

Overview of the geology and structure of the Salt Range, with observations on related areas of northern Pakistan

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ABSTRACT

The Salt Range and its Trans-Indus extension bridges the reentrant between the outer ranges of the northwestern Himalaya and the Sulaiman Mountain arc. Upper Proterozoic to Recent successions occur in the range, which makes up the southern thrust front of the orogen.

There are two regional features of particular interest. The first is the occurrence of thick saliferous deposits of Eocambrian age, overlying Precambrian basement in the Potwar Plateau and thrust southward in the Salt Range over the alluvial Cenozoic. Thick, saliferous deposits also occur within the Eocene sequence of Kohat. These incompetent formations played a significant role in determining structure. The second feature is the presence of four major unconformities: between the marine Eocambrian to Cambrian sequence and the glacial, Lower Permian conglomerates, and below the Paleocene, the Miocene, and the late Pliocene-Pleistocene formations.

Metamorphic rocks, linking with the Precambrian crystalline basement of northwestern India, crop out only in the Kirana Hills some 80 km south of the Salt Range. Within the Salt Range and related areas, unmetamorphosed sedimentary rocks compose the exposed succession, mainly shallow-water marine, until mid-Tertiary time, and lacustrine and fluvial from Miocene time onward.

Prior to Quaternary time, only epeirogenic forces affected the region, accompanied occasionally by local warping. In contrast, during Quaternary time, the effects of the Himalayan orogeny extended southward. Accentuated by movement within the Eocambrian saliferous formation, the Salt Range developed as a complex anticlinorium, emplaced southward along a major thrust, which has recently been determined by seismic reflection measurements to involve a décollement of at least 20 km. Complex fold and fault structures resulted elsewhere within the region.

INTRODUCTION

More than a century has passed since A. B. Wynne carried out the pioneer survey of the Salt Range and adjoining geologically related areas of the Upper Indus Basin (Fig. 1). His memoirs (Wynne, 1875, 1878, 1880) covering this region bear witness to the excellence of his work in the field. Subsequently, the region has attracted the attention of many geologists. Fossils being prolific in many of the formations, extensive paleontologic research has been carried out; the controversial question of the age of the saliferous deposits has added considerably to the literature.

Primarily during the 1930s, I, then a member of the Geological Survey of undivided India, resurveyed the Salt Range on a scale of 2 in to 1 mi. Summarized results of that survey were given in symposia on the age of the Salt Range Formation (Gee, 1945, 1947). Those papers include detailed maps of selected areas.

As a result of the Second World War and subsequent limited publication facilities in Pakistan, the presentation of maps covering the complete survey was delayed. Eventually published with a scale of 1:50,000 (Gee, 1980), these maps may be pur-

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chased from the Geological Survey of Pakistan. From them, Plate 1 (in pocket inside back cover) has been compiled.

Data provided by oil companies and the published results of field work and laboratory research, particularly during the past decade, have added substantially to an understanding of the geologic history of the region. Finally, with the very recent interpretation of reflection seismic lines crossing the Potwar, the Salt Range, and the adjoining plains (Lillie and others, 1987), our knowledge of the subsurface structure has been greatly enhanced.

The revised nomenclature for the stratigraphic units of the pre-Neogene formations of the region, selected by the Stratigraphic Committee of Pakistan (Fatmi, 1973; Shah, 1977) is adopted herein; in the case of the Neogene formations and Quaternary time, the recently revised chronostratigraphy (Johnson and others, 1979, 1986) is adopted. Equivalent terms, used previously, are given in brackets in Table 1.

SALT RANGE

With its Trans-Indus extension, the Salt Range bridges the angle between the outermost ranges of the northwestern Himalaya and of the Sulaiman Arc to the west. Rising abruptly out of the alluvial plains, it forms impressive scarps, usually 750 to 1,000 m in altitude, although Sakesar Mountain rises some 1,500 m. The hillslopes and plateaus are relatively barren of vegetation; rock exposures are usually excellent. Within the scarps and gorges, complete sections of the older formations are often exposed, whereas in the dip slopes to the north the younger Tertiary sequence links with that of the Soan Basin of the Potwar Plateau.

Stratigraphy and geologic history

The exposed formations of the range are all unmetamor-

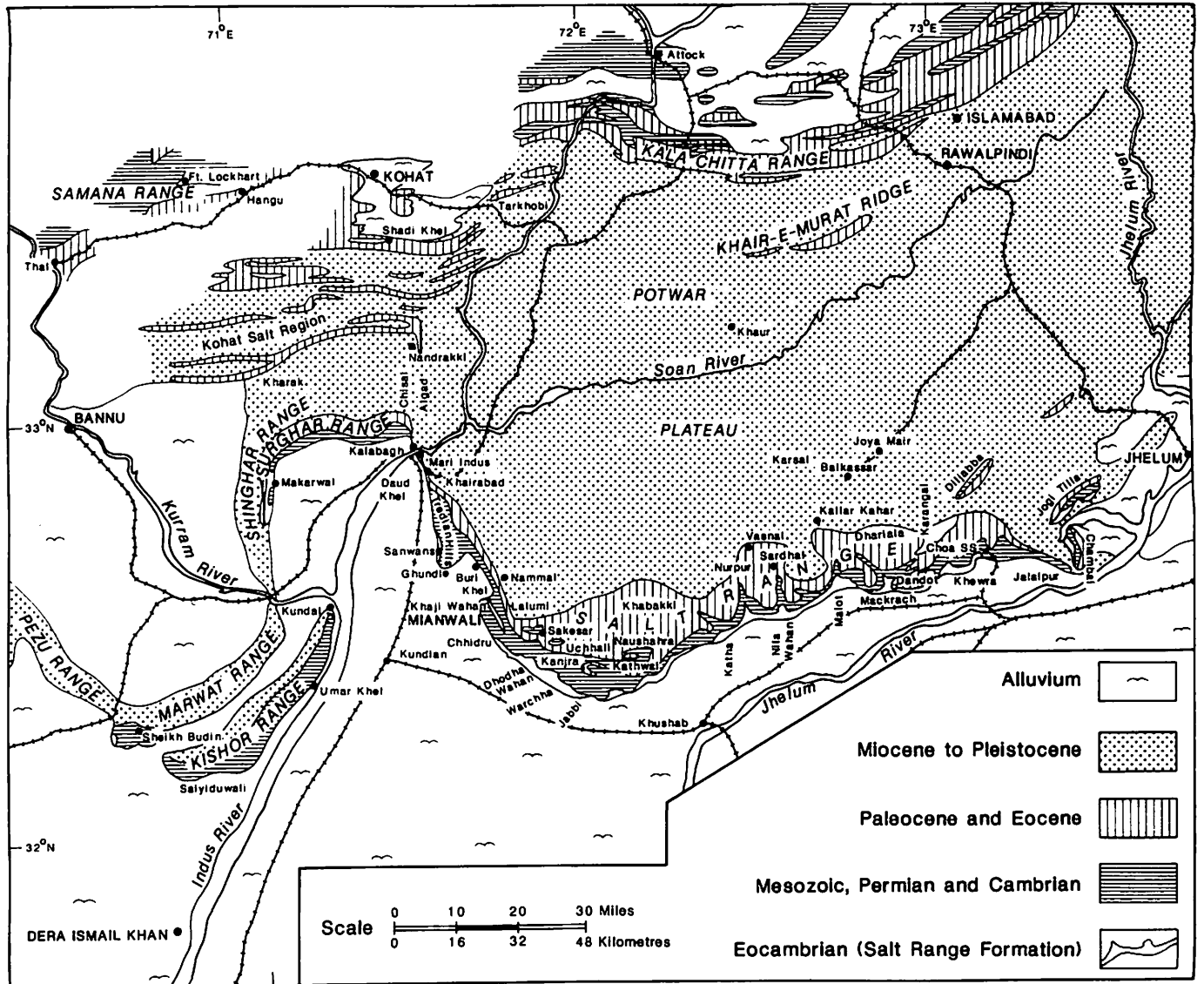


Figure 1. Location map of the Salt Range and related areas. After Gee (1983).

TABLE 1. STRATIGRAPHIC SEQUENCE IN THE SALT RANGE

Age	Group and Formation	Type of Formation
Recent	Alluvium	Alluvial deposits, boulder fans
Pleistocene and Late Pliocene	Kalabagh Conglomerates (Naushahra sandstone and conglomerates)	Brown and gray conglomerates with sandstone and clay interbeds

Major Unconformity

Pliocene and Late Miocene	Siwalik Group	(Soan	Light colored sandstone and conglomerates, light red and gray clays
		(
(Dhok Pathan		Red-brown clays with gray sandstones; conglomeratic near Indus	
(
Late Miocene		(Nagri	Greenish-gray sandstones and clays, conglomeratic near Indus
		(
Middle Miocene		(Chinji	Bright red clays with sandstone
	(
Early Miocene	Fawalpindi Group	(Kamliail	Massive red and brown sandstones, dark red clays
		(
		(Murree	Massive sandstones, dark red and purplish clay-shales; basal conglomerate
		(

Major Unconformity

Early Eocene	Chharat Group	(Chor Gali (Bhadrar Beds)	Olive-green shales with bedded limestones
		(Sakesar	Massive and nodular limestones, with marls; chert in upper part
		(Nammal	Light gray calcareous shales and limestone
Paleocene	Makarwal Group	(Patala	Green shales with coal seam in east; thin limestones
		(Lockhart (Khairabad)	Gray, semi-nodular and marly limestones
		(Hangu (Dhak Pass)	Impure limestones, sandstones, and shales, often carbonaceous

Major Unconformity

TABLE 1. STRATIGRAPHIC SEQUENCE IN THE SALT RANGE (continued)

Age	Group and Formation		Type of Formation
Early Cretaceous	Surghar Group	(Lumshiwai	Light-colored sandstones with carbonaceous bands
Early Cretaceous and Late Jurassic		(Chichali (Belemnite Beds)	
		(Unconformity	
Middle Jurassic	Baroch Group	(Samana Suk (Baroch Limestones)	Gray and purple bedded limestones with shale interbeds
		(Shinawari	
Early Jurassic		(Datta (Variegated Beds)	Sandstones with limestones carbonaceous shales and lateritic zones
Unconformity			
Late Triassic	Musa Khel Group	(Kingriali (Kingriali Dolomite)	Massive light colored dolomite and dolomitic limestones, with sandstones
Middle Triassic		(Tredian (Kingriali Sandstone)	
Early Triassic		(Mianwali (Ceratite Beds)	
Paraconformity			
Late Permian	Zaluch Group	(Chhidru (Up. Productus)	Limestone, marl, and calcareous sandstone
		(Wargal (Middle Productus)	
		(Amb (Lower Productus)	
Early Permian	Nilawahhan Group	(Sardhai (Lavender Clays)	Dark purple and lavender clays with subordinate sandstones
		(Warchha (Speckled Sandstones)	
		(Dandot (Conularia Beds)	

TABLE 1. STRATIGRAPHIC SEQUENCE IN THE SALT RANGE (continued)

Age	Group and Formation	Type of Formation
Early Permian (continued)	(Tobra (Talchir (Conglomerates)	Conglomeratic sandstones and shales, boulders mainly igneous or metamorphic
Major unconformity		
Middle and Early(?) Cambrian	(Baghanwala (Salt (Pseudomorph Beds)	Blood-red shales and flaggy sandstones; with salt pseudomorphs
	(Jutana (Magnesian (Sandstone)	Massive light-colored dolomite and dolomitic sandstones; subordinate shales
	(Kussak (Neobolus (Shales)	Gray and purplish shales and glauconitic sandstones; pebble-bed at base
	(Khewra (Purple (Sandstones)	Massive maroon fine-textured sandstones; maroon shales and flags below
Eocambrian	Salt Range Formation (Punjab Saline Series)	Red gypseous marl with rocksalt; gypsum-dolomite above; occasional oil shale; Khewra "trap" in the east

phosed sediments, with the exception of thin local occurrences of Khewra Trap, a much-weathered lava flow occurring sporadically within the gypsiferous stage at the top of the Salt Range Formation of the eastern part of the range.

Basement rocks occurring at depth beneath the range are, in all probability, akin to the metamorphic Precambrian complex exposed in the Kirana hills of Sargodha, Chiniot, and Sangla some 80 km to the south of the range. Relevant to this assumption is the evidence from a borehole drilled in 1959 by the Pakistan Shell Oil Company (unpublished report) through the relatively undisturbed sequence at Karampur (29°59'N; 72°22'E), 280 km south of the Salt Range. This proved to be a sedimentary sequence comparable to that of the Salt Range. At a depth of about 2,100 m, the Salt Range Formation, some 900 m thick, was found to directly overlie an igneous-metamorphic Precambrian basement. The stratigraphy of the Salt Range is listed in Table 1. Formation thicknesses are given in Figure 2. (after Fatmi and others, 1984).

Stratigraphically, the Eocambrian and Early(?) to Middle Cambrian sequence (Salt Range Formation and Jhelum Group), so well exposed in the Salt Range scarp and occurring in the Karampur borehole, correlates with certain of the Vindhyan formations of northwestern India (Gee, 1945).

The early Permian Tobra Formation of the Indus Basin, represented by fluvio-glacial conglomerates and overlain by clastic sediments containing a *Gangamopteris-Glossopteris* flora, indicates a close connection with the Gondwana continent. This

affinity is also seen in nonmarine intercalations of the Late Permian, Middle Triassic (Tredian Formation), and Early Jurassic (Datta Formation), as witnessed by the fossil floras of those formations. But until Miocene time, when the deposition of thick fluvial and lacustrine clastic sediments commenced, sedimentation was mainly marine, deposited under relatively shallow-water conditions, and broken periodically by well-marked unconformities. In contrast to the rapid rate of deposition of the thick Miocene-Pleistocene clastic sediments, that of the older, mainly marine, sequence, even allowing for the Ordovician-Carboniferous hiatus, was obviously slow. Apart from the saliferous Salt Range Formation—whose thickness is uncertain, but probably is on the order of 1,000 m—the pre-Miocene deposits of Cambrian and Permian to Eocene age do not total more than 2,500 m, and were probably less than 2,000 m over much of the area.

The distribution of the various formations within the Salt Range is governed by four major unconformities (Fig. 3):

1. At the base of the Permian. The conglomeratic Tobra Formation oversteps the Cambrian westward and northward, coming to rest directly on the Salt Range Formation of the western part of the range.

2. At the base of the Tertiary. In the extreme eastern part of the range, the Paleocene directly overlies the Cambrian Jhelum Group. Westward and northwestward it rests progressively on Permian and Mesozoic formations. The junction is often marked by a lateritic bed.

3. At the base of the Lower Miocene Rawalpindi Group. In

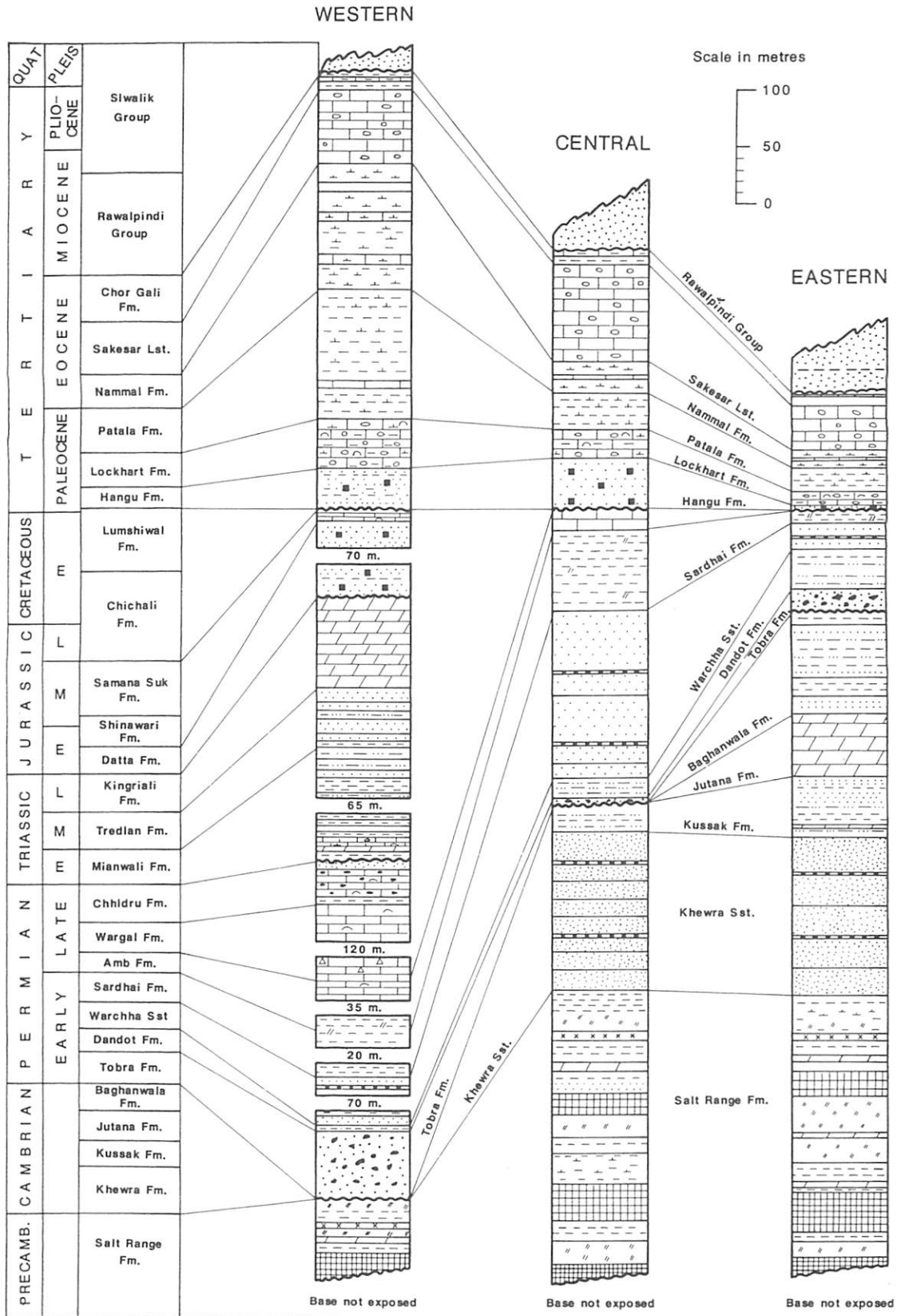


Figure 2. Columnar sections of the sedimentary sequences in the Salt Range. After Fatmi and others (1984).

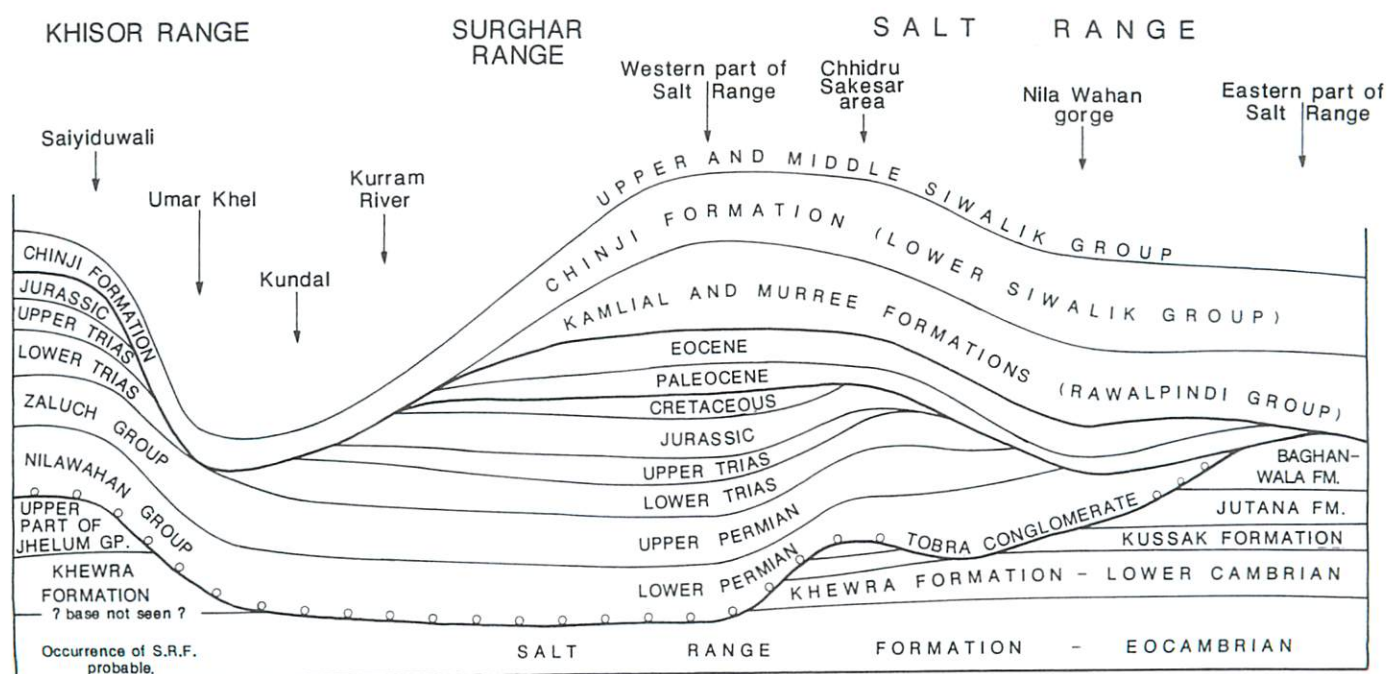


Figure 3. Diagrammatic illustration of the major unconformities in the Eocambrian to Tertiary sequence of the Salt Range-Surghar Range-Khisor Range.

general, this unconformity intensifies southward; as a result, Upper Miocene formations occasionally rest directly on diminutive Eocene or on Triassic in the southern repetitions of the western part of the scarp.

4. At the base of the late Pliocene-Pleistocene Kalabagh Conglomerates of the western half of the range. In addition, at least local unconformities occur within the Jurassic sequence (Fatmi and others, 1984), illustrated in Figure 4.

The geologic history of the Range may be summarized as follows:

Eocambrian to Middle Cambrian (Salt Range Formation and Jhelum Group). Subsidence of the Precambrian basement, attended by a widespread shallow-marine transgression; rapid evaporation resulting in the deposition of the saliferous deposits of the Salt Range Formation, followed by mainly clastic sediments of the Jhelum Group.

Late Cambrian to end of Carboniferous. Epeirogenic movements resulting in uplift above sea level and peneplanation of the land surface. A gentle southeasterly dip was imposed on the greater part of the range, resulting in increased removal of the formations of the Jhelum Group northwestward and exposing the Salt Range Formation northwest of the Sakesar area. Local warping led to the preservation of the complete Jhelum Group in the lower slopes below Sakesar and near Chhidru.

Permian. (Nilawahhan and Zaluch Groups) Widespread subsidence was attended by the deposition of glacial and fluvioglacial conglomerates of the Early Permian Tobra Formation, closely followed by clastic sediments with temperatures favorable locally to the growth of an early Gondwana flora. Topography

was initially undulating, resulting in considerable thickness variations of the basal conglomerates. More regular bathymetry followed, with the deposition of the younger, shallow-water, marine formations of the Nilawahhan Group.

Later Permian times witnessed a widespread change to predominantly calcareous sedimentation, with conditions favorable for marine life. These conditions usually continued throughout the remainder of Permian time during the deposition of the Zaluch Group, with temperatures suitable for the prolific growth of corals and bryozoa, together with brachiopods and mollusca. In contrast, immediately following the deposition of the Amb Formation, thin carbonaceous shales containing a Lower Gondwana flora were deposited locally.

Until late Mesozoic times, the complete Permian sequence probably extended over the whole of the Salt Range; its present distribution is limited to the western half, as a result of Late Cretaceous uplift and erosion.

Triassic (Musa Khel Group). Lower Triassic deposits rest conformably on the topmost member (Chhidru Formation) of the Permian, although on paleontological and palynological grounds (Kummel and Teichert, 1966, 1970; Balme, 1970), a time break is indicated. Marine conditions, mainly shallow, prevailed during much of the period, supporting a characteristic cephalopod fauna in the lower shale-limestone member (Mianwali Formation). This gave way to mainly arenaceous deposition, with the preservation of imperfect plant fragments during mid-Triassic times (Tredian Formation), followed during Late Triassic times by calcareous and dolomitic sedimentation (Kingriali Formation).

As in the case of the Permian formations, the present extent of the Triassic sequence, limited to the western half of the range, was in all probability determined by erosion that preceded Tertiary deposition.

Jurassic and Cretaceous (Baroch and Surghar Groups). An oscillatory bathymetry, varying from shallow-water marine to exposure above sea level, characterized Jurassic time. A definite hiatus is indicated at the base of the sequence on the evidence of weathering of the underlying Kingriali dolomites at several places; near Sakesar, an unconformity developed (Fig. 4).

The Early Jurassic Datta Formation is mainly continental arenaceous, with carbonaceous and lateritic interbeds; calcareous bands also occur. A widespread marine transgression followed and continued during Middle Jurassic time, resulting in deposition of the Shinawari and Samana Suk Formations, predominantly limestone, thinly developed in the western part of the range. These Jurassic formations were included in the Baroch Group by Fatmi (1987).

Regression and emergence occurred near the end of the Middle Jurassic and were followed in Late Jurassic and Early Cretaceous time by the clastic, shallow-marine sedimentation of the Surghar Group. The Chichali Formation (Fatmi, 1972; Hallam and Maynard, 1987) includes dark green, glauconitic sandstones and shales with cephalopods. As a thin sequence in the northeastern slopes of the Khaji Wahan west of Sakesar, it directly overlies the Shinawari Formation; it is absent in the Nammal gorge, but occurs in the northern part of the Tredian Hills, where the Samana Suk limestones are included in the sequence

(Fatmi and Haydri, 1986). The final phase of Mesozoic sedimentation is represented by the arenaceous Lumshiwal Formation of late Early Cretaceous age; it occurs only in the extreme western part of the Range.

The latter part of the Cretaceous period witnessed a regression of the Tethys sea northwestward, accompanied by uplift and erosion of increasing intensity southeastward. As a result, by the end of Mesozoic time, the land surface consisted of Lower Triassic and Upper Permian formations over the central parts of the Salt Range, the Lower Permian Nilawah Group in the eastern part, and the Cambrian Baghanwala and Jutana Formations in the Jogi Tilla and Chambal areas, respectively, in the extreme east. These epirogenic movements were probably associated with uplift along the Precambrian Sargodha high to the south. Prior to the widespread marine transgression of Paleocene time, the land surface weathered in many places to form an impure lateritic or bauxitic capping.

Paleocene and Eocene (Makarwal and Chharat Groups). Late Cretaceous uplift, erosion, and weathering of the land surface was followed in Early Tertiary (Paleocene) time by widespread subsidence attended by the "Nummulitic" marine transgression. In the Salt Range, deposition at the Mukarwal Group commenced with a variable sequence of sandstone, shale, and limestone—the Hangu Formation. Subsequent deposition included the predominantly calcareous Lockhart Formation overlain by the argillaceous-carbonaceous Patala. The Lockhart Formation varies considerably in thickness. Thin and marly in the east, it thickens westward as a nodular limestone to 50 to 100 m;

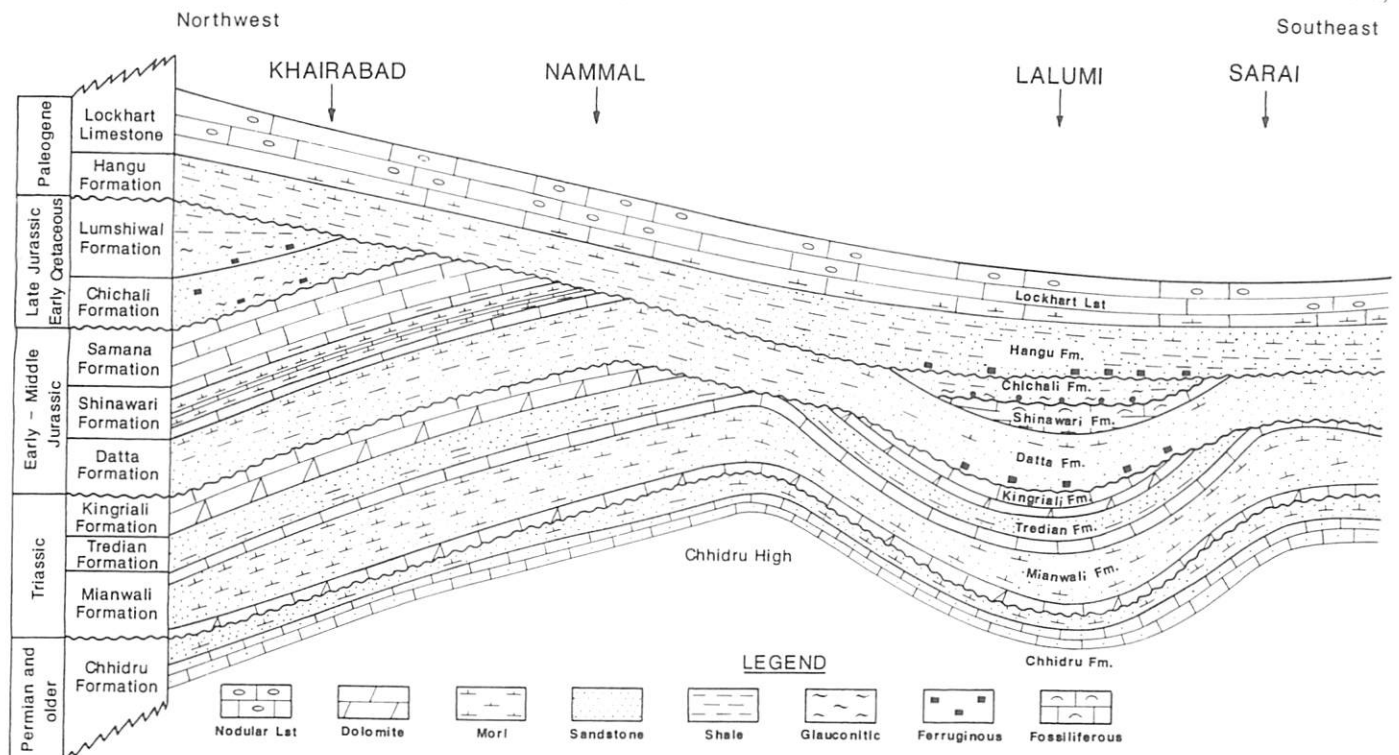


Figure 4. Unconformities in the Mesozoic to Paleocene sequence of the Lalumi area. After Fatmi and Haydri (1986).

in the Tredian hills it thickens to possibly 300 m, indicating a local downwarp in mid-Paleocene time. During the late Paleocene, a lacustrine environment developed over parts of the eastern and central Salt Range, resulting in the formation of workable subbituminous coal within the Patala Formation.

More stable marine conditions followed during early Eocene time, with the deposition of the calcareous Nammal, Sakesar, and Chor Gali Formations of the Chharat Group. In the extreme north of the Tredian Hills, deposition of massive gypsum replaced the normal cherty limestones of the Sakesar Formation. In the western half of the range, the limestone-shale sequence of the Chor Gali Formation loses its shale content, and on geological maps, is included in the Sakesar limestone.

Late Eocene–Oligocene uplift and erosion. No representatives of the younger Eocene formations are present in the Salt Range; it is very probable that, by late Eocene time, epeirogenic movements resulting in the emergence of the area above sea level had commenced, and continued, with erosion, during Oligocene time. In general, the amount of uplift and denudation increased southward, resulting in the removal of all, or at least part, of the Lower Tertiary sequence, as seen in the lower repetitions of the stratigraphic sequence between Sakesar and Chhidru in the west, as well as north of Jalaphur and in the Jogi Tilla and Chambal ridges in the extreme east. This uplift phase was again probably related to positive movements in the Sargodha High, definite evidence of which is seen in the Khisor Range (see below under Related areas).

Miocene, Pliocene, and Quaternary (Rawalpindi and Siwalik Groups and Kalabagh conglomerates). Following the marine regression of late Eocene–Oligocene time, sedimentation occurred in lacustrine and fluvial environments, with increasing subsidence northward within the Soan Basin. Clastic deposition took place rapidly, with no regional unconformities until late Pliocene time. The Salt Range remained relatively elevated during the early Miocene, the Murree Formation being comparatively thin as compared to the sequence in the northern Potwar. In fact, in the lower repetitions of the Salt Range scarp in the western part of the range, deposition was delayed until at least Pliocene time; reference the section in the Salgi Wahan to the south of Sakesar, where late Siwalik conglomerates directly overlie eroded Eocene limestones, and again in the slopes above Chhidru, where Siwalik sandstones transgress onto Triassic and lower Jurassic formations. Quaternary time witnessed the intense orogenic movements that resulted in the complex fold and fault structures seen today.

Structure

Structurally, the Salt Range is the result of tectonic forces imposed during the later phases of the Himalayan orogeny in late Cenozoic time; the occurrence of the thick, incompetent Salt Range Formation at the base of the sedimentary sequence has strongly influenced the structure.

The Salt Range is a complex salt anticlinorium within which

this Eocambrian saliferous formation is tectonically repeated by Cenozoic subsurface flow to attain a thickness in excess of 2,000 m in certain of the anticlines. This structural interpretation is indicated by evidence from a borehole drilled on one of the major anticlines at Dhariala in the eastern part of the range (Gee, 1983); this hole was abandoned in rock salt after drilling 2,310 m of the Salt Range Formation. Within this borehole, the dip of the marl and gypsum-dolomite interbeds, often steep and variable, in no way conforms to the structure of the overlying competent formations. The original depositional thickness of this saliferous sequence was probably at least 1,000 m. At Dhariala, its present thickness is considered to be, at least partially, the result of isostatic plastic flow southward from the Soan Basin where, beneath the much greater thickness (at least 5,000 m) of Miocene-Pliocene sediments (as compared to those in the Salt Range area), gravitational forces could be expected to play a significant role.

The Salt Range anticlinorium is, in the main, a series of salt anticlines of the "salt pillow" type (Trusheim, 1960) in which the saline sequence has not penetrated the overlying nonsaliferous formations. But diapirism has been a major factor at a few localities; namely, Kallar Kahar, Vasnal, and strikingly, at Mari Indus and Kalabagh near the Indus.

Those acquainted with the geology of the area are agreed that the junction between the Salt Range and the formations underlying the alluvial plains to the south is a zone of reversed faulting—the major thrust of the area. This Salt Range Thrust has brought the older formations of the range upon the less disturbed late Cenozoic sequence that underlies the alluvium. The thrust zone is usually hidden by recent alluvial deposits and conglomerates, but evidence is exposed locally, for example, just west of Jalalpur at the eastern end of the range where, near the foot of the scarp, the Cambrian sequence and uppermost stage of the Salt Range Formation is thrust upon Late Tertiary sandstones (Gee, 1945, 1947; Yeats and others, 1984). Similar reversed faulting is seen near the Indus at Kalabagh, whereas at several localities along the foot of the scarp, local outcrops of conglomerate of probable late Pleistocene age are overthrust by Paleozoic formations. This is clear evidence of the very recent age of the Earth's movements, as emphasized by Yeats and others (1984) and supported by the results of investigations based on magnetostratigraphy and tephrochronology (Keller and others, 1977; Johnson and others, 1979; Reynolds and Johnson, 1985).

Until recently, the exact nature of the Salt Range Thrust, in particular the extent of the displacement, was a matter of conjecture (Lehner, 1945). With the recent interpretation of seismic reflection profiles across the Potwar, Salt Range, and alluvial plains to the south (Baker, 1987; Baker and others, 1988; Lillie and others, 1987), combined with drillhole, gravity (Farah and others, 1977), and paleomagnetic data (Johnson and others, 1979, 1986), these uncertainties have been largely resolved. Their interpretation indicates the presence of a décollement, with the Eocambrian and overlying Paleozoic-Cenozoic sequence displaced southward at least 20 km in the central Salt Range (Fig. 5).

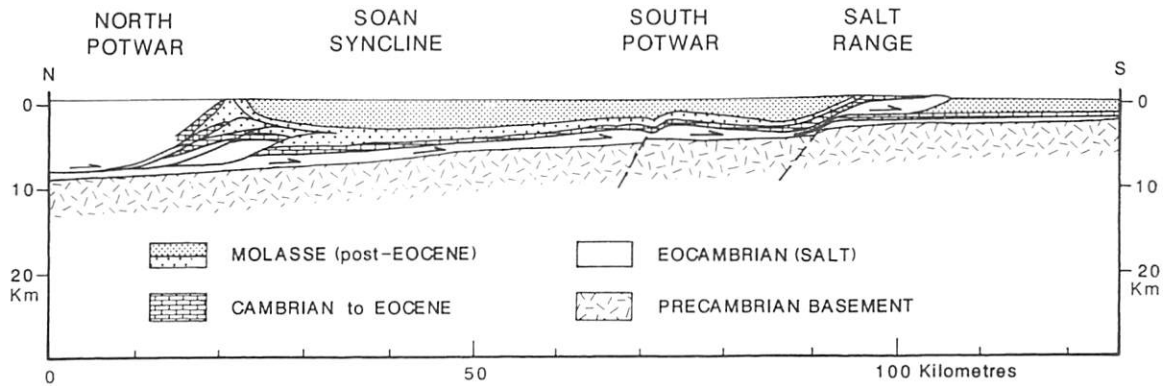


Figure 5. Section across western Potwar and the west-central Salt Range. After Jaumé and Lillie (1988), with minor modification.

The depth to crystalline basement beneath the Salt Range is estimated at about 3 km (Lillie and others, 1987). The seismic reflection data allow prediction of the succession below the Salt Range Thrust, which may prove to be of interest to oil companies (Gee, 1983; Khan and others, 1986). The western part of the Salt Range and nearby alluvial plains—where a more complete Mesozoic succession and well-developed Paleocene and Eocene limestone formations occur—would appear to offer the more favorable prospects. Seismic profiles of the Nammal–Musa Khel area and across the Tredian Hills would be of great interest.

Eastern end of Salt Range (Jogi Tilla to Khewra) (Plate 1: Sections p-q, t-u)

At its extreme eastern end, in the Jogi Tilla and Chambal ridges and for several miles west of Jalalpur, the Salt Range is narrow and restricted in width to steeply dipping monoclines, rendered structurally complex by reversed faults and vertical tear faults. Of the latter, one probably links the Jogi Tilla and Chambal ridges beneath the Bunhar River alluvium. Another develops from the thrust at the base of Chambal scarp and continues as a zone of vertical tear faulting, involving the Eocambrian-Cambrian, to link up with the sequence northwest of Jalalpur (Gee, 1947; Yeats and others, 1984).

In this eastern end of the range, erosion was intense during Late Cretaceous and late Eocene–Oligocene time. As a result, in Jogi Tilla only a thin Lower Permian and Eocene–Paleocene sequence occurs between the Cambrian and the unconformable Miocene sediments, whereas in Chambal and in the main range immediately west of Jalalpur, the Murree Formation directly overlies the upper members of the Cambrian succession. Some 15 km west of Jalalpur, Tobra conglomerates and sandstones of the Dandot Formation develop within the scarp sequence, underlying relatively thin Paleocene and Eocene limestones and shales that cap the plateau to the north; a workable coal seam occurs in the Patala Formation.

Westward to the Khewra–Choa Saidan Shah area, the Salt Range Formation and the Cambrian Jhelum Group continue in

force; the Tobra Conglomerates overlie a variable thickness of the Baghanwala Formation. Within the Khewra salt mine, the thick seams of good-quality rock salt dip northward in general conformity with the overlying sequence. In the Billianwala tributary valley immediately south of the salt mine, sub-recent sandstones, clays, and gypsiferous conglomerates occur with northerly dips of 40°, indicative of Late Quaternary to Recent thrusting within the Salt Range Formation (Fig. 6).

The broad, open synclines and close, often faulted anticlines of the plateau are bounded to the northwest by the Diljabba-Karangal Thrust, which terminates near Choa Saidan Shah. It is replaced by one of similar trend, but of opposite throw, repeating the complete sequence in the Gandhala Valley to the southwest.

Central part of Salt Range (Khewra to Warchha) (Plate 1: Sections g-h, i-j, k-m, n-o)

Westward to near Sakesar peak, the range widens to some 30 km. The orogeny having continued during Quaternary times, the topography of the plateau conforms in many respects to the geologic structure. In the north, the Eocene formations, capped in places by sandstones and clay-shales of the early Miocene and overlain unconformably by late Pliocene–Pleistocene Kalabagh Conglomerates, occur as broad, east- and west-plunging anticlines and synclines of varying wavelengths. The plunge variation results in large domes and basins, e.g., between Dharia and Kallar Kahar and westward via Vasnal and Khabakki in the approach to Sakesar. Several of these folds are faulted. Other faults occurring in the exposed older formations appear to be of normal type, locally accentuated by subsidence into the saliferous Salt Range Formation. In addition, steep-angle fault zones, probably tear faults, running obliquely to the general east-west structural trend, intersect the eastern plateaus between Makrach and Kallar Kahar, and at Vasnal, the movement is accompanied by the diapiric intrusion of the Eocambrian salt.

Where the range attains its greatest width between Kathwai and Uhhali, the belt of open folding is succeeded southward by a number of closely folded, often faulted anticlines and synclines,

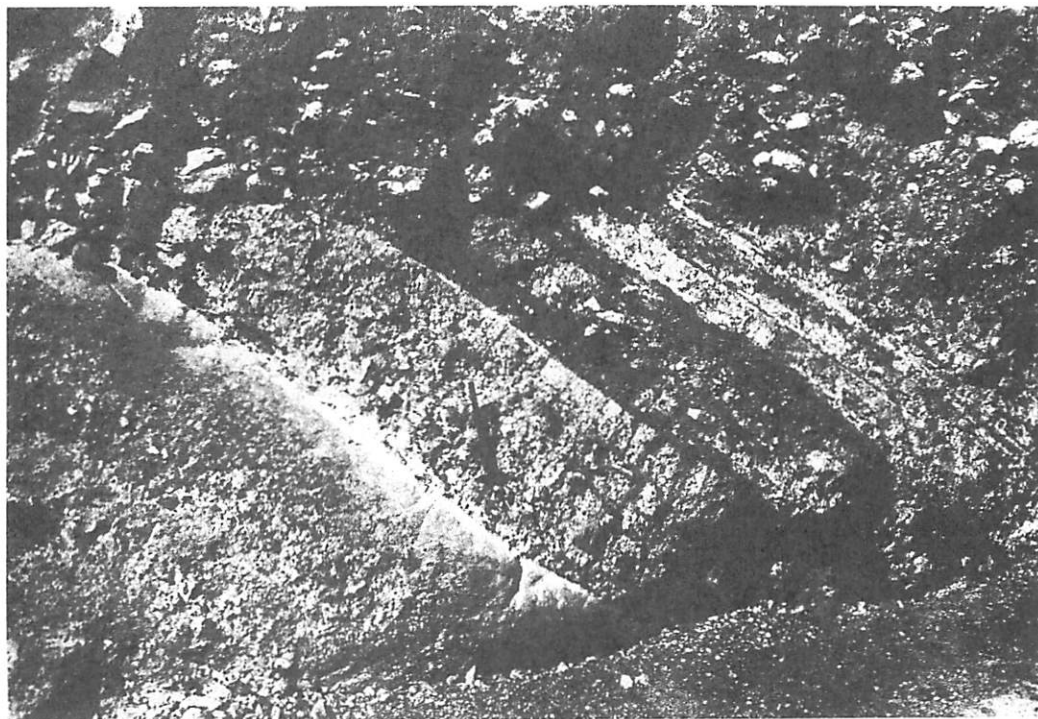


Figure 6. Sub-Recent sands, clays, and gypseous conglomerates dip northward in Billianwala nala, Khewra. From Gee (1947).

exposing in the anticlinal crests the Triassic Ceratite Beds (Mianwali Formation) and the underlying Permian formations. Sporadic faulted outcrops of the Khewra and Salt Range Formations also occur on the Permian limestone plateau.

The scarp slopes, in which the older formations are well exposed, are also structurally complex. East-west-trending overfolds occur at several places, e.g., below Dandot (Fig. 7) and Malot, whereas many of the gorges follow the line of transverse, north-south anticlines, often faulted along their axes, in which the Salt Range Formation is widely exposed. Slumping of the harder formations on the saline marl of the latter and on the incompetent clays of the Sardhai Formation adds to the complexities.

Within this central part of the Salt Range, the stratigraphic sequence changes considerably. The Eocene thickens from 105 m at Dhariala to some 165 m in the west at Khabakki; the coal-bearing formation of the Paleocene (Patala Formation) passes westward into a marine, mainly shale, facies, and the underlying Lockhart Formation develops as a nodular cliff limestone. West of Kallar Kahar, the shales and limestones of the Chor Gali Formation pass laterally westward into a predominantly calcareous facies merging with the uppermost Sakesar Limestone.

Below the basal Tertiary, the unconformity continues to rise westward. The full sequence of the Lower Permian Nilawahan Group is developed westward from the Sardhai gorge, and, in the next main ravine (the Nilawahan below Nurpur), the Upper Permian Amb Formation first appears. Higher members of the Zaluch Group develop rapidly westward, with the Wargal Lime-

stones coming in north of Katha and the Chhidru Formation a few kilometers farther west. These limestone formations form extensive outcrops above Jabbi and Warchha.

Near Kathwai, the Mianwali Formation (Lower Triassic) first occurs beneath the Tertiary unconformity. In the compact east-west folds southwest of Naushahra, sandstones, probably belonging to the Datta Formation of the Jurassic, appear to directly overlie the Mianwali Formation; the younger formations of the Triassic are missing.

Within this central Salt Range area, the unconformity below the Permian Tobra conglomerate intensifies in a northwesterly direction across the Cambrian sequence; of the Baghanwala Formation, only the lower portion remains, restricted to the vicinity of Makrach. In the Nilawahan, the Jutana Formation, which is present in the lower part of the gorge, dies out upstream, whereas in the gorge northwest of Katha, the Kussak Formation is overstepped; the Tobra Formation rests directly on the sandstones of the Khewra Formation. The latter thins westward, but persists to beyond Warchha.

The Salt Range Formation continues to be well developed throughout the area, with a gypsum-dolomite member often capping the sequence. Within this unit, brown bituminous shales as much as 5 m thick occur sporadically, e.g., in the Khewra gorge, and up the Nawabi Kas west of Makrach. The underlying red Salt Marl member with rock salt, worked in the Khewra and Warchha mines, forms wide outcrops, especially in the lower scarp slopes and gorges. Marl with massive gypsum and dolomite

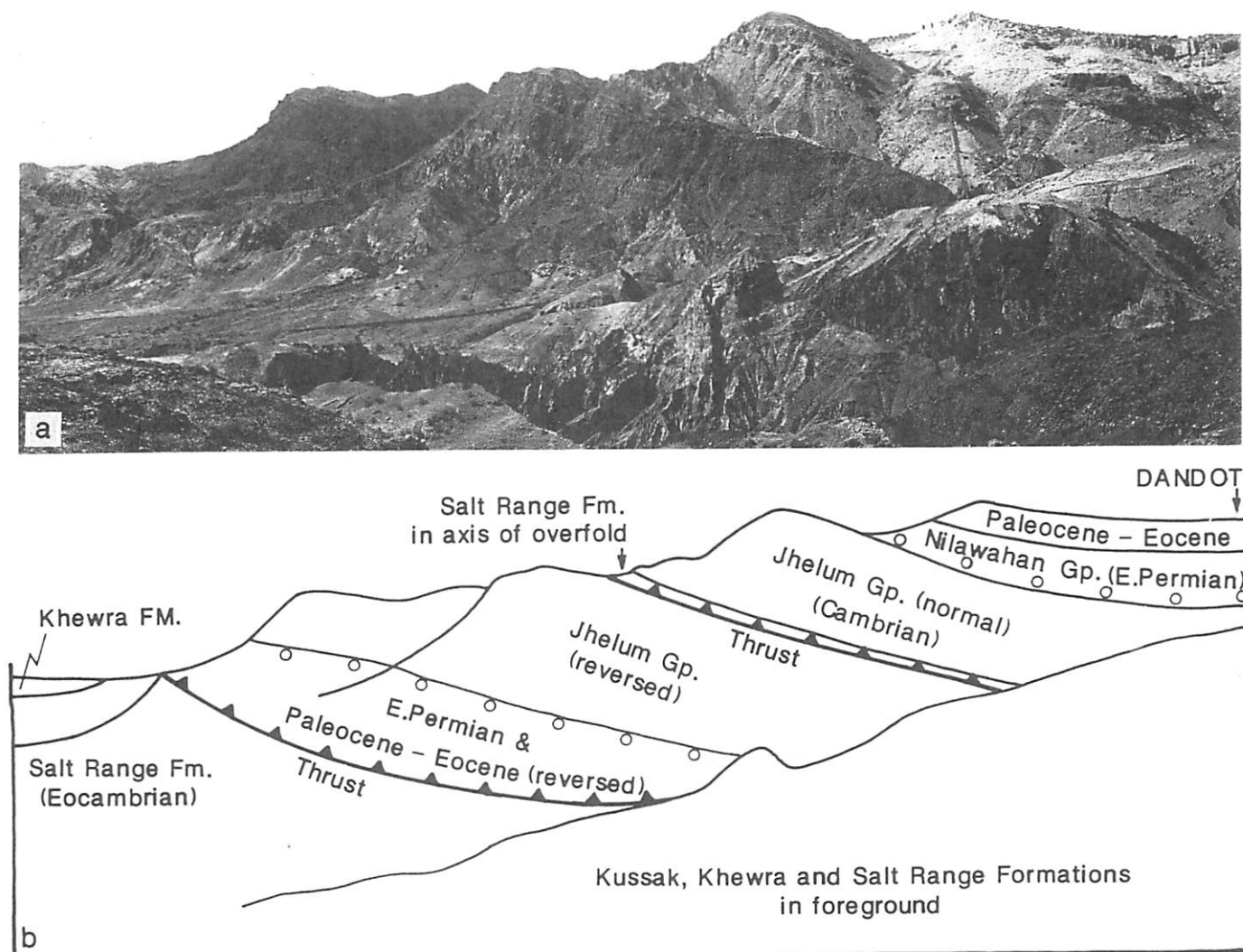


Figure 7. Looking westward at the thrust overfold below Dandot. a, Photo. b, Line drawing. From Gee (1947).

occurs in the lower exposures. In the gorges above Warchha and Chenki, oil shales and bituminous flaggy dolomite again occur.

Western part of Salt Range (Sakesar to Kalabagh), Sakesar-Chhidru area (Plate 1: Sections e-f, g-h)

Here, the range curves northwestward. This directional change coincides with a change in the strike of the formations accompanied by complex fault lineaments. The latter are well exposed in the steep southern slopes of Sakesar ridge overlooking the Dhodha Wahan. This section also provides critical evidence on the age of the Salt Range Formation in the unconformable overlap of the Tobra Conglomerates onto that formation. The sequence and structure are illustrated in Figure 8.

Briefly, the section in the right-hand slopes of the Dhodha Wahan gorge includes three repetitions of the Eocambrian-Paleozoic succession; thrust faults separate these repetitions. In the lower western slopes, the Salt Range Formation is overlain by the complete sequence of the Cambrian Jhelum Group on which the Tobra Conglomerates rest with an angular unconformity. In the second repetition—which crops out in the middle scarp slopes, crosses the gorge, and continues south of the Kanjra Range—the overstep of the Tobra Formation has appreciably increased, the conglomerates resting on varying thicknesses of the Khewra sandstones. Finally, in the third repetition, below Sakesar, the latter formation is also missing as a result of pre-Permian erosion; the conglomerates directly overlie the saliferous Salt Range Formation.

Similar faulted repetitions are seen in the Chhidru Hills a

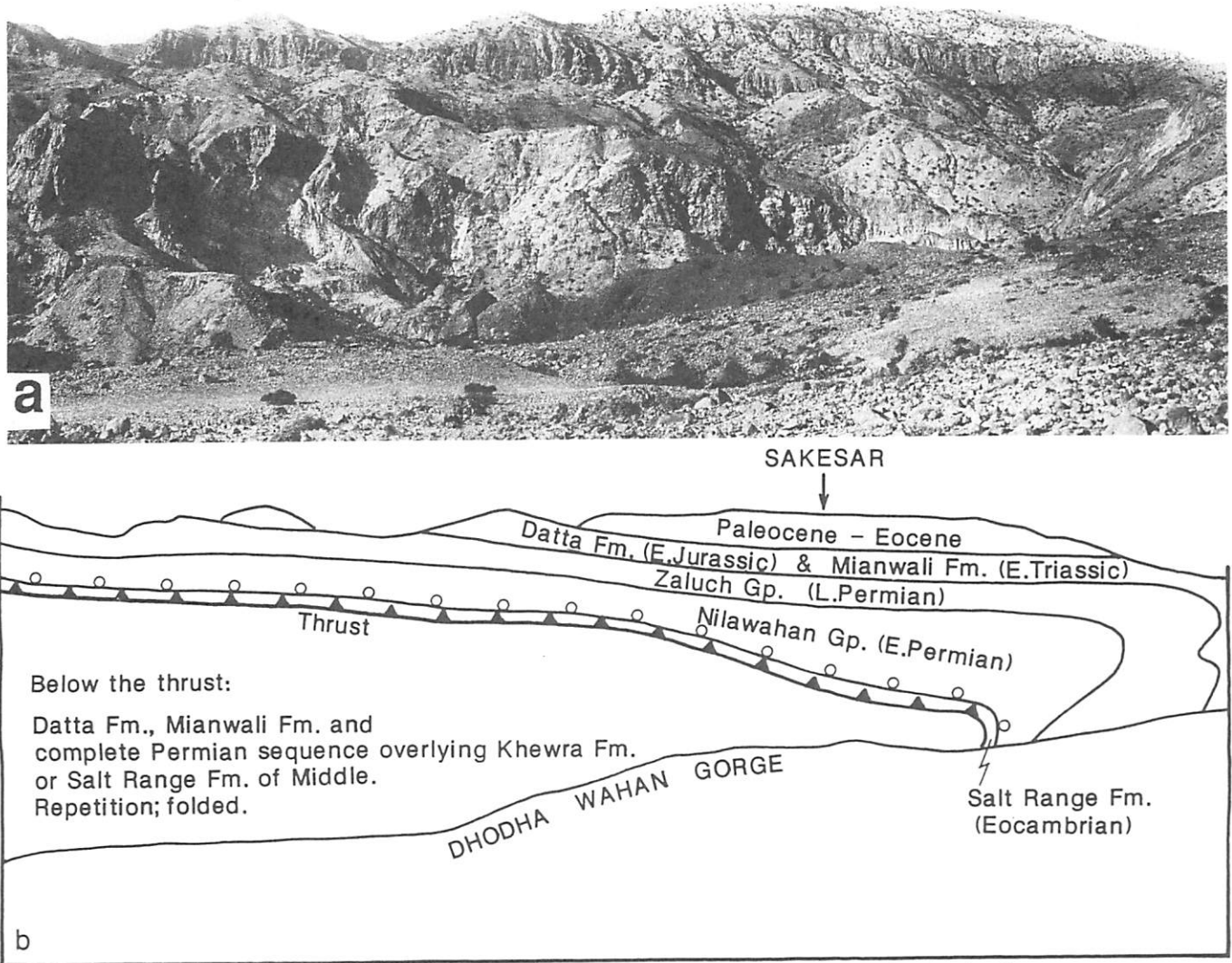


Figure 8. Looking north-northwest at the repetitions below Sakesar. a, Photo. b, Line drawing. From Gee (1947).

few miles to the northwest, with the full Cambrian sequence represented in the outcrops near the base of the scarp and the markedly transgressive Tobra Conglomerates resting directly on the Salt Range Formation in the inner repetitions. Where it overlies the formations of the Cambrian sequence, as throughout the central and eastern parts of the Salt Range, the Tobra Formation is usually mainly arenaceous and varies from a single boulder bed to a conglomerate about 30 m thick. From Sakesar northwestward, where it rests directly on the Salt Range Formation, it is a predominantly argillaceous facies, as much as 100 m thick.

In all of the above-mentioned repetitions between Sakesar and Chhidru, the complete Permian and Lower Triassic sequence occurs, being directly overlain by sandstones of the Lower Jurassic Datta Formation. In the highest repetition, which forms the

main Sakesar ridge, the overlying lower Tertiary and Miocene formations are present as steep folds, in some cases overfolded. Similar overfolding is seen in the Permian limestones of the Kanjra Range to the south of the upper reaches of the Dhodha Wahan (Fig. 9). In the northeastern slopes of the Chhidru Hills overlooking the Khaji Wahan and in the isolated hills to the northwest, evidence of late Quaternary folding is apparent in the several occurrences of post-Tertiary conglomerates, unconformably overlying the older formations, and in some instances, involved in the folding and faulting.

The Range near Nammal. From Sakesar, the upper repetitions of the Dhodha Wahan section continue north-northwest through Nammal to link with the Tredian Hills near Buri Khel; exposures are excellent. The sequence, ranging in age from Per-

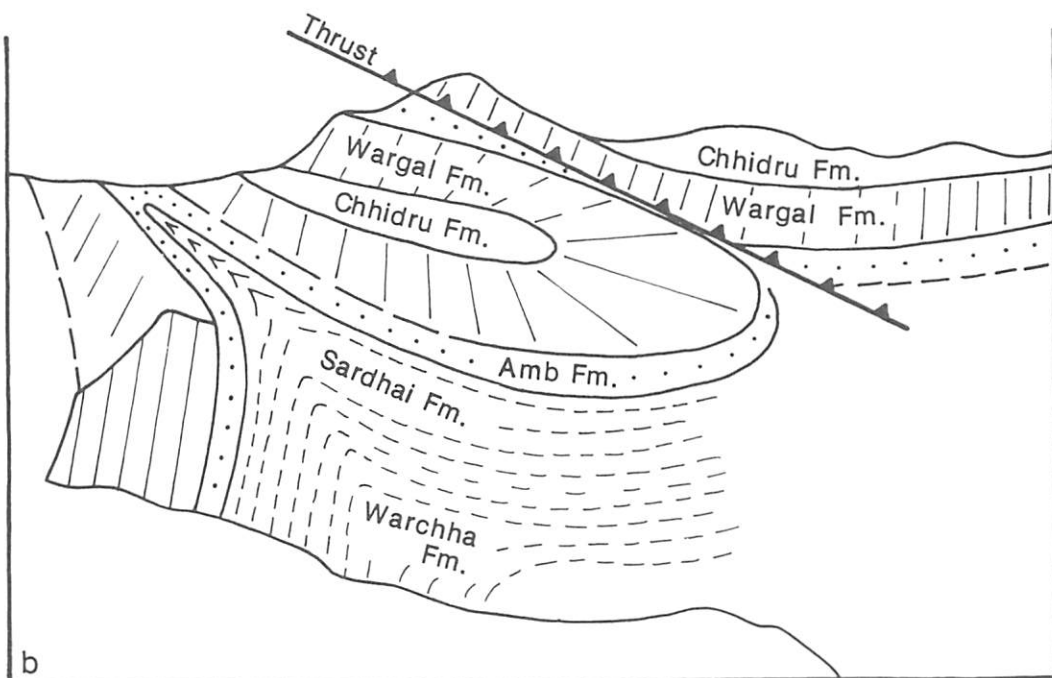


Figure 9. Looking northward at overfolding of Permian strata in the Kanjra Range. a, Photo. b, Line drawing. From Gee (1945).

mian to Pleistocene, generally dips east-northeast at moderate angles in the lower scarp slopes, increasing to vertical in the southern outcrops of the Murree Formation and the unconformable late Pliocene-Quaternary conglomerates. Subsidiary sharp folds, often faulted, occur in the southern outcrops and again in the approach to the Tredian Hills.

Tredian Hills (Plate 1: Section c-d). This triangle-shaped area, 12 km wide in the south and tapering northward to the Jaba Nala near Khairabad, is exceptional in that the lineaments run northwest-southeast, that is, oblique to the northerly trend of the scarp. The area consists of a succession of folds that are tighter in the southwestern outer slopes of outcropping Permian and Mesozoic formations, and more open toward the northeast in the younger sequence.

Within this area, the Late Cretaceous unconformity rises, and the Surghar Group appears toward the north. In several of the gorges near their exit, inliers of the Salt Range Formation crop out in anticlinal cores, overlain by the Tobra Conglomerates. Thrust repetitions of these two formations occur north of Buri Khel, near Ghundi and at Sanwans.

In the higher part of the area, capped by the Paleocene-Eocene sequence, the folding is more open, although the flanks are often steeply inclined to vertical. In the northern part of the area, the Paleocene Lockhart limestones are exceptionally thick (ca. 300 m). In the approach to the Jaba Nala, the Sakesar Formation is represented by massive gypsum and anhydrite. The dip-slopes to the east and north, consisting of steeply inclined Murree and Chinji Formations, are capped unconformably by an extensive development of the Kalabagh Conglomerates. Evidence of the involvement of the latter formation in the final phase of overthrusting occurs at the base of the scarp near Ghundi (Gee, 1980; Yeats and others, 1984).

Daud Khel-Mari Indus-Kalabagh area (Plate 1: Section a-b). This northwestern extremity of the Salt Range includes an extensive broken-hill area in the east, which comprises a Miocene-Pliocene sequence free of complex tectonics (Hussain and others, 1979) and an extremely complex outer fringe, characterized by steep dips, numerous faults, and by the diapiric intrusion of the Eocambrian Salt Range Formation in the vicinity of the debouchment of the Indus onto the alluvial plains at Mari Indus and Kalabagh (Gee, 1947; Yeats and others, 1984). There, the outer, tectonized area is bounded on the east by a well-marked strike-slip fault, the Kalabagh Fault of Yeats and others (1984), which continues northward up the Chisal Algad (the Luni Wahan of certain previous publications), whereas at the western foot of Kalabagh Hill, adjoining the alluvial plains, there is more evidence of thrusting of the Salt Range Formation onto Quaternary conglomerates.

Thrusts and steep-angle faults associated with the Kalabagh fault have resulted in vertical outcrops of the Salt Range Formation, Tobra Conglomerates, and Tertiary formations at the southern end of this area immediately north of the Jaba Nala, and again in the approach to the Mari Indus salt dome where Cretaceous and Tertiary formations are involved. The Kalabagh fault

can be traced northward (Gee, 1945, Plate 1, and unpublished geologic map 38012 [scale, 1 in. = 1 mi]) within the Siwaliks to some 15 km north of Kalabagh, where it swings westward and decreases somewhat in dip. This suggests a close relationship between the thrusting and the tear faulting. The characteristics of the Kalabagh fault, of the thrusts associated with the main Salt Range Thrust and those in which the Quaternary deposits are involved, are described in more detail by Yeats and others (1984).

Within Kalabagh Hill, overlying the Salt Range Formation with a marked discordance, is a complex of younger formations ranging in age from Permian to Pleistocene. The sequence is comparable to that of the Tredian Hills but with a thinner development of the Paleocene and Eocene and the Murree Formation. Capping Kalabagh Hill, the late Pliocene-Pleistocene Kalabagh Conglomerates, folded and overlying the older sequence with an impressive unconformity, provide evidence of a Late Quaternary orogenic phase and uplift in sub-Recent times.

To the east of the Kalabagh Fault, the Nagri Formation consists of massive sandstones, in part conglomeratic, and subordinate clay-shales. This facies contrasts with the normal, sandstone-clay sequence occurring across the tear fault on the western side of the Chisal Algad. Considerable dextral displacement along this strike-slip fault is indicated. A recent survey by McDougall (1988) covers this structurally complex reentrant and its linkage with the Surghar Range and Kohat region.

RELATED AREAS

Neighboring areas of the Upper Indus Basin, that are closely related stratigraphically to the Salt Range are the Trans-Indus Ranges and adjoining Bannu Plain to the west, the Soan Basin of the Potwar Plateau to the north, and the Kohat Salt Region west of the latter (Figs. 1, 10).

Trans-Indus Ranges and Bannu Plain

These regions include the Surghar-Shinghar Range, the Marwat and Khisor Ranges, and the Pezu, Manglin, and Manzai anticlines to the southwest, flanking the Bannu Depression.

At the foot of the Surghar Range scarp, though hidden by alluvium, the Salt Range thrust zone can be expected to continue; an equivalent thrust must underlie the alluvium near the base of the Khisor Range. Borehole evidence on the plains near Kundian (Fig. 1) indicates a vertical component on the thrust of at least 1,500 m.

In the reentrant north of Kalabagh, the structure of the Surghar Range is complex; Quaternary conglomerates are involved, often dipping at steep angles. Beyond this, the range is an asymmetric, in places overfolded, anticline; the axis of the fold runs along the lower scarp slopes and curves from east-west to north-south through Makarwal Colliery. The oldest formations exposed are of the Permian Zaluch Group, overlain by a Mesozoic-Lower Tertiary sequence comparable to that of the west-

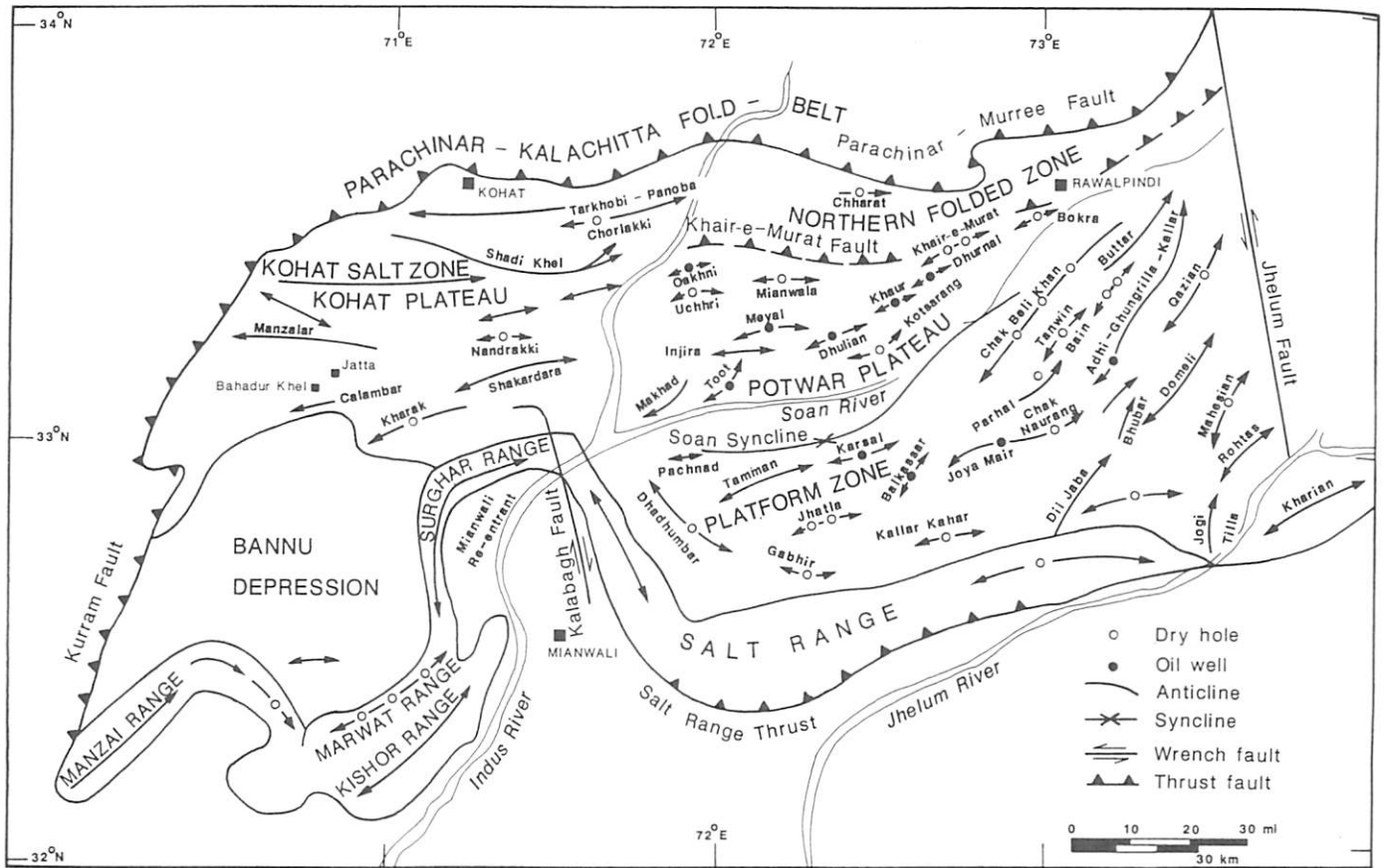


Figure 10. Structural map of the Kohat-Potwar depression. After Khan and others (1986), with minor modification.

ernmost part of the Salt Range, but with the development of a workable coal seam in the Hangu Formation of the Paleocene. Southerly thinning of the Miocene occurs as it does east of the Indus, and the Murree and Kamli Formation are progressively overlapped southward by the Siwaliks.

As in the Surghar Range, the eastern anticlinal flank of the Khisor Range is deeply eroded to form steep scarps exposing the older formations. This sequence portrays the effects of the Sargodha High, which during the late Eocene-Oligocene period of uplift and erosion, folded the area along an east-west axis and exposed the Upper Permian Chhidru Formation in the middle part of the Khisor Range, the Triassic Mianwali Formation at its northern end, and stratigraphically higher Triassic-Lower Jurassic formations in the southwest. The Siwalik sequence rests unconformably on these formations. In the lower scarp slopes of the southwestern end of the range, near Saiyiduwali, beneath the Tobra conglomerates, the Cambrian is exposed; this exposure includes the Khewra Formation at the base adjoining the alluvium, overlain by higher members of the Jhelum Group, here largely gypsiferous.

The Marwat Range to the west is an impressive anticline exposing the Siwalik sequence, with steep dips in the eastern limb. At the southwestern end in Sheikh Budin Mountain, the

older exposed sequence—comparable to that of the Surghar Range—ranges in age from Late Permian to Early Cretaceous. Eocene-Paleocene formations are apparently absent throughout the Marwat Range.

Running northwestward from the southwestern end of the latter, the Siwalik formations continue as an arc, linking with the foothills of the Sulaiman Range. They occur as low domes with axial tear faults. The unconformity at the base of the Siwaliks lifts northwestward, as proved by a borehole on the Pezu structure. There, beneath 628 m of Upper Tertiary sandstones and clays, an Eocene-Paleocene sequence 155 m thick occurs, underlain by Cretaceous-Jurassic formations totaling 1,440 m. The borehole terminated in the Lower Jurassic Datta Formation.

Enclosed by the Trans-Indus Ranges to the east and south, by the Kohat salt region to the north, and by the Tertiary foothills of Waziristan to the west, the Bannu plain is capped by alluvial deposits. Formations of the Siwalik Group undoubtedly underlie these superficial deposits, to be followed in depth by a sedimentary sequence, in general comparable with that of the surrounding hills. This sequence is confirmed by the results of seismic lines described recently by Khan and others (1986). As the sequence is the structural equivalent of the Soan Basin, at least gentle folding can be expected.

Soan Basin of the Potwar Plateau

The site of Pakistan's producing oil fields, the Soan Basin has been explored since the early part of the present century by several companies, and more recently by the Oil & Gas Development Corporation of Pakistan. Based on the results of field work, drilling, and seismic surveys, an up-to-date account of the area is given in Khan and others (1986).

Trends of the major unconformities within the sequence, as exposed in the Salt Range, suggest that the Cambrian formations of the Jhelum Group may be absent in the western parts of the Potwar Plateau. Only the Khewra Formation occurs in the Joya Mair dome; the younger Nilawahan Group formations are expected to occur throughout the basin, and the Upper Permian and Mesozoic sequence to develop progressively northwestward. In the southern structures, the Permian first appears at Karsal. The Paleocene and the Nammal and Sakesar Formations are present throughout the Soan Basin in variable thickness, overlain by the Chor Gali Formation in the extreme north.

Anticlinal trends are shown in Figure 10. In the extreme north of the Potwar Plateau within the Northern Folded Zone (Khan and others, 1986), where the Murree Formation occurs at maximum thickness, possibly more than 3,000 m, the structure is very complex, consisting of tight east-west folds, in part isoclinal and sheared by steep-angle faults. Here, gypsiferous shales and thin limestones of the Chor Gali Formation crop out in folded inliers, whereas to the south the Khair-e-Murat ridge comprises steeply dipping lower Eocene limestones.

The Kala Chitta Range, consisting of a Lower Tertiary-Mesozoic sequence, structurally complex, rises immediately north of the Soan Basin, separated from the latter by a major thrust zone, the Parachinar-Murree fault.

Kohat salt region

The region is bounded on the north by the westward continuation of the Parachinar-Murree thrust zone. The surface formations of Kohat are all of Tertiary-Quaternary age; the post-Eocene sequence is similar to that of the Potwar Plateau. The latter fills the synclines; mainly Eocene formations crop out in the anticlines (Figs. 1, 10).

Beneath this Tertiary cover, it was reasonable to conclude on regional grounds that a Mesozoic-Permian sequence, similar to that occurring beneath the western Potwar Plateau, can be expected in Kohat (Gee, 1983). Whether the Salt Range Formation underlies the latter has yet to be determined. On the evidence of limited seismic data, Khan and others (1986) inferred the occurrence of a Paleozoic, Mesozoic, and Paleogene succession in the subsurface.

Uncertainty regarding the depths to this underlying sequence and to the structure in depth results from the occurrence of a rock salt formation (Bahadur Khel Formation) of unknown thickness within the Eocene over much of the region. That the pre-Eocene formations are tightly folded and faulted in many instances is very probable; to what extent the complex surface structures are the

result of a décollement within the Eocene salt is, at present, uncertain. Seismic surveys will no doubt eventually provide an answer.

The salt is exposed in anticlines, usually faulted, between Nandrakki and Kharak in the south; its northern limit is in the vicinity of the Shadi Khel structure. North of the latter, in the Panoba-Tarkhobi area, it is replaced by the Panoba Shale Formation. In that anticline, the gypsiferous shales and thin limestones of the Eocene are acutely folded. In contrast, the underlying, massive Paleocene limestone crops out as an inlier at Tarkhobi, in an unfaulted dome although with steep dips in the flanks. A tectonic discordance between the incompetent Eocene sequence and the underlying, more competent Paleocene formation is indicated. Similar situations can be expected at depth within certain of the superficially complex folds in the salt-bearing area to the south.

CONCLUDING REMARKS

The Salt Range and its Trans-Indus extension are the southern margin of the Tertiary to Recent Himalayan orogen in Pakistan. The structures that now characterize these ranges and the related areas of the Potwar Plateau, Kala Chitta Hills, and Kohat Plateau were determined mainly by the tectonic forces that developed in the northern parts of the orogen from late Eocene time onward, particularly during Quaternary time.

Advance of the thrust sheets southward toward the northern edge of what is now the Soan Basin and the filling of the latter with 5 km of Miocene to Recent strata apparently led to migration of Eocambrian salt southward and thickening of the latter in the frontal thrust sheet of the Salt Range. The new reflection seismic data provide evidence of at least 20 km of southerly displacement on this thrust; underlying, younger successions may prove interesting targets for future hydrocarbon exploration.

The field evidence and data from boreholes suggest that uplift along the Sargodha High to the south of the Salt Range played a significant role from Late Mesozoic time. The absence of Upper Cretaceous strata, the major unconformity at the base of the Paleocene, and the stratigraphy of the Paleocene and Eocene formations indicate that tectonic instability along the Indian continental margin started at least by Early Tertiary time. In the eastern half of the Salt Range and adjoining Soan Basin, Lower Tertiary formations, particularly the Paleocene, thin southward; they are both absent from the sequence beneath the eastern alluvial plains; reference the boreholes near Lilla and Warnali (Khan and others, 1986; Lillie and others, 1987) in the approach to the Sargodha High.

That the suggested early uplift of the Sargodha High continued during late Eocene and Oligocene time is indicated by the major unconformity at the base of the higher Tertiary sequence in the lower scarp slopes of the western Salt Range near Chhidru and in the Khisor Range. If this uplift of the high is related to tectonic loading of the outer, northern edge of continental India, as suggested elsewhere (e.g., Duroy and others, *this volume*), then the thrusting in the far north may have started earlier than have previously been suggested.

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