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THE THAL INTERFLUVE, PAKISTAN
GEOMORPHOLOGY AND DEPOSITIONAL HISTORY

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SUMMARY

Landforms and depositional history of the semi-arid and arid Thal desert and the adjoining Indus floodplain in Pakistan are described and discussed. Climate and sand relief are controlled by three wind regimes: southern monsoon from the Arabian Sea and eastern monsoon from the Bay of Bengal in summer, and northern winds in winter. Present vegetation ranges from wooded steppe to (arid) desert steppe.

The sands deposited by the Pleistocene Indus river were reworked into longitudinal and transverse ridges, alveolar (honeycomb-pattern) sands and locally barchan dunes, depending upon wind directions and forces. Abandoned Pleistocene Indus channels containing narrow clayey strips occur in this area, the eastern ones mostly obscured by wind resorting.

The Holocene Indus floodplain shows four depositional stages: the sandy base of a braided river system; two stages of a thin fine-textured cover; and recent moderately coarse sediments.

INTRODUCTION

Thal[4)] occupies an area of some 25.000 square kilometres in Pakistan between the Indus and the Jhelum and Chenab river (fig. 1). Soil surveys undertaken in 1968 (Mushtaq Ahmad et al, 1968, Baig et al, 1968) disclosed several landforms formed mainly by wind action. These, together with the wind regimes presumed responsible for their formation, have been described in detail elsewhere (Higgins, Baig and Brinkman, in press). Landforms resulting from river action also occur in Thal. A general account of landforms and soil parent materials in West Pakistan was given earlier (Brinkman and Rafiq, 1971). This paper presents a specific account of the geomorphology of Thal and postulates a geomorphological history of the area.

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Survey methods

The basis of the soils and landforms investigations was air-photo interpretation supported by ground observations. Preliminary stereoscopic interpretation of 1 : 40.000 scale air photos (flown 1953-54), supplied by the Survey of Pakistan, was undertaken prior to field work. Preliminary mapping units were recognized through the normal stages of air-photo interpretation. Subsequent field investigations included descriptions of soil, vegetation, slope, erosion and land use within the recognized units. The intensity of observations was dependent on the complexity of the unit. In some complex areas, observations were made as close as every ten metres, while in simple uniform areas, distances of up to fifteen kilometres separated points of investigation. A total of 8,000 observations were made in the survey area resulting in an overall intensity of approximately one observation per three square kilometres. Final delineation of landforms was made in the field, preliminary photo interpretation units being amended, combined or further subdivided whereever necessary. Detailed cross-sections were made in representative areas of each landform, height differences being measured by dumpy level and distances by tape measurement and pacing. The final landform boundaries were plotted on alternate air photos, matched and subsequently transferred to the relevant 1 : 50.000 topographic maps of the Survey of Pakistan. The units thus delineated were further reduced and generalized to the composite landforms presented in figure 3.

Climate

The climate of the area is controlled by three main wind regimes: a) monsoon winds from the Arabian Sea affecting southern and western parts in the summer months; b) monsoon winds from the Bay of Bengal affecting northern and eastern parts in the summer months; and c) winds from the north, north-east and north-west affecting the entire area in the winter months. These winds regimes control the distribution of rainfall, three-quarters of which is received during the summer months as a result of monsoon air movements from the Bay of Bengal and, much less, from the Arabian Sea. Wind regimes are dealt with in more detail by Higgins, Baig and Brinkman (in press).

LEGEND

LANDFORMS	*SOIL PARENT MATERIALS*
1 MOUNTAINS	ROCK, RESIDUAL MATERIAL AND LOCAL COLLUVIUM
2 PIEDMONT PLAINS AND TERRACE REMNANTS	SUBRECENT AND SOME OLD GRAVELLY AND LOAMY TO CLAYEY PIEDMONT ALLUVIUM
3 DISSECTED OLD LOESS AND ALLUVIAL TERRACES (POTWAR UPLANDS)	LOESS, RESIDUAL MATERIAL, OLD RIVER ALLUVIUM AND SUBRECENT OUTWASH
4 ROLLING SAND PLAINS	OLD AND SUBRECENT WIND-REWORKED SANDS
5 OLD RIVER TERRACES (BAR UPLANDS)	OLD MAINLY SILTY RIVER ALLUVIUM
6 SUBRECENT RIVER PLAINS	SUBRECENT SILTY AND CLAYEY RIVER ALLUVIUM
7 INDUS DELTA	SUBRECENT AND SOME RECENT SILTY AND CLAYEY ESTUARY ALLUVIUM WITH SOME CLAYEY COASTAL ALLUVIUM
8 ACTIVE AND RECENT RIVER PLAINS	RECENT AND SOME SUBRECENT SILTY AND SANDY RIVER ALLUVIUM

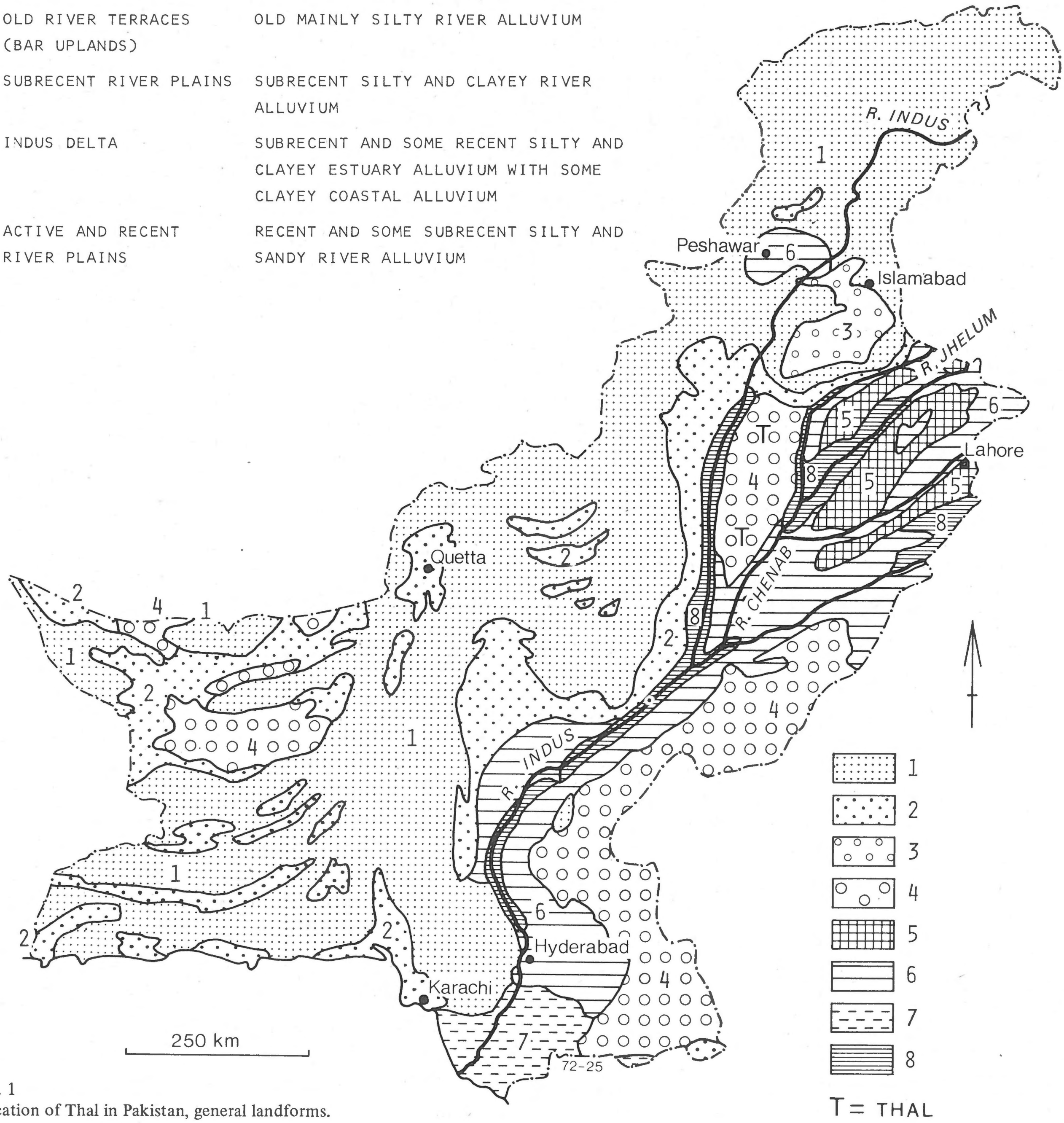

Fig. 1
Location of Thal in Pakistan, general landforms.

Long-term rainfall data (more than twenty years) is available from only three stations (Khushab, D.I. Khan and Multan) in the immediate vicinity of the area (table 1). The data record an average annual rainfall of 261 mm, varying from 385 mm in the north-east to 169 mm in the south. It should be noted that rainfall is strongly variable in time as well as space.

The effect of the Bay of Bengal monsoon air stream is much stronger in the north-east of Thal, where the average summer rainfall is 301 mm, than in southern areas with 135 mm summer rainfall.

The north-eastern area also benefits more from rain-bearing winds from the Asian land mass during winter, rainfall for the period October to March averaging 85 mm in the north-east in comparison with 36 mm in the south. Isohyets of average summer, winter and annual rainfall are shown in fig. 2a-c. Trends from shorter term records have additionally been used in their construction.

A study of agro-climatology in semi-arid zones of the Near East (FAO/UNESCO/WHO 1962) suggests the following rainfall limits for different climatic zones: arid, less than 200 mm annual rainfall; semi-arid, 200-500 mm; and sub-humid, more than 500 mm. The semi-arid zone is further subdivided into "true semi-arid" (300-500 mm) and "very dry semi-arid" (200-300 mm). In accordance with the above classification, the area from south to north-east consists of: arid, very dry semi-arid and true semi-arid zones. The delineation of the zones is shown in fig. 2d.

Mean annual temperatures in Thal are about 25 degrees Centigrade; mean summer temperatures about 31 degrees; mean winter temperatures about 18 degrees. Annual potential evapotranspiration is about 1800 mm (Ahmad, Sarfraz and Akram, 1965).

Vegetation

The vegetation of the area has been ascribed by Ibrahim and Anwar Khan (1969) to the Sindo-Saharan region (eastern sub-region) with a predominance of tropical plants. At present, the natural vegetation is rarely found in an undisturbed state, much of the original vegetation having been subject to cutting, lopping and over-grazing. From considerations of phenotype, Ibrahim and Khan recognize three main vegetation types: wooded steppe; shrub steppe; and desert steppe.

The wooded steppe of the relatively wetter (north-eastern) areas is dominated by perennial bunch grasses and scattered trees. The common floristic characters of this type are the predominance of species belonging to the genera *Lasurus* and *Cymbopogon* and the omnipresence of *Salvadora, Prosopis* and *Acacia.*

The shrub steppe is dominated by tussock grasses such as *Pennisetum dichotomum* and *Lasurus hirsutus* as well as a fair amount of shrubs, notably *Calligonum* and *Capparis* with scattered bushes of *Haloxylon.* This type receives less rainfall than the wooded steppe and predominates in mid-northern, eastern and western areas.

The desert steppe is dominated by a sparse cover of species such as *Eleusine, Cymbopogon* and *Aristida* as well as *Haloxylon, Aerua* and *Calligonum.* This type dominates the driest (central and southern) parts of the area. A full account of the vegetation is given in Higgins and Ibrahim (1970).

GEOMORPHOLOGY

General

The Thal desert presents a complex pattern of alluvial deposition, mainly by the Indus river and locally by the Chenab; progressively followed by wind resorting of the sediments into various forms of sand ridges; resorting and further deposition within spill channels; locally, modification of the sand ridges by river action; deposition of floodplain sediments; and present-day wind resorting of all sediments and dune formation.

Table 1
Average annual, seasonal and monthly rainfall (mm) *)

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Khushab	18	23	26	23	19	36	99	89	35	4	2	11	385
				Summer 301						Winter 84			
D.I. Khan	11	15	24	18	10	15	58	48	16	3	4	6	228
				Summer 165						Winter 63			
Multan	8	8	11	7	9	13	49	40	15	2	1	6	169
				Summer 135						Winter 36			
Average	12	16	20	16	13	21	69	59	22	3	2	8	261
				Summer 200						Winter 61			

*) Data supplied by Pakistan Meteorological Department (1967)

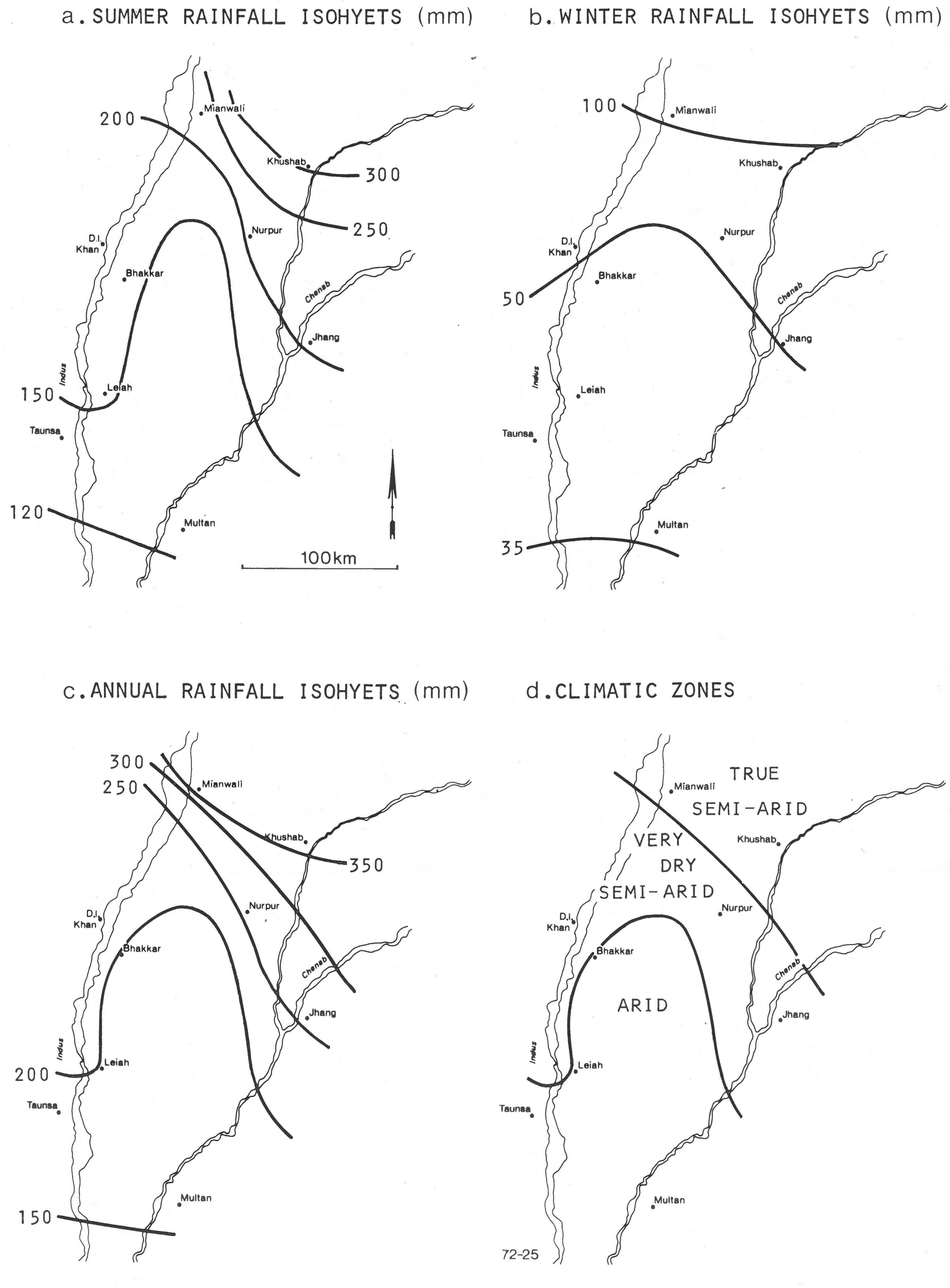

Fig. 2
Average rainfall and climatic zones

Traces of long abandoned river channels abound throughout the Thal desert and many present-day drainage lines mark the location of previous main courses of the Indus river. One of such courses is located 120 kilometres to the east of the present Indus bed. The material deposited in these chunnels is of a yellowish brown to olive brown colour characteristic of Indus sediments and in marked contrast to the material deposited by the adjacent Jhelum and Chenab rivers, which is of a more reddish brown hue.

The braided Indus river has deposited essentially sandy material throughout Thal. Geological cross-sections (Wapda, 1963) reveal no continuous or extensive silty or clayey deposits to depths of more than 120 metres. More than ninety-five per cent of Thal is shallowly underlain by great depths of fine sand. Subsequent to the western migration of the river, the deposits, equivalent to the old river terraces (locally called "Bar Uplands") of other interfluve areas, underwent a considerable period of thorough wind resorting. The resulting sand ridges are the most extensive landform units and cover the major part of Thal: the Thal desert, in contrast to the Holocene floodplain areas of the Thal interfluve. The different landforms are shown in a generalized map: figure 3.

Sand ridges

The formation of sand ridges is a subject described by many authors, among whom Bagnold (1965) is perhaps the best known. Bagnold defines a dune as a "mobile heap of sand whose existence is independent of either ground form or fixed wind obstruction", and recognizes two main types: the seif (longitudinal) dune and the barchan dune. More recent work reported by Gorshkov and Yakushova (1967) recognizes no less than thirty-six distinct sand relief forms (varying from longitudinal barchan ridges to compound circular dunes), within which three principal zonal types and three principal wind types are identified.

The Thal desert formations are comparable with the sand relief forms described by Gorshkov and Yakushova and mainly comprise the semi-overgrown zonal type of sand ridges, usually found in non-tropical deserts under complementary and opposing wind conditions. Five main forms of sand relief have been recognized in the Thal area: longitudinal sand ridges; transverse sand ridges; alveolar (honeycombed) sands; ridgy alveolar (honeycombed) sands; and barchan dunes. The formation of the various forms of sand ridges is dependent upon the wind regimes of the localities in which they occur.

In Thal, longitudinal sand ridges (map units 9 and 10) occur in all unmodified sandy areas with complementary[1] wind regimes and their orientation is in accord with the direction of the strongest winds.In the north-east of the area, where the direction of the strongest (monsoon) wind is from the east or south-east, the ridges are aligned E-W or SE-NW and the slip faces of the ridges are oriented to the SW, away from the main modifying, weaker, winter winds. The north-west of the area is also occupied by longitudinal ridges but aligned SW-NE, i.e. at right angles to those previously described. The reason for the change in alignment is the difference in direction of the stronger summer wind which, in the north-western area, is from the south-west causing the ridges to be aligned in that direction.

Transverse sand ridges (map unit 11) occur in the south of the area in localities where the wind regimes are directly opposing. Summer winds are from the south and winter winds from the north. The ridges are aligned E-W or ESE-WNW, at right angles to the prevailing winds.

Alveolar sands (map unit 12) occur to the north-east and north-west of the transverse ridges as a transition between that system and the longitudinal sand ridge system, and bear more relationship to the former than to the latter. Alveolar sands occur where one of the opposing winds is slightly dominant over the other, while transverse ridges occur where the winds are also opposing but are of equal strength.

Ridgy alveolar sands (map unit 13) occur to the north of the transverse ridges, also as a transition to the longitudinal sand ridges, but bear more relationship to the latter than to the former. Ridgy alveolar sands occur where the winds are opposing, but one of them is strongly dominant, whereas alveolar sands occur where one of the winds is only slightly dominant.

Barchan dunes normally take the form of asymetrical crescentic dunes with the apex pointing towards the direction of the prevailing wind and the wings or tails extending down-wind. In Thal, they constitute a very small part of the area (less than five per cent) and are the only form of sand relief that can be called true 'dunes'. They are completely devoid of vegetation and mainly occur in abandoned channel positions with complementary wind regimes.

Abandoned channels

Abandoned channels occur throughout the length and breadth of Thal and are remnants of previous main river systems. Previous main channels, once they had been abandoned by the river, acted as drainage lines for flood waters, so that subsequent material infilling them not only underwent additional mixing and redeposition, but also remained moist for considerable periods in comparison with adjacent areas. Dune formation commenced on the outer margins of the channels as these progressively became drier with further retreat of the river. In years of exceptional flooding, the channels again acted as spill channels and the infilled material was further mixed. Additionally, the channels acted as drainage lines for large catchment areas and received most of the runoff from the sand relief in years of exceptional rainfall.

The abandoned channels predominantly run from north to south, lie some 1.5 to 3 metres below the general level of the surrounding land and vary in width from some 10 kilo-

[1] Angles between dominant summer and winter winds 0 to 120 degrees.

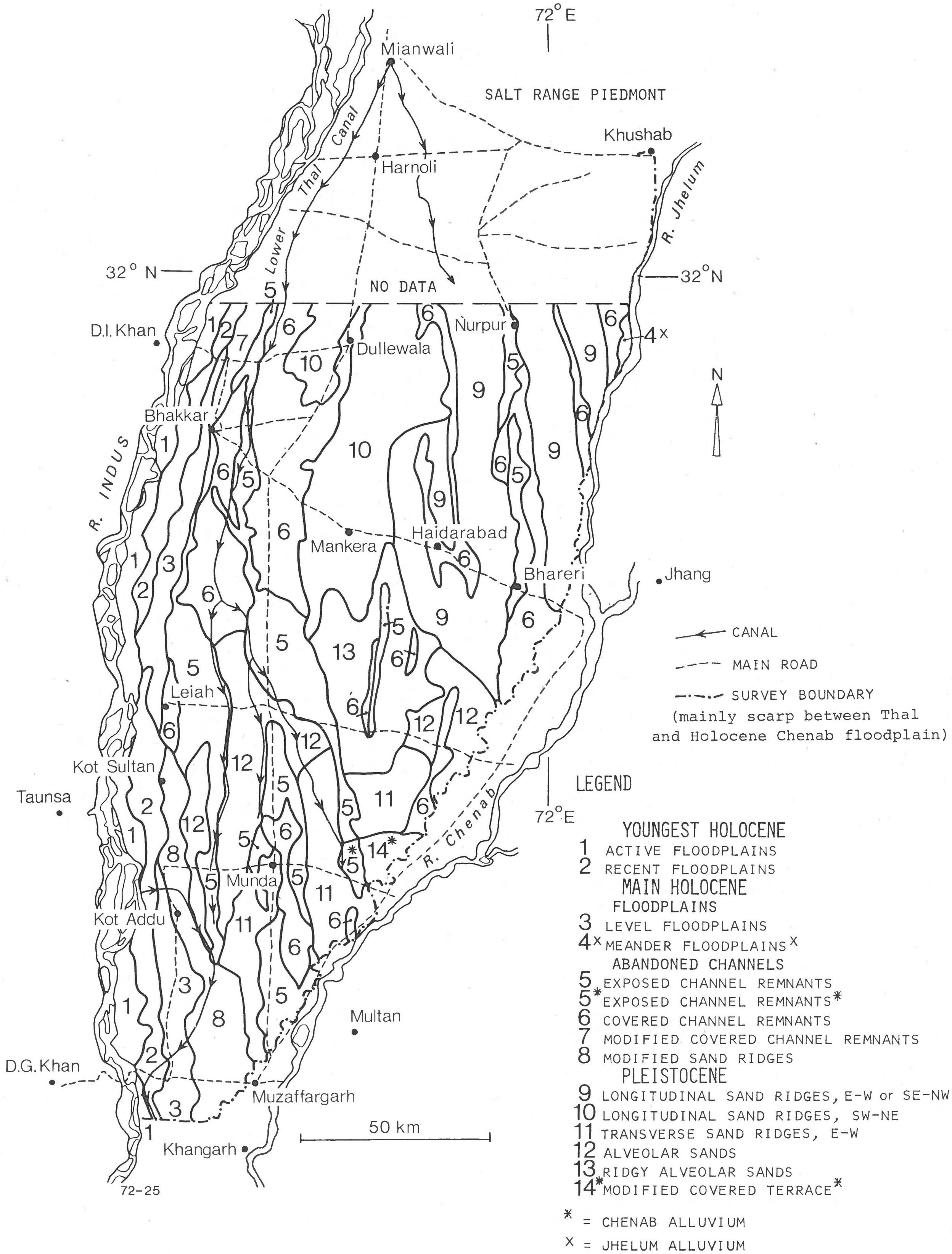

Fig. 3
Geomorphology of Thal.

metres in the east to approximately 30 kilometres in the west. The variation in width is presumed due to the longer abandonment and therefore increased dune formation in eastern channels. The western limits of individual abandoned channels are commonly marked by a high (7 to 10 metres) symmetrical sand ridge, conspicuously oriented N-S through various sand ridge systems. The N-S oriented ridge clearly delineates the western edge of individual channels and was probably formed by wind action on a high sandy levee. The eastern boundary of an abandoned channel is usually gradual, merging through an increasing thickness of wind-reworked material into the obscuring sand ridges.

Three types of abandoned channels have been recognized: exposed channel remnants; covered channel remnants; and modified covered channel remnants.

Exposed channel remnants (map unit 5) are generally flat but may contain some barchan dunes. Such channel remnants are the site of major settlement and cultivation in the desert area and have been so for centuries, as reflected by the presence of ancient forts at intersections of E-W lines of communication and N-S channels. Within the majority of the channels occur irregular narrow strips of massive, olive-coloured, silty clays which are excavated and used as building material. This material was probably deposited from slow-moving water in narrow channels within the main channel area in times of low flood during the process of abandonment. Most of the material contained in the abandoned channels is similar to the normal sand relief material of the Thal desert but is not so well sorted, having undergone considerable periods of remixing and redeposition by water. Coarse and medium hard lime nodules, developed under the influence of groundwater, occur in the channel material, in contrast to the fine nodules scattered in the sand relief material.

In one exposed channel remnant in the south-east of the survey area (map unit 5* in figure 3) small areas of Chenab alluvium occur within Indus alluvium. Such areas are presumably due to incomplete burial of an older Pleistocene (Chenab deposited) terrace by Indus alluvium.

Covered channel remnants (map unit 6) contain both sand ridges and recognizable traces of channel material, as opposed to areas of sand ridges where the wind resorting has been sufficient to completely obscure the original nature of the deposits. Areas of covered channel remnants usually occur adjacent to exposed channel remnants and separate the latter from the completely wind resorted areas (map units 9-13).

Modified covered channel remnants (map unit 7) are areas of covered channel remnants where subsequent water movement has reoriented the alignment of the covering sand ridges. Such a landform occurs in the north-west of the area, where the system is presumed to have consisted originally of a covered channel with longitudinal ridges aligned NE-SW. River action through the terrain resulted in the destruction of many of the ridges and distortion and reorientation of the remnants to a generally N-S alignment. The resultant landscape consists of irregular and somewhat curved longitudinal ridges, 2 to 3 kilometres long, 5 to 8 metres high and 100 metres wide, separated by concave, nearly continuous valleys approximately 400 metres wide. The ridges are steep (eight to twenty-five per cent slope), dome-shaped and merge, over a distance of some 100 metres, with the outer edges of the valleys. The alignment of ridges in the southern part of the unit is NE-SW following the line of flow of the water into the present-day Indus floodplain.

Modified sand ridges

In the south and south-west of Thal, an area of modified sand ridges occurs (map unit 8) which is presumed to have consisted originally of transverse ridges aligned E-W or ESE-WNW. River action has resulted in the modification of the original system to a generally N-S alignment, turning to NW-SE in the northern areas where the flood waters emerged from the present day Indus floodplain. The resultant landscape consists of variously sized (one to eight metres high), regular, symmetrical ridges some 150 metres wide and 2 to 3 kilometres long separated by flat infilled valleys 70-300 metres wide. The valleys are wider and the ridges smaller in the west of the system than in the east, where the proportion of ridge to valley was progressively increased by wind action as the amount of flooding and infilling diminished.

Modified covered terrace

In the south-east of the area occurs a relatively small terrace (not merely an infilled channel) of exposed Pleistocene alluvium deposited by the Chenab river, which was subsequently partially covered by wind deposits (map unit 14*). Recognizable Chenab alluvium underlies the sand ridge formations in many other places in the eastern part of Thal but, due to its buried nature (10 metres below present topography), its exact extent is not known. Besides the small channel remnant described above (unit 5*), the area where it is exposed comprises only this modified covered terrace, consisting of flat terrace remnants on which sand ridges have been superimposed. The ridges occupy some fifty per cent of the terrain and rise to a height of about 15 metres. The ridges are oriented NW-SE and probably have been aligned thus by non-depositing water movement from the adjacent abandoned channel areas to the Chenab floodplain.

Floodplains

The floodplain areas of the Thal interfluve have been mainly formed by the Indus river and, in northern locations, are separated from Thal proper by a bluff, 10 to 16 metres high. To the south, the bluff becomes progressively lower, attaining a height of only 3 metres at Leiah, and disappearing near Kot Sultan where the floodplain sediments merge with those of Thal proper and infill the inter-ridge valleys.

The Indus river is a braided river: one which has more than one channel; is very wide and shallow and which exhibits large differences between high and low water levels.

Superficially, the Indus floodplain is unlike one normally associated with a braided river: the surface deposits are uniform and fine or moderately fine, and the floodplain contains numerous meandering stream coures. However, detailed examination reveals that the meander channels are erosional n nature, merely draining excess water from the floodplain, and are not depositional. The uniform fine and moderately fine deposits are only shallow (about a metre thick) and overlie greater depths (3 metres) of the sand normally deposited by a braided river system. The whole forms a remarkably uniform level floodplain within which four stages of deposition are discernible: coarse textured sediments, deposited mainly as sand banks in the braided river system; silty clays and clays, deposited in the form of a level floodplain by bank-topping floods when the river carried a non-characteristic fine load (probably as a result of catastrophic landslides in the Himalayas); silty clays and clays of similar origin but of later age; and moderately coarse young sediments deposited by the present Indus river channel and by a few smaller channels running through the level floodplain.

In northern areas, the different depositional regimes are particularly marked, and there are sites where all four deposits have been identified within a depth of 3 metres. The oldest floodplain deposits are well developed and have a definite zone of lime accumulation which does not exist in the younger deposits. The younger sediments comprise the mapped active and recent (younger Holocene) floodplains, while the older sediments are at the surface in the areas recognized as level floodplains and meander floodplains. The meander floodplain is confined to the small areas of Jhelum river deposits in the north-east, while the level floodplain mainly occurs along the western margin of Thal.

The high bluff which separates the level floodplain from Thal proper in north-western areas is effective in retaining deep summer flood waters on the level floodplain. As a result, considerable leaching of the floodplain sediments takes place and alkali soils are not present. In southern areas, where the flood waters are not confined by high bluffs, flooding is shallower and of shorter duration. As a result, the amount and period of leaching is less and the period of upward water movement is longer, giving rise to considerable areas of alkali soils in the southern part of the level floodplain.

The active and recent floodplains occupy a belt of terrain adjacent to the present course of the Indus river. Changes of river course are frequent in the active floodplain and still have to be reckoned with within the recent floodplain. Both landforms contain mainly moderately coarse deposits which are little developed and are usually stratified within 50 cm of the surface. Flooding is expected once every two or three years in recent floodplain areas and annually in the active floodplain.

DEPOSITIONAL HISTORY

As a result of the investigations, it is possible to postulate a geomorphological history of Thal along the following lines.

Stage 1. The Chenab river moves eastwards leaving a deposit of silty clay (the present modified covered terrace, map unit 14) on the eastern edge of the area. The Indus river probably flows to the east along the piedmont of the Salt Range and then south through the area of Chenab material, depositing fine sands. Subsequently, the Indus river shifts westwards (earlier abandonment of eastern channels, inferred from width differences), the main Indus channel being successively located at Bhareri, Haidarabad, and Mankera (narrow remnant, not shown in fig. 3). Some blocking of the main course with piedmont material from the Salt Range may have taken place during this stage causing abrupt changes in the course of the main channel. Areas of Indus deposits away from the main courses dry up and undergo wind resorting into variously aligned dune fields. Old main courses act as spill channels and remain moist with no dune formation. Soil formation in inter-dune areas probably commences at this stage. The present depth of homogenization (more than 1.5 metres) of soils in these locations suggests a late Pleistocene dating by correlation with other areas in West Pakistan.

Stage 2. The Indus river continues to move westward. Old main channel courses in eastern areas dry up and outer areas are wind resorted to dune fields (covered channel remnants, map unit 6). Central parts of old main channels (exposed channel remnants, map unit 5) undergo periodic water resorting and receive some clayey deposits from slow-moving drainage water, especially in northern areas. By its westward shifts the Indus river enters previously formed old wind resorted Indus terrain and water resorting of this material takes place. The main channels contain loams and do not dry out. The degree of development of the channel soils suggests an Early Holocene dating of this stage by correlation with other areas in West Pakistan. The Indus river subsequently moves into the locality of the present-day floodplain and downcutting results in the formation of a bluff bounding Thal proper. The downcutting in northern areas probably extends into the Middle Holocene, having commenced in the Early Holocene. Fine sands are deposited in the floodplain. High rainfall conditions exist, and the dune fields become vegetated and stabilize to sand ridges. The intensity of soil formation on the ridges and in the hollows, with some formation of clay minerals, is probably at a maximum in this stage. Some hollows overtop with flood waters and drainage lines form to the nearest old channels. Topsoil, especially clay developed by weathering, begins to be washed from sand ridges to hollows.

Stage 3. Presumed Middle Holocene Vegetation continues to grow on the stabilized sand ridges. Weathered topsoil material, containing clay, moves from the ridges and accumulates in the hollows, building up de p homogenized soils except where continuous drainage lines have formed by flooding of hollows and overtopping flood water breaching low places in the dividing ridges. The sand ridges remain at an early stage of soil development due to removal of weathered products. The old channel remnants continue to act as drainage lines, but resorting of channel material diminishes and soil formation commences in these locations. The water table remains high in channel remnant areas and is responsible for the formation of a zone of lime nodules ("kankar"). Bank-topping floods from the main Indus course deposit the first fine-textured level floodplain sediments (part of map unit 3) in the main Holocene floodplain, and this is followed by the commencement of soil formation in these areas.

Stage 4. Presumed Late Holocene. Development continues as described for the previous period in Thal proper, but a second stage of fine-textured level floodplain sediments (part of map unit 3) is deposited in the main Holocene Indus floodplain, and meander floodplain sediments (map unit 4* by the Jhelum river. Salinization and alkalization processes commence in low-lying areas in the southern part of the level floodplain. The northern areas of the level floodplain remain subject to annual flooding and leaching.

Stage 5. Youngest Holocene (the last few centuries or, for salinization, the last few decades). Settlement by man commences and some devegetation takes place in Thal proper, with the formation of barren, active barchan dunes. The old channel remnants dry up, except in minor areas which receive sufficient drainage water from local catchment areas. Moderately coarse sediments are deposited in the youngest Holocene floodplain adjacent to the main channels of the Indus river (map units 2 and 1). Inter-ridge hollows are infilled by similar deposits in the lower south-western margin of Thal. The water table in some parts of Thal proper is raised by canal irrigation (particularly in western areas) and a stage of more rapid and extensive salinization is initiated.

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