse sand, pebble, gravels, and even small boulders, 6 to 10 cms long. (Photo 6) These clastic sediments have been partly derived from the proximal segment and the scarp slope behind them and partly from the in-situ developed grus. The distal pediment has a slope of less than  $1^{\circ}$  to  $1.5^{\circ}$ . This gentle slope matches well with the natural angle of slope of the large clastics which, as a result, come to stay for long, until at least the time when debris removal is much faster than debris supply. The distal segment, in itself, is gently planar but joins the middle segment at an extremely low angle, at most sites almost imperceptible.

Between the higher and steeper proximal segment and the lower and gentler distal segment lies the fairly wide middle segment. This segment has a slope of  $2^{\circ}$  to  $4^{\circ}$ , at most sites the values hover around  $2^{\circ}$  or a little higher. The form of the segment is basically planar but toward the upper and lower extremities can be observed subdued minor curves which mark the continuous stretch from the proximal to distal segments. It is in the middle segment that one observes a mixture of finer-textured and coarse-textured clastic debris, the former descending from the proximal segment and the latter contributed both by high slopes and insitu disintegration of bedrock. This is truly the segment of transportation. The annual sheetflood and slow soil creep and mass-movements along with minor gullies transport the sediments down the slope. It may be noted that the fall in elevation from the head to the toe is almost 5 to 8 metre;

It bears repeating that the Punjab piedmont is a part of a truncated classical slope system in which the free-face and waxing slope are totally missing. In the field one is struck by the repetitive occurrence of the steep, constant slope or slope of transportation and the pediment stretching below it. The constant slope has a remarkably concordant relationship with the steeply dipping beds. (Photos 3, 4 and 5) In contrast the pediment with a much less steep slope has a discordant relationship with bedrocks. At many sites the constant slope sits on the scarp slope of the hogback ridge and is thus an anaclinal slope, the structural dip matching with the topographic slope. The proximal, middle, and distal segments in combination produce the well known pediment form of a concave profile, the upper one far steeper than the lowest one. There is a slight rise in ground on the distal parts, but on the whole the concavity persists.

## GENETIC INTERPRETATION

Studies on the formation of pediments have a respectable age in geomorphology. One of the earliest investigations was attempted in 1897. (McGee, 1897, pp. 87-122) The studies are being continued unabated as investigations are spanning a large diversity of lithological, tectonic, structural, and climatic types. It is largely because of the diversity of contexts that such a large number of hypotheses or theories of origin have been proposed. Of the three climatic-pedologic contexts, arid and semi-arid, tropical savannah, and humid, the first has claimed 32 theories, while the second and third have spawned 20 and 18 theories respectively. It was only in 1938 that the humid (Davis, 1938, pp. 1337-1416) and in 1948 that the tropical savannah (Fair, 1948, pp. 71-79) attracted the attention of the geomorphologists interests in the problem of pediment formation.

Essentially, the theories can be classified into five groups : sheet flow, backweathering, lateral planation, exhumation, and composite action. Although a particular group is more effective for a particular climatic context, in most cases it is a combination of more convincing explanation on both logical-deductive and empirical grounds. The sheet flow theory first propounded by McGee had continued to interest the geomorphologists till the early 1980's, its life spanning almost a century. The interesting fact, however, is the application of all the groups of theories to more than one or even all the climatic contexts, leading to the suggestion that the processes proposed by them are climatic analogues of each other.

In order to identify the theory or the combination of theories which will explain best, at least tentatively, both the formation and the attributes of the Punjab piedmont pediments it is important, at the outset, to determine the approximate geological period

of their formation. Three field observations suggest that the pediments are Upper Pleistocene and Holocene and more likely later Upper Pleistocene and Holocene in age :

- (a) the dipping Siwalik beds were tilted only in the Middle Pleistocene (Mukerji, 1979, pp. 98-107; and Mohapatra, 1979, pp. 107-135),
- (b) the pediments are everywhere observed flanking the extended gullies and *choes* which originate much south of the main water-divide in the Siwalik Hills and are consequent upon the youngest south-facing hogbacks, and
- (c) the pediments have everywhere developed on the Boulder Conglomeratic beds.

It was only after the Boulder Conglomerate beds were uplifted and tilted during the later phases of the Middle Pleistocene corresponding roughly to the Mindel Glacial and Mindel-Riss Interglacial that the climatic and geological context of the pediment genesis could be established (Fig. 6). It should be noted, however, that the Riss and Wurm glacials and Riss-Wurm Interglacial were less humid even though the surface run-off and rainfall were not inconsiderable. (Mohapatra, 1979, pp. 110-111; Mukerji, 1976, pp. 12-13; Vishnu-Mittere, 1965, p. 332; and Zeuner, 1953, pp. 242-253) These climatic fluctuations have been worked out by several investigators. (Mukerji, 1976, pp. 13-14; and Mohapatra, 1979, pp. 110-111)

There were two tectonic events having crucial bearing on the pediment formation :

- (a) the hog-back ridges on which the pediments sit as concordant with anacinal slopes were created after the structural deformation of the Boulder Conglomerate took place

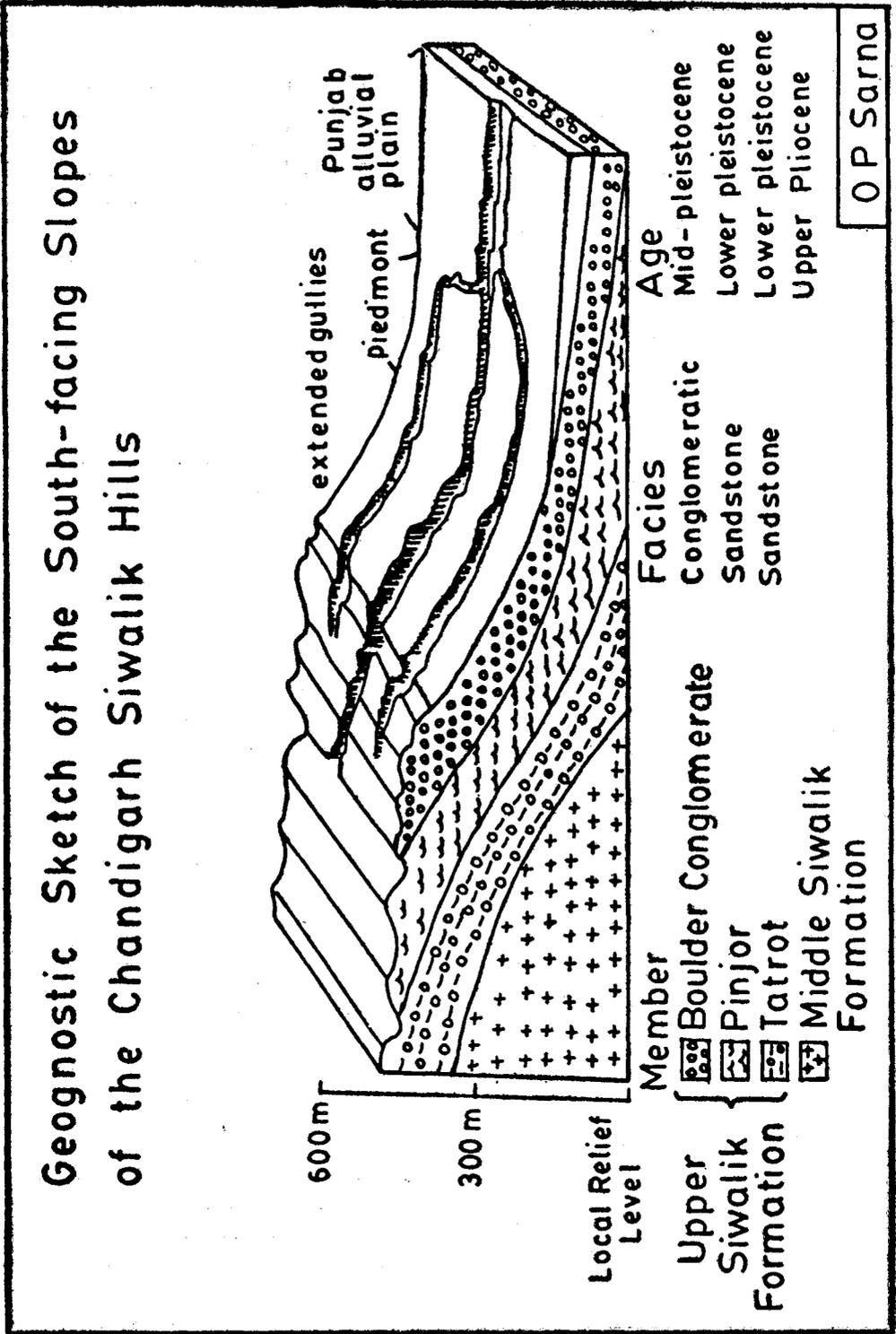


Fig. 6

during the Mindel Glacial and Mindel-Riss Interglacial; and

- (b) there was a fairly long, sub-regional faulting within the Boulder Conglomerate beds to the south of the main mass of the Pinjor formation (Fig. 3), throwing a narrow block of the Boulder Conglomerate bed down toward the piedmont plain.

The fault must be one of the events of the neotectonic movements recorded in the vicinity of the southern flanks of the Himalaya. (Nakata, 1975, pp. 111-118) The fault runs parallel to the grain of the Siwalik Hills, in the northwest-southeast direction.

Although all the theories of pediment formation can successfully explain the processes operating in different climatic contexts and combinations are still more effective some theories, at least, can be discarded from their application to particular contexts. The exhumation theory is simply not applicable to the Punjab piedmont pediments as there are no evidences for deep surface and subsurface rotting and their subsequent exhumation by removal. Since the Boulder Conglomerates provided the first surface on which the pediment forming processes could operate and the pediments are presently sitting on them, it is clear that the pediments have not been created though the removal of a younger bed and the weathered material overlying them. The Boulder Conglomerate is the youngest bed of the Siwalik formation. Thus, the process of exhumation did not operate here. It may also be pointed out that during a fairly long period during the later phases of the Upper Pleistocene and well within the Holocene arid climatic conditions continued entirely eliminating the possibility of deep surface and subsurface rotting.

The exhumation theory applied by a large number of geologists and geomorphologists

(Oberlander, 1974, pp. 849-875; Ruxton, 1958, pp. 353-377; Ollier, 1960, pp. 137-148; Tuan, 1959, pp. 1-140; and Budel, 1957, pp. 201-228) to the semi-arid and arid as well as Savannah regions was specially directed on the pediments which are genetically related and locationally attached to the inselbergs and tors. Since the inselberg-landscape or tor landscape itself was considered as the result of deep surface and subsurface rotting and their subsequent removal by sheetflow, the process of exhumation, it was suggested that the pediments were also the exhumed surface. Now, in the Punjab piedmont zone the pediments are attached to the Siwalik Hills and their hogback ridges and their south-facing slopes and nowhere to inselbergs and tors. Thus again the exhumation theory cannot be applied to the Punjab piedmont pediments.

Considering the context of their present occurrence one could suggest that the pediments need a composite theory for their comprehensive understanding. But this composite theory has to be a bit more comprehensive than the composite theory proposed earlier. (Bryan, 1935, pp. 765-775) The Bryan composite theory involves lateral planation by stream, backweathering, sheet flow, removal of detritus by sheet flow, sheet wash, diffuse flow, laminar flow, and turbulent unconcentrated flow and was formulated by combining the theories of lateral planation, backweathering and recession, and sheet flow. Essentially two kinds of flow, sheet and turbulent, and two kinds of basic processes, lateral planation and backweathering are involved in this theory.

The lateral planation proposed in the composite theory is achieved only by stream but it is quite clear that this process, in order to create wide, perceptible, and long pediments, would have to operate either through wide swing of the stream laterally or through the lateral spreading of water in the form of

strong over-bank flow of spill-over water. This assumes that the streams are of moderate size and their discharge, when they are suddenly activated, is considerable. In such a situation the interfluves will completely disappear, an evidence that is completely missing in the Punjab piedmont region. Also it needs to be emphasised that the pediments thus created through lateral planation by rivers must be very extensive while the pediments of the Study Area are far smaller and there are no permanent, large streams in this tract. Almost all the streams, *choes*, gullies, extended gullies, and minor channels have permanent channels but ephemeral discharge. For most parts of the year the streams of all orders do not carry any water at all and when the discharge is full the steep gradient of the slope facet hardly allows any lateral swing and therefore lateral planation. On the other hand, by extending the arguments formulated by Wirthmann (Wirthmann, 1981, pp. 165–204) against the climatic controls and emphasising the influence of rocks exposed on the surface on the pediment forming processes, it should be suggested that in the case of the Punjab piedmont pediments both the specific rock types and rainfall characteristics have been of crucial importance. The presence of the resistant Boulder Conglomerate on the surface and the innumerable gullies quite clearly indicate that both rock types and climate have been important during the Upper Pleistocene and Holocene times and at present in the formation of the pediments.

Eliminating the lateral planation by streams but not lateral planation as such the question of the origin of this process becomes quite evident. It is proposed here that this lateral planation is really a form of areal (sheet) erosion caused by overland sheet flow. Whether the sheet flow attains the dimensions of sheet flood in the down pediment sections or not is not really that crucial.

It has been claimed that essentially areal (sheet) erosion is caused by bed-load progression in the downslope segment. (Seuffert, 1981, pp. 141–164) Seuffert explains that this kind of change leads to a poly-linear convergence of the belt which is eroded by the running water. The main factor responsible for this erosion is the structure of the distribution of rain in space and time within the river catchment in question. Seuffert makes a very important suggestion that highly convectional rains with a very limited areal extent and a high and highly varying intensity are most favourable for bed load progression downslope and therefore for areal (sheet) erosion. (Seuffert, 1981, pp. 141–164)

On the basis of the arguments stated in the preceding paragraphs we propose a different formulation on the formation of the Punjab piedmont pediments. This formulation or model is a modification of the Bryan composite theory to some extent but it does incorporate some original arguments as well.

To begin with we have to explain the recession of the hill-side slope and extension (widening and lengthening) and shaping of the pediment. At many, if not all, places the hill-side slopes are steep scarps. These scarps stand at the head of the pediments. Thus, essentially we are here dealing with the retreat of scarps. The shaping of the pediments mainly refers to the processes by which the lateral and longitudinal extents are produced. It is important to remember that a combination of processes effect the formation of the pediments.

There were clearly two stages through which the pediments were formed : tectonic followed by erosion. Thus both the hypogenic and epigenic processes were involved. In the first state, a very brief one, a linear fault of modestly regional scale ran through the tract of the Boulder Conglomerate that stretches along the southern edges of the

south flanking slopes of the Siwalik Hills. (Fig. 3) The faulting that took place here caused a downward displacement of a narrow strip of the Boulder Conglomerate toward the piedmont and upward movement of the remaining part toward the Siwalik Hill southern flanks. In the initial stage, therefore, the junction between the lower and upper strip blocks of the Boulder Conglomerate was initiated by faulting. It was a part of the neotectonic movements which have been widely documented. (Nakata, 1975, pp. 111-118) This junction led to the creation of the geological context in which the pediments later developed, the junction angle of the pediment with the scarp, and the topographic slope of the scarp.

The scarp retreat was essentially achieved by planar erosion. A continuous deep notch was horizontally cut into the junction by several gullies jumping from the hill-side-slope (corresponding to the upthrown strip block of the Boulder Conglomerate) on to the surface that would later become the pediment (corresponding to the downthrown strip block of the Boulder Conglomerate). The long notches are thus located at the base of the scarp. However, these notches are very different from those located at a higher site and proposed in the model of scarp retreat through the enlargement of the notches inside the base, undermining of the foundational support of the scarp, and steep rock-fall leading to its retreat. (Twidale and Milnes, 1983, pp. 325-343) In the pediments of the Study Area the scarp retreat was essentially achieved by gullies, some independent and some joining to form thin sheets. (Photos 2, 3, 9 and 11) It was a combination of gully erosion and sheet erosion that helped in the recession of scarp and the creation of a particular junction angle and topographical slope that at most sites is concordant with the structural dip. The gullies are concentrated mostly

on the Boulder Conglomerates themselves and disappear on their entry into the piedmont alluvium, at the point where some of them integrate to form larger *choes*. (Fig.6)

During the early periods of the Holocene arid and semi-arid periods prevailed in the Punjab piedmont zone. Several scholars from different disciplines have adduced massive evidence for the period of desiccation during the Holocene. (Wissman 1956, pp. 278-303; Zeuner, 1953, pp. 242-253; Bhatia and Khosla, 1967, pp. 507-509; and Mohaparra, 1979, pp. 107-135) The desiccation was mainly characterised by a combination of thundershower and convective downpour and far less the advective-orographic variety. The thunderstorm rainfall, essentially sharp and spotty shower, is highly characteristic of semi-arid (BS), arid (BW), and modified monsoonal (Cwg) climatic regimes. The intensity of rain is very high indeed leading to the generation of rapid sheet flow and sheet wash on slopes built of rather resistant, impervious, and unresponsive rock surfaces having a sparse vegetation cover. The Boulder Conglomerates of the south-flanking slopes of the Siwalik Hills answer this description of ideal conditions.

The second stage in the pediment formation begins with the generation of climatically generated processes (Fig. 7). The sharp spotty shower coming down from thunderstorms and strong convective ascent associated with cumulo-nimbus clouds of the summer monsoons generates diffuse run-off and sheetwash. The innumerable rills and gullies create a mesh and sheet of water on the pediments (Photo 12). Together, the rills and gullies and the sheet erosion effect the parallel retreat of the scarp developed on the beds of the Boulder Conglomerate. The junction is cleared off the *grus* by the sheet-flow and gullies which bring them down after eroding the scarp slope. The sharpness of the junction is striking. There is no

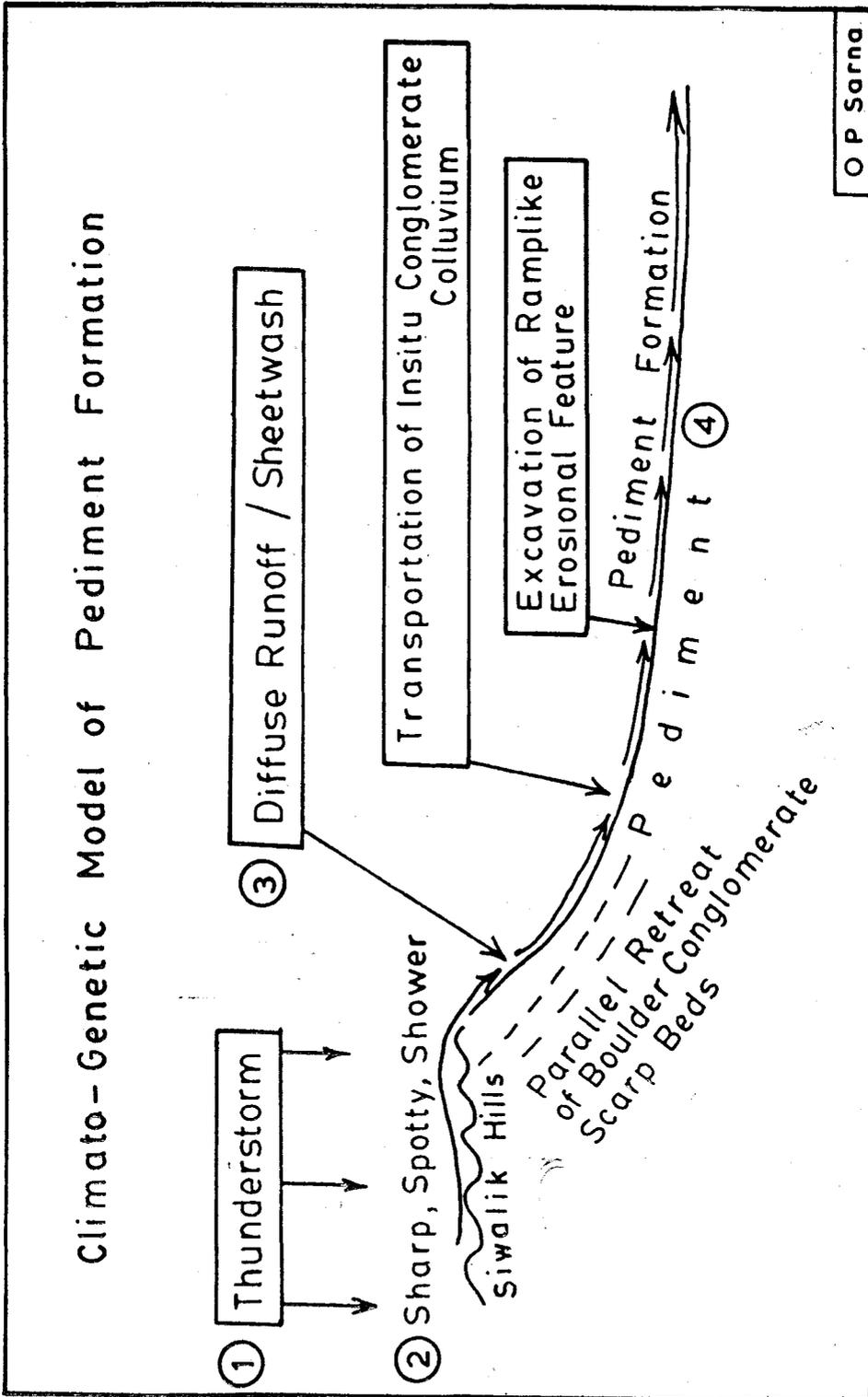


Fig. 7

doubt that colluvium and grus through insitu weathering are produced during the long period of dry months of the year but the accumulation is prevented by their removal by sheetwash and gullies during the monsoon months (Photo 3). As the sheetwash moves down its velocity and turbidity increase and it excavates into the bedrock a ramplike erosion feature, the pediment which extends downslope corresponding with the out-cropping of the bed rocks. It needs to be noted that in the Punjab pediments there are no talus or grus cones at the foot of the scarp.

### CONCLUSIONS

The Punjab piedmont pediments are formal homologues of their Rajasthan counterparts but not their climatic analogues. The Punjab pediments are not the integral elements of the classical King model as they are backed by a constant slope with free face and convex slopes missing. Their origin is located in the later phase of the Upper Pleistocene and the early phase of the Holocene but is not associated with lateral planation by streams. Two processes occurring in temporal sequence

lead to their genesis : faulting and sheet erosion. A recent regional fault running through the Boulder Conglomerate strip lead to the relative, displacement of two linear blocks, the higher provided the setting for the evolution of the scarp and the lower was the ground on which developed the pediment. Sheetwash and backweathering generated by high intensity, spotty, thunder-showers were the dominant pediment forming processes. Although the climaxial stage of evolution was attained and passed in the late Holocene there has been a slow, rather imperceptible change in the pediment in the later geological periods. Presently, the pediments appear, more or less, dead features, fossil in character. The pediments are features of both climatic geomorphology and structural geomorphology.

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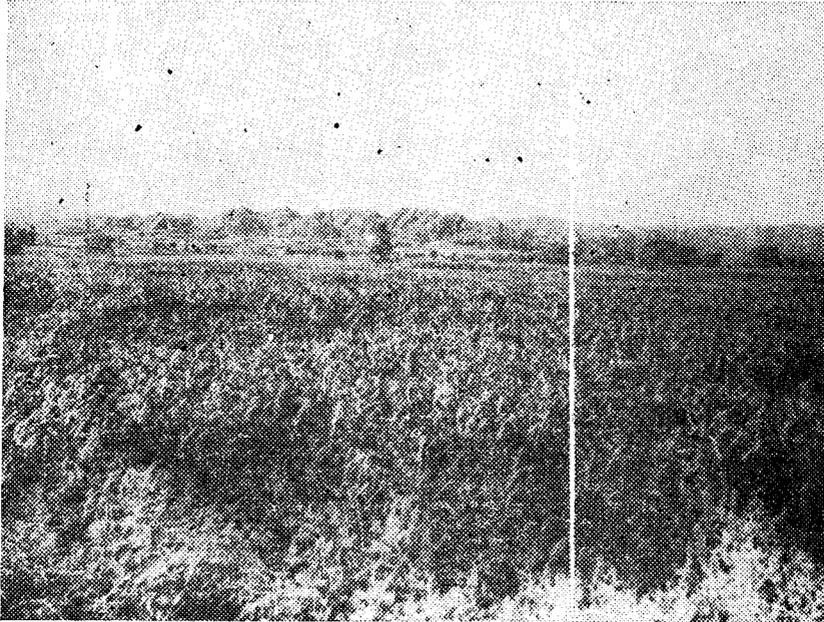


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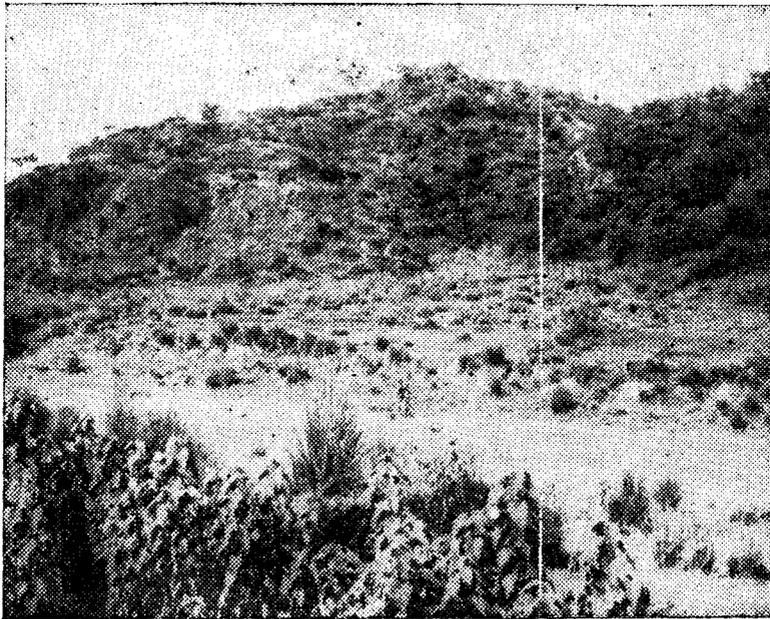


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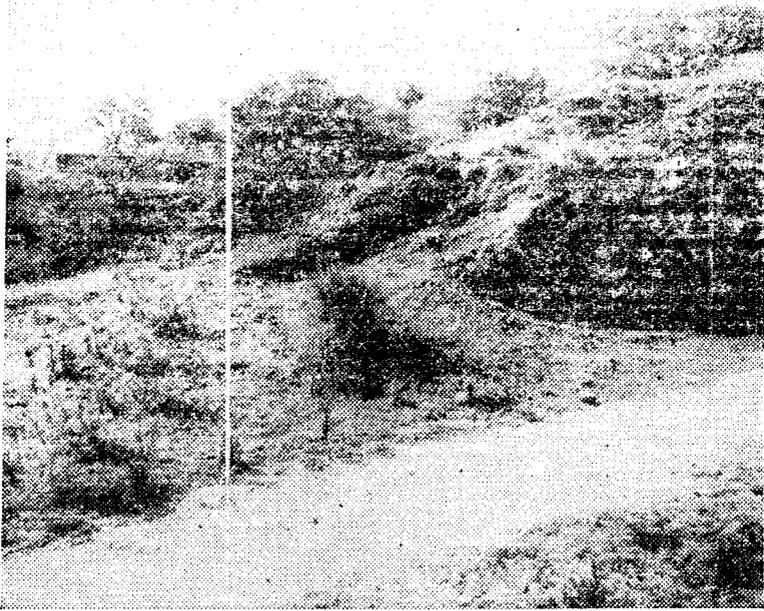


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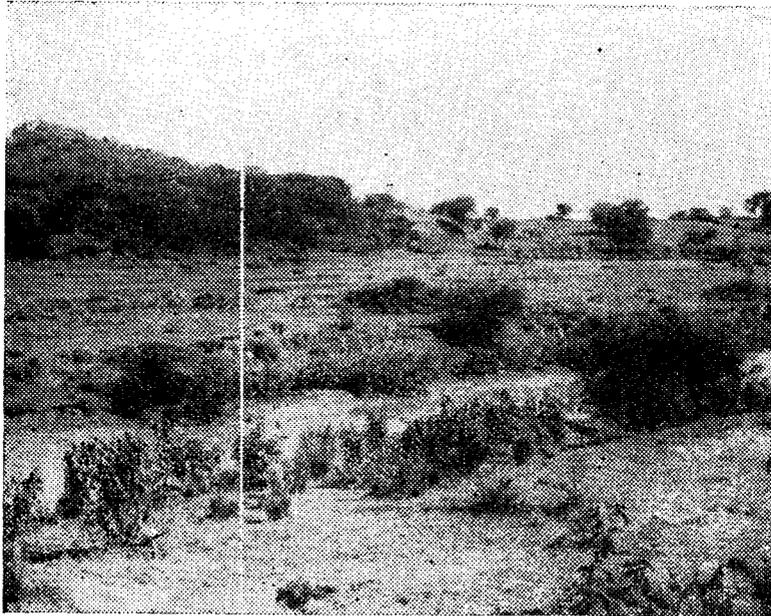


Photo 4



Photo 5

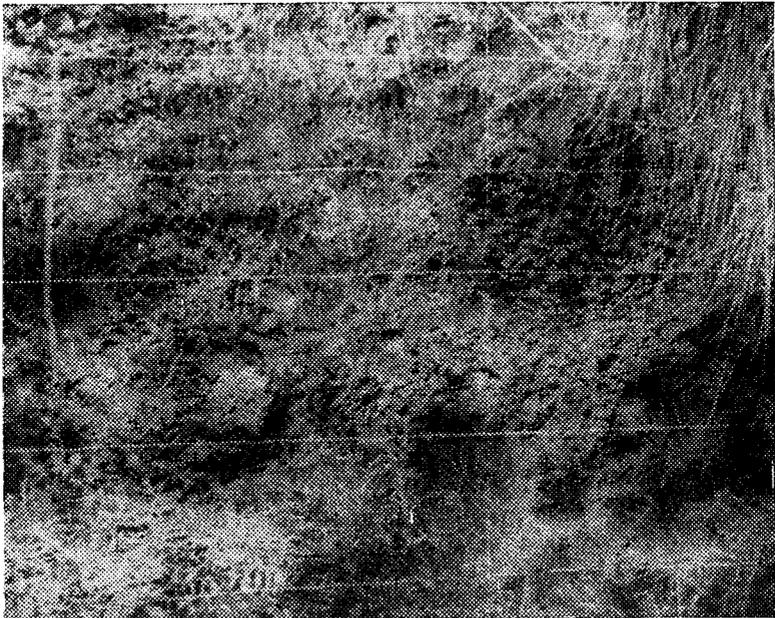


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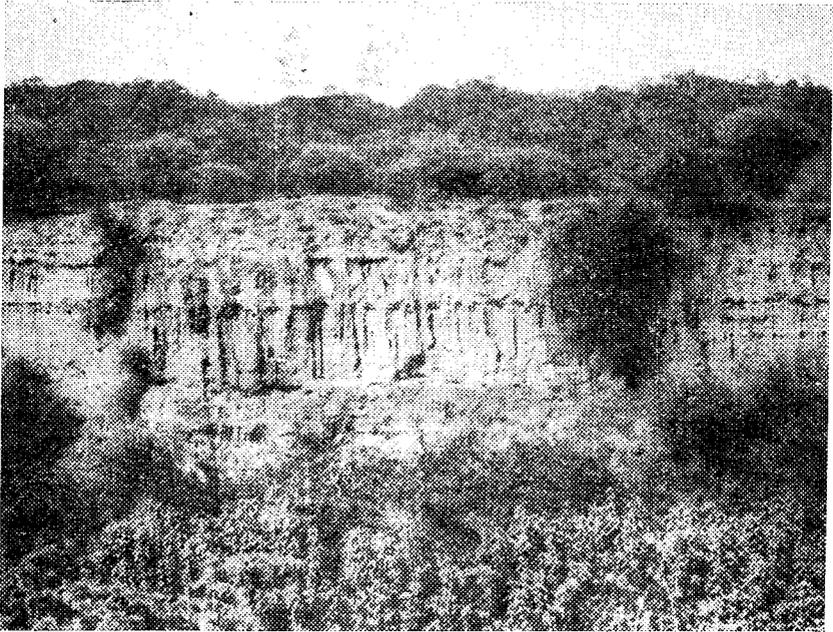


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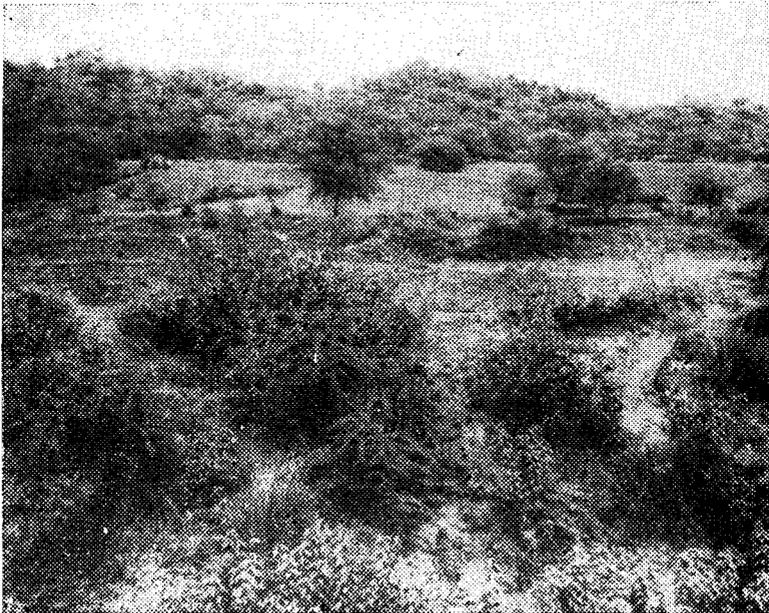


Photo 8

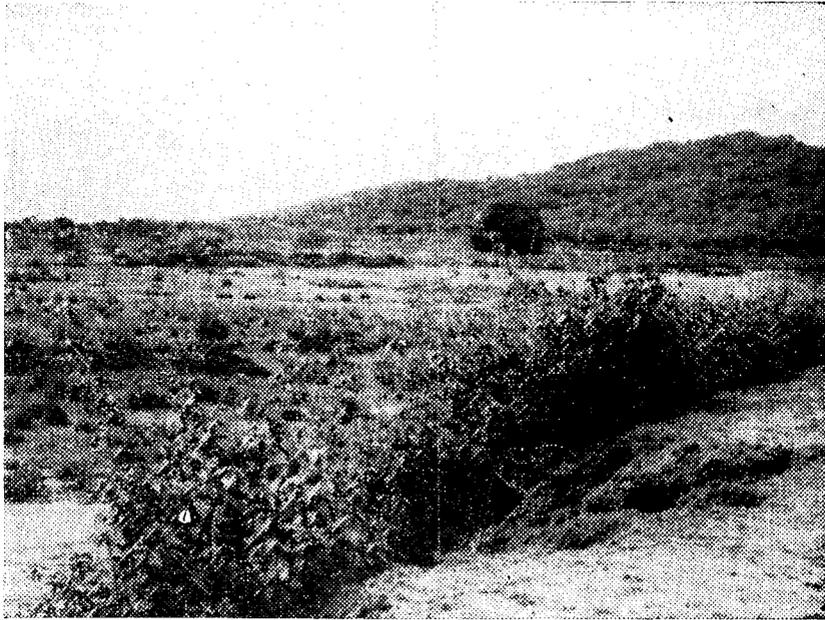


Photo 9

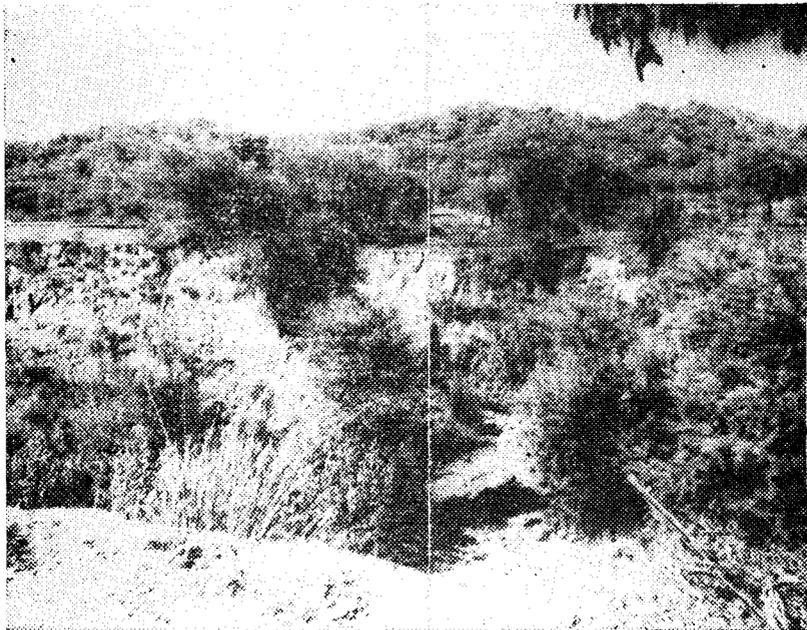


Photo 10

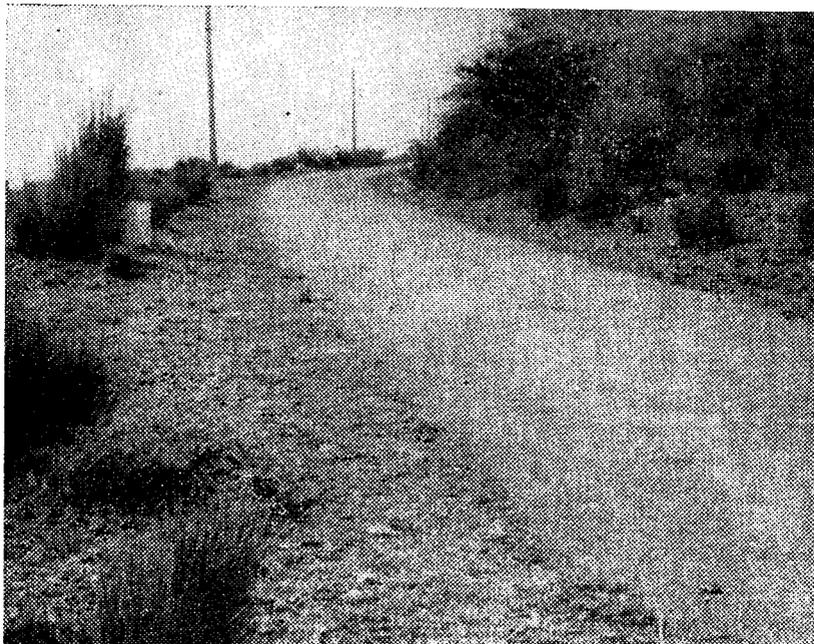


Photo 11



Photo 12