Results of Geologic and Ground-Water Investigations in the Punjab Plain, W. Pakistan

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SYNOPSIS

The Punjab Plain, comprising the Thal, Rechna, Chaj and Bari doabs and adjacent narrow strips of land on the right bank of the Indus and the left bank of the Sutlej, is underlain almost everywhere by 1,000 feet or more of unconsolidated alluvium consisting predominantly of medium- to fine-grained sand, silt, and clay. In spite of its heterogenous composition, the alluvial complex forms a unified, highly permeable aquifer in which water is generally unconfined.

In the natural environment that existed prior to the inception of canal irrigation, the ground-water system was in a state of dynamic equilibrium in which total ground-water recharge was balanced by total discharge; there was no long-term trend toward a major change in the position of the water table. With the exception of the upper parts of the Rechna, Chaj, and Bari doabs, where precipitation was a significant source of recharge, leakage from the rivers was the principal source of ground-water replenishment in the area. The general direction of ground-water movement was downstream from the rivers, toward the central axes of the doabs.

Inception of perennial canal irrigation disturbed this equilibrium and introduced additional factors of recharge which brought ground-water levels in most places to within a few feet of the land surface. In the Rechna and Chaj doabs a new equilibrium has set in. But in Thal and Bari, the water table is still rising and has not yet been stabilized.

The entire Punjab Plain is believed to be underlain by saline water at variable depths. The distribution of fresh and saline water is controlled largely by the nearness of the water to the sources of fresh-water recharge; that is, virtually everywhere close to the rivers and in the upper part of the

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Rechna, Chaj, and Bari doabs, where recharge from precipitation is greater, the ground water is of acceptable quality, the concentration of total dissolved solids being generally less than 1,000 ppm (parts per million). In the lower part of the doabs, away from the sources of recharge, except for local thin zones of water of good quality, the ground water is highly mineralised. The poor quality of water in these sectors of the doabs is believed to be due to stagnation, under the prevailing low hydraulic gradients, and not to any local source of saline water.

The alluvium underneath about 21 million acres contains water of acceptable quality (less than 1,000 ppm of total dissolved solids) to a depth of about 450 feet. Assuming an effective porosity of the alluvial sediments of 20 percent, about 2 billion acre feet of ground water of acceptable quality is available in the Punjab Plain. Considering the calculated potential recharge rate of 1.0 foot per year to the acquifer under present canal diversions, the tubewell reclamation schemes will certainly serve the development purpose of providing supplemental supplies of water and subsurface drainage. This view has been fully endorsed in principle by the U. S. President's Science Advisory Committee.

If our ground-water resources, which hitherto have largely remained untapped, are scientifically developed and properly managed, they will prove a better and more reliable source of water supplies for irrigation than surface-water reservoirs.

A long-term research program, in all phases of ground-water development, is essential for the best use of our ground-water resources in the Punjab Plain. Surface-water played the major role in providing water for irrigation in the past. Now let the ground-water share the burden.

The area considered in this paper is that part of the northwestern Indo-Gangetic Plain which is popularly called the Punjab Plain. It includes the Thal, Chaj, Rechna, and Bari doabs and narrow strips of land on the right bank of the Indus and left bank of the Sutlej rivers, comprising about 30 million acres (fig. 1).

In 1954 a comprehensive program of ground-water investigations in the Punjab Plain was initiated under a cooperative agreement between the United States International Cooperation Administration and the Government of Pakistan. The purpose of the project was the formulation of a reclamation and development program aimed at combating water-logging and salinity. This paper, summarizing geohydrologic conditions in the Punjab, is based on data collected during the investigation and their interpretation, as contained in two reports, issued by WASID (Water and Soils Investigation Division), one on the geology (Kidwai, 1962) and one on the regional hydrology (Greenman, Swarzenski and Bennett, 1963).

GEOLOGY

General Geology

The Punjab Plain is a part of the Indo-Gangetic Plain, which forms one of the most prominent and extensive physiographic divisions of the Indian subcontinent. Geologic evidence suggests that the Indo-Gangetic Plain lies in a great tectonic trough which came into existence in mid-Tertiary time. However, the present boundaries of the trough were formed during the post-Siwalik period. Since that time (late Pleistocene) the mighty Indus and its present and ancestral tributaries have deposited vast quantities of sand, silt, clay, and gravel in the subsiding trough. A variety of erosional and depositional processes, associated with the constantly shifting courses of the rivers, has given rise to the formation of an alluvial complex which is essentially heterogeneous in character.

The alluvial complex of Quarternary age has been deposited on a basement of metamorphic and igneous rocks of Precambrian age in parts of the Rechna, Chaj and Bari doabs, in the area of the so-called buried ridge. Elsewhere, the alluvium presumably overlies Tertiary or older sedimentary rocks. Test holes drilled to a maximum depth of more than 1,500 feet to the northeast and southwest of the buried ridge area have penetrated only alluvium. Therefore, the total thickness of the alluvium and the nature of the underlying bedrock in most of the Punjab Plain remain unknown.

Ground-water investigations were concentrated mainly in the alluvial complex which forms the reservoir for our ground-water resources. However, the possible influence of the buried ridge on the movement of ground-water was not left unexplored.

Alluvial complex and its water-bearing characteristics

The alluvial complex consists of predominantly fine- to medium-grained sand, silt, and clay. In many areas, kankar, impure calcium carbonate concretions of secondary origin, are found in association with fine-grained sediments. Gravel or very coarse sand is uncommon, except in parts of Thal Doab. Thick clay horizons within the alluvium are comparatively rare. With the exception of local clay bodies, which are a few feet thick, the finer portion of the alluvium consists generally of sandy or silty clay.

The study of cross sections and panel diagrams constructed on the basis of the lithology of the alluvium, as inferred from the examination of the well samples and electric logs, showed the random distribution of the clay zones within the alluvium and the heterogeneous character of the uppermost 600 feet of the alluvium in downstream and transverse directions. Individual strata have little lateral or vertical continuity. Local concentrations of fine-grained material are found in the upper parts of all the doabs and in the vicinity of the buried ridge.

Local and regional variations in the water-bearing characteristics of the alluvium, as revealed by pumping tests, are in general agreement with observed lithologic changes, up to the explored depth of about 600 feet. The alluvial complex, in its heterogeneity, forms a unified whole in which particular bodies of relatively fine-grained material apparently are distributed at random. Present knowledge does not permit the subdivision of the alluvium into different geologic units. It must be borne in mind that no particular lithology is typically associated with any physiographic subdivision of the area and that the relatively older alluvial deposits of the bar upland are similar to the alluvium of present and abandoned flood plains.

The alluvial deposits of the Punjab Plains form an extensive, highly permeable aquifer in which ground-water is generally unconfined. Coefficients of transmissibility of 0.5 to 1.0 cusecs per foot (cubic feet per second per foot) are common in the more permeable zones of the alluvium, particularly in its upper-most 300 feet. Pumping tests conducted in areas having local concentrations of fine-grained deposits yielded correspondingly lower coefficients of transmissibility, on the order of 0.2 cusecs per foot, or less.

Coefficients of storage commonly range from 1×10^{-2} to 1×10^{-1}. Lower storage coefficients determined in some pumping tests suggest semi-artisian conditions, because of the presence of layers of comparatively less permeable clays and silts within the aquifer.

PRECAMBRIAN ROCKS—BURIED RIDGE

The oldest rocks exposed in the area are represented by a group of metamorphic and igneous rocks of Precambrian age. This group of rocks is exposed at Kirana, Chiniot, Sangla and Shah Kot (fig. 2). The total area of the outcrops is negligible when compared with the vastness of the surrounding alluvial plains. The bedrock hills are projections of a ridge that tends northwesterly and is largely buried by the alluvium. For practical purposes, the Precambrian rocks are impermeable and define the lower limit of the alluvial aquifer.

The position of the Precambrian basement rocks and some of the irregularities in the relief of the bedrock ridge were revealed by a large number of test holes in Chaj, Rechna and Bari doabs. As shown in figure 2, the buried ridge extends from the southwestern part of Chaj Doab across the central part of Rechna Doab. The buried ridge extends southeastward, beyond the River, into Bari Doab, where weathered bedrock was penetrated at a depth of about 1,000 feet near Niaz Beg. The known northern limit of the ridge is found in some outcrops near Charnali, approximately 5 miles south of Sargodha, The width and extent of the buried ridge are defined by the contours shown in figure 2. There are indications that slopes toward the northeast are somewhat steeper than those to the southwest. Test drilling has revealed that at many places between the outcrops of Shah Kot, Sangla, and Chiniot, Wedrock valleys extend to a depth of 500 to 600 feet below land surface. Some of these valleys are narrow gorges, being bordered by outcrops that are less than one mile apart. The relief features of the buried ridge are illustrated by figure 3, a geologic section drawn parallel to the trend of the ridge.

HYDROLOGY

Prior to the inception of perennial canal irrigation the major factor of ground-water recharge in the region was the infiltration of water from the rivers. This was augmented in the upper reaches of the doabs by the infiltration of precipitation which locally exceeds 30 inches per year. In most of Thal and the central and lower parts of the other doabs where average precipitation ranges from about 5 to 12 inches, the infiltration of rain water to the water table was probably negligible. River water was, therefore, the principal source of ground-water replenishment in these areas. The general direction of ground-water movement was from the rivers downstream and toward the central axes of the doabs. In approximately the upper halves of the doabs the hydraulic gradient was steeper than the topographic slope; the water table reached depths of more than 100 feet below the land surface near the centre of Rechna Doab, and more than 70 feet near the centre of the Chaj and Bari doabs. In the lower halves of the doabs the hydraulic gradient was less than the topographic slope and the depth to water diminished downstream until the water table merged with the rivers at the lower ends of the doabs.

In the pre-irrigation environment, the ground-water system of the Punjab was in a state of dynamic equilibrium; that is, over a long period of time recharge to the ground-water reservoir balanced discharge; there was no long-term trend of a rising or declining water table. The advent of perennial canal irrigation disturbed this equilibrium and introduced additional factors of recharge which resulted in a rise of the water table. In the Rechna and Chaj doabs a new equilibrium has been established, but in the Thal and Bari doabs the water table is still rising and has not yet reached a stable position. The rise of the water table, resulting from canal leakage, has caused a reversal in the direction of ground-water flow, which is now from the centres of the doabs toward the rivers in many parts of the area.

QUALITY OF WATER

The evaluation of the quality of the native (pre-irrigation) ground-water, depicted by isogram lines in figure 4, is based on about 2,600 chemical analyses of water samples from 800 test holes. Water samples were collected from all major bearing beds penetrated by bore holes up to a depth of about 450 feet. For the interpretation of the quality of the native ground-water, data for samples from depths of less than 100 feet were generally ignored because of possible contamination by water from shallow sources which is not native to the aquifer but was derived from leakage from the irrigation system.

On a regional basis, the mineralization of the ground-water is largely the result of the pattern of circulation that existed in the pre-irrigation environment (fig. 4). Under that system, ground-water moved from the rivers and from upstream areas, where, precipitation was a factor of recharge, downstream into areas of progressively diminishing precipitation towards the southern parts of the doabs where stagnation and discharge through evapotranspiration were the dominant factors in the ground-water regimen. With increasing distance from areas of recharge and active circulation, ground-water in transient storage became progressively more mineralized (fig. 4). The distribution of fresh and saline ground-water zones is apparent from figure 4. Water of good quality is confined generally to the upper part of the doabs and to areas adjacent to the rivers. At depth the entire area of the Punjab is believed to be underlain by saline ground-water. The maximum thickness of any fresh-water zone, locally exceeding 1,000 feet, is found nearest to the main sources of recharge: along the river courses and in areas of relatively high precipitation.

PRINCIPAL RESULTS OF THE INVESTIGATION

Summing up the foregoing discussion, we find that the entire area of the former Punjab Province is underlain by 1,000 feet or more of unconsolidated alluvium which is saturated in most places to within a few feet of the land surface. Most of the area, totalling about 30 million acres, is underlain by highly permeable strata and large-capacity wells yielding 4 cusecs (cubic feet per second) or more can be developed at virtually any site. The alluvium beneath about 21 million acres contains water of acceptable quality to a depth of about 450 feet. Assuming an effective porosity for the sediments of 20 percent, about 2 billion acre-feet of water of good quality is in storage. The average concentration of dissolved solids in this water is less than 1,000 dpm. Moreover, water containing higher concentrations of salt can be used for irrigation, provided it is diluted with canal water.

Potential recharge to the aquifer, including the infiltration of river water and precipitation, has been estimated to be about 1.0 foot per year; in the calculations it has been assumed that total canal diversions will be continued at the present rate (45 million acre-feet per year, 1950-59) and that water levels will be lowered sufficiently by the tubewells to prevent evapotranspirative waste. At the calculated recharge rate of 1.0 foot, about 30 million acre-feet would be added annually to the ground-water reservoir.

IMPLICATION OF THE TUBEWELL PROGRAM

The principal results of the investigation from the basis for designing a reclamation and water-supply development project using tubewells. Basically, the plan is to develop additional water supplies from ground water; it has been proposed that the program covers about 25 million acres which would entail construction of 30,000 to 40,000 tubewells of 2 to 5 cusecs capacity. The conclusions of WASID have been fully endorsed in principle by the U. S. President Science Advisory Committee. Obviously the tubewell program will serve the dual purpose of providing supplemental water for irrigation and subsurface drainage.

As estimated earlier, about 2 billion acre-feet of usable ground water is in storage beneath the Punjab Plains. It is equal to many times the yearly surface-water discharge from the entire Indus Basin and is probably more than the combined yield of Mangla and Tarbela Dams over a period of 100 years. There are many advantages to the use of the vast storage capacity of the ground-water reservoir for the optimum management of the available water supplies of the region. There is no limit to the life of the ground-water reservoir. In contrast the storage capacities of actual or potential surface reservoirs are relatively small and the life span of these is further limited by siltation. For long-term management of available water supplies, it will be necessary to develop new storage facilities, and it might become economically feasible to divert a considerable part of the rivers' high-water flow into ground-water storage. The acquifer is favourably situated with respect to both availability of recharge and to areas of use of the water.

While the ground-water resources of the Punjab appear to be adequate to meet the regional requirements for supplemental irrigation supplies, the relations between the availability of ground water and the need for supplemental supplies throughout Punjab is not entirely favourable. For example, the ground-water potential for irrigation use generally diminishes from north to south. On the other hand the demand for irrigation supplies tends to increase toward the south which is more arid than in the north. It is evident that a program of maximum exploitation of the ground-water resources must be based on regional hydrologic factors rather than on local demand factors.

Despite the feasibility and inherent advantages of reclamation by pumping from tubewells, caution, is necessary with regard to the distribution of withdrawals and maintenance of a favourable salt balance. In the tubewell reclamation program, yield will not be as much a problem as the quality of water. Pumpage will bring changes in the hydrologic environment that in turn will influence the quality of water in the aquifer. Several factors will tend to deteriorate the quality of ground water with time. The effects of these factors will be counterbalanced somewhat by additional components of recharge. Considering the quantity of ground-water in storage in relation to the annual rate of recharge under the development regime, it is believed that the rate of change in quality will be slow and that within the economic life of 40 to 50 years of the present program no serious problems will arise.

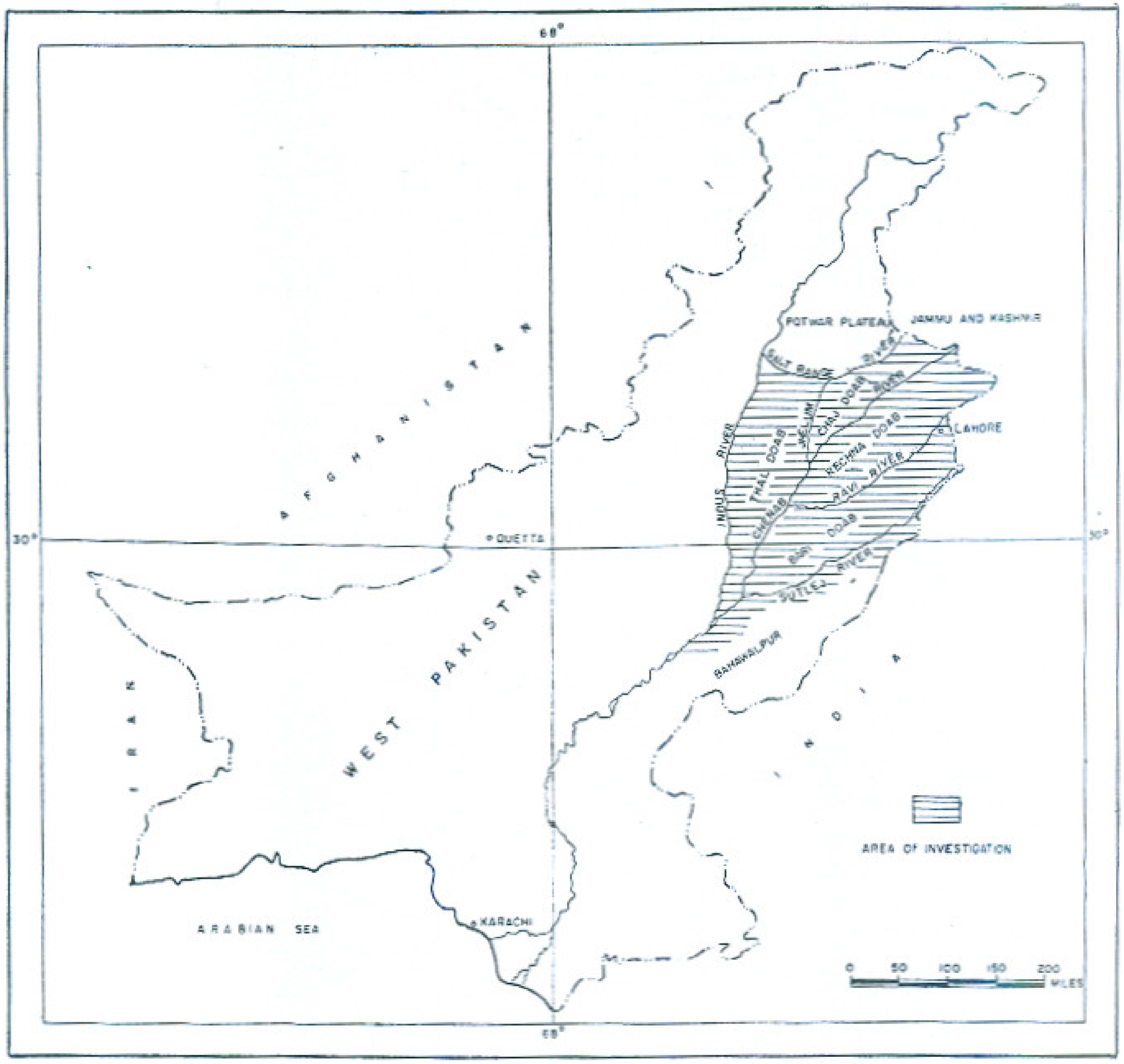
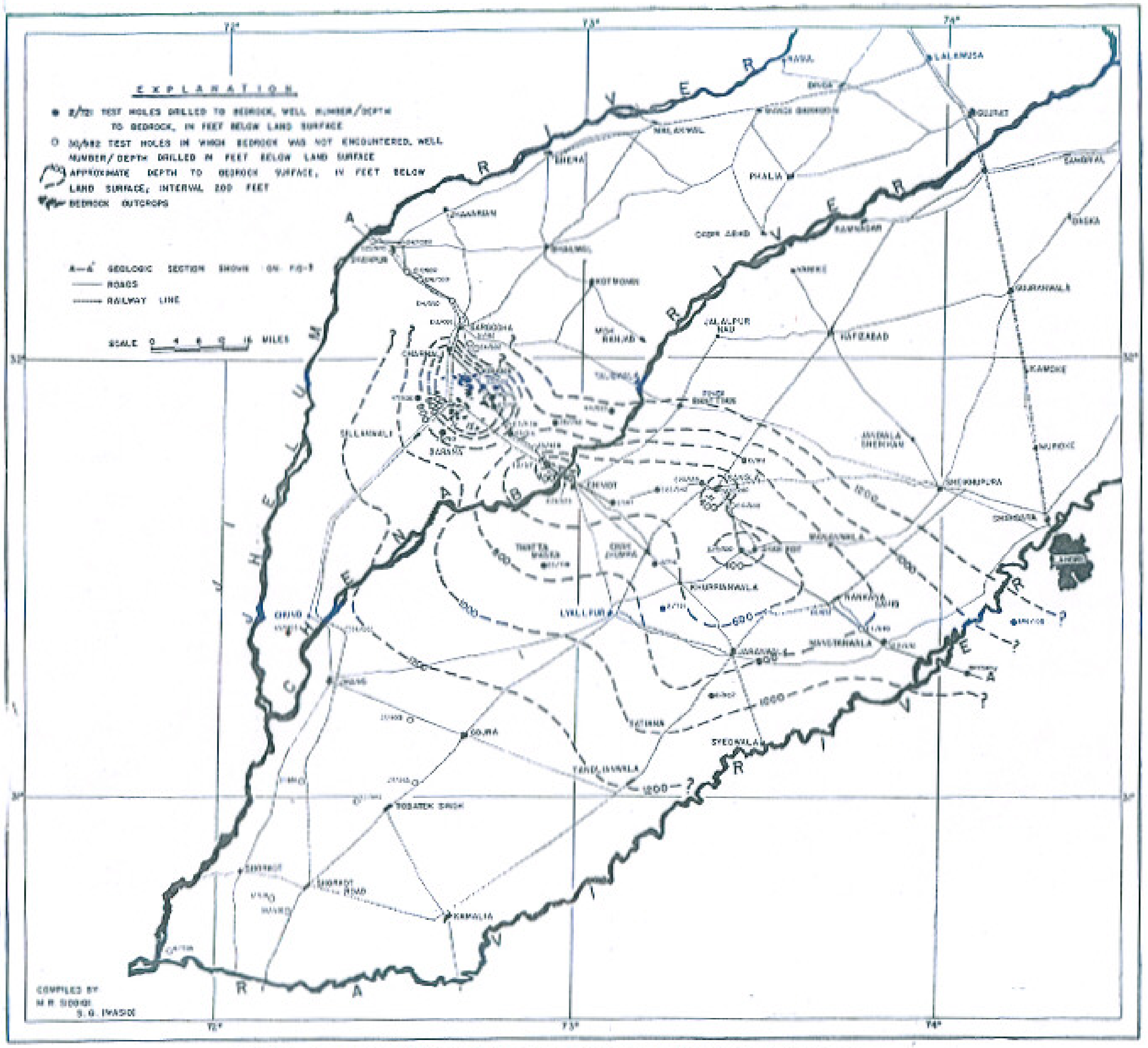


FIGURE 1 MAP OF WEST PAKISTAN SHOWING AREA OF INVESTIGATION



FIGURE—2 MAP SHOWING DEPTH TO BEDROCK IN AREA OF BURIED RIDGE.

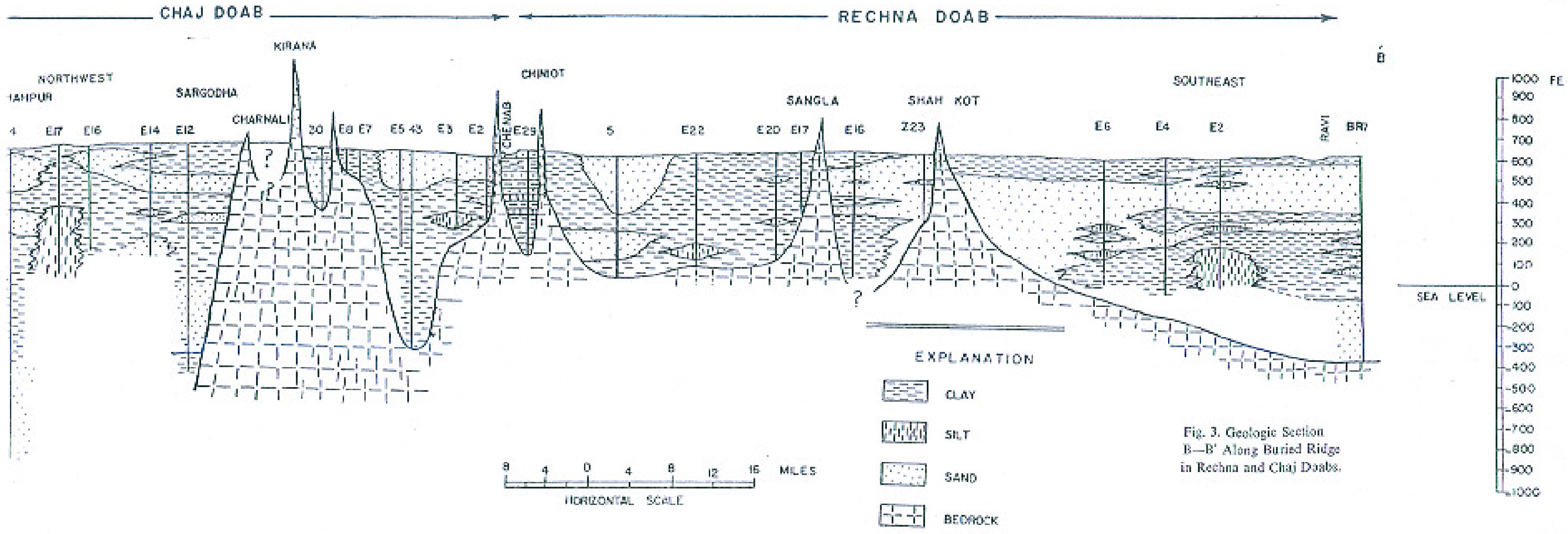


Fig. 3. Geologic Section B—B' Along Buried Ridge in Rechna and Chaj Doabs.

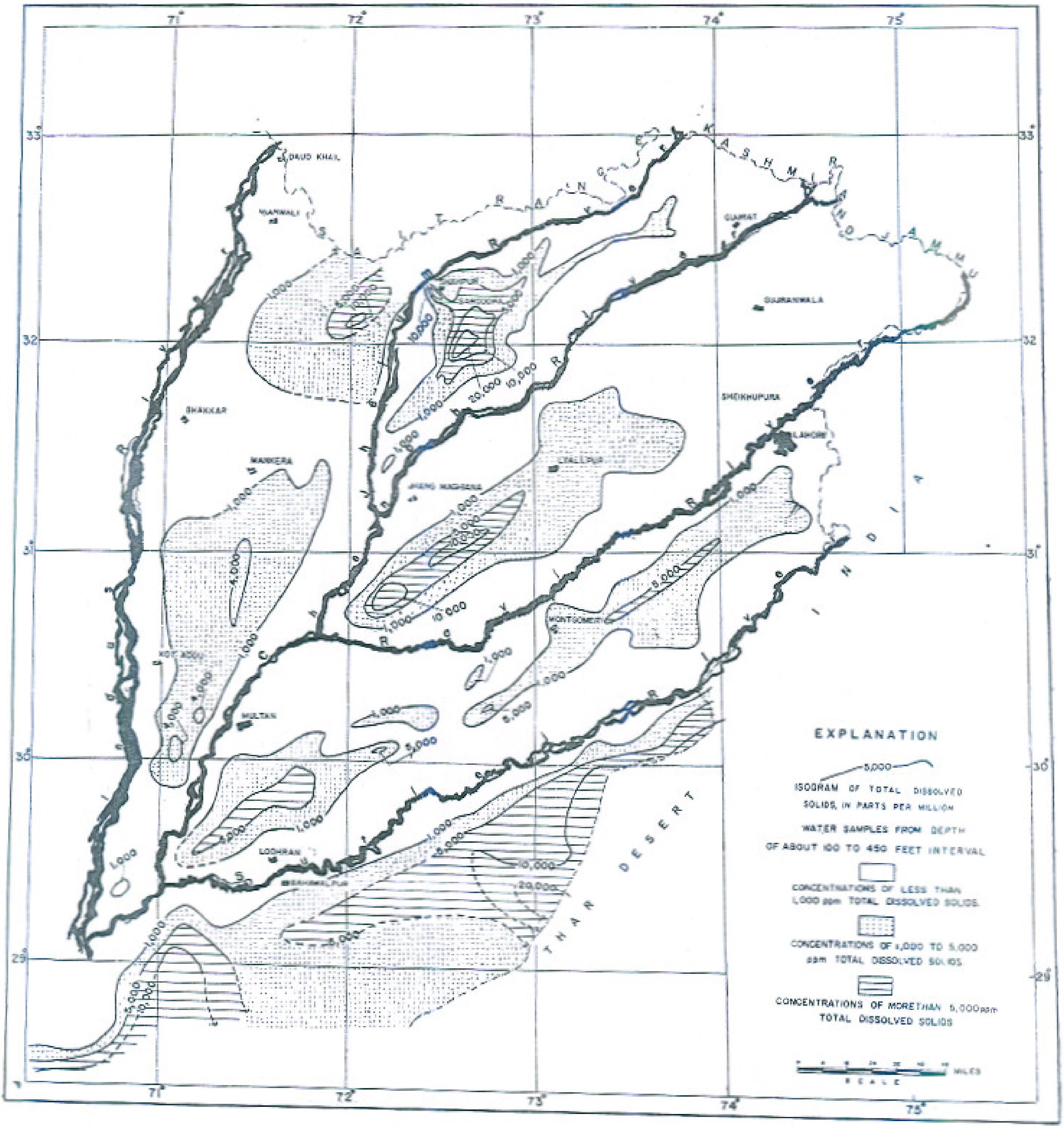


FIGURE 4 MAP SHOWING MINERAL CONTENT OF NATIVE GROUND WATER IN THE PUNJAB