Distribution, Thickness, and Lithology of Paleocene Rocks in Pakistan

GEOLOGICAL SURVEY PROFESSIONAL PAPER 716-E

Prepared in cooperation with the Geological Survey of Pakistan under the auspices of the Government of Pakistan and the Agency for International Development, U.S. Department of State

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By CHARLES R. MEISSNER, JR., *and* HABIB-UR RAHMAN

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Thicknesses, clastic ratios, and sandstone-shale ratios are shown for Paleocene rocks of the Indus and Baluchistan Basins

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FOREWORD

In 1956, the Geological Survey of Pakistan and the U.S. Geological Survey began a cooperative program to intensify the mapping and appraisal of the geological resources of Pakistan. The program was initiated under an agreement dated October 1955 between the Government of Pakistan and the International Cooperation Administration, predecessor of the Agency for International Development, U.S. Department of State. It included joint geological reconnaissance of unmapped areas, detailed mapping and appraisal of mineral districts, and development of facilities and staff to increase the capacity of the Geological Survey of Pakistan.

This volume entitled "Geological Investigations in Pakistan" is intended to present some of the more significant results of the cooperative program in Pakistan, which extended from 1956 to 1970. It consists of papers that have been prepared by U.S. Geological Survey geologists and by their counterparts in the Geological Survey of Pakistan, summarizing the investigations believed to be most important for those interested in the geology and resources of Pakistan. More detailed information from these investigations, as well as reports from other studies made during the program, are available from the Geological Survey of Pakistan in Quetta. Much of the regional geological information obtained during this program, and from surveys made earlier, was summarized in a new Geological Map of Pakistan prepared cooperatively and published by the Geological Survey of Pakistan in 1964.

The cooperative program in Pakistan, which directly involved the services of about 110 professional personnel from Pakistan and 43 from the United States, operated successively under the direction of four Directors-General of the Geological Survey of Pakistan and three Chiefs of Party appointed by the U.S. Geological Survey. Program directors for Pakistan were E. R. Gee (1956–59), N. M. Khan (1959–64), A. F. M. M. Haque (1964–69), and A. M. Khan (1969–70). United States participation was supervised by J. A. Reinemund (1956–63), M. G. White (1963–66), and D. L. Rossman (1967–70), each of whom also served as senior geologic consultant to the Director-General.

Geologic specialists provided by the U.S. Geological Survey were supplemented by four mining engineers from the U.S. Bureau of Mines, who provided collateral assistance to the Pakistan Department of Mineral Development, and by a drilling specialist and an administrative specialist from the Agency for International Development. The Geological Survey of Pakistan, through the Ministry of Industries and Natural Resources, provided counterpart personnel facilities, and services for the program, and arranged cooperative support from the Pakistan Department of Mineral Development, as well as from the Pakistan Industrial Development Corporation, Pakistan Council of Scientific and Industrial Research, and other agencies concerned with resource development.

This program would not have been possible without the excellent support of all agencies involved, both in Pakistan and the United States. The geological information and institutional growth obtained through this program should contribute significantly toward orderly economic and scientific development in one of Asia's largest and newest nations.

A. M. Khan

Abdul Mannan Khan, Director-General
Geological Survey of Pakistan

John A. Reinemund

John A. Reinemund, Chief
Office of International Geology
U. S. Geological Survey

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By CHARLES R. MEISSNER, JR., U.S. Geological Survey,
and HABIB-UR RAHMAN, Geological Survey of Pakistan

ABSTRACT

An isopach map and three lithofacies maps show the distribution, thickness, and lithology of Paleocene rocks in Pakistan and help to explain their depositional history.

The isopach map shows a pattern of thickening and thinning of Paleocene rocks and reveals the three depositional provinces of the Indus Basin to the east and suggests two depositional provinces in the Baluchistan Basin to the west. Lithofacies contour maps of Paleocene rocks reveal high clastic and high sandstone-shale ratios along the eastern side of the Indus Basin, generally parallel to the Precambrian Indian Shield. These high ratios suggest that the main influx of sediments into the Indus Basin was from the east. Low clastic ratios along the western side of the Indus Basin reflect carbonate deposition farther offshore.

The Baluchistan Basin of Pakistan is separated from the Indus Basin by the so-called central axis, along which exposures of Paleocene rocks have not been found, owing to erosion or nondeposition. Data on Paleocene rocks in the Baluchistan Basin are inadequate to construct satisfactory lithofacies maps. The little information available indicates that Paleocene rocks in the northern part of the Baluchistan Basin have high clastic ratios and that the rocks contain beds of volcanic material. The sandstone-shale ratio increases from the north and from the south toward the central part of the Baluchistan Basin, an east-west axial zone where Paleocene rocks are probably absent.

Study of the lithology and thickness of oil-bearing Paleocene rocks in the Potwar-Kohat depositional province might provide criteria for oil exploration elsewhere in Pakistan.

INTRODUCTION

PURPOSE AND SCOPE OF THE STUDY

Isopach and lithofacies maps of Paleocene rocks in Pakistan were prepared by the Geological Survey of Pakistan as part of a project to compile similar maps of most of the stratigraphic units in the country. It was intended that the first maps be of the lithostratigraphic interval known as the Dunghan Formation, which includes rocks of Paleocene age in the Sulaiman province of the Indus Basin. The upper boundary of this formation, however, extends into the Eocene at places, and the lower boundary has been extended by some workers to include rocks of Cretaceous age. Moreover, the term "Dunghan Formation" is confined to the Sulaiman province, whereas Paleocene rocks in the Potwar-Kohat province are known by many formation names, including the Dhak Pass Formation, Khairabad Formation, Patala Formation, Hangu Formation, and others. A similar diversity of stratigraphic nomenclature applies to rocks of Paleocene age in other sedimentary provinces and basins in Pakistan. Inasmuch as analytical maps of the Dunghan Formation would apply only to the Sulaiman province and, for the purposes of regional interpretation, would have to be supplemented by similar maps of equivalent formations in other parts of the country, it was decided to prepare isopach and lithofacies maps of rocks deposited during a chronostratigraphic interval, the Paleocene Epoch.

The authors are jointly responsible for the organization of the work, selection and study of the stratigraphic logs and columns, demarcation of boundaries of the unit studied, and the preparation of the maps and report. The senior author, particularly, is responsible for the plotting of data.

ACKNOWLEDGMENTS

This report was prepared as an activity of the Mineral Exploration and Development Program undertaken by the Geological Survey of Pakistan and the U.S. Geological Survey on behalf of the Government of Pakistan and the Agency for International Development, U.S. Department of State.

The authors acknowledge the overall guidance provided by Curt Teichert, U.S. Geological Survey, and the assistance of E. B. Fritz, U.S. Geological Survey, who identified Paleocene age boundaries.

Credit and appreciation are also extended to S. S. M. Naqvi, Geological Survey of Pakistan, for his assistance in the preparation of the maps and tabular work.

Thickness and lithologic ratios were extrapolated from data at the Geological Survey of Pakistan, National Stratigraphic Library; these data are mostly well logs and descriptions of measured outcrop sections.

DISTRIBUTION AND THICKNESS OF PALOCENE ROCKS

The locations of selected drill holes and measured outcrop sections were plotted on a base map of Pakistan at scale 1:2,000,000; these control points were annotated to show the thickness of Paleocene rocks. A map of Paleocene rocks (pl. 1) was prepared on which isopachs (lines that indicate equal rock thickness) were drawn at intervals of 500 or 1,000 feet, depending on the density of lines. These contours show a pattern of thickening and thinning of the Paleocene rocks and reveal the Baluchistan Basin to the west and the three depositional provinces of the Indus Basin to the east.

INDUS BASIN

Paleocene rocks of the Indus Basin are limited on the east by a subsurface erosion edge along the east side of Pakistan, roughly parallel to the Indian Shield. The western limit is parallel to the central axis, a belt of folded rocks that separates the Indus Basin from the Baluchistan Basin. The three depositional provinces of the Indus Basin have been called the Potwar-Kohat, the Sulaiman, and the Kirthar (Rahman, 1963).

POTWAR-KOHAT DEPOSITIONAL PROVINCE

The thickest section of Paleocene rocks in the Potwar-Kohat depositional province is near the town of Kohat, where the sequence is more than 3,800 feet thick. To the north, Paleocene rocks are bounded by a belt of metamorphic and igneous rocks. To the south, the province is separated from the rest of the Indus Basin by a west-northwest-trending positive axis which extends from the Indian Shield through the Kirana-Sargodha hills (which contain outcrops of Precambrian rocks) and farther west, in the subsurface, to the vicinity of Tank. The Khisor Range, where Paleocene rocks are absent, may be the surface expression of this axial trend. On the south and southeast edges of the province, Paleocene rocks gradually thin southeastward toward the eastern end of the Salt Range, where they are absent. This gradual thinning southeastward suggests a shoreward shallowing of the sea during Paleocene time. Erosion along the eastern edge of the basin during regression of the sea accounts for some of the thinning and the absence of Paleocene rocks along the ancient shoreline of the province.

The Kirana-Sargodha hills and the Khisor Range are nearly on trend with each other and may have been connected, thereby forming a ridge in the Indus Basin sea that partially barred the open sea from the Potwar-Kohat province to the north. Such a silled basin, where waters are calm, clean, and clear, is an environment favorable to abundant organic life. These conditions may account in part for the petroleum found in Paleocene rocks underlying the Potwar Plateau in the eastern part of the Potwar-Kohat province. Oil-bearing Paleocene rocks range in thickness from approximately 300 to 500 feet and are mostly limestone.

SULAIMAN DEPOSITIONAL PROVINCE

The Sulaiman depositional province is the central province of the Indus Basin. It extends south and southwest from the Khisor Range to the town of Quetta. Paleocene rocks reach a maximum thickness of approximately 1,500 feet in two areas, one in the mountains northwest of the town of Dera Ghazi Khan and the other northeast of the town of Jacobabad at the site of Pakistan Petroleum Limited Sui No. 1 gas well.

Sui gas apparently is produced from limestone of Eocene age. In the Sui area, however, the basal part of a continuous section of limestone, the so-called Sui Main Limestone in Sui No. 1 gas well, may be the subsurface equivalent of the Dunghan Formation, which on several logs of measured outcrop sections in the mountains towards Quetta is shown to be partly Paleocene and partly Eocene in age. The isopach map shows the thickness only of the part of the Sui Main Limestone that is Paleocene in age; the overall thickness of the Dunghan Formation (Paleocene and Eocene) usually is at least twice as thick. If all the logs of measured outcrop sections in the mountains between Quetta and Sui showed the Dunghan Formation to be partly of Paleocene age and partly of Eocene age, then part of the Dunghan would have to be treated separately for this study. The Dunghan Formation at most of the sections in the same general area is considered to be entirely of Paleocene age, a fact that shows the disagreement among paleontologists as to the age classification of rocks of the Dunghan Formation. This

discrepancy is not found in the northern part of the Sulaiman province where the Dunghan Formation is considered to be only Paleocene in age. A reclassification of the Dunghan Formation may be necessary in the southern and western part of the Sulaiman province to make a distinction between rocks of definite Paleocene age and rocks of definite Eocene age.

The Sulaiman province is separated from the Kirthar province by the Jacobabad subsurface high. Pakistan Petroleum Limited's Jacobabad No. 1 and No. 2 test wells (58 miles southwest of Sui No. 1) drilled west of the town of Jacobabad penetrated the Eocene Sui Main Limestone which rests directly on Jurassic rocks; Pakistan Petroleum Limited's Uch No. 1 gas well (35 miles west of Sui No. 1) north of Jacobabad (pl. 1) penetrated the Eocene Sui Main Limestone overlying Cretaceous rocks, marking an unconformity in that area. About 80 miles south-southwest of Sui No. 1, Pakistan Petroleum Limited's Khairpur No. 2 well penetrated only 80 feet of Paleocene rocks on the approximate southeastern extension of the Jacobabad high. South of the Khairpur No. 2 well, however, Paleocene rocks thicken toward the Kirthar depositional province.

KIRTHAR DEPOSITIONAL PROVINCE

The trough-shaped Kirthar depositional province extends from Karachi and Hyderabad on the south to Khuzdar on the north. It is comparable in size to the Sulaiman province; both are more than three times as large as the Potwar-Kohat province. The Kirthar province contains the thickest sequence of Paleocene rocks in the Indus Basin; more than 5,700 feet was penetrated in Pakistan Hunt International Oil Company's Sari Singh No. 1 well. Neither oil nor gas has been found in this province, although shows of oil and gas in the Hunt-Lakhra No. 1 well were reported.

BALUCHISTAN BASIN

Few outcrops of Paleocene rocks are found in the Baluchistan Basin, and subsurface information is scarce. The greatest thickness of Paleocene rocks shown on the isopach map (pl. 1) is in the northern part of the basin, west of the town of Kharan Kalat. Strata thicken abruptly northward in the Ras Koh Range from 845 feet at Pakistan Standard Vacuum Oil Company's section No. 173 to possibly 10,750 feet at Pakistan Tidewater Oil Company's section No. 224. According to a Pakistan Tidewater Oil Company report [1] this thickening of Paleocene strata may be due to a fault, downthrown to the north, where movement was contemporaneous with deposition. On the basis of scanty and dubious data, it is postulated that the Paleocene rocks that trend westward throughout the southern part of Chagai District (Kharan Kalat to the Iranian border) thicken to the north; then, from approximately the central part of the district, they thin rapidly toward the Afghanistan border (R. H. Nagell, oral commun., 1964). Additional work in this part of the Baluchistan Basin is needed to show a more accurate picture of the thickness of Paleocene rocks.

Southward from this thick sequence, Paleocene rocks apparently thin to zero in the Central Makran Range in the central part of the Baluchistan Basin. Paleocene rocks crop out again farther south in at least two isolated fault blocks in the Ispikan area, west of the town of Turbat near the Iranian border. It is inferred that Paleocene rocks thicken southward from the Central Makran Range toward the Makran coast of Pakistan, a region where younger rocks crop out. This strongly suggests that the area termed "Baluchistan Basin" is actually two basins and that the term should be redefined. In this report, however, the old usage is retained because of lack of information need to accurately establish the actual depositional basins present.

According to E. B. Fritz (oral commun., 1964), the Paleocene fauna in the Khuzdar area of the Kirthar depositional province is similar to the Paleocene fauna in the Ispikan area. Fritz believes that this similarity suggests that the Paleocene seas of the Kirthar province were closely connected with Paleocene seas of the Baluchistan Basin, probably in the south.

CLASTIC RATIOS OF PALEOCENE ROCKS

The clastic ratio is the statistical relationship of the percentage of clastic rocks in a stratigraphic section compared with the percentage of nonclastic rocks in the same section (Krumbein and Sloss, 1951, p. 271). A clastic ratio map of Paleocene rocks of Pakistan (pl. 2) was prepared on which clastic ratio contours (lines that indicate equal ratio) were plotted from outcrop and subsurface information.

INDUS BASIN

Paleocene rocks in the central part of the Potwar-Kohat depositional province are predominantly lime-

[1] Pakistan Tidewater Oil Company, 1961, Reconnaissance geologic report on the stratigraphy of the Ras Koh Range, Baluchistan, West Pakistan; unpub. rept. prepared by I. B. Kadri and J. E. Lieftink, available at Geol. Survey Pakistan, Natl. Strat. Library.

stone or other calcareous rocks, as indicated by a clastic ratio of 1 or less. It is noteworthy that the only oil field in Pakistan produces from Paleocene rocks within this area. The clastic ratio increases outward on the flanks of the Potwar-Kohat depositional province towards the so-called shoreline of the province. The ratio reaches infinity (that is, all rocks are clastic) to the southeast near the erosion edge bordering the Kirana-Sargodha hills (pl. 2).

In the Sulaiman depositional province, the clastic ratio generally increases to infinity from west to east towards the approximate subsurface erosion edge of Paleocene rocks along the western side of the Indian Shield. Areas where the ratio is 1 or less are along the western side of the Sulaiman province in the mountains between Fort Sandeman and Dera Ismail Khan and the mountain area between Quetta, Loralai, and Sibi. A finger of Paleocene rocks with a clastic ratio of 1 or less protrudes southward from east of Loralai through the Pakistan Petroleum Limited's Sui No. 1 well to the Kandhkot No. 1 well. Gas is produced in the Sui field from the Eocene part of the Sui Main Limestone of Paleocene and Eocene age. Although the Paleocene rocks do not produce gas at Sui, gas might occur in the thick limestone sequence within the finger where the clastic ratio is 1 or less.

Farther south, in the Kirthar depositional province, the clastic ratio increases to infinity from west to east, reflecting the clastic nature of the Paleocene rocks along the entire eastern side of the Indus Basin. Two separate areas along the western side of the province have a clastic ratio of 1 or less; one is in the mountains around Khuzdar, and the other is a smaller area east of Bela. Paleocene rocks are very clastic in the rest of the Kirthar province, and in the southern half they are almost entirely composed of sandstone and shale.

The high clastic ratio on the eastern side of the Indus Basin indicates that the main influx of sediments into the Paleocene seas of the Indus Basin was from the Indian Shield landmass to the east. As the strength of carrier currents decreased offshore away from the source of sediments, finer clastic materials were deposited, forming shale. There evidently were areas of calm clear waters along the western side of the basin, where organic life thrived and limestone and calcareous sandstone and shale were deposited. Not all rocks of the western side of the Indus Basin are calcareous, however. The clastic-ratio contour map shows channels of clastic inflow immediately south of the Khisor Range, where the clastic ratio reaches infinity; south of the Jacobabad high, where a high clastic ratio is shown; and also between the Khuzdar and Bela areas. From the Bela area south, the clastic ratio increases to infinity.

BALUCHISTAN BASIN

The Baluchistan Basin is separated from the Indus Basin by the central axis along which exposures of Paleocene rocks seem to be absent because of erosion or nondeposition. In the northern part of the Baluchistan Basin, the Paleocene rocks are markedly different from those in the Indus Basin. Clastic ratios are very high, and the rocks contain beds of volcanic material. Limited data indicate that the clastic ratio increases northward. Little information is available on clastic ratios in the southern part of the Baluchistan Basin, except in the Ispikan area where Paleocene rocks crop out in two fault blocks. This scanty information indicates that the clastic ratio increases southward. The northern and the southern parts of the Baluchistan Basin are separated by an area where Paleocene rocks apparently are absent. This area, which bisects the Baluchistan Basin, might be an expression of a western spur of the central axis.

SANDSTONE-SHALE RATIOS OF PALEOCENE ROCKS

The sandstone-shale ratio is the statistical relationship of the percentage of sandstone in a stratigraphic section compared with the percentage of shale in the same section; this ratio is independent of the amount of nonclastic materials present. A sandstone-shale ratio map of Paleocene rocks of Pakistan (pl. 3) was prepared, on which sandstone-shale ratio contours (lines that indicate equal ratio) were plotted from outcrop and subsurface information.

INDUS BASIN

In the Potwar-Kohat depositional province the amount of sandstone in the sedimentary section decreases away from the original shorelines of the Paleocene sea which occupied the province; this relationship is indicated by a decrease in sandstone-shale ratios toward the central part of the province. The fact that limestones were deposited away from the primary source of clastic sediments was discussed in relation to the clastic ratio map. An analysis of the lithofacies maps showing the sandstone-shale ratio and clastic ratio indicates whether limestone is interbedded with sandstone or shale. In the Potwar-Kohat province, limestone and shale are

associated more in the central part of the province (including the oil fields) than along the edges. The edges of the province generally contain more sandstone.

At the northern end of the Sulaiman province, the sandstone-shale ratio is very high in a trough-shaped area south of the Khisor Range. This high ratio probably reflects an area where channeling of carrier currents brought in coarser materials from the higher, eroding Khisor Range area.

Low sandstone-shale ratios, except for two areas of sandstone protruding from the north, are in the southern and western parts of the Sulaiman province. These areas of sandstone may indicate channeling of the carrier water or subsidiary source areas to the north. The sandstone content increases to nearly 100 percent toward the eastern edge of the Sulaiman province and along all the east side of the Indus Basin, indicating that the main source of sediments was the Indian Shield. The sandstone-shale ratio is 0 in most other parts of the Sulaiman province.

In the northern part of the Kirthar depositional province, a relatively high sandstone content is found in a trough-shaped area south of the Jacobabad high. This area, however, contains less sandstone than the area south of the Khisor Range. Paleocene rocks on the eastern and southern margins of the Kirthar province have a high sandstone-shale ratio, which decreases to 0 along the western side of the province.

BALUCHISTAN BASIN

Information about Paleocene rocks in the Baluchistan Basin is inadequate to construct a satisfactory sandstone-shale ratio map. The little information available indicates that the sandstone-shale ratio increases both northward and southward toward the central part of the basin where Paleocene rocks are probably absent. The decrease in thickness and increase in sandstone content toward the central part of the basin suggests that it was a positive landmass flanked by basins in Paleocene time.

GROSS LITHOLOGY OF PALEOCENE ROCKS

A lithofacies map (pl. 4) combines the clastic ratio and sandstone-shale ratio contours to show combinations of the three principal types of Paleocene rocks: limestone, shale, and sandstone. Each principal rock type includes the calcareous, argillaceous, or arenaceous component of the other two rock types. The calculated percentage of all calcareous materials, including the carbonate content of calcareous shale, calcareous sandstone, and impure limestone, were added together to obtain the cumulative thickness of nonclastic rocks in a section; similar calculations were made to determine the argillaceous and arenaceous components. A triangular diagram was prepared, each corner representing one of the three principal rock types: 100 percent nonclastic, 100 percent shale, or 100 percent sandstone. Subdivisions of the triangle show nine different combinations of nonclastic materials, shale, and sandstone, and the areas containing rocks of the compositions indicated by these subdivisions are shown on the combined clastic ratio and sandstone-shale ratio lithofacies map.

ECONOMIC SIGNIFICANCE OF THE STUDY RELATIVE TO OIL AND GAS

A comparison of the combined lithofacies map (pl. 4) with the isopach map (pl. 1) helps explain the depositional history of Paleocene rocks. Study of the lithology and thickness of oil-bearing Paleocene rocks in the Potwar-Kohat province might provide criteria for oil exploration in Paleocene rocks of similar nature elsewhere in Pakistan. Oil-bearing Paleocene rocks in the Potwar-Kohat province are 300 to more than 500 feet thick and have a clastic ratio of 1 or less and a sandstone-shale ratio of less than 1/4. Thus, the oil zones are found in an interbedded sequence of mostly limestone and shale that has a thickness of 300 feet or more. Oil has not been found in Paleocene rocks that are predominantly clastic. Using these criteria as factors related to oil accumulation, the search for petroleum should be extended to other areas in which similar Paleocene rocks occur.

One favorable area where gas and possibly oil might be found in Paleocene rocks is north of the Sui gasfield within the area bounded by a clastic ratio of 1 or less, but south of the area where the sandstone-shale ratio is about 1/4. The thickness of Paleocene rocks in this area may be more than 1,000 feet. All the conditions favorable for the generation and accumulation of hydrocarbons may be present here in Paleocene or Eocene rocks.

A second promising area where petroleum might be found is in the mountainous region in the western part of the Sulaiman province between Loralai, Sibi, and Quetta. In this large area, Paleocene rocks are more than 300 feet thick and are mostly limestone and shale. Paleocene rocks in this area have been exposed to erosion in many of the mountain ranges,

but they are likely to contain oil or gas where they are deeply buried in intermontane basins.

A third area possibly favorable for petroleum is in the mountains near Khuzdar where thick sequences of Paleocene rocks have a clastic ratio of 1 or less and a sandstone-shale ratio of less than 1/4.

A fourth area with favorable clastic and sandstone-shale ratios is east of Bela; however, the thickness of Paleocene rocks in this area may be less than 300 feet, and the area is rather small.

This study of the distribution, thickness, and lithology of Paleocene rocks suggests that at least some conditions which seem to be related to the accumulation of oil or gas in Paleocene rocks are present in at least three heretofore unexplored regions in Pakistan, one in the southern Sulaiman province, one in the western Sulaiman province, and one in the northwestern Kirthar province. Further exploration and possibly test drilling would be required to determine the petroleum potentiality of these regions.

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