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THE ALLUVIAL MORPHOLOGY OF THE INDO-GANGETIC PLAIN: ITS MAPPING AND GEOGRAPHICAL SIGNIFICANCE

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As the chief habitat of mankind at the dawn of civilization in western, southern and eastern Asia, alluvial plains are of profound significance; while, with regard to re-development in the future, the extreme delicacy of the deposition and modelling brings difficulties in their irrigation if this is to prove beneficial, not harmful, to the intensive cultivation of their gently sloping surfaces associated with varied soils and a changing water-table. To Europeans accustomed to their hilly, island-girt peninsula, the apparent flatness of the plains has made them extremely difficult to map with accuracy. Partly in consequence, plains have tended to be almost ignored in geomorphology, instead of providing a central theme for physical study in world geography. Their populations of hundreds of millions, the unique part played by them in world civilization through history and protohistory, the newly acquired independence of their peoples and, as in the case of India-Pakistan, the frontier problems of water distribution arising from partition boundaries drawn across the plains: these are but a few of the elements that indicate the importance of alluvial morphology.

The two aims of this paper are (i) to exemplify the landforms of the Indo-Gangetic Plain by the publication of selected manuscript maps, newly contoured, and here reduced from 1/1 million or topographic scales; and (ii) to interpret the forms, within the changing zones of structure and climate, in relation to the forces of running water and silt charge. The paper is divided into two main parts. The first introduces a selective summary of structure in relation to the Plain: the second, which includes three re-contoured regional maps, describes the major landforms of the Plain which slopes from the Himalayas to the Plateau edge and towards the deltas of the Indus and of the Ganga-Brahmaputra.[1] An appendix describes the task and methods of mapping, in correcting the basic errors of published maps and providing needed detail for the plains.

The paper is illustrated by six figures which may be classified as follows:

Re-contoured maps of regions in order of complexity (much reduced from 1/1 million scale)	*Topography, illustrating surfaces, processes and hydrodynamics (little reduced, or from topographical scale)*
Figure 1. Bihar Plain: deposition of cone and inter-cone.	Figure 2. Deposition and erosion: two block diagrams.
Figure. 4. Panjab Plains: two surfaces of deposition and incision.	Figure 3. Sutlej and Ravi: *bangar* and *khadar* or flood plain.
Figure 6. Bengal Plain: complex factors, structural and alluvial.	Figure 5. Yamuna-Ganga confluence: control by rock spur upstream.

(Methods of re-contouring are illustrated in the topographical examples. For general location, atlas maps should be consulted.)

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Morphology, Structure and Hydrodynamics of the Plain

In plan and surface the primary features of the relief of the subcontinent are three, of which the boundaries are best defined on a geological map:[2]

(i) The Great Plain, extending from the mouths of the Indus to the mouths of the Ganga-Brahmaputra, a gently sloping surface of alluvium accumulated in an underlying trough of unknown depth;

(ii) To the north, the great bordering arc of the Himalayas, source of the Plain's major rivers and its accumulated alluvium, flanked by ranges of lesser altitude bordering Sind to west and Bengal to east; and

(iii) To the south the Indian Plateau, contributing comparatively little run-off to the Plain and little alluvium except for the intermittent fringe of relatively small alluvial cones. Eastward from Delhi to Bengal, its rocky northern edge with spurs acts as a 'guide bank' which controls or guides the course of the Yamuna-Ganga; its action trims the southern margin of the Plain and fixes points of river-confluence and sites of cities. Westward of Delhi Ridge and beyond the salty marsh-lakes artificially drained to the Yamuna, the edge of the Plateau, except for an occasional spur (29° N., 76° E.), is mantled by the sands of the Thar steppe-desert. Along its foot a desiccated string of pools, the Sarasvati-Ghaggar once fed from the Outer Himalayas, loses itself and can no longer reach the Sutlej-Indus. The surface of the Plateau bordering the Plain includes relatively smooth uplands, widely leached, dissected and barren, with vales, overlooked by abrupt ridges and 'island hills' or inselbergs.

In so vast a region as this, much is known and more remains to be discovered. Here one can simply outline elements relevant to the form and evolution of the Plain; summarize accepted theories and question points of doubt; and link facts of rock structure in mountain and plateau to forms and processes of deposition in the surface and underlying layers of the alluvium. While geology has worked from rock and structure to alluvium in the subcontinent, alluvial geomorphology may usefully complement this by closer examination of processes, forms and soil structures in the Plain and its bordering margins, Contemporary and Recent, Quaternary, Tertiary and earlier, so throwing light on structure and rock form.

Unsolved problems of structure include those of how the massive block of the Plateau may have underthrust and interlocked with the successive folds, overfolds and overthrusts of the vast Himalayan arc, backed by the world's greatest high plateau or 'median mass', Tibet. In plan the parallel folds of the great arc are sharply flexed where the Jhelum bends to the Plain from north-west to south. Thence they radiate south-westward in successive ranges bordering Baluchistan and overlooking the plain and delta of the Indus. It may well be that a similar flexure at the far eastern end, where Assam meets Tibet, has determined the trend of the steep ridges enclosing Assam, bordering Bengal and prolonged southward through the Arakan Yoma to Cape Negrais, the natural breakwater behind which has accumulated the delta of the Irrawadi.[3]

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Sir E. H. Pascoe's final views (1950)[4] were that 'whether the continental drift hypothesis be accepted or not, the strike of the rock folds resulting from the Himalayan movement ... has been regulated by the shape and direction of the shield (or Plateau) margin, ... against which the folds impinged'. When we turn and transfer our attention 'to folding in Burma or in north-west India it appears necessary to imply compression, from east and from north-west. Thus compressional forces acted upon the Plateau from directions from north-west to east, round three-eighths of the compass'. Du Toit had compared the folds around the plateau mass to the waves around a half-submerged submarine.[5] In allusion no doubt to this, Pascoe continued 'This *quasi*-hydrostatic quality of the folding fits into the concept of a continental mass moving northward and invading the marine sediment deposited off the coast of a large bay or bight in another such continental tract occupying northern Asia'. The varying strike of the Himalaya and lateral foldings 'would have been governed ... by the orientation of the ... approaching coast-lines'. Structural evidence for the hypothesis of continental drift, most suggestive along and to south of the mid-world belt of Tertiary folding which includes India, has stimulated geology to the possibility of notable horizontal displacements necessary to explain the genesis of mountain chains. It was this stimulus which led to Pascoe taking the views quoted, so different from those he had put forward thirty years before.

Between and north of the visible spurs of the Plateau which jut out to east in the basaltic or trap hills of Rajmahal (88° E.) and which project at the Delhi Ridge and less strikingly in the northern Thar (76° E.), the Plateau mass is buried deep in sediments, with alluvium, no doubt overlying marine, lagunar and estuarine sediments, visible in the Lower Tertiary ranges around it. Yet isolated portions of Plateau rock outcrop to north-west and north-east. In the north-west a sub-alluvial 'ridge' has been traced to where, on either bank of the Chenab river and close to the Salt Range, outcrops of rocks of the Aravalli series occur. The geodetic survey by which it was traced was undertaken because of the rise of the water-table following the irrigation of the Jhelum-Chenab *doab* which, it was thought by a soil chemist early alert to the danger of alkalinization, might be partly due to sub-alluvial damming by this ridge.[6]

Structurally, the narrowness of the Plain in its valley is notable as compared with the length. Extending some 1775 miles along the mountain foot from the Indus to upper Assam, where it is narrowest, it measures 175 miles in width opposite Allahabad but only 100 miles opposite the Rajmahal Hills, Delhi and the hill-tops which appear above the sub-alluvial ridge extending from the Aravalli Hills to the Chenab river. Southward the plain extends to its deltas for 270 miles from Rajmahal and 600 miles from the Chenab hill-tops. The seaward flanks of the Plain show a contrast between Bengal widening towards the delta shore, which measures 300 miles, and Sind which is narrow and less than 100 miles across the lower Indus to Kutch.

As to north-west, so to north-east towards Rajmahal and still more beyond,

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the wedge or coign of the Plateau had been subjected to severe stresses and strains. This led to rifting west-east along the Damodar rift-valley, with its Lower Gondwana (Permian-Carboniferous) coal beds. With this rift may perhaps be associated the alluvium-covered Garo-Rajmahal Gap (through which the Ganga and Brahmaputra enter lower Bengal), and also the low Rajmahal Hills. In these hills the coal beds are overlain by lavas of Upper Gondwana age and, in contrast with mere dykes in the Damodar rift, these extrusions indicate great stress and strain. By position, strike and rock types, the west-east Shillong or Garo-Khasi Plateau, which stands only 130 miles to east-north-east across the gap from Rajmahal, has long been recognized as a fragment of the main Indian Plateau. Similar lavas, the Sylhet trap, cap the south edge of the Garo-Khasi Plateau (near 91½° E.). The eastern side of the north-south rift, further weakened by extrusion and by the weight of the lavas, may have downwarped or 'sag-faulted' toward the synclinorium (or downfold system) now buried beneath the alluvium of the upper deltaic plain of Bengal.[7]

From the Patkoi ridge which forms the water-parting between the Brahmaputra and the Chindwin and Irrawadi at their sources, an anticlinorial belt of Upper to Middle Tertiary rock curves south towards Rangoon. This has been interpreted as the axis of an Eocene Irrawadi subsequently cut off from Assam by uplift and leading to the development of the Assam Brahmaputra.[8]

To a great extent, the Himalayas still remain geologically unexplored, though widely traversed and mapped from Kashmir to Nepal and Sikkim. The causes are not only their height, length and diversity, but also the political barriers of Afghanistan and Tibet, Nepal and Bhutan, and the dangers of bullets in the rocky north-west and of arrows in the jungles of the north-eastern Frontier Agency. Yet a great deal is known and, from this, much can be inferred and asked. The Himalayan folding, induced perhaps by concealed underthrusts of the Plateau which may be buried beneath the Outer Himalayas and the Plain's deep alluvium-filled trough, was overfolded towards the Plain. Overfolding was followed by the overthrusting of vast rock-sheets of which many must still be unmapped. The thrust sheets from the Simla hills approach the Outer Himalayas or Siwalik Hills and the Plain;[9] others actually bury the Outer Himalayas near the Tista gorge, below Darjeeling.[10] Meantime, glaciers and rivers were constantly at work but not, as was assumed until forty years ago, down little varying courses. Erosion was constantly renewed by structural change as where, north of Simla, the Sutlej re-excavated its westward longitudinal valley in a gorge cut deep into southward thrust-sheets[9]. Not only was detritus taken down through the last gorge exit on to the Plain: when a recumbent fold rolled southward and downward over the rocks beneath, enormous masses of rock debris were developed by the breakage of its advancing edge and these, drawn down by gravity from mountains of unequalled height, were simultaneously pushed, as by a gigantic bulldozer, towards the plain. The recognition and mapping of a few thrust-sheets suggests overthrusting on a massive scale along the Himalayan arc, repeatedly interfering with river courses and diverting

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them from high in their catchments down to the hillfoot.[11] Thus from the world's highest plateau and mountain range the detritus, formed on what must have been an unequalled scale, plunged to the Plain. Movements continued into the Pleistocene in which tear faults in the Outer Siwaliks guided the emergence of Yamuna and Ganga on to the Plain.

These reasons account for the vast amounts of water-worn stones and pebbles accumulated in later Tertiary time, the Siwalik beds which were upfolded, eroded and redeposited, as now, over the pebbly hillfoot belt, the *Bhabar*, where they may form new beds which may in time be uplifted and eroded afresh. Although thickest near the gorges of the major rivers, the boulder and pebble beds and the *Bhabar* are continuous from the north-west end of the Himalayas to near the Tista. The uplifted, northward-dipping and still unbroken strata capping the Great Himalayas, including Everest, offer great resistance to erosion; the thrust-sheets lower down offer less; while the beds of rounded boulders and pebbles of the Outer Himalayas offer least. The series could be compared, in diminishing strength, to structures of massive concrete, of shattered brick and mortar, and finally of ill-consolidated ball bearings.

After a big flood one sees the characteristic lie of the pebble beds and individual shingles, as in November 1955 above the damaged headworks of the Ravi and along the Yamuna and the Kosi. Most of the shingles are laid level with, or rather parallel to, the river's slope of 10 in 5000 or more. But here and there a flattish shingle is half-thrust over its downstream neighbour and left tilted against it. The same lie is seen on lesser hillfoot cones and it is repeated in remnants of the former boulder beds left in terraces 50 or 100 feet above the present courses; their plunge after leaving the rock floor of the gorge is seen where an outlying terrace bank is undercut.

Turning to the past, we find this lie of the shingles unmistakable in the adjacent Tertiary pebble beds of the gently or steeply folded Siwalik ridges. Photographs and geological sections of bedding at many places show that the Siwalik shingles, like those of today, lie from the Himalaya towards the Plain, not laterally. The significance of this detail will be seen in relation to the formation of the Plain and its main river courses.

In order to explain these Siwalik pebble beds, a completely different hypothesis was put forward by Pascoe in 1919,[12] nearly thirty years before he reached the final views quoted, and independently by Pilgrim in 1919.[13] As this is still discussed, it deserves mention here.[14] It was suggested that the pebble beds must have been laid down by a river with a continuous flow along the mountain foot from east to west. This was named 'the Siwalik river' by Pascoe, the 'Indobrahm' by Pilgrim. No mention of these occurs in the volume by Pascoe quoted; and unfortunately after his death 'no trace could be found' of the revised, final volume of his manual, which was to deal with the Siwaliks and the Indo-Gangetic alluvium.

Knowledge was, of course, less advanced when the hypothesis was first

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published. Thrust-sheets, studied in the Alps, had been surmised in the Himalayas but had not been investigated there. Even now comparatively little attention has been given to their destructive influence in relation to deposition in the Ganga trough. The plainward lie of the Siwalik shingles does not seem to have been discussed by either author. On problems of hydrodynamics, consultation with irrigation engineers should have made it clear that a river, assumed to be flowing parallel to a mountain range, could not trundle boulders or roll pebbles for a length of 1750 miles or more but would have flowed over sands and silts. The assumption of a continuous shield to the south involved postulating an outlet either eastward, transversely across the rising structures south of Tibet, or north-westward right across the mountains of the Hindu Kush to the Caspian Depression — as Pilgrim, though not Pascoe, suggested. L. D. Stamp's proto-Irrawadi from north-east Assam to lower Burma would in any case imply a south-eastern outlet in Eocene times; and as to north Afghanistan, its structure is massive. The change from the Indobrahm's hypothetical sole outlet to outlets by the Gulf of Sind and Bengal was not ascribed to structure but to river piracy or capture. Yet a classic sign of piracy is the narrowness of the gorge of capture, associated with differences of gradient; whereas a plain of 60 miles in width at its narrowest marks the present outlet of the Indus system to Sind, and one of 130 miles marks the outlet of the two rivers Ganga and Brahmaputra.[15]

The hypothesis just discussed of a great river flowing for some 1750 miles along the whole length of a mountain foot would invite comparisons with the relief of mountain, plain and plateau in other lands and continents, did space allow. The hypothesis might have been more rapidly and conclusively rejected had its exponents and critics noted that no mountain chain in the world overlooks such a longitudinal river. Once rivers have escaped from the mountain folds they contribute by their deposits to a piedmont plain, down which they slowly flow. All that can be suggested here is a scrutiny of continental maps for comparison with the patterns of (i) the Indus system of converging tributaries, joining to form one great river flowing between the plateau blocks of the Thar and Baluchistan, and (ii) the Yamuna-Ganga and the Brahmaputra, thrown across their plains against the Indian and Garo-Khasi plateaux until they too join, after emerging between these two blocks, the great and small. Naturally the low but significant range of altitude which usually distinguishes plain from plateau is concealed, rather than revealed, where contours at conventional intervals are not helped out by accurate hachuring. Geological mapping complements the forms, so long as the rock is not concealed by a soil cover and its boundary is correctly generalized, as it is on the smaller (1/6 million) map of the geology of India though not on the earlier (*c.* 1/2 million) map: on the latter the rock is made to terminate some distance south of the reaches of the Yamuna-Ganga to be examined, although they are actually bounded and guided by rock. The 'classic' threefold pattern of mountain, plain and plateau needs further revision; even a general study of the world's plains is lacking. These receive scant notice not only in texts on physical geology but even in those on

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physical geography, in spite of their immense environmental significance, both past and potential.

Since intensive study of one of the world's most significant plains calls for comparative study, one example may throw light on others. For rapid visual comparison with a map of the subcontinent, it is helpful to turn a map of the Americas so that the great continuous range from Alaska to Cape Horn stands at the top and the varied patterns of plateaux, lowlands and gulfs below. Allowing for differences in dimensions and complexity, in South America the Paraguay-Parana, gathering the rivers from the Andes over the Gran Chaco at the edge of the eastern plateau, may suggest comparison with the Yamuna-Ganga; and similarly for the Orinoco. The pattern of the Amazon may suggest the pattern of the Indus. Low, ill-determined water partings divide the systems. In southern North America the 'Great Central Plains' are traversed by the tributaries of the southward course of the lower Mississippi, which flows close to outworks of the Appalachian 'plateau'. Farther north, complexity of structure and changes in drainage, following glaciation, lessen similarities; yet there too comparisons can usefully be made. In Eurasia north of the twofold mid-continental belt of mountains with its median plateaux, the rivers flow out to inland seas or desert basins, their waters now being re-harnessed to fan out over their irrigable plains. Comparisons can be made around the Alps and Transylvanian Alps where small plains descend gently to the Danube flowing against the limiting plateau blocks of Bohemia or the Balkan massif. Tributaries from the Alps flow across the alluvial plain of Lombardy to join the Po, which flows close to the lower Apennines until it reaches the head of the delta. The narrow plain or 'corridor' of the Rhône is traversed by tributaries collected by the Rhône, thrust against the Central Massif.

Turning to Pleistocene times, the element of unity in the watering and drainage of the Plain is seen from the evidence both of morphology and of the distribution of river fauna, contemporary and recent. The shifting or repeated temporary effacement of the watershed zone was due less to structural causes than to changing factors in alluvial deposition and erosion. The fanning out of the Yamuna distributary streams, now westward, now south-eastward, over its cone, repeatedly linked the waters of the Ganga and Indus, mixing their fauna.[16] Somewhat as small lakes form at the foot of the Plateau to the west of Delhi, drained artificially by a cut through the Ridge, so along different reaches of the Plateau-foot, lakes would have formed readily along the drainage line when the Himalayan rivers distribute the waters and sands over their cones. Such lakes or 'lagoons' would further assist the free movement of fauna between the Ganga and the Sutlej, now in one direction, now in the other.

Summing up the structural development of the Plain from early Tertiary times in the setting of Pascoe's latest interpretation, it seems justifiable to think of the Plain as based upon the continental shelf of a sea narrowing through Tertiary times and shallowing to marine, lagunar or estuarine gulf, and ultimately — though with pulsations — to the formation of a plain. At this late

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Tertiary stage one should not think of a single one-way Tertiary river along the Himalaya foot, hemmed in to the south by a continuous Plateau. As in other continents or regions and as now, drainage from the Himalaya would be collected, not at the foot of the mountains but at the foot of the plain built of their detritus, that is at the edge of the Plateau, along which it would flow to ocean outlets in opposite directions. The periodically shifting watershed was latterly the zone extending for 60 miles west from the Delhi Ridge. The structural and hydrodynamic forces of geologically recent times can be visualized as at work far back into Tertiary times.

The Relief of the Plain, Major and Minor, and the Rivers' Discharge and Silt Charge

Extending from delta to delta and from sea to sea, the Great Plain is essentially one. Much as the irrigation waters of the great rivers, from the Indus to the Ganga and beyond, now fan out over their alluvial cones, so rivers fanned both westward and eastward from their gorge exits during the deposition of the main alluvial surface. The spreading waters of the Yamuna were collected at the foot of the Plateau's western extension, the Thar, to flow mainly to the Indus and the Plain of Sind. Thus irrigation has restored the physical unity of the Plain, abolishing the geologically temporary water-parting at the western Yamuna bank. The waters of the Yamuna, the Ganga and other Gangetic tributaries, have been redirected westward. Conversely each of the rivers of the Indus tributary system incised a single course to south-west and south, which irrigation is redirecting eastward. From the Himalaya foot the alluvium of the valley plain slopes continuously towards the Plateau. Westward of Delhi the slope ceases at the Thar's edge and at the drying bed of the lower Sarasvati-Ghaggar; eastward of Delhi it ceases where the Plateau edge is washed by the Yamuna-Ganga. At just below 700 feet a string of brackish pools, dried up in the Hot Weather, marks the shifting belt of water-parting presently to be described.

Beyond the Himalaya foot and its five- to ten-mile belt of pebbly *Bhabar*, the Plain may be crossed without a single stone being seen. But across the Yamuna-Ganga, children can fling stones from a rock spur into the river to their hearts' content while their fathers quarry the sandstones to be carried by barge to build Delhi, Allahabad or Banaras. Yet it is misleading to speak of 'Indo-Gangetic alluvium' without qualification. Partial consolidation, both mechanical and chemical, season by season, has long proceeded, both before and since the millennia during which alluviation ceased over the western cones and gave place to incision. West of the Sōn and Gogra, the 20- to 50-foot concave bank of an incised meander hardly yields to the thrust of a metal-shod stick: the 'alluvium' may offer considerable resistance to bank-erosion. *Kankar*, chemically altered concretionary beds, lenticular in shape, lie with sands (fine or coarse) at varying but shallow depths below the soil or subsoil, or are laid

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bare in barren swells. From the Panjab to mid-Bihar, *kankar* is grey-white or yellowish in colour; but eastward of the Kosi into rainy Bengal, it is a brick red. *Kankar* serves as second-class road metal and grey *kankar* can be used for making lime. Dating is difficult. Throughout the Plain it would be well to restrict the term 'New' to the present incised flood plains (with their terraces) and to the lower surfaces of the deltas. The main surfaces, but for a thin continuous veneer of soil and shallow subsoil, might be termed Recent; thus leaving the term 'Old Alluvium' for the relatively well-defined, conspicuously reddened lateritic upland surfaces to be described, which fringe the coastal plains and the delta of Bengal and are found in northern and east-central Bengal.

The direction of slope west-east *across* the two lateral deltaic plains of Sind and of Bengal differs from that north-south across the great valley plain for, in both deltaic plains, slope trends away from the Plateau and towards their flanking hills. These are relatively low and give little deposition from behind their parallel alignment. This slope must also be due in part to the understructure of the lateral plains: the synclinorial down-warping and down-folding is accompanied by up-warping of the Plateau. The main stream of the Indus in Sind passes twice between outliers of the Baluchistan folds, at the Sukkur Barrage site and west of Hyderabad's low Tertiary ridge. In Bengal the main Ganga-Brahmaputra estuary and its lateral channels meet the sea close to the Assam-Burma arc.

Climatically, the plains show a gradual transition from the aridity of the lower Panjab and Sind to the copious rainfall of Bihar and Bengal, heaviest at the mountain-foot. Westward of the low water-parting at Delhi, which divides it from the present Yamuna-Ganga tributary system, there gather the confluent 'Five Rivers' of the Panj-Ab. By the fivefold Panj-nad they join the braided Indus, in what is climatically a desert plain unrelieved by any other river. The Yamuna-Ganga system is enriched by one confluent river after another, and gains not only from the heavy rainfall and snow-melt of the eastern mountain catchments but from the heavy monsoon rains of the valley plain itself until, in the combined Brahmaputra-Ganga delta plain, the monsoon brings a rainfall of from 60 inches at Calcutta to 100 inches in the east of Bengal.

Thus, while the north-western rivers, losing water, soon drop their sands and silt, the eastward rivers, gaining water, tend to carry their silt-charge farther. The Plain of the Ganga forms part of its water 'catchment'; in contrast, the Plain of the Indus could truly be described as an area not of water catchment but of 'losement'. The consequences are notable. On the Plateau itself the Thar, with its accumulation of sands varied by clay hollows, contrasts with the Plateau east of the Aravallis, which is washed by rain and scoured by rivers. The entire Plain may be said to be the work of the Himalayan rivers except for the cone of the Sōn, sloping smoothly to Patna. The deposits exhibit a gradual differentiation with no marked boundary between west and east. The Panjab Plains have coarser soils, most marked next to the Indus, and they have

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silted up to a higher altitude; while only 100 miles beyond the Indus delta's shore lies the 100-fathom line (*c.* 200 metres). The Ganga-Brahmaputra plains have finer soils; their surface lies at a lower level; while the 100-fathom line is carried considerably farther out. The zone of water-parting with the Indus system has long lain upstream near the axis of the Yamuna gorge instead of midway along the Himalayan arc and, as will be seen, scour and incision from the Ganga plain latterly worked headward to the gorge.

Within the broad unity of the Plain may be discerned the recurrent major and minor patterns of relief. The major pattern is twofold. It consists of the alternation of (i) great alluvial fans or *cones*, fanning out from the gorge exits of all the great Himalayan rivers, except the Gogra, with (ii) the intervening slopes which may be called *inter-cones*. The cones, triangular or rather segmental in plan and convex in form, have their apex at the gorge mouth from which their axis runs to their base towards the Plateau edge, or the sea; the inter-cones are reversed in plan, tapering from the Himalayas, and are slightly concave at the edges of their even slopes. Cones with gradients of over 1 foot per mile, and inter-cones with rather less, merge, where space allows, in a *cone-foot plain* with a gradient of 6 inches and less per mile (1/10,000-1/12,000). This gradient is continued to the delta and the sea. The characteristic trend of conal contours is well exemplified by the convex arc of a deltaic shore. Most of the major cones were formed by a single Himalayan river, but two are composite, the cone of the Beās-Ravi and that of the Mahananda-Tista in north Bengal. The rivers Rapti and Gogra emerge (at 82° and 81° E.), not across the structure, but between folds at a bias with the main curve of the range, in echelon, their axes pitching westward. This may explain their lack of cones. The inadequate mapping of Nepalese territory so far published leaves the question open here, but surveys in 1955-56 for hydro-electricity may have solved the problem.

The Bihar Plain: Deposition of Cone and Inter-cone

The plain of north Bihar between the Himalayas and the Ganga consists of the three-cones of the Gandak, the Kosi and (in part) the composite Mahananda–Tista cone, with the two inter-cones between (Fig. 1). The contours are drawn at 10-foot intervals from either bank of the Ganga upwards to near the foot of the hills, to south and north, and at wider intervals above 250 feet, or less on steepening slopes. These three cones exhibit a typical radial pattern of distributaries. Those of the Kosi have moved westward for the last 150 years, and their floods and deposition of micaceous sands have caused the colossal damage which has earned it the epithet of 'Bihar's sorrow'. The north-south embankment west of the gorge outlet is ancient and is said to have been built by 'giants'; it has been heavily breached. The Kosi is being contained, it is hoped, by the vast dykes, within a tract over five miles in width, and commanded by a weir or barrage; but control by the essential dam, planned to stand four miles above the gorge outlet with a height of 750 feet, has had to be postponed for lack of capital.

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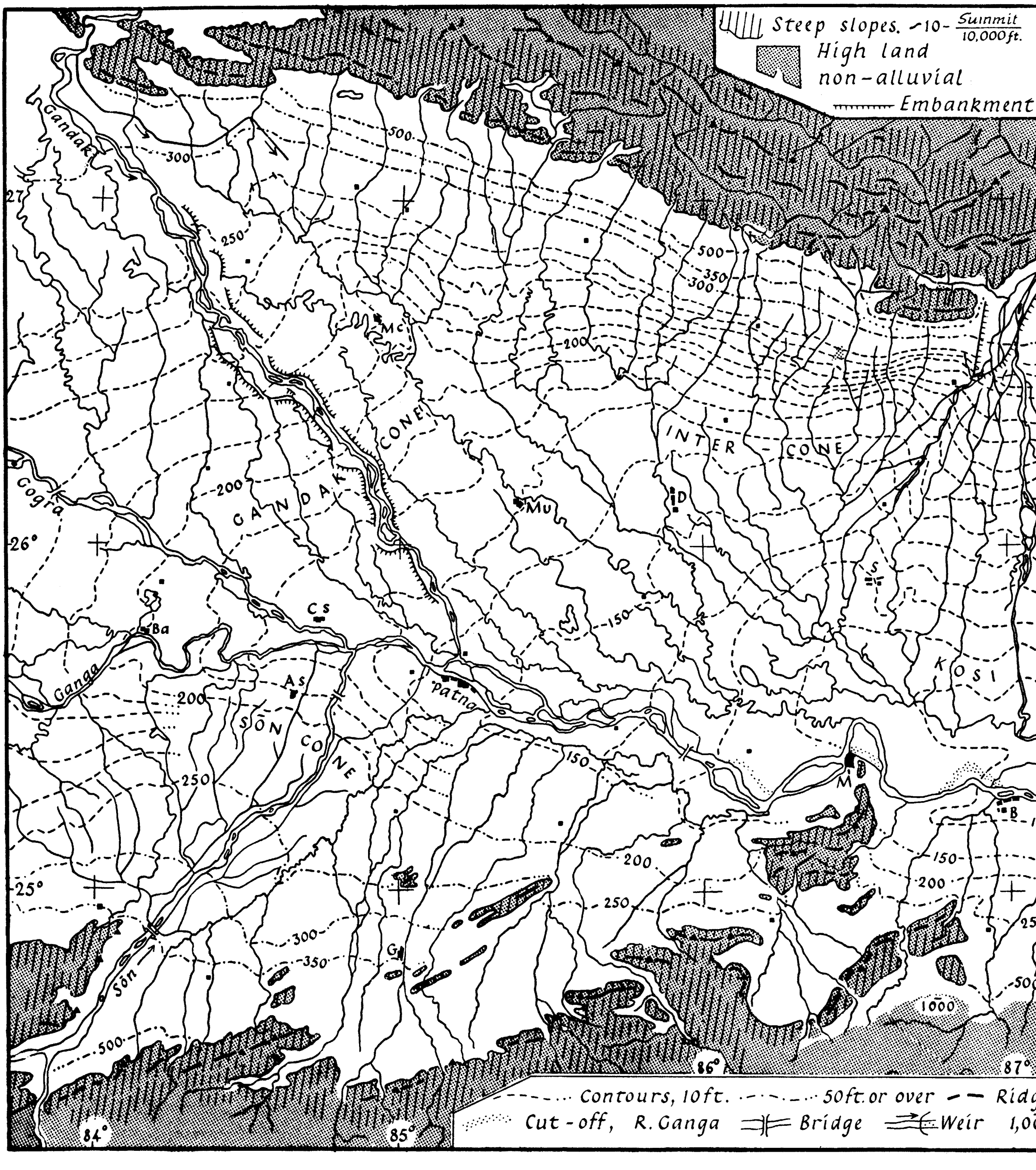

FIGURE 1

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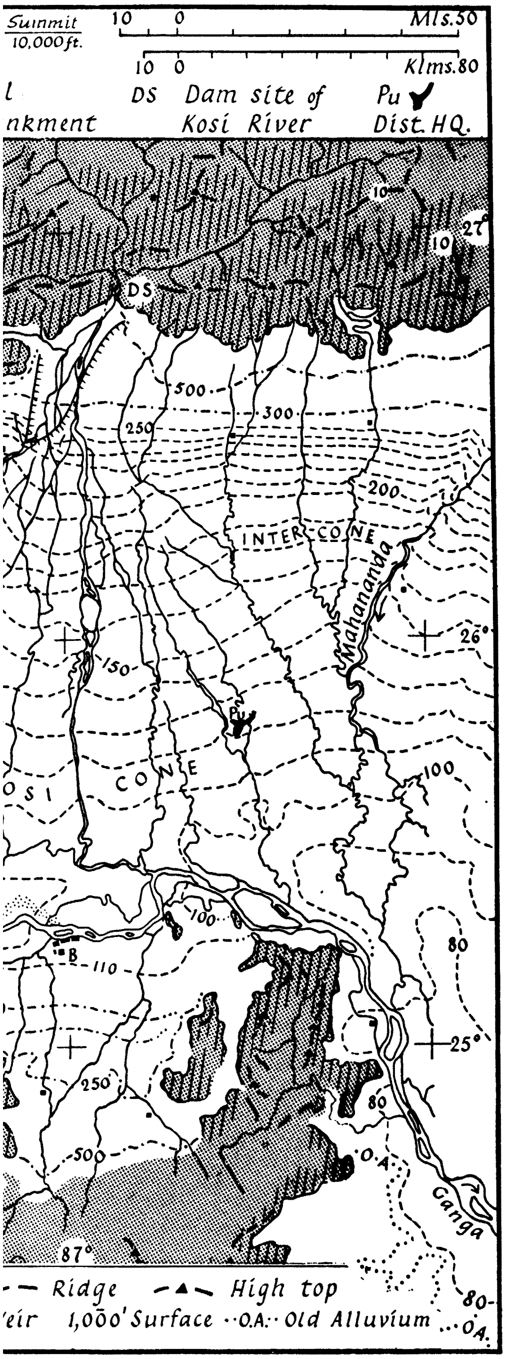

FIGURE 1—The major relief of the plain of Bihar: alluvial cones of the Gandak, Kosi and Mahananda-Tista (part) and of the Sōn emerging from the Plateau. Radial deposition still continues. On the Kosi an ancient dyke, built 'by giants', between the 220- and 350-foot contours. The shift of the Kosi floods from Purnea (Pu) to the extreme west, A.D. 1800-1938 (weir and containing dykes in construction, 1955-59). Projected dam site in gorge (DS). Note the form of the Gandak-Kosi inter-cone with its convergent, minor river pattern, but the absence of a clear cone from Gogra to Chapra, Saran District Cs. Note the Ganga's spill-hollows and the southern rock spurs. Irrigation from Sōn (and Gandak) and now from Kosi. Crop types differ on cone and inter-cone. Few bridges. Contours at 10 feet north of the Ganga up to 250 feet, and south of the Ganga up to 150 feet, drawn from data supplied by courtesy of the Irrigation and Railway services and from the Survey of India topographical maps. The headquarters of Districts are initialled.

As Arrah (Shahabad)
Ba Ballia
B Bhagalpur
Cs Chapra (Saran)
D Darbhanga
G Gaya
Mc Motihari (Champaran)
M Monghyr
Mu Muzaffarpur
Pu Purnea
S Saharsa.

Note on the scale of the figures

The one-degree grid (1° N.-S. = *c.* 69 statute miles) indicates *c.* 65 miles west-east along 25° N., and *c.* 60 miles along 30° N.

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The course of the upper Gandak, though much less unstable, shifted a mile (near contour 350 feet), causing the railway bridge to be dismantled in the 'twenties; and during last century, the river shifted eastward (below the 230-foot contour) from the 'Old' or *Buri* Gandak to the new, contained within embankments. The longitudinal mountain valleys of the two rivers show striking contrasts when seen from the air over Nepal. Whereas the slopes of the westward Gandak valley are terraced for rice and stabilized down to the river's edge, the unstable slopes of the eastward San Kosi valley, on which erosion is hastened by destruction of woodland for occasional broadcast crops, plunge to a high boulder terrace above the wild rushing river.

Along the hollow where the convex flank of a cone meets the even flank of an inter-cone, inter-conal streams are gathered and diverted laterally. The Kosi's pair of flanking drainage courses are perennial, meandering and lightly incised; and on the farther, relatively flood-free bank of one of them, that accessible from Bengal, grew up Purnea (Pu.). West of the Yamuna such flanking drainage courses are seasonably intermittent.

Alluvial factors determining the size of a cone were the discharge and the silt-charge of the river as it emerged from the Himalayas on to the Plain during the phase of deposition. The discharge depended upon the area, precipitation and run-off of its catchment. A standard measurement is in cubic feet per second (cusecs). Where irrigation is concerned, it may be expressed in terms of the area which may be covered through season and year to a given depth, i.e. in acre-feet. This may also be suggestive for visualizing the condition where sheet floods cover vast areas of a cone. The amount of debris brought down to a gorge-mouth depended partly on the cutting power of the river's tributary system, due to the general fall and the irregularity of the profiles, and partly upon the structure and its rate of uplift and change, and on the resistance or weakness of the rocks.

During the Pleistocene Ice Age, or Ages, the lowering of sea-level brought about scouring of narrow channels and headward erosion from their sea mouths, followed by infilling when sea-level rose again. In the Mississippi delta and gulf shores, scouring went down to 400 feet.[17] This process must have affected the deltas of the subcontinent and may also have worked back rapidly in alluvium, to considerable distances. In the mountains the retreat of glaciation must have increased both the discharge of rivers and their charge of morainic boulders, sands and silt, until a sufficient time had elapsed for stabilization. Climatically, changes of temperature may well have been accompanied by changes of precipitation. It may be that the top layer of the cones was spread during the retreat of the ice and that incision followed stabilization. A given discharge can carry a calculable silt charge and no more. Even in a normal season the Kosi's sands may raise a belt of flood plain by a foot. After the Bihar-Nepal earthquake, involving landslides from the foothills, disturbance on the Plain ruined the railway system, and the surveys necessary for re-laying the track north from the Ganga at Monghyr (M.) showed a

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rise on the cone averaging one foot, though the track lay west of the main flood belt.

Minor Relief: Spill Patterns and Incision

The minor relief pattern of each cone is complex, owing to the play first of deposition and later of bed-scour or incision with lateral bank-erosion. The depositional pattern consists of the radiating distributary streams of which now one, now another will dominate in turn so long as deposition may still cause a change of direction, as in the Kosi. From boulders in the gorge to pebbles at the apex, and then sands, the material dropped is finer downstream; and, as a big distributary in extreme flood rushes down its slope, swinging to right and left and swirling its sands, some of the rush spills to one side and, forthwith, as movement checks, the sands drop to build 'spill-banks' or natural levées. Thereafter the spill-water flows with decreasing speed and power, dropping finer and finer loams until it fills a depression or spill-hollow, when only the finest clay is left and is dropped as a fine film (Fig. 2a). Thus, following the trend of a contour round a cone, after crossing the course of a distributary there is traversed in turn (i) its spill-bank of sands, (ii) its slope or spill-slope of loams, and (iii) the spill-hollow of clay, from which there is an almost imperceptible climb upward to the next spill-bank and distributary. Thus in soil texture the cones are of mixed materials ranging from sands through loams to alkaline clays, while the adjacent inter-cones are more uniform and prevailingly of finer texture, of heavier loams

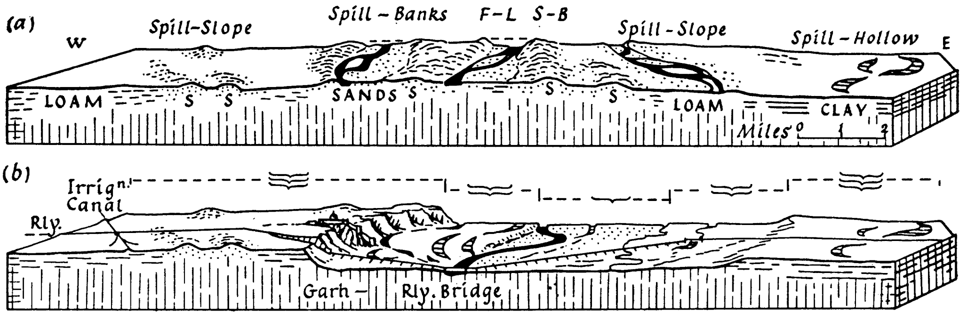

FIGURE 2—Minor relief across the river Ganga, viewed upstream. Phase (a) deposition (restored) and (b) present incised flood plain with terrace, following scour, incision and bank erosion. The railway bridge (28° 46′ N.) is 90 miles below the gorge-exit and canal head-works at Hardwar and 47 miles east by north of Delhi. The river's gradient is *c.* 1½ feet (19 inches) per mile: 1/3,300. Area 20 by 4 miles; vertical exaggeration, 50 times. Altitudes along front section (cf. Fig. 4) are as follows: spill-banks, at old flood-level (F-L), 720-700 feet; loamy spill-slopes, *c.* 695-685 feet and clay spill-hollows, 675-670 feet. The bridge and the 700-foot contour can be located in Figure 4.
Utilization: Railway, with 10-foot cutting on western bank and 7-foot embankment on flood-plain; its V route downstream guides the shifting channel to the bridge. Road: ferry in Rains and bridge of boats in dry season. Fort-Temple town (with market), Garh-Mukhtesar, symbolized. Irrigation commanded from branch canal on higher surface of spill-bank and spill-hollow.

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and of clays. Hence in the Gangetic Plain, the marshy malarial zone of the hill-foot *tarai*, now being reclaimed from jungle, is wider on the inter-cones. It is the spill-hollows which suffer earliest from water-logging after irrigation, inducing alkalinization with its glistening, salty sheets which are death to crops.

A deltaic plain shows a comparable threefold pattern of minor relief. From the Panjnad confluence downstream to the Delta, the spill-waters of the braided Indus are building up its spill-banks and its bed, so raising its flood-level above the level of the land on either side. On the Bengal Delta a similar pattern is seen.

Much as annual changes on the cone of the Kosi leave their trace in new and in abandoned spill patterns, so on the surface of the western cones in which a single course has been incised, the last-formed spill pattern is distinctly seen, together with traces of earlier patterns. Below the surface too, the assortment of lenticular beds of sands, loams and consolidated concretionary clays must embody the successive overlays of old spill patterns. One would expect the substrata of the inter-cones to be less irregular than those of the cones. If this is so, it is fortunate, as the digging of the traditional irrigation wells and the sinking of the modern tube wells are more important in the clayey intercones. Within each climatic zone of the Plain, the main types of seasonal cropping correspond to the major relief, differing on cone and intercone, while on a village scale they correspond to the minor relief, according to the spill pattern and also to incision. Following the dominance of deposition, the second, complementary process of bed-scour with bank-erosion became paramount. The two phases of deposition and incision are sketched in Figures 2A and 2B. The latter figure shows a reach of the Ganga where it is crossed at 650 feet by the parallel of 28° 46′ N., while the former is its restoration, based on studies of neighbouring but unincised distributaries. In principle variations in the charge of sand or silt affect a river's area, slope and velocity, shape of cross-section and width of channel, wetted surface or wetted perimeter. Owing to the seasonal interplay of these and other variables, all the quantitative formulae as yet proposed are imperfect.[18] Hence their choice and application for the control or training of a river must start from observation and be guided by experiments with models. Qualitatively, the effects of charge are small on the area and on the mean velocity, and are great on slope, shape and width. In the Panjab rivers, it is the clear waters of the dry season which visibly scour a river bed, in spite of the fact that their discharge is so small. But it would over-simplify to say that the monsoon floods merely deposit. At their peak they may scour, carrying the river beds along by their swirling, heavily laden discharge, until the peak subsides, the carrying power is lost, and the burden dropped. The difficulty is that these factors can be observed and measured at low water but not in high flood. Bridges suffer heavily from such floods and attacks by their shifting courses. The railway embankment shown proves exceptional foresight in the alignment of its embankment, a downstream V, to guide and concentrate the floods to the bridge point.

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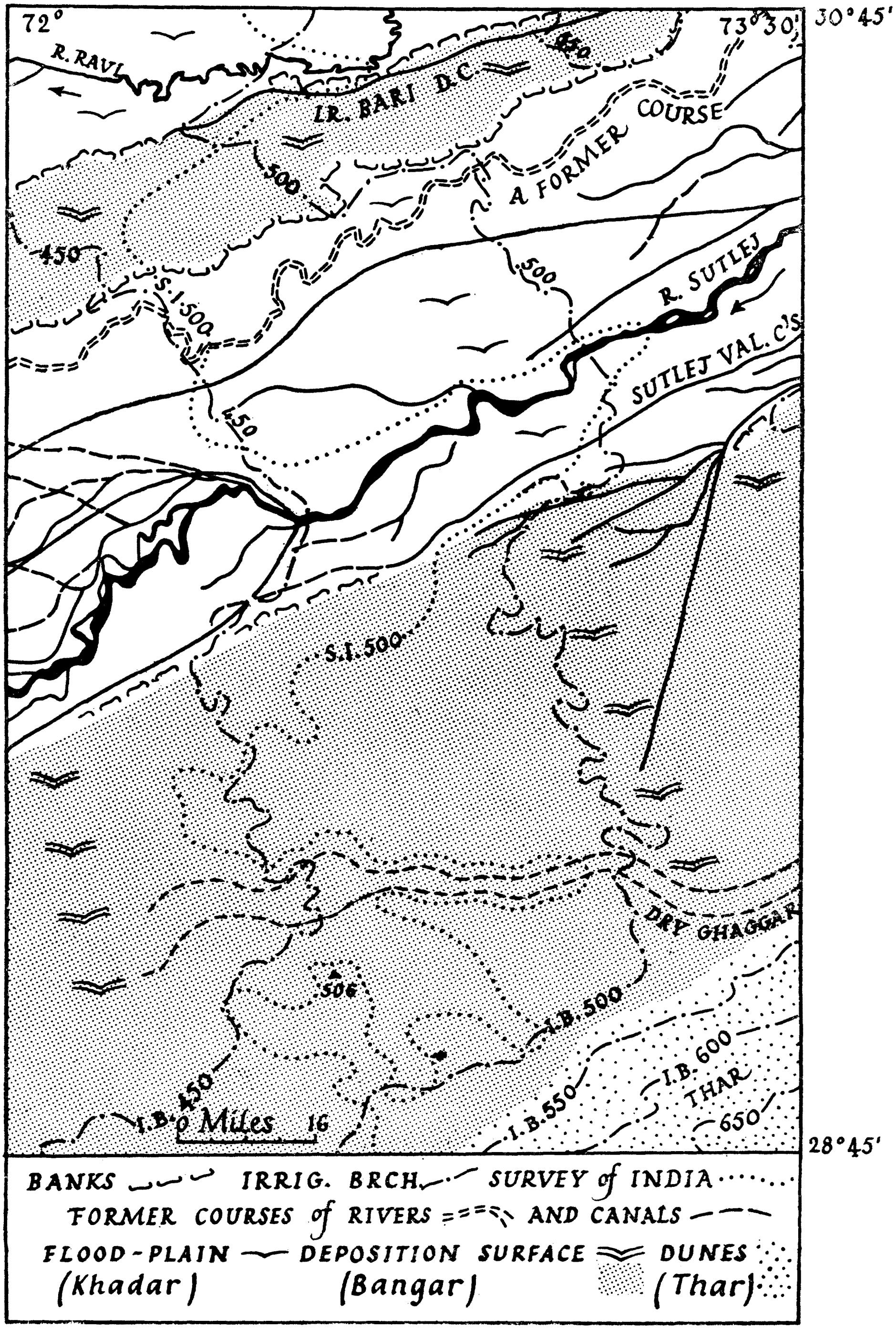

FIGURE 3.

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The Plains of Upper Ganga, Yamuna and Panjab

Whatever the reasons, incision took place during geologically recent times though evidently before late pre-history, as seems shown by the terrace-sites of the proto-historic riverside Indus cities of 5000 years ago. The maps of the Panjab Plains with the upper Yamuna and Ganga show the two resulting surfaces over the whole region (Fig. 3 and 4). The radiating distributaries of the Yamuna once spread towards the Indus system and, judging from the forms, probably some westward floods from the Ganga as well. But once incision had begun on the Yamuna and Ganga, the greater eastern rainfall would tend on each cone to reinforce the headward scour of the shortest and steepest eastward channel (formerly a merely occasional distributary) and so to establish the present water-parting between the Indus and the Ganga systems, i.e. between Sutlej and Yamuna. From Yamuna to Gandak, each incised river course trends eastward of the conal axis. It follows that irrigation restores a westward flow.

On the cones of the Panjab from the Sutlej west to the Jhelum, the slope to Sind was a decisive force in directing incision westward. These cones are four: the Sutlej cone, the composite Beās-Ravi cone, the Chenab cone and the Jhelum cone. The Indus, at its outlet from the Salt Range gorge, had deposited and spread its coarse sand to south and south-south-east, forming a tract of shifting sands, the Thal or Sind Sagar, of which the irrigation was halted by the Second World War but is now well advanced. Thus from Indus to Sutlej, irrigation has to be taken mainly eastward. Partition having delayed the continuation of long-planned projects, the World Bank has assisted in arranging for their resumption and adaptation.

Following scour, lateral erosion ensued along the braided flood courses of the rivers. Partly by a corkscrew or drilling action, the swirling, sandy rush cuts against the submerged and soaking layer of a bank, undermines the whole bank, and causes it to crack along its length, slip, subside and topple into the river. Scour and bank-erosion have established the flood-plains with their terraces which, from the Panjab to the upper Ganga, may measure from 5 to 20 miles in total width and 10 or 20 to 90 feet in total depth (Figs. 3 and 4). In the Panjab the original surface is known as the *bangar* while the terraced flood-plains are known as the *khadar* and along the Yamuna as the Yamuna *tarai.*

Rock Spur and Guide Bank: the Control of Meander and Confluence

The contact of Plain with Plateau along a marginal river is illustrated by the Yamuna, upstream from its confluence with the Ganga (Fig. 5). The relief, based on the topographical map, was completed by observations on land and

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FIGURE 3—The rivers Sutlej and Ravi showing two alluvial surfaces: the incised flood-plain or *khadar* and the surface of former deposition or *bangar* of cone and cone-foot plain (stippled). The edge of the sandy dune-surface of the Thar rises in the south-east, overlooking the dry river Sarasvati-Ghaggar. The contours at 50-foot intervals, completed from large-scale maps of the Irrigation Branch, P.W.D., accord with spot heights and banks (to 25 feet) and gradients of rivers and canals; but the Survey of India 500-foot contour from 1/1,000,000 maps has not accorded until now (cf. Fig. 4).

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river and by additional data, as explained in the appendix, so permitting the drawing of the contours and the interpretation of the hydrodynamics and the resultant forms. The point, or rather area, of confluence is seen to be controlled by the rock spur with 60-foot islet crowned by a temple, and by the cliff, which act as groyne and guide bank to stabilize the Yamuna's major flood meander downstream. The swirling, muddy water of the braided Ganga is thus held within its broad flood-plain. The map shows the banks as they were in 1917; by 1950 the Ganga had swung far to the eastern, left bank, leaving a wide grassy terrace between it and Akbar's Fort; thereafter the Ganga attacked this terrace, and its bank, when visited in 1955, was collapsing hour by hour. Hindu pilgrims are rowed out to witness the meeting of the muddy Ganga with the clear Yamuna, below which the mingled waters of the river course are in constant change. Navigation is difficult up to Allahabad and is halted there. The ancient city is sited not on the Plateau but in the Plain, near the bank of the safer, rock-guided river. Just downstream the Fort was stoutly built, at the very limit of safety. By scrutiny of the reduced 1/1 million maps, something may be guessed of comparable or contrasted river-sited cities, and characteristics of contact between Plain and Plateau may be perceived. Gullying is severe upstream from Allahabad, particularly on the Yamuna's Plateau bank.

The Bengal Plain: Complex Forms and Factors

Following the forms of the Indo-Gangetic valley plain into Bengal one must look there for comparability of conal form and also for the effects of a highly complex structural framework, visible and concealed. In Bengal, the main structural trend of the valley plain, curving west-east parallel to the mountain arc, crossed by a roughly north-south trend, or trends, causing the Garo-Rajmahal Gap; moreover the steep southern scarp of the Garo-Khasi Plateau forms an additional west-east structural axis. On the eastern border of the deltaic plain the low, Tertiary anticlinal ridges plunge northward beneath the alluvium and marsh-lakes overlooked by the scarps of the Garo-Khasi Plateau. The earthquakes of the subcontinent are most severe to north-west and north-east, i.e. near the lateral folds in Quetta and the Sulaiman Range and from Bihar to Assam and east Bengal. Broadly speaking, along the arcuate axis of the valley plain seismic processes do not greatly disturb the simplicity of alluvial forms, but within Bengal's unstable structure it is otherwise. The occurrence of six severe shallow earthquake shocks in the last two centuries in and around this plateau, and the eruption of mud volcanoes off the Bengal-Burma coast, demonstrate the contemporary action of structural on alluvial processes. An epicentre of deeper shocks lies just within the confluence of the Ganga-Padma and the Brahmaputra-Jamuna (24° N.). Within Bengal from the Himalayan foothills to the curving shore-line, alluviation has been at work, increasingly modified seaward by deltaic influence. These processes left their characteristic conal forms, attacked by erosion in greater or lesser degree but also modified and fragmented by complex structural change.

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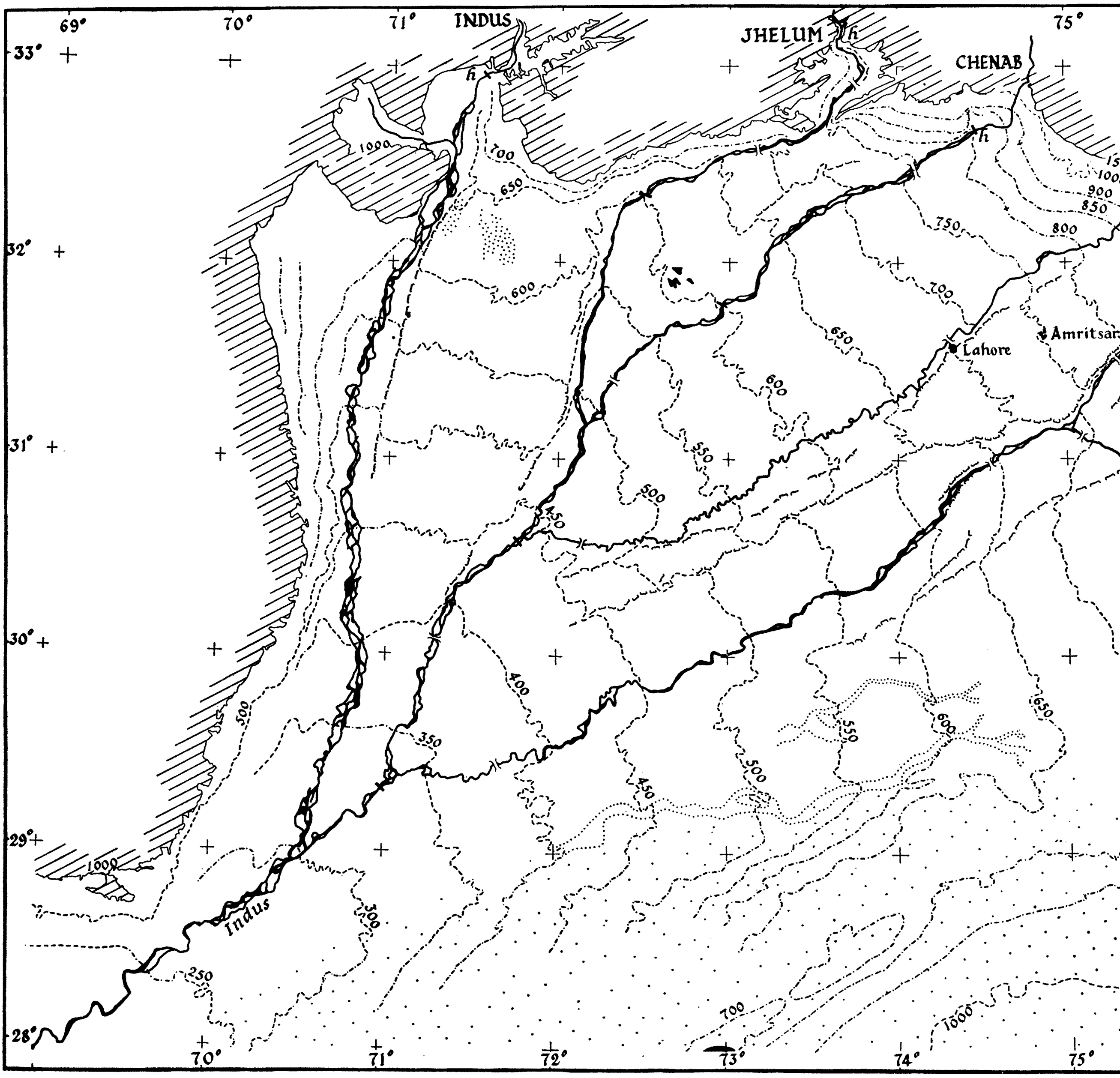

FIGURE 4—The Panjab Plains and Ganga, showing flood-plains (*khadar*) incised in upper surface (*bangar*). The upper is composed of
and Yamuna; the former drainage course of the Yamuna is now the Sarasvati-Ghaggar, seen fro

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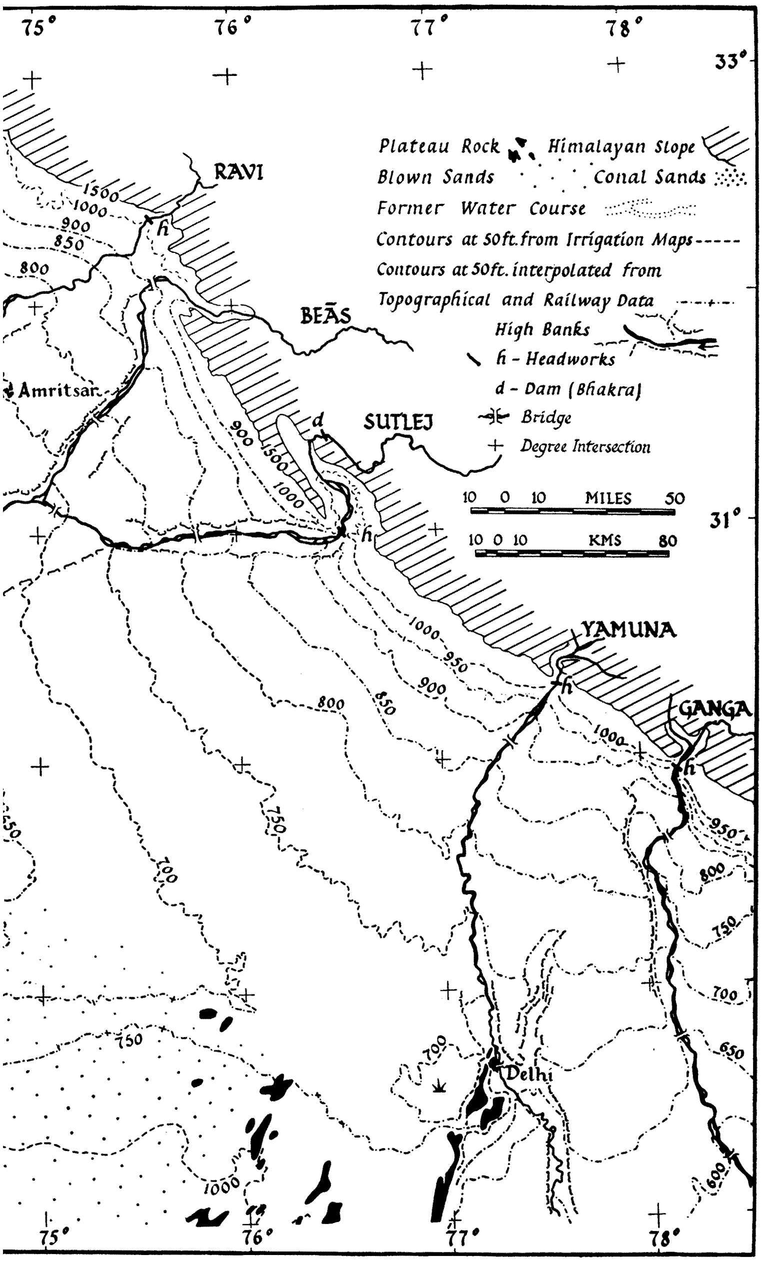

FIGURE 4

posed of the alluvial cones of the Indus, Jhelum, Chenab, Ravi-Beās, Sutlej
, seen from 650 to 400 feet near the Thar.

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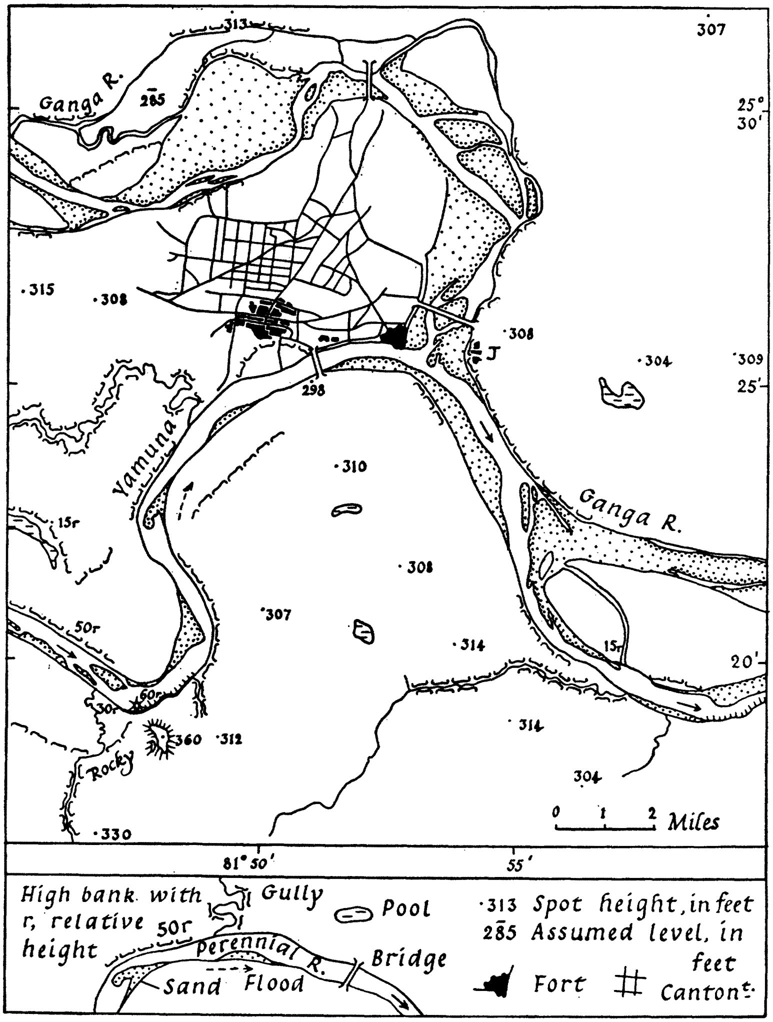

FIGURE 5—The confluence of the Ganga and the Yamuna at Allahabad (ancient Hindu Prayag). Its age is suggested by the remains at Jhusi (J) from the third century B.C. The calm meanders of the Yamuna have little silt and are guided by a rock spur 10 miles upstream from the confluence; in full flood the Yamuna follows the pecked arrow. The silt-laden Ganga swirls, depositing silt and changing its course from year to year and decade to decade. The ancient city and Akbar's Fort at the confluence have withstood change on the Yamuna bank.

Heights are in feet above mean sea-level, with relative heights of banks (e.g. 50r) and of rock islet (60r). Spot heights are from topographical maps and from corrected railway ground levels (MS); where these are lacking, one flat is shown with approximate height, 285 feet. The Old City and Fort are in black; cantonment roads are shown as lines. The three bridges were built upstream from the confluence. Quarry at spur, 360 feet.

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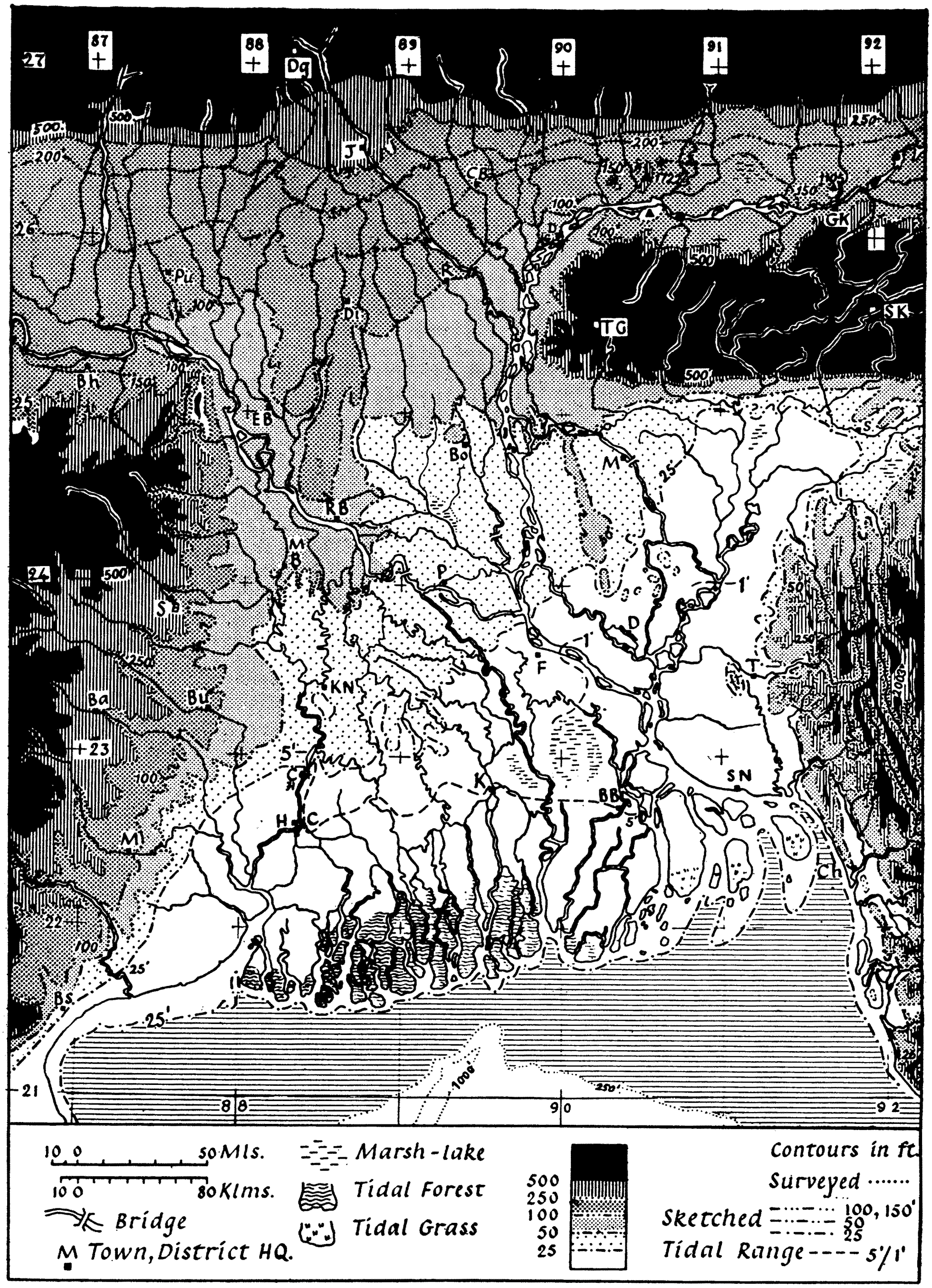

FIGURE 6.

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Before the complex forms of east and north Bengal are examined the Contemporary deltaic cone of the Ganga should be described (Fig. 6). After flowing round the north-east shoulder and spurs of the Indian Plateau and through a 50-mile long meander belt, the Ganga throws off a right bank lateral distributary, the Bhagirathi-Hooghly, due south, while its main stream, the Padma, takes a south-easterly course, with three towns on its banks, Rampur Boalia, Pabna and Faridpur. The apex lies at about 55 feet, and the contours at 50 and 25 feet show the convexity and indicate the main axial spill-bank 'ridge' south-south-east towards Khulna which is now being developed as an estuarine port. Thus the Padma is almost a lateral distributary on the left bank, the extreme lateral course having flowed from Rampur Boalia through Dacca. Within the broadly radiating pattern of distributaries, the complexity of detail is due to changes in course. Deforestation on the Plateau and on the western Old Alluvial uplands, roughly bounded by the 100-foot contour, has tended to block the Bhagirathi-Hooghly while exceptional floods straight down the Damodar past Burdwan have shot over its cone across the Bhagirathi, as shown by the reddened spill-banks of the continuing river (23° N.). While the greater rainfall on the east of the plain has helped to keep the eastern channels open and has minimized the construction of embanked railways and roads and of bridges, on the drier west embanked routes were multiplied for a century past and channels blocked. Hence passage down the Bhagirathi-Hooghly, difficult for boats in Moghul times, became increasingly difficult, while other western distributaries became known to the peasantry as 'dead rivers', and those towards Faridpur have been described as moribund or dying. A tidal range contour of five feet goes from Howrah-Calcutta eastward through Khulna to Barisal though the tidal bore on the Hooghly itself carries it thirty miles upstream beyond Calcutta; up the Padma there is a tidal range of over a foot almost to Faridpur and also up the Meghna-Surma to 24° N. Between the tidal contours lie the chief swamp-lakes of deltaic Bengal (23° N., 90° E.). Seaward lie the tidal forests of the Sundarbans, while in the eastern estuarine gulf the islands are fringed with tall grass. Thus the general surface from Calcutta to Faridpur and even Dacca can chiefly be explained in terms of alluviation, merging into deltaic

FIGURE 6—The Plain of Bengal, inset in the framework of the Himalaya and three other highlands. Contours surveyed for irrigation (e.g. east of 24° N., 88° E.) fit those sketched previously. Note the successive contours required: of tidal range, and of 25, 50, 100 feet and over. Owing to steep slopes of the hills to south-east and along the Bay of Bengal, deeper shading commences from the 25-foot contour northward to 23½° N. at T (Comilla, District Tippera). To the west, the cones of the smooth New Alluvium rise to *c.* 100 feet, the dissected Old Alluvium to *c.* 250 feet, with soils on rock above this. The contour of the deltaic plain (25 feet) shows the characteristic spill-banks above the intervening spill-slopes and spill-hollows, largely flooded by the end of the Rains.

The initials are those of cities and of headquarter towns of Districts, those named in the text being listed below. Where the District name is not that of the headquarters, its initial is added.

C, Calcutta; D, Dacca; Ch, Chittagong;

Bo, Bogra; Bu, Burdwan; B B, Barisal (District Bakergunj); Di, Dinajpur; E B, English Bazaar (Rajmahal and its hills lie due west); F, Faridpur; K, Khulna; M, Mymensingh; P, Pabna; R, Rangpur R B, Rampur Boalia (District Rajshahi); S K, Shillong (Khasi Hills); T G, Tura (Garo Hills).

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formations. To north and east forms are far more complex and the causes harder to disentangle.

If Contemporary and Recent simplicity of substructure is assumed, one would expect, within the structural framework, the formation of a conal deltaic plain fanning out into the Bay of Bengal, with a convex shore-line of which the radial axis might lie from the middle of the Garo-Rajmahal gap towards the mid-Bay, i.e. east of south. The shore-line does, in fact, bend inland to east, at the present mouths of the Meghna. The 25-foot contour runs inland to the local fans of the southern Khasi torrents 200 miles from the sea (25° N.) and encircles the freshwater Surma system, which in the Rains forms one vast inland sea patterned with village archipelagoes. The resistance of a mass of still water to deposition is not enough to explain this hollow along a north-north-east axis from the Meghna mouth. Moreover, the ever-shifting estuarine islands have gained and lost with little if any net advance since the first surveys of 1764-73.[19] From the Meghna mouth (23° N.) to north-north-east, the stream gradient is extraordinarily gentle, being hardly more than 1 inch per mile (0.11 foot per mile). Clearly subsidence must be continuing along this axis nearly to the foot of the Khasi Plateau. Allowing for this curving axis of subsidence in the east of the Bengal basin one would expect an eastward skew of conal forms and in fact this is suggested by the curve of the 25-foot contour rimming the Brahmaputra's south-eastern distributaries which radiate from their apex at the western end of the Garo-Khasi scarp (near 25° N., 90° E.).

From their adjacent Himalayan gorges (88½° E.), the Tista and Mahananda have thrown out a cone to south or south by east. It is marked by the radial direction of north Bengal rivers and by the contours at 250, 200 and 150 feet. The southward slope continues down to about 100 feet (Tista railway bridge near Rangpur town and south of Dinajpur). Most of it is covered by new alluvium. But southward of Dinajpur the land actually rises for the next sixty miles to a surface at about 140 feet, before resuming a gentle slope terminated by a steep slope commanding the western Ganga or Padma (west of Rampur Boalia). This southward upland is marked by the red tinge of its soil and its red eroded subsoil, its Old Alluvium being revealed by denudation south of Dinajpur almost to the Padma near Rampur Boalia and west to east from English Bazar (25° N., 88° E.) to Bogra. It forms the Barind of which the higher, western portion slopes south-eastward, the lower eastern portion rather to south-west, towards a marsh-lake hollow (40 miles east of Rampur Boalia). These convergent slopes suggest that the southern spur of the western Barind shows traces of the apical portion of a former Gangetic cone radiating from the salient of the Indian Plateau (where the present river bends from east to south), while the eastern Barind represents the western fringe of a former Brahmaputra cone, skewed through 90° from south-west to south-east. Thus the remaining south-east portion of the former Brahmaputra cone would in that case be found in the belt of upland above the 50-foot contour, called the Madhupur Jungle, which extends southward from the point (or small area) whence the present Brahma-

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putra now distributes most of its waters due south by the Jamuna to join the Padma, partly south-east by Mymensingh. This, the Old Brahmaputra, was the main recorded channel prior to the change which occurred between *c.* 1785 and 1820.

Turning now to structure, one would have hoped that thorough geological surveys of the Plain and its framework would have shown whether its substructure and surface are undergoing such movement as to endanger possible irrigation works, as suggested by F. C. Hirst in 1916,[20] or whether the surface forms are simply due to 'normal' processes of alluvial formation and erosion, as presumed by H. H. Hayden and E. H. Pascoe in 1919.[21] Yet neither before the Second World War and its famine, nor since Independence has an adequate survey been undertaken, the chief geological research having been associated with the search for oil[22], not with the fundamental conditions for agriculture, cash crops and food supply.

It was left to a 'reconnaissance' by two visitors from the University of Louisiana, J. P. Morgan and W. G. McIntire, to throw fresh light on the Quaternary geology of the Bengal Basin.[23] Briefly, they have shown that 'structural activity, primarily faulting' has been of significant influence upon the Old Alluvium of Tertiary and Quaternary date. Block faulting and echelon faulting with structural uplift of Old Alluvial uplands have continued into the Recent epoch. A series of echelon faults on the western edge of the Madhupur Jungle, together with evidence of some structural control of stream courses, suggest the presence of a subsiding structural trough or major fault at depth. This would lie along an axis north-north-west from the eastern delta up the course of the Jamuna to the undivided Brahmaputra, roughly the axis Barisal–Faridpur–Rangpur. The forces at work may be those of compression and shear, or of torsion, or of both together.

While comparatively little attention has been paid by Morgan and McIntire to alluvial processes which, as suggested above, should not be ignored, their field observations, use of aerial survey and inductions constitute a real advance, which they are following up by coastal deltaic studies. Whether for reasons of 'pure science' or for the needs of seventy or eighty million people, fuller study, from whatever agency, is long overdue in Bengal.

Summary

The significance of Asian alluvial plains to world civilization from protohistoric times is recalled and their potentiality at the present suggested, whence the importance of mapping and interpreting their landforms, soils and hydrodynamics. For the Indian subcontinent, evidence on the structural relationship of the Indian Plateau to the Himalayas is reviewed. The earlier (1919) hypothesis of Pascoe of a mountain-foot river is contrasted with his mature views (1950). The importance of thrust sheets in causing massive erosion, in interrupting and changing the lower courses of Himalayan rivers, and so contributing to the

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pebble beds of the Outer Himalayas and the pebbly hill-foot *Bhabar* is remarked, and the plainward lie of the pebbles is noticed. Comparisons are briefly made with plains in other continents which slope from a mountain-foot to the edge of a plateau. Rock spurs of the Plateau, by controlling a major flood-meander downstream, stabilize the position of confluences and the sites of cities, for example, Allahabad.

The major relief of the plains is mapped, and is described as composed of cones of varied soils alternating with inter-cones, which may coalesce into cone-foot plains in contact with the Plateau. The Plain, subdivided by a shifting water-parting zone, terminates at opposite ends in two fanning conal deltas. The minor relief of the cones is composed of spill-bank (levée), spill-slope and spill-hollow, deposited by distributaries radiating from the major Himalayan gorges. The subsequent incision along one distributary course is noted, leaving the original surface ('upland' or *bangar*) from 10 to 50 feet or more above the flood plains (*khadar*, or Yamuna *tarai*) with terraces. Gullying is most severe near the gorges and along the Yamuna's Plateau banks. Irrigation of the cones from their apex renews the earlier distribution of waters. The eastward trend of incision on the system of the Ganges or Ganga leads to irrigation westward over its cones; the westward incision of the Indus system to Sind involves irrigation eastward. The complex forms of Bengal are outlined. Form and process are illustrated by re-contoured manuscript maps of three regions reduced from 1/1 million scale, by a pair of block diagrams (of deposition and erosion), and by topographical maps. Appendix A explains the cartography employed in re-mapping the surfaces.

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Acknowledgment is also made to the Survey of India for permission to use their maps.

NOTES

[1] Names follow the *National Atlas of India:* Ganga for Ganges; Yamuna for Jumna; Banaras for Benares.

[2] Reference may be made to J. BARTHOLOMEW, *Map of India, Pakistan and Ceylon* (1/4 million) (1960), with contours for the Plain redrawn from the writer's manuscript maps; *The Times Atlas*, volume ii (1960), with contours redrawn for the Ganga plain and inset city plans redrawn for physical features; and W. D. WEST, map of the *Geology of India* [and Pakistan] (*c.* 1/6 million) (Calcutta, 1949). It is understood that the forthcoming edition of the *National Atlas of India* is using the writer's maps, exemplified here.

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[3] D. N. Wadia, *Geology of India* (2nd ed., 1939), 314, 184.

[4] E. H. Pascoe (ed.), and others, *A manual of the geology of India and Burma* (3rd ed., 1950), 7.

[5] A. du Toit, *Our wandering continents* (1937), 183.

[6] B. H. Wilsdon, 'A gravitational survey of the sub-alluvium of the Jhelum-Chenab-Ravi doabs, and its application to problems of water-logging', *Punjab Irrigation Research Institute, Research Publication*, 6 (1934), no. 1, 1-6.

[7] J. B. Auden, 'The age of the Garo-Rajmahal Gap', *Proceedings of the National Institute of Sciences of India*, 15 (1949), 315-40.

[8] L. D. Stamp, 'The Irrawaddy river', *Geographical Journal*, 95 (1940), 329-56.

[9] W. D. West, 'The structure of the Shali "window" near Simla', *Records of the Geological Survey of India*, 74 (1939), 133-63.

[10] A. Heim, 'The Himalayan Border compared with the Alps', *Records of the Geological Survey of India*, 72 (1938), 413-21.

[11] J. B. Auden, 'The structure of Himalaya in Garhwal', *Records of the Geological Survey of India*, 71 (1937), 407-33; 'Traverses in the Himalaya', *Records of the Geological Survey of India*, 69-70 (1935-36), 146.

[12] E. H. Pascoe, 'The early history of the Indus, Ganges and Brahmaputra', *Quarterly Journal of the Geological Society*, 75 (1919), 138-55.

[13] G. E. Pilgrim, 'The Siwalik River', *Journal of the Asiatic Society of Bengal*, 15 (new series, 1919), 81-99.

[14] See, for example, the following for discussions of the Indobrahm or Siwalik river:
L. D. Stamp, *Asia: a regional and economic geography* (rev. ed., 1957), 196-7;
O. H. K. Spate, *India and Pakistan: a general and regional geography* (2nd ed., 1957), 28-33.
M. S. Krishnan, *Geology of India* (2nd ed., 1956), Madras, 502-13.
Wadia, op. cit. (1939), 40-2.

[15] M. S. Krishnan and N. K. N. Aiyengar, 'Did the Indobrahm or Siwalik river exist?' *Records of the Geological Survey of India*, 75 (1940), no. 4.
J. B. Auden, op. cit. (1949), 329-32.

[16] B. Prashad, 'The Indobrahm or Siwalik river', *Records of the Geological Survey of India*, 74 (1939), 555-61.

[17] R. J. Russell, 'Quaternary history of Louisiana', *Bulletin of the Geological Society of America*, 51 (1940), 1199-1234.

[18] India, Central Board of Irrigation and Power, V. D. Joglekar, *Manual of river control and training* (1956), 14.

[19] J. J. Rennell, *An account of the Ganges and Burrampooter rivers*, Appendix to Memoir on map of Hindoostan or the Mogul Empire (1793), 336-64.

[20] F. C. Hirst, *Report on the Nadia rivers, 1915* (1916).

[21] H. H. Hayden and E. H. Pascoe, *Report on the Hooghly river and its headwaters*, vol. i (1919), Appendix 1, 17-21.

[22] P. Evans and W. Crompton, 'Geological factors in gravity interpretation; illustrated by evidence from India and Burma', *Quarterly Journal of the Geological Society*, 102 (1946), 211-49.

[23] J. P. Morgan and W. G. McIntire, 'Quaternary geology of the Bengal Basin, East Pakistan and India', *Bulletin of the Geological Society of America*, 70 (1959), 319-42.

APPENDIX A

The Cartography of Surfaces and Surface Water

To exemplify the two main surfaces in the Panjab Plain, the incised, river-swept *khadar* and the arid *bangar*, and also to demonstrate the necessity for accurate mapping, a tract is selected extending for 140 miles from the edge of the sandy Thar in the south-south-east north-westward across the lower Sutlej and Ravi rivers (Fig. 3). Three contours, at 450, 500 and 550 feet, reveal the flood plains of the Ravi and of the Beās-Sutlej — together with 'a former course' — and the intervening upland surface with banks 20 feet high, trimmed by lateral erosion, i.e. the *doab* of the Beās-Ravi or Bari Doab with its Lower Canal. This upper surface is resumed to the south as a terrace extending for a width of 30 miles to the Thar foot. The two levels of canal can be recognized, irrigating *khadar* and *bangar*.

Upon this map, based on contours reduced from those of the Irrigation Branch with short additions for completeness, is also traced a 500-foot contour from a Survey of India 1/1 million map of

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1920, now being corrected, which cuts the Irrigation Branch 500- and 450-foot contours at various angles. Thus errors ranged up to 50 miles in distance and exceeded 55 feet vertically. Now the canals are correctly placed on Survey of India atlas maps, and the shifting courses of the rivers accord as well as can be, allowing for different years of survey; they are drawn for printing in blue. Each plate was liable to be drawn by different draughtsmen, without appreciation of alluvial topography. Banks, shown with 'relative heights' on the topographical maps prepared by field parties, may also be printed, in black. Lastly, the contours, in brown, were interpolated usually without reference to the banks, mainly from a few high triangulation points, correct to a fraction of an inch. Unfortunately, in the plains such points, of necessity chosen for visibility, stand well above the level of trees and village knolls. These points may be high ruined forts, ancient, abandoned sites of towns, or railway stations on embankments of unspecified height; failing these, towers have been constructed. Spot heights are sited sporadically, regular alignments across country being the exception. Only very rarely are contours drawn on a one-inch topographical map of the plains; when they have been, the author's own contours have accorded with them. To draw a contour map of mainly continuous surfaces, with a marginal error of no more than 3 to 5 miles, one must compile all available data and guide the eye by a study of simple patterns of deposition and erosion.

On the *Carte Internationale* (1/1 million) the range of error tends to be magnified and may reach 70 miles downstream. Significant features may be obliterated by errors. For instance a rounded cauldron or plunge-pool characterizes the incised flood plains of the Ganga and Yamuna where they emerge from the hill gorges (Fig. 4). On the *U.S. World Air Chart* (1/1 million, 1945, American Aeronautical Chart and Information Service), this incision is suggested for the Ganga by the 1000-foot contour, but the contour is reversed for the Yamuna and bends downstream, as if no flood plain had been incised.

It may be asked how such a wide margin of error has arisen for the most accessible area in the subcontinent which, where not already densely populated, is irrigable and of greatest potentiality. There is no doubt of the Survey of India's accuracy in triangulation and the value of its topographical maps, which covered vast areas of every kind of country at minimum cost. Maps were on scales termed topographical or 'tactical' and atlas or 'strategic'. For strategy in the plains, contours seemed of little account in view of the political obsession of danger from over the mountainous north-west. Actually, when invasion from the south-east threatened Bengal, the defence of the delta required maps showing the nature and extent of inundation and of flood-free spill-banks, and the character of rivers.

On the other hand for the civil engineers of the Irrigation Branches to plan their canals, distributaries and channels, contours were required at from 5- to 1-foot intervals, with relative but not geodetic accuracy. The Survey of India corrected triangulation and later surveyed areas such as the Indus cone for the Thal Project. Similarly, railway engineers had to align actual ground levels for efficiency of transport and safety from floods, but with economy. When utilizing ground levels at every 2 miles over a long-distance railway such as the historic line from Howrah (Calcutta) to Delhi with a cumulative error of 1/90,000, corrections were made from spot heights for the maps here, as along the southern margin in Figure 5.

The renewed emphasis on social and economic development in the subcontinent demands new surveys. Since Partition divided the Plain both in Bengal and in the Panjab, official cartographers may hesitate for administrative reasons to give detail beyond the new 'national' boundaries; hence other geographers must make all the more effort to do so. In nature undivided, these regions form environmental wholes, and correct mapping involves critical compilation of the accessible data, illuminated by appreciation of morphological process and form.

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