Resource Evaluation of Selected Minerals and Industrial Commodities of the Potwar Plateau Area, Northern Pakistan

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Chapter H of

Regional Studies of the Potwar Plateau Area, Northern Pakistan

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Abstract

A part of northern Pakistan was reviewed by a multidisciplinary team to provide a broad geological synthesis in connection with a study of the coal resources of the country. This review was designed to help the earth-resource explorationists and planners, as well as to provide a means for mutual training in team studies and in some geological specialties. An integral part of this synthesis is a survey of the distribution and assessment of the development potential of certain metals and industrial commodities.

Because knowledge of the distribution and potential of most industrial commodities had been published (Zaki Ahmad, comp., 1969, Geological Survey of Pakistan Records, v. 15, pt. 3), the primary task involved compilation of available data. This effort showed that the quality of the basic data was mixed. An improved means of recording data on site, using modern topographic maps, for systematic check of the accuracy of basic commodity identification and summary geologic description would greatly benefit future assessment efforts of Pakistan's resources.

Data on the occurrence of metallic mineral resources were meager and provided one opportunity for a reconnaissance study to contribute to a resource evaluation. Most rocks of the Potwar Plateau area proved to lack the degree of induration suitable for vein deposits, but a vein system does cut the older, more indurated rocks of the northernmost part of the study area. Enough of these veins carry anomalous amounts of the base metals copper, lead, zinc, and mercury; the precious metal silver; and the indicator metals arsenic and cadmium to illustrate that hydrothermal systems are present, particularly in Proterozoic phyllites. The transition of the vein system to aplite sheets links the anomalous abundance of metals to granitic stocks as a possible source of metal-bearing fluids, as well as of heat to drive the hydrothermal systems. This suggestion, however, is based on a cursory field study and remains unsupported by geophysical data of the sort commonly applied to seek out likely sites of blind stocks.

The results of this resource study corroborate the knowledge that industrial commodities such as salt, gypsum, cement rock, and certain clays are present in abundance and that the potential for their further development is excellent. Basic stratigraphic principles can be applied to exploration because these commodities are contained in particular formations. The presence of many other industrial commodities, such as bauxite, glass sand, other clays, and hematite iron ores, is also well known, but these are present in marginal quantity or quality or do not have a ready market. The development of these commodities is likely, at least for certain limited applications (for example, bauxite is unlikely to occur in sufficient quality and quantity to provide the basis for an aluminum industry, yet it may serve as an additive in the cement industry). The link between commodity conditions and industrial economy was explained by Ahmad (1969).

The resource potential for metallic minerals, particularly for copper, lead, zinc, and silver, is low over most of the region and remains unknown in the southernmost part, which is extensively covered by alluvium. Over most of the central Potwar Plateau region, geological and geophysical data are sufficient to assign a low potential for mineral resources at a high degree of confidence. A low-potential rating is given only a low degree of confidence in the northernmost part of the study area, where geochemical reconnaissance is incomplete and geophysical data are nonexistent. In other words, there is a possibility in this northernmost terrane of turning up additional favorable evidence that could lead to the designation of some tracts as having a moderate or even good potential.

Introduction

The Potwar Plateau study of Pakistan (figs. H1, H2) was designed to demonstrate the effectiveness of a team approach to analysis of regional coal basins, as currently practiced by the U.S. Geological Survey. Although the focus remained on coal-related studies, a more general study of resource potential was added. Counterpart scientists of the Geological Survey of Pakistan participated in the study to gain hands-on training.

This chapter is a product of a cooperative program between the Geological Survey of Pakistan and the U.S.

Figure H1. Location of the Potwar Plateau study area (box).

EXPLANATION

Alluvium (Quaternary)—Deposits of basins or lowlands

Sedimentary and metasedimentary rocks (Quaternary to Proterozoic)—Mainly rocks of the foothills; also present in the Himalayas

Granite (Pliocene to Jurassic)—Mainly rocks of the high Himalayas; small bodies in the foothills

Diorite (Tertiary? to Mesozoic)—Rocks of the high Himalayas

Amphibolite (Mesozoic?)—Includes ophiolite; rocks of the high Himalayas

Thrust fault—Dotted where concealed, sawteeth on upper plate

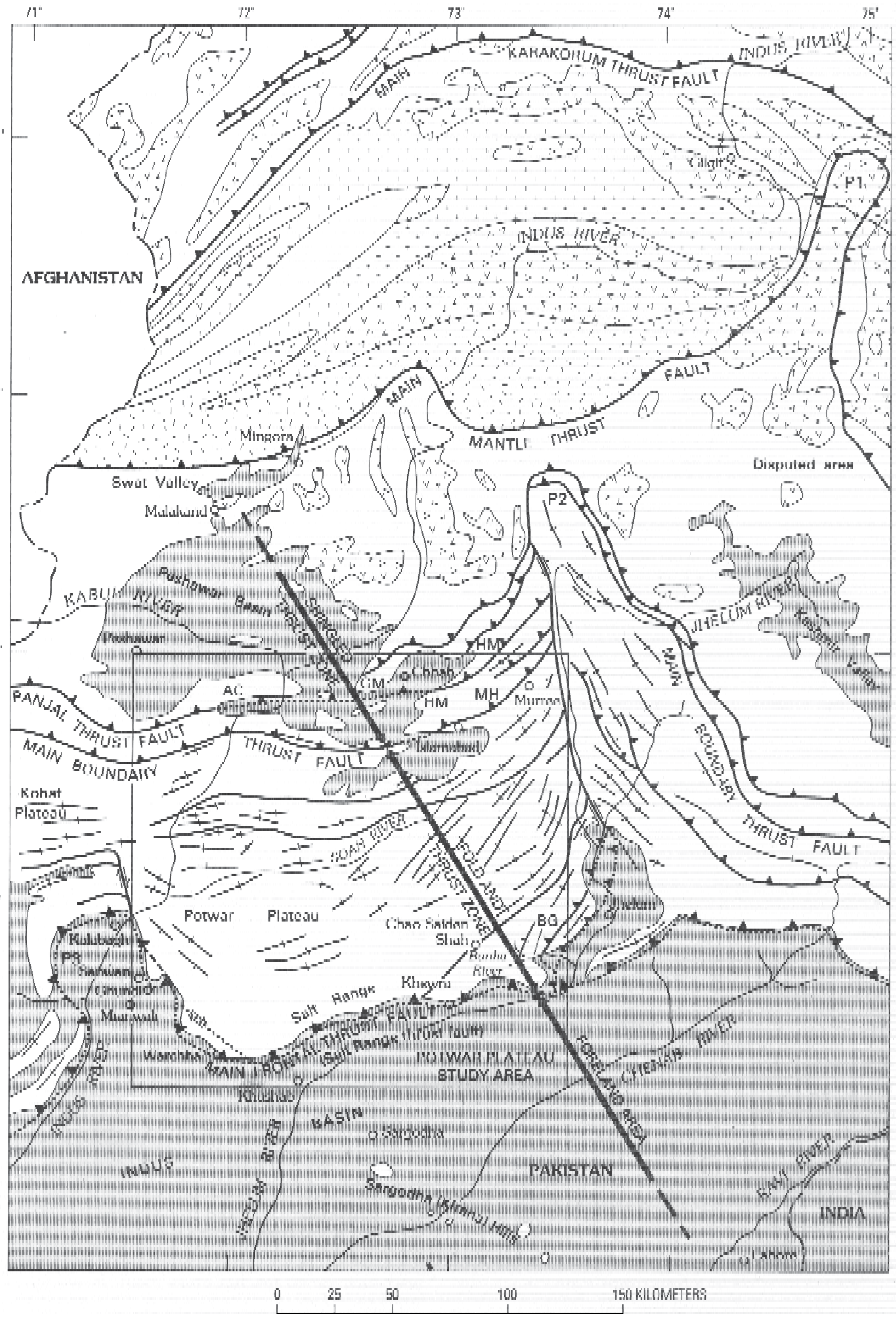
Strike-slip fault—Dotted where concealed or where it becomes a concealed (blind) oblique-slip ramp. Arrow couple shows relative movement

Fold axis

P1 **Pivot point**—Approximate site of vertical pivot axis for syntax; showing, by number, order of inception

Tectonic zones and foreland area—Discussed in text; dashed where extent remains undetermined

Figure H2 (above and facing page). Geologic setting of the Potwar Plateau study area (box). Sites: AC, Attock-Cherat Range; BG, Bunha River gap; GM, Gandghar Range; HM, Hazara Range; MH, Margala Hills. Figure from Drewes, 1995, figure 2, on which the geology was adapted from Kazmi and Rana (1982) and unpublished geologic mapping compiled by M.A. Bhatti, Feroz-ud-din, J.W. McDougall, P.D. Warwick, and Harald Drewes (1991–94).


AFGHANISTAN
KARAKORUM THRUST FAULT
MAIN MANTLE THRUST FAULT
INDUS RIVER
Gilgit
P1
P2
Disputed area
Mingora
Swat Valley
Malakand
KABUL RIVER
Peshawar
Peshawar Basin
JHELUM RIVER
HM
MH
HM
GM
AC
Murree
PANJAL THRUST FAULT
MAIN BOUNDARY THRUST FAULT
Kohat Plateau
SOAN RIVER
Potwar Plateau
FOLD AND THRUST ZONE
BG
Chao Saidan Shah
Kalabagh
Khewra
Salt Range
MAIN FRONTAL THRUST FAULT
(Salt Range thrust fault)
POTWAR PLATEAU STUDY AREA
Mianwali
FORELAND AREA
CHENAB RIVER
INDUS BASIN
Sargodha
PAKISTAN
Sargodha (Kirana) Hills
RAVI RIVER
INDIA
Lahore
71°
72°
73°
74°
75°
36°
35°
34°
33°
32°
0 25 50 100 150 KILOMETERS

Geological Survey (USGS), sponsored by the Government of Pakistan and the U.S. Agency for International Development (USAID). Funding was provided by USAID through project 391–0478; Energy Planning and Development Project, Coal Resource Assessment Component 2a; and Participating Agency Service Agreement (PASA) 1PK–0478–P–IC–5068–00.

Project Aims and Logistic Restraints

This chapter offers a review of the known and potential distribution of selected metallic minerals and industrial commodities in the Potwar Plateau area, Pakistan. Under Pakistani policies, the development of oil, gas, and uranium energy resources is the responsibility of agencies other than the Geological Survey of Pakistan; therefore, these commodities were not studied, although oil field sites are indicated for general information on plate H1, the commodity distribution map.

Reconnaissance field checks were made of sedimentary deposits (or sedimentary-hosted hydrothermal deposits(?)) and vein-hosted hydrothermal deposits. Sediment-hosted deposits were reported previously (Fleming, 1852; Crookshank, 1954; Gilani, 1981; Abbas, 1985); vein deposits are newly recognized as potential targets. Because the sediment-hosted deposits had been tested and described (Gilani, 1981), our effort concentrated on the veins, mainly through geochemical reconnaissance. Iron occurrences are treated with the sedimentary rock-related commodities to which they are genetically related. This limited focus to our field efforts, plus some key geological observations of rock conditions, restricted the area in need of testing to a manageable extent. The process of selecting a worthy topic of field investigation, aimed at extending resource knowledge and manageable in the few weeks of available field time, plus support from existing chemical laboratories at the Geological Survey of Pakistan, was of itself a part of our training-by-doing operation.

It was also determined that the resource chapter would not treat the widely distributed but economically vital commodities, usually developed locally, such as sand and gravel, road metal (crushed rock for construction needs), brick clay, and common building stone. Commonly, their sources are only located close to markets, and their further development is unlikely to be influenced by contributions we might offer.

Remaining for consideration are, mainly, salt (NaCl), gypsum, cement rock (limestone), and certain clays, as well as less common occurrences of other clays, glass sand, potash salt, celestite, ocher, and barite. Some of these materials are utilized in local industries; others are not utilized, in part, because their abundance is too sparse or quality too poor.

Other commodities are mentioned for completeness rather than for their significance. Alluvial gold and jadeite have been obtained from the Indus River deposits in the Potwar Plateau area. Details on these occurrences remain unknown to us, and we suspect this signifies the deposits were economically submarginal. In any case, testing for such occurrences was not feasible, mainly because the river was accessible by vehicle in very few places.

As a result of all these considerations, we show on plate H1 primarily two kinds of data. First, the sites of known industrial commodities and those metals not further tested are shown. Second, we show the sample sites and elements in anomalous abundance from our study of vein geochemistry. Both kinds of data are briefly described in tables H1 and H2 (tables follow References Cited), keyed to the commodity distribution map (pl. H1).

Additionally, large steep faults and intrusive igneous rocks, which can offer channelways for hydrothermal fluids migrating upward, were checked in a cursory manner for mineralization. This check turned up only a few sites on faults containing visibly mineralized rock and only a few sites providing geochemical anomalous results. The chief exceptions concerned a vein along the Panjal thrust fault in the Hazara Range (fig. H2).

Thus restricted in field scope and commodity types reviewed, we had a feasible objective that could offer an opportunity to gain new insights into the resource potential of a large region, while illustrating how such an investigation might benefit by a team approach.

Project Methods

Various work methods were utilized in an effort to adapt to particular field and office situations. Initial field efforts were directed toward getting acquainted with rocks, faults, and outcrop conditions, learning to utilize old reports, and managing without the base maps. During visits to potentially mineralized sites, grab samples were taken of altered rock, veins, and alluvium, according to what was present. Typically, each sample consisted of about six or eight chips 4–8 centimeters (cm) across, or as many handfuls of alluvium, from which a surface layer, organic material, and pebbles were removed.

Many of the samples taken during the first field visit (1989) were analyzed in a laboratory of the Geological Survey of Pakistan before the second field visit (1990). Results of the first round of sampling were thus useful in sharpening our focus on what and where to collect during the second field season, namely, the quartz veins in the northernmost ranges. Field work and analytic work were completed, and an industrial commodity map was compiled during a second phase of the study.

Project Results

The rocks in much of the Potwar Plateau region are unsuitable as hosts of metallic mineral deposits. That this region was not prolifically endowed with metal accumulation has long been known; the ancient Indus Valley cities, such as Harappa, obtained their copper from western Baluchistan, probably as smelted but unrefined copper, to judge by the small accumulations of slag at that city. In essence, then, most of the study area is assessed as having a low potential for vein deposits because the rocks are too poorly indurated, which probably reflects their very shallow tectonic position and young geologic age. The absence of young intrusive rocks is also a major detrimental factor. Sedimentary ore deposits are also expected to have a low potential here because a rapid rate of deposition characterizes the rocks, thereby diluting, rather than concentrating, the deposits from any favorable process leading to sedimentary occurrences of metals.

The remainder of the study area does have rocks with sparse veins, and some of these do carry anomalous concentrations of base, precious, and indicator metals, which suggest past hydrothermal activity (pl. H1). The resource potential rating for these parts of the study area is thought to be low because of the absence of other favorable factors from geologic sources as well as from geophysical data. Results from a more systematic geologic and geochemical reconnaissance could change this rating, particularly in the oldest, deepest tectonic-level rocks of the northernmost ranges, which are not covered by any geophysical study. Consequently, the terrane of scattered veins is divided into two assessment tracts, distinguished by the degree of confidence with which the low potential rating is assigned. Basically, we conclude that, although present knowledge of the northern ranges has some favorable signs for vein-type ore deposits, they are sparse. However, too little geological, geochemical, and geophysical work has been done there to discount the possibility completely.

The industrial commodity distribution is compiled on plate H1. Although tracts of favorability are not delineated on the map, their potential for further development is reviewed below. This potential varies markedly among the commodities, being particularly good for those already in major production, such as salt, gypsum, cement rock (limestone), and certain clays. The assessment of coal is covered by Warwick and Shakoor in chapter I of this volume.

An unexpected result of this project was the realization that what was seen in the Potwar Plateau area applied also to southern Arizona and New Mexico. Both areas lie in the frontal half of an orogen. There are, of course, differences in age of deformation, as well as in the composition of the subducted plate. The Arizona-New Mexico deformation is older and took place at 40–50 million years ago (Ma). Because of this age difference, the Pakistan analog showed what the conditions of youngest cover rocks might have been like in Arizona-New Mexico during the Eocene (Drewes, 1991), with that cover subsequently eroded.

General Geologic Relations

In the Potwar Plateau area, the occurrence of anomalous concentrations of metals and industrial commodities is associated with certain geologic features—some formations, a few faults, and particularly veins and dikes—which are therefore briefly described herein. For a general review of the local structural and tectonic setting, refer to chapter A (by Warwick) of this volume and Drewes (1995).

Regional Setting

The Potwar Plateau area lies along the distal part of the southern flank of the Himalayan orogen (figs. H1, H2). This orogen developed through the collision of the Indo-Australian and Eurasian continental plates beginning at least as long ago as the Cretaceous and is still progressing (LeFort, 1975). During an early stage of convergence of these continental plates, the intervening Tethyan seaway was closed, and its deposits were deformed, massively intruded, and, along the central zone, intensely metamorphosed. As convergence continued, the orogen grew wider, extending chiefly southward but also northward. As a result of this development, the tectonic zones typical of such orogens, namely, foreland area, fold-and-thrust zone, imbricate (shingled)-thrust zone, and core zone with its suture line, formed and gradually shifted toward the orogenic foreland. Deep beneath this belt of deforming rock, the Indo-Australian plate was subducted beneath the Eurasian plate. At present, the forward or southerly propagation of the deformed zones is still in progress, and internally, the orogen is undergoing rapid uplift and erosion to ever deeper tectonic levels. The basic tectonic features are shown by Kazmi and Rana (1982).

Along its axis, the orogen has irregularities in the form of arcuate lobes and syntaxes. A major orogenic lobe occupies easternmost central Pakistan and northern India. Another such lobe, with modifications, extends through western Pakistan. Between these major lobes, the Potwar Plateau region and its southern marginal Salt Range form a minor lobe (fig. H2). Syntaxes separate this minor lobe from the adjacent major lobes. These syntaxes are complex features whose margins record a variety of strike-slip, oblique-slip, and normal faults, as well as some lateral thrust faults. Syntaxes in metamorphic terranes show considerable upward ductile flowage; the rocks of the study area are more typically deformed in a brittle style.

The terrane southeast of the Salt Range makes up part of the Indo-Gangetic foreland basin of the Himalayan orogen, whose successor depocenter axes parallel the frontal line, and the various tectonic lobes. South of the foreland basin, or locally at uplifts within it, as at the Sargodha Hills, 80–120 kilometers (km) to the southeast, bits of the Indo-Australian plate are exposed in knobs of Proterozoic metasedimentary rocks rising boldly above the flood-plain deposits (fig. H2).

Proterozoic metasedimentary rocks, which may be Tethyan basement, are also exposed in the northernmost part of the study area. Just north of the western part of the study area is the intramontane Peshawar Basin, a major tectonic sag (Yeats and Hussain, 1987). Proterozoic and Paleozoic rocks lie north of this basin, and a few tens of kilometers north of the eastern part of the study area are granitic stocks and the

Kohistan island arc complex (Yeats and Hussain, 1987; Pogue and others, 1992).

Key Geologic Features of the Potwar Plateau Area

The Potwar Plateau is a low-relief upland except where dissected by the Soan River and its tributaries (fig. H2). South of the plateau are the somewhat arcuate Salt Range, and its eastern and western extensions along the syntaxes, and the alluvial areas of the Indus and Jhelum Rivers. To the north of the plateau are, first, a zone of deformed Tertiary to Paleozoic sedimentary rocks and, then, a zone of Proterozoic metasedimentary rocks appearing in aligned moderately high mountain ranges. Each zone has a distinctive tectonic style and suite of rocks. These features are summarized with emphasis on only those rocks and structures of key interest to the resource assessment.

The Potwar Plateau is underlain mainly by Miocene to Pleistocene clastic rocks of the Rawalpindi and Siwalik Groups. (By Pakistani convention, the latter group is known simply as "the Siwaliks," a usage followed herein.) These rocks are generally so poorly indurated that they hold no fractures and thus offer few avenues of concentration for mineralizing fluids. The rocks form an open syncline (the Soan syncline, fig. A4 in chapter A of this volume), whose flanking anticlines contain oil traps at moderate depth. These rocks and structures overlie the rocks that crop out in the Salt Range and its eastern and western extensions. The northwest syncline flank is cut by shingled thrust faults having moderate amounts of displacement and involving only Neogene rocks.

The Salt Range zone is underlain by Eocambrian, Paleozoic, Mesozoic, and Paleogene rocks of a major thrust plate. The underlying northwest-dipping Main Frontal thrust fault, locally known as the Salt Range thrust fault, is spatially associated with the Salt Range Formation, a thick marl unit containing abundant salt and gypsum. Salt tectonism has strongly affected the rock sequence of this zone, particularly the lower part; salt and gypsum masses have moved from their initial stratigraphic position, probably from early times to the present, into overlying rocks, both along faults formed by regional tectonic stress and faults formed by the flowage of the salt itself and the consequent settling of overlying rocks of abundant limestone and shale and some sandstone and dolomite units. Of key interest are the salt and gypsum-bearing Eocambrian Salt Range Formation, the Lower Permian Warchha Sandstone and its local poor-quality coal seams and reported sedimentary-hosted metals, and two Jurassic units, the Chak Jabbi Limestone used as cement rock, and Datta Formation that contains glass sand and interbedded fire clay. Also of local interest are the Paleocene Hangu Formation, which has some oolitic iron ore and locally has coal seams, and the Patala Formation, which contains some clays and coal.

The subsurface rocks of the alluvial plains to the south remain largely unknown except for data from scattered oil wells. Baker and others (1988) indicated that Siwalik rocks directly overlie Paleozoic rocks just south of the Salt Range. In places to the east and west, the flood-plain deposits are underlain by the Siwaliks, typically folded and locally upended by the tectonic encroachment of the rocks above the Salt Range thrust fault. Near Mianwali, unpublished geophysical data from the Oil and Gas Development Corporation of Pakistan (OGDC, 1962, 1963) suggest the presence beneath the alluvium of a salt or gypsum stock, which implies a subsurface extension of the Eocambrian rocks and perhaps also some other units of the Salt Range.

The zone of Paleozoic to Tertiary sedimentary rocks north of the Potwar Plateau is characterized by shingled thrust faults and moderately tight abundant folds trending east-northeast (Yeats and Hussain, 1987). The southernmost and structurally lowest fault is the Main Boundary thrust fault, which dips north-northwestward; movement along this fault has placed Paleocene, Mesozoic, and Paleozoic rocks on the Miocene and younger rocks. Cement is produced from rocks of the Precambrian Shekhai Limestone and the lower Eocene Margala Hill Limestone. The Paleocene Hangu Formation and Lockhart Limestone have some coal seams, bauxite, and clays. These rocks contain calcite veins; many carry anomalous amounts of base metals; and a few also have silver, mercury, and arsenic.

The northernmost zone is underlain by Proterozoic metasedimentary rocks, namely, argillite, subgraywacke, phyllite, and, locally, phyllitic schist, which are thrust upon the Paleozoic and younger rocks of the Main Boundary thrust plate. The Panjal thrust fault separates these zones; it is commonly seen in outcrops as a reverse fault, but it is believed to flatten downdip to the north-northwest. These rocks are cut by quartz veins; those of the northwest flank of the northernmost range, the Gandghar Range, grade into aplite sheets by way of feldspar-bearing quartz veins that follow the same fracture system as the quartz veins.

Industrial Rocks and Minerals

Industrial rocks and minerals of the Potwar Plateau area are characteristically hosted by the Cambrian to Paleogene sedimentary formations and, therefore, occur in the Salt Range and in the zone of shingled thrust faults and folds. The economically important commodities are salt, gypsum, cement rock, and certain clays. Also mined from moderate-sized deposits, or on a part-time basis, are dolomite, other clays, and building stone. Still other commodities such as potash salt, celestite, barite, and alluvial jadeite were mentioned in the compilation of Ahmad (1969) but may not have had any systematic production. The distribution of these commodities is shown on plate H1, which is keyed to a summary of specific occurrences on table H1. Data on this plate and table were generated chiefly by Ahmad (1969); some new work on clays was obtained from Whitney and others (1990) and from unpublished sources.

Salt

Salt has long been mined in the Salt Range, thereby giving the mountains their name. Salt, as used in this report, means common table salt, also referred to mineralogically as halite or chemically as NaCl. Salt is widely used in industrial processes, as a preservative, and as a food additive. The earliest time of salt production is likely to have preceded the beginning of historical records, for the Indus Valley was the site of an ancient civilization, and the salt in the Salt Range was accessible at the surface. However, as salt from the surface sites was depleted, the need increased to locate deeper deposits. As a result, knowledge of its field occurrence and structural habits became important.

Salt is typically an evaporite obtained directly from the sea or indirectly from an ancient sea in the form of rock salt. Salt is commonly associated with other evaporites, such as gypsum, dolomite, limestone, and potash salt. Initially, rock salt is distributed as a bedded deposit like the associated carbonates, clays, and marls. However, because salt has a low specific gravity relative to the associated rocks and because it recrystallizes readily, it tends to flow upward in response to load or to tectonic stress. Primary bedded salt may thus be intruded as a secondary deposit in plugs. In these secondary occurrences, the bedded aspect of salt and associated rocks is disrupted and, in some plugs, is gradually obliterated, leaving a chaotic mixture of salt and gypsum pods among contorted layers of clay, marl, and carbonates. In developing such plugs, material is transferred laterally along the initial bed to the site of upward injection, thereby allowing overlying rock to collapse over depleted parts of a salt bed. This results in a network of block faults, some of which are also intruded by salt and clay.

Being as old as Eocambrian, the Salt Range Formation has probably been mobile in response to diverse stresses for a long time. The load of overlying Paleozoic rocks probably initiated flowage. Downwarping of the base of the Tethyan seaway, largely during the Mesozoic Era, likely set up new crustal stress to which salt movement responded. Later, the collision of the Indo-Australian and Eurasian continental plates generated compressive stress that resulted in the folding and thrust faulting of rocks, and some of that thrust faulting focused on the mechanically weak layer of the Salt Range Formation. The salt thus acted as a tectonic lubricant and, in turn, was chaotically injected into subordinate and mostly steep faults. Even at the present land surface, the salt and gypsum are sites of extensive slump masses, which had not been separated from intrusive salt masses on the geologic maps of the Salt Range (Gee, 1980).

In the Salt Range, the potential for finding additional bodies of salt is high, although doing so is likely to be challenging. The larger intrusive masses should be most attractive for exploration. The determination of targets that may contain large deposits is hampered, however, by the present lack of detailed mapping of extensive slump fields along the southern flank of the Salt Range. Additional mapping is needed, such as that done by the Pakistan Mineral Development Corporation (PMDC, 1986), to distinguish surficial masses of salt-bearing rock from intrusive masses. Additional detailed gravity studies, such as those conducted by Ahmad and others (1979), may be helpful in furthering subsurface exploration. Certain other geophysical tests may also be effective.

An additional area for the possible occurrence of salt or gypsum is in the plains near Mianwali (pl. H1), where a strong negative gravity anomaly suggests the presence of a plug of rock with low specific gravity beneath the alluvium. The possible depth of such a plug may be modeled through the addition of a ground gravity study to the airborne gravity study. An added attraction to the inference of a blind salt plug is the possibility of finding oil and gas traps flanking the plug.

Other sites of negative gravity anomalies occur along certain faults, such as the second large fault north of the Soan River (fig. H2). These anomalies probably indicate that faulting was facilitated by salt or gypsum intrusion along lower reaches of the fault. However, there is no evidence of either the depth, extent, or kind of salt present here, and as long as shallow bodies are available, deep mining of salt pods seems unattractive.

Gypsum

Gypsum ($CaSO_4 \cdot 2H_2O$) and its anhydrous form, anhydrite ($CaSO_4$), are other important industrial commodities abundantly present in the Potwar Plateau area. They are widely used in the construction industry as an additive to cement and a base for the manufacture of plaster; they are also used as a soil conditioner in agriculture. Although associated with salt in many places, they are commonly more widespread than salt. In the Potwar Plateau area, they are not only found in the Salt Range Formation, but occur also in the Cambrian Khisor Formation, the Permian Sardhai Formation, and the Eocene Datta and Kuldana Formations.

Gypsum has an origin and many physical properties similar to those of salt. Large amounts of relatively pure gypsum are obtained largely from the Salt Range Formation (pl. H1); the other sources mainly satisfy local agricultural needs. The potential for developing additional gypsum resources is similar to, but probably better than, that for locating more salt. The bodies in the Salt Range Formation are likely to be podiform but may be purer than those in other formations. Major bodies are likely to occur at the larger plugs, and these may be found at major fault intersections. The development of an expanding market for gypsum is likely to be of greater concern than the finding of more of this commodity.

Cement Rock

Cement rock contains limestone or marlstone sufficiently free of silicon, iron, and magnesium and has a suitable ratio of carbonate to clay (generally 9.5:1). In the Potwar Plateau area, these conditions are met by the Chorgali Formation and the Margala Hill and Lockhart Limestones, all of Tertiary age, and by the Cretaceous Kawagarh Formation, the Jurassic Samana Suk Formation, and the Precambrian Shekhai Limestone. In places where these rocks are close to markets or to rail lines, they are quarried in large quantity for construction uses.

Because cement rock is present in many formations that are commonly extensive, the likely potential for cement rock production is excellent, and the expansion of existing sites is probably possible for a long time. Doubtless, cement rock may be found at other sites or possibly even in other formations.

Clay

Clay deposits are of several kinds of material that are used for a range of construction and industrial purposes. Most widespread, perhaps, is the clay utilized by the local brick industry in or near many large towns and all cities. Typically, these local kilns use clay from nearby soils, and so this study can do little toward supporting their continued customary development. They are not further considered.

The other clays are the focus of a separate study by Whitney and others (1990). These clays are the important fire clay and the moderately important bentonite, high-aluminum clay, laterite, bauxite, china clay, alum, and ocher. Descriptions of these commodities were given by Whitney and others (1990), but the distribution and summary of occurrences are shown on plate H1 and in table H1.

Most clay deposits occur as lenticular bodies less than a meter thick and at least a few thousand meters long. Shallow pits at most sites operate on a part-time basis, apparently serving some particular local need or industry. Projections of deposits along strike are typically easy to make; few clay deposits have the value to encourage downdip development. Accordingly, areas of gentle relief and flat-lying rocks are likely to be more productive than areas of strongly tilted rock and steep hills. Specialty clays, of course, permit development in geologically less favorable situations.

Other Commodities

Building stone is widely used where readily available, but its availability generally has not been of sufficient concern to lead to the systematic keeping of records. Typically, the stone is hand cobbed from surface occurrences or pried by simple methods from outcrops near markets. Less commonly, building stone is quarried and shaped for dimension stone or crushed for aggregate and ballast. Crushed rock sites may be adjacent to cement quarries and probably are not reported separately. Other sites of building stone, shown on plate H1, may be for dimension stone, for they appear to be of moderately indurated, yet workable sandstone, probably of a kind widely used in the more distant large cities. Sheikh and others (this volume, chap. G) discuss the resources of rock aggregate in the Islamabad area.

Sandstone, referred to as glass sand, is reported as generally present in the Datta Formation east of Mianwali. The vagueness of the site location suggests that the commodity is known or potentially present there but is not mined on an ongoing basis, perhaps because of the absence of a local market. No mention was noted in the literature of its use as an abrasive.

Celestite in calcite veinlets and potash salt near the Khewra salt occurrence are mentioned as “shows” rather than as significant deposits (Ahmad, 1969). Quartz crystal is known at one site, but commodity descriptions are not known. Sulfur is mentioned in connection with pyritiferous black shale, an association hardly likely to have commercial value (Ahmad, 1969).

Metallic Minerals

A minor first part of this review covers several kinds of sedimentary-hosted metallic minerals, probably having only low potential for development. A second part covers base- and precious-metal occurrences of probable hydrothermal association. None of these metals is being exploited; more work may be justified on testing ore, possibly for precious metals in veins.

Sedimentary-Hosted Iron Ore

Subeconomic deposits of iron ore occur at Kalabagh, about 25 km west of the study area, and at Mazari Tang (lat 33°45′ N., long 71°55′37″ E.) in the northwestern part of the study area (pl. H1). The iron ore prospect near Kalabagh has a reserve of about 292 million tons of low-grade (32 percent) hydrous iron silicate that is presently uneconomic. The Mazari Tang deposit, of unspecified tonnage, is a bedded oolitic hematite in Jurassic limestone and has an FeO content of 44.6 percent. Further details are available in Ahmad (1969) and in unpublished reports used by Ahmad.

Sedimentary-Hosted Base Metals

Copper, lead, and tin occur in the Lower Permian Warchha Sandstone and the Permian Sardhai Formation northeast of Mianwali and also north of Nilawahan Gorge (pl. H1) (Fleming, 1852; Crookshank, 1954; Gilani, 1981; Abbas, 1985; Abbas and Qureshi, 1985). Analytical results of preliminary trench samples were not encouraging, and the present review of a second site was also unattractive.

Near the village of Sanwans and 3 km east of Ghundi, both in the Mianwali area, copper and tin minerals were identified in the arkosic beds of the Warchha Sandstone and in sandy shale beds of the Sardhai Formation. The arkose is referred to in some accounts as the speckled sandstone; the flecks apparently are caused by oxidized particles of ore minerals. Some 300 samples were taken in 15 trenches in a study reported by Gilani (1981). Anomalous amounts of metals in an unspecified number of samples were reported from only two of these trenches. The report fails to mention the amount and kind of metals present in the anomalous samples. This sampling study was augmented by an ore microscopy review that indicated (1) that the tin occurs in stannite and cassiterite and as native tin and (2) that the copper occurs in chalcopyrite and malachite. The tin and copper minerals occur as thin shells around other material.

Logistical problems prevented a visit to these sites, but the same formations were examined at nearby sites and at another site (site 22f, pl. H1) along the road to the long-vanished Turta Resthouse, a landmark commonly used in reports of copper and lead in speckled sandstone. Alluvial samples taken downstream from the suspect formations and composite chip samples from the rocks themselves were taken at 11 sites. Only five of these samples had anomalous amounts of arsenic, mercury, lead, and zinc in various combinations; none contained copper, and tin was not tested for. Speckled sandstone was only faintly recognized at a few sites.

Fragmentary data suggest that, although base metals are present, concentrations are low and their distribution is erratic. The potential for occurrence of such base-metal deposits remains low, at a moderate degree of confidence. Nevertheless, it is desirable to address this problem of sedimentary-hosted base metals again with a more thorough and systematic geochemical study.

Vein-Hosted Base and Precious Metals

The combined results of reconnaissance field observations and geochemical analyses indicate a low potential for vein-type deposits of copper, lead, zinc, and silver. These data were inadequate to provide much confidence in the low potential assignment or to provide a basis for more detailed reconnaissance for sites of metal accumulation, but they do indicate that metal-bearing hydrothermal systems are present and that the reconnaissance method used can be fruitful.

Field Observations

Roadside and trailside observations on veins, faults, and igneous rocks provide useful information on alteration and mineralization of rocks in the Potwar Plateau area. The kind and number of such observations were limited by the logistical factors previously explained and by the need to devise a field plan that both utilized available knowledge and resulted in a distinct training objective. In other words, in the brief time available, we wanted to test one exploration concept or technique that could lead to a concrete result. This exploration concept actually grew as field experience was gained and as analytical results were obtained from the laboratory.

Representative and accessible steep structures, namely, faults, dikes, and veins, were initially checked for possible effects of past movement of hydrothermal fluids. Early examination over much of the study area indicated that the rocks of the several successor foreland basins are mostly so young and were so rapidly deposited that they are unindurated or very weakly indurated. According to Van Houten (1969), sedimentation rates were about 0.3 meter per 1,000 years (m/1,000 yr). As a result, the rocks do not fracture, and consequently, fluids passing through them likely would disperse rather than concentrate. Even faults in such rocks offer few advantages to passing fluids. Through this recognition, most of the Potwar Plateau central area, some of the Salt Range, and all of the Indo-Gangetic plain were eliminated from further consideration. The chief exception lay in the oldest of the basin deposits, the Murree Formation, where it was strongly incised in the Murree Hills. In the older, more indurated rocks to the northwest, the occurrence of veins provides useful signs of mineralization.

Major steeply inclined faults were checked at widely spaced intervals. Many of those of the Salt Range were related to salt tectonism and thus were deemed to be tight features that are unfavorable as conduits for fluid movement. Furthermore, these faults are likely to have developed only in the upper plate of the Salt Range thrust fault and thus would not have been practical conduits for fluids rising from great depth. Nevertheless, some of the faults of the area, such as strands of the Kalabagh fault (fig. A4 of chapter A, this volume), a major cross fault within the Salt Range near Choa Saidan Shah, an inferred structure east of the Salt Range lobe, a segment of the Soan thrust fault, and other major thrust faults of the northern part of the study area were checked at selected sites. The thrust faults in this check were steep structures, either reverse faults or reverse-faultlike leading edges or ramp zones of generally flatter features, or they were tilted after thrusting. Their effect, in any case, was that they could have provided egress to rising fluids of the sort that may carry metals. In all cases, faults were barren, except for locally, the skimpiest of iron oxide coating on fracture surfaces and, in a few cases, where veins followed segments of a fault, as was noted along the Panjal thrust fault in the Hazara Range.

Variations in the composition of the veins reflect changes in either the composition of the host rock, the tectonic level, or the proximity to the source of their hydrothermal fluids. In the limestone-rich Paleozoic, Mesozoic, and Paleogene formations, and locally, even in the limestone-poor Miocene formations, the only veins found consisted of calcite. Mostly they are a centimeter or two thick, and there is no obvious systematic orientation. Veins in Proterozoic argillite and phyllite are mainly of quartz. A few veins near the southeastern border of the zone of Proterozoic rocks were of calcite or of quartz and calcite. Veins in the northwestern flank of the northernmost range, the Gandghar Range, were of quartz and feldspar, a few centimeters thick. There, too, thin aplite sheets followed the same general fracture system in which the veins occurred. North of the study area and the Peshawar Basin, at Malakand, aplite sheets make up 5–10 percent of the rock, and nearby is a granite stock that may be a source of the aplite.

A few of the veins in the Gandghar Range carry pockets of iron oxide, possibly limonite pseudomorphs after pyrite, as well as greenish-gray unknown minerals, possibly a matte of fine crystals of chlorite or uralitized amphibole. Near some of the veins in this range, pyrite is abundant in host rocks of sheared black shale 3–10 m thick. These pyrite occurrences are associated with finely laminated algal limestone beds, which suggests that the pyritiferous zones had an organic depositional control, rather than a hydrothermal origin.

Intrusive rocks were examined wherever possible, but the available geologic maps do not record their distribution. In the Salt Range Formation near Khewra are a few dikes composed of trachyte, known as the Khewra Trap (Martin, 1956; Faruqi, 1986). The trap outcrops seen were of large blocks in the salt melange, apparently derived from dikes that once intruded the Salt Range Formation. These are medium-gray fine-grained rocks of conspicuously acicular-textured mafic minerals. In thin section, the mafic minerals appear to be amphibole altered to uralite and iron oxide minerals. Possible pyroxene and trace amounts of iron oxides are also present in the trap rock. It is proposed here that the dikes are somehow related to the Cretaceous-Paleogene Deccan traps of northwestern India. They do not show an association with mineralization.

Diabase dikes occur in and near the Cherat lime plant quarries about 30 km southeast of Peshawar. One such dike of diabase (or diorite(?)) cuts the Precambrian Shekhai Limestone. Neither dike nor host rock was mineralized.

Five dikes and sills were seen on a kilometer-long traverse across the southwest end of the Gandghar Range above the village of Bhedian. These are 1–10 m thick and light to dark greenish gray; one of the bodies had the acicular texture of the Khewra Trap. A sixth dike was seen on another traverse near Dirgi, also in the Gandghar Range. Although none of these six dikes was mineralized, the one at Dirgi was cut by quartz veinlets.

Geochemical Results

A geochemical reconnaissance was part of the vein study; the sampling method gives results of qualitative rather than quantitative significance. The intent was to determine which elements were mobile and their general geologic association. Chemical analyses indicate that most of the quartz veins and some of the calcite veins carry base metals, mercury, and silver in various combinations. The only distributional pattern noted was a concentration of samples with slight silver anomalies in the northeast corner of the study area.

Veins and alluvium were sampled. Samples were composited from 8–10 grab chips, each 1–2 cm across, taken from groups of veins, generally over roadcut or streamcut outcrops, covering 100–200 m in extent. The chips are pieces of vein, as well as altered wall rock, where present. Stream-sediment samples were also composited of 8–10 small handfuls of fine material taken at 10-m intervals across wide washes, or over 100- to 200-m segments of narrow ones. At these alluvium collection sites, the surface layer was first removed, as were pebbles, twigs, and leaves. Sites of possible contamination were avoided.

Rock chips were ground in agate mortars and sieved to –80 mesh. Alluvial samples were simply sieved to –80 mesh. All samples were then analyzed by the Geological Survey of Pakistan laboratory in Karachi for silver, arsenic, gold, cadmium, copper, mercury, lead, and zinc, using an atomic absorption method (table H2). Gold is not shown on the table because it was undetectable at 0.02 parts per million (ppm). Cadmium is not shown because it was undetected at a level of 2 ppm in a first group of samples and was a uniformly low 2–5 ppm in the second group.

In the absence of a regional body of data on normal or background values for the reported elements, judgment of background and anomalous values was made from this suite of samples plus some general experience by the first author in the southwestern United States. In the case of mercury, where analytical procedures or styles of reporting seem to have changed between the two sample groups, separate background values were estimated for each group. On table H2, anomalous values are given in boldface type. We emphasize again, these values have only limited quantitative significance and are intended to show which metals were mobile.

Geophysical Results

Airborne gravity and magnetic maps (OGDC, 1962, 1963) are available for much of the Potwar Plateau study area but do not show precisely that northern tract of greatest geologic and geochemical interest. Perhaps the most conspicuous features on these maps are strong gravity lows at scattered sites in the Salt Range. These are believed to reflect accumulations of considerable amounts of salt or gypsum at shallow depth. Such evaporate pods are, of course, known in many parts of the Salt Range. A similar very strong gravity low appears southwest of Mianwali largely just outside the area of plate H1. As already inferred, this anomaly could mark the site of a blind salt or gypsum plug, which may lie beneath the alluvium at a depth shallow enough to make the feature accessible to exploration.

Similar, but weaker, negative anomalies occur in places south of the Salt Range, as well as aligned a few kilometers north of the Soan thrust fault (Drewes, 1995). Likely, these places are also underlain by intrusive evaporites; the weaker anomalies there suggest either smaller masses, deeper masses of light rock, or a mass having less gravity contrast with adjacent rocks.

A less direct gravity and magnetic signature consists of a northwest-trending linear feature extending roughly across the central Potwar Plateau and Salt Range area. This linear feature is characterized by offsets in the patterns of gravity highs and lows and is believed to be in the lower plate of the Salt Range thrust fault, which probably cuts the Proterozoic rocks of the subducting Indo-Australian continental plate exposed along the Jhelum River lowlands. Here, then, is a subsurface fault that may have guided the upward flow of ore fluids. The upper plate high-angle faults should be tested for signs of mineralization where this inferred subsurface fault is overridden by the Salt Range rocks. Perhaps it is no coincidence that the Khewra Trap rock occurs at its Khewra locality near this proposed basement fault.

Resource Potential and Recommendations

Resource assessment principles used by the U.S. Geological Survey are applied to the Potwar Plateau area. The levels of resource potential and the levels of certainty of such assignment, given in the format of a matrix diagram, appear as appendix H1. To a large extent, the levels of resource potential reflect the kind of geologic evidence applied and the variety and strength of supporting geochemical, geophysical, and remote sensing data. As incomplete or even lacking as these supporting studies are in this case, it is necessary to apply greater emphasis on basic geology and experience.

Three major assessment tracts are identified for metallic minerals, none of which is either high or even moderate. The resource potential is unknown in the extensive flood plains of the south; essentially, no data are available from there. Geophysical coverage of the Jhelum River flood plain is of little help without some ties to known mineralized areas, particularly when the thickness of alluvial deposits and the Siwaliks is unknown.

In the remainder of the study area, the resource potential for metals in all deposit types is low. In other words, there are scattered signs that conditions may be favorable, but they make no useful patterns or association with ore-related features and are not corroborated effectively by other studies. The data from the mineralized veins are cursory; sample collections and analytical results are of interest only insofar as they indicate the possible presence of vein-type deposits of metals not likely to be of economic interest. The significance of these observations is best incorporated into the level-of-confidence factors of the assessment matrix.

Accordingly, our determination of low potential for the Salt Range, Potwar Plateau, and shingled thrust fault zone of Paleozoic and younger rocks is assigned with a high level of confidence, but that of the Proterozoic zone to the north is assigned a low level of confidence. We indicate thereby that, given more extensive geophysical and more thorough geochemical and geologic coverage, this terrane stands a chance that tracts with a higher level of potential will be uncovered.

The resource assessment of industrial rocks and minerals was not undertaken for reasons explained in the introductory section of this chapter. Coal and clays are covered in other reports. Energy resources other than coal are outside the concern of the Geological Survey of Pakistan. The general abundance of some major commodities is apparent through their occurrences in bedded rocks, and for the minor commodities there is either little potential or perhaps no demand, and thus little information is available in the literature. Many practical comments on the diverse commodities, their field setting, beneficiation requirements, and commercial uses were covered by Ahmad (1969).

This resource assessment study leads us to offer several recommendations both for improving the assessment basis and for general improvement in geologic studies and training programs. The most pressing need for a better resource assessment is for completing the geophysical coverage of the northern part of the Potwar Plateau area. Also pressing is the more systematic geochemical reconnaissance of the northern ranges plus the Murree area and, particularly, of those tracts near geophysical signatures of possible blind stocks. Geologic mapping of the three zones of the older rocks should incorporate more observations of dikes, veins, and, if any, altered ground, all features of little interest to stratigraphers.

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Tables H1 and H2 and Appendix H1

Table H1. Summary of industrial and metallic commodities from the Potwar Plateau area, northern Pakistan.

[Commodity deposit size: L, large (>1 million tons); M, moderate (1 million to 100,000 tons); S, small (<100,000 tons, includes small shows and unsubstantiated reports); U, size unreported but likely small. Do., do., ditto; dash (—), no data]

Site (shown on plate H1)	Commodity	Deposit size	Location detail[1]	Reserves (in tons or million tons (mT) where known)	Remarks
1a	Salt (NaCl)	L	Khewra	35 mT	
b	do.	L	Warchha Mandi	2.5 mT	
c	do.	L	Kalabagh	1.0 mT	Salt and gypsum intermittently present in Eocambrian Salt Range Formation.
2a	Gypsum or anhydrite.	U	Choa Saidan Shah	—	
b	do.	U	North of Lilla	—	
c	do.	U	East-northeast of Kattha Saghral	—	
d	do.	U	Northwest of Khushab	—	
e	do.	L	Daud Khel	55 mT	
3a	Limestone (cement rock).	L	Near Spin Kana village	—	Precambrian Shekhai Limestone, in tight folds.
b	do.	L?	Wah Cantonment	—	Probably large reserves.
c	do.	L	Margala Hills	—	Large reserves; Eocene limestone (probably undeveloped resources).
d	do.	U	Tarki	—	
e	do.	U	Northwest of Kulki	—	
f	do.	U	Kagha and west	—	
g	do.	U	Warchha Mandi	—	
h	do.	U	Nali and to east and northwest	—	
i	do.	L	Southeast of Daud Khel	—	Probably large reserves.
j	do.	U	Kalabagh	—	
4	Dolomite	U	16 km north of Khewra	—	Data incomplete.
5a	Iron ores	S	Mazari Tang	—	Hematite; bedded in limestone; 44.6% FeO.
b	do.	L	Kalabagh	292 mT	Hydrous silicate; Fe 32%.
6a	Fire clay	M	Choi area	—	
b	do.	U	North of Chailabdal of Kot Bahadar.	—	
c	do.	M	Wehali Cupi	125,000	Lentil 0.8 m thick; Patala Formation.
d	do.	M	Wehali	400,000	Do.
e	do.	M	Manhiala	800,000	Lentil 1.8 m thick; Patala Formation.
f	do.	U	Nail	—	
g	do.	U	Northwest of Ratuchha	—	
h	do.	L	Dalwal	3.4 mT	Lentil 0.8 m thick; Dhak Pass(?) Formation.
i	do.	U	West of Waralah	—	
j	do.	U	Karuli	—	Average 0.6 m thick.
k	do.	U	North of Karuli	—	
l	do.	S	Goli Wali	—	Average 1.2 m thick; poor quality; Datta Formation.
m	do.	U	Chattawala Nala	—	
n	do.	M	Mozehbazar	650,000	3 beds, each 1–2.8 m thick; Datta Formation.
o	do.	U	Dama	—	

Table H1. Summary of industrial and metallic commodities from the Potwar Plateau area, northern Pakistan.—Continued

Site (shown on plate H1)	Commodity	Deposit size	Location detail[1]	Reserves (in tons or million tons (mT) where known)	Remarks
p	Fire clay	U	Dama	—	
q	do.	L	Dhak Pass	1.7 mT	3 beds, each 0.6–1.3 m thick; Datta Formation.
r	do.	L	Chabil	2.5 mT	3 beds in Datta Formation.
s	do.	U	Mandoha	—	
t	do.	U	Rikhi	—	
u	do.	U	Kharwagnala	—	
v	do.	U	Sirin Nala	—	
7a	Bentonite	U	Dheri Chohan	—	
b	do.	U	Dheri Langhal	—	
c	do.	U	Akori	—	
d	do.	U	Shah Kamir	—	
e	do.	U	Dheri Maliaran	—	
f	do.	U	Pind Savika	—	
g	do.	U	Padhrar	—	
h	do.	U	East of Quadirpur	—	
i	do.	U	Southeast of Bhilomar	—	
j	do.	U	Northeast of Bhilomar	—	
k	do.	U	Chinji	—	
8a	High-aluminum clay.	U	Rattakund	—	Flint clay.
b	do.	U	Nawa	—	
c	do.	U	Sidhandi Dala Dher	—	
d	do.	U	Ratuchha	—	
e	do.	S	Uchhali	—	1.2 m thick; along contact sandstone; Eocene limestone interbedded in sandstone.
f	do.	S	Sarai	10,000	Do.
g	do.	U	Sakesar Hills	—	
9	China clay	U	West of Karuli (Rakh Simbli)	—	
10a	Laterite	U	Choi	—	
b	do.	U	South of Wehali Zerin	—	Occurs with bauxite.
c	do.	U	Northeast of Wehali Bela	—	
d	do.	U	Karuli (Rakh Simbli)	—	Occurs with fire clay.
e	do.	U	Dhok Karuli	—	
f	do.	U	Chambanwala Mohar	—	
11a	Bauxite	S	Near Spin Kana	—	
b	do.	S	Jallozai	—	Occurs along Eocene-Cretaceous unconformity.
c	do.	S	Choi	—	Two sites close together.
d	do.	M	Surg	250,000	Fe-clay along Eocene-Cretaceous unconformity.
e	do.	S	Tanewala Mager (Dherikot)	—	Pisolitic Fe-clay.
f	do.	S	Ganj Bhal (Dherikot)	—	Do.
g	do.	S	Jhalar	—	Do.
h	do.	S	Nawa	—	Do.
i	do.	S	Kawah	—	Do.

Table H1. Summary of industrial and metallic commodities from the Potwar Plateau area, northern Pakistan.—Continued

Site (shown on plate H1)	Commodity	Deposit size	Location detail[1]	Reserves (in tons or million tons (mT) where known)	Remarks
j	Bauxite	S	Mirza	—	Pisolitic Fe-clay.
k	do.	S	Pindi Trer	—	Fe-clay on Eocene-Cretaceous unconformity.
l	do.	S	Gakkar	—	Do.
m	do.	S	Hasan Abdal	—	Pisolitic Fe-clay.
n	do.	S	Kheramar	—	Do.
o	do.	M	Margala Hills	860,000	To 9 m depth; poor grade, pockets along Eocene-Cretaceous unconformity.
p	do.	U	South of Wehali Zerin	—	Occurs with laterite.
q	do.	U	Karuli (Rakh Simbli)	—	
r	do.	S	Nilawahan Gorge	—	Occurs with Fe-laterite.
s	do.	S	Nakkar	—	Do.
t	do.	S	Chambanwala Mohar (Samawali).	—	Do.
u	do.	S	Kattha–Pail	—	
v	do.	S	Arara	—	Do.
w	do.	U	Kattha Saghral	—	
x	do.	U	Kattha	—	
y	do.	U	Chambanwala Mohar? (Kathwai).	—	Do.
z	do.	S	Zaluch Creek	—	Occurs with laterite.
zz	do.	S	Daud Khel (Paikhel)	—	Do.
12	Alum	S	Kalabagh	—	Occurs in shale.
13a	Celestite	S	East of Jaba	—	Irregular veinlets.
b	do.	S	do.	—	Do.
c	do.	S	West of Jaba	—	Do.
d	do.	S	Daud Khel	—	Do.
14	Potash salt	S	Northeast of Khewra	—	Associated with impure salt and marl.
15	Ocher	S	Uchhali village	—	Yellow and red ocher.
16a	Building stone	M?	Rawalpindi area	—	Sandstone of Murree Formation, purple sandstone, Cambrian “magnesian” sandstone, and limestone from unspecified quarries.
b	do.	M?	Jutana	—	Sandstone(?).
c	do.	M?	Chammal	—	Do.
17	Quartz crystal	S	Mari and Kalabagh	—	Occurs in gypsiferous marl of Salt Range Formation.

Table H1. Summary of industrial and metallic commodities from the Potwar Plateau area, northern Pakistan.—Continued

Site (shown on plate H1)	Commodity	Deposit size	Location detail[1]	Reserves (in tons or million tons (mT) where known)	Remarks
18a	Sulfur	S	Panoba	—	
b	do.	S	East of Margala Pass	—	
c	do.	S	Luni-i-Kasi	—	From pyritiferous black shale.
19a	Barite	S	Tipra	—	$BaSO_4$ 87%; veins in Hazara Formation.
b	do.	S	Faquir Muhammad	100	$BaSO_4$ 58%–92%; with quartz veins in Eocene limestone.
20	Antimony(?)	S	Karangli Hill	—	Veins; stibnite(?) may be misidentified galena.
21a	Lead	S	Southwest of Faquir Muhammad	—	Galena in quartz-barite veins in Eocene limestone.
b	do.	S	Karangli Hill	—	Galena in “magnesian” sandstone.
c	do.	S	Khewra	—	Do.
d	do.	S	East of Musa Khel	—	Galena in Cambrian “speckled” sandstone.
22a	Copper	S	Nilawahan Gorge	—	Cuprite and malachite in “speckled” sandstone.
b	do.	S	Lufiaria	—	Do.
c	do.	S	Kharli	—	Do.
d	do.	S	Kattha-Pail	—	Do.
e	do.	S	Warchha	—	Do.
f	do.	S	Turta (site abandoned)	—	Cuprite and malachite in “speckled” sandstone; Turta Resthouse no longer shown on maps.
g	do.	S	Turta (alternate site)	—	Do.
23a	Glass sand	M?	Salt Range east of Mianwali and to northwest.	—	Datta Formation; probably a resource not site specific.
b	do.	M?	Salt Range northeast of Mianwali.	—	Do.

[1]Only selected features shown on plate H1.

Table H2. Concentrations of selected elements (in parts per million) determined by geochemical analyses of reconnaissance samples from the Potwar Plateau area, northern Pakistan.

[Elements also tested for but not found in anomalous abundances: Au, Cd. Analysts: A.A. Mahmood and Z.A. Khan (Geological Survey of Pakistan, written commun., 1989, 1990). Analytic results in bold face considered anomalous. Do., do., ditto;. <, less than]

Sample number	Field number	Geology		Element and anomaly threshold (ppm)						Remarks
		Host or source[1]	Rock analyzed	Ag (2)	As (10)	Cu (40)	Hg (15)/0.1[2]	Pb (50)	Zn (50)	
1	89D30	Hazara Formation	Alluvium	<2	<5	29	14	23	**89**	New galvanized pipe in canyon (nala).
2	29	Limestone in Hazara Formation.	Calcite veins, specularite.	<2	<5	19	[2].09	20	20	Some autoclastic breccia.
3	28	Shekhai Limestone	Diabase or diorite	<2	<5	16	**18**	12	28	Epidotized quartz and calcite gouge.
4	27	do.	Quartz and calcite veins.	**2**	**11**	23	**85**	20	**270**	FeO stained.
5	90D36b	Murree Formation	Calcite veins	<2	<5	39	.09	20	**100**	
6	36a	Dachner Formation	Alluvium	<2	<5	21	.092	20	40	
7	34	Hazara Formation	Quartz veins	<2	<5	**42**	.06	**200**	**250**	
8	35	Fault zone	do.	<2	<5	38	**.1**	**300**	**120**	Fault between Dachner and Patala Formations.
9	89D35	Samana Suk Formation.	Calcite veins	<2	<5	11	.7	42	20	FeO stained.
10	90D37	Hazara Formation	Quartz veins	<2	<5	**113**	**.101**	**140**	**60**	Do.
11	89D31	Uch Khattak Limestone.	Calcite veins, altered pyrite.	<2	<5	30	**.88**	**460**	**160**	
12	32	Manki Formation	Calcite veins	<2	<5	**88**	**1.03**	20	**140**	Do.
13	33	Uch Khattak Limestone.	do.	<2	<5	**55**	**39**	**81**	**128**	FeO, boxwork structure.
14	90D38	Hazara Formation	Quartz veins	<2	<5	21	.092	20	40	FeO stained.
15	39	Dachner and Manki Formations.	Alluvium	<2	<5	39	.085	40	**120**	
16	89D34	Hissartang Formation	Calcite veins	<2	<5	19	**.73**	42	40	
17	25	Hazara Formation	Quartz/aplite veins	<2	5	**380**	.075	20	20	Veins sheared like host.
18	90D24	do.	Alluvium	<2	<5	**43**	.088	40	**140**	
19	19	do.	Graphitic shale	<2	**13**	**140**	.08	**60**	**180**	Quartz pods; FeO in shale, sheared.
20	20	do.	Graphitic shale, pyrite.	<2	**32**	**215**	.09	**80**	**440**	Quartz pods, FeO.
21	89D68	Samana Suk Formation.	Calcite veins	**3**	<5	7	8	26	10	Gash fractures.
22	90D22	Hazara Formation	Quartz veins	<2	<5	**185**	.081	**160**	**80**	Some host garnetiferous.
23	30	do.	Quartz/aplite veins	<2	<5	38	.065	**120**	40	
24	28	do.	Graphitic shale	<2	<5	**61**	**.125**	20	**200**	Quartz-aplite pods; altered pyrite.
25	17	Kingriali Dolomite	Alluvium	<2	<5	37	.09	40	**60**	Alluvium contains andesite, specularite, quartz.
26	18	do.	do.	<2	<5	**104**	**.1**	**320**	**700**	Site and clasts as for sample 30.
27	16	do.	do.	<2	<5	**65**	.08	20	**60**	Alluvium has some andesite; organic material.
28	3	Hazara Formation	Quartz veins	<2	<5	32	.083	40	**60**	FeO stained.

Table H2. Concentrations of selected elements (in parts per million) determined by geochemical analyses of reconnaissance samples from the Potwar Plateau area, northern Pakistan.—Continued

Sample number	Field number	Geology: Host or source[1]	Geology: Rock analyzed	Ag (2)	As (10)	Cu (40)	Hg (15)/0.1[2]	Pb (50)	Zn (50)	Remarks
29	5	do.	Alluvium	<2	<5	35	.077	40	**100**	
30	2	Fault zone	Calcite veins	<2	<5	18	0.094	40	40	Pyrite(?), FeO stained.
31	89D67	Hazara Formation	Quartz veins	<2	<5	16	5	41	23	FeO stained.
32	90D 7	do.	do.	<2	<5	19	.089	0	40	Unknown greenish-gray mineral.
33	8	do.	do.	<2	<5	36	.081	20	**60**	FeO stained.
34	11	Hazara Formation	Quartz veins and pyrite.	<2	<5	31	.082	**60**	40	Synclinal keel of limestone; specularite.
35	12	do.	Quartz and calcite veins.	<2	<5	**67**	**.105**	20	**80**	Sheared margin of limestone unit.
36	13	Fault zone	Calcite vein, gouge	<2	<5	15	.080	20	20	Fault between Hazara Formation and Margala Hill Limestone.
37	89D63	Hazara Formation	FeO stained slate	<2	<5	**49**	.07	40	**60**	FeO along fractures.
38	64	do.	Quartz veins	<2	<5	7	3	26	39	FeO alteration, amphibole(?).
39	65	do.	Alluvium	<2	<5	30	9	31	**124**	
40	66	do.	Quartz veins, FeO zones.	<2	<5	**137**	**40**	10	**313**	
41	62	Cretaceous limestone	Calcite veins	<2	<5	12	.09	40	20	
42	61	Cretaceous shale	do.	<2	<5	11	.088	40	40	FeO stained.
43	36	Jurassic and Cretaceous formations.	Alluvium	<2	<5	12	12	24	30	
44	40	do.	do.	<2	<5	19	**18**	18	39	
45	41	do.	do.	<2	<5	30	**19**	20	**81**	
46	42	do.	Alluvium	<2	<5	14	10	18	31	
47	59	Jurassic limestone	Calcite veins	<2	<5	8	**.77**	40	20	FeO stained.
48	58	Paleocene limestone	do.	**3**	<5	6	14	16	5	Near a major fault.
49	60	Fault zone	do.	**2**	<5	7	1	27	7	Jurassic limestone.
50	48	do.	do.	**2**	<5	6	6	14	5	Paleocene formations.
51	52	Samana Suk Formation.	do.	<2	<5	12	**.93**	40	20	Near major fault; sheared veins.
52	54	Chichali Formation	do.	**3**	<5	5	12	14	15	FeO stained.
53	47	Murree Formation	do.	**3**	<5	5	12	42	7	
54	45	do.	do.	<2	<5	34	**.96**	**60**	20	
55	43	do.	do.	**2**	<5	6	8	48	19	Epidote(?).
56	56	Siwalik Group	do.	<2	<5	10	**.93**	40	20	
57	89D26	Formation contact	do.	**3**	<5	8	8	21	9	Jurassic limestone, Paleocene limestone; FeO stained.
58	25	Lockhart Limestone	do.	**3**	<5	5	1	16	8	FeO stained.
59	23	Cambrian and Permian formations.	do.	<2	<5	5	3	18	6	
60	12	Warchha Sandstone	Alluvium	<2	<5	13	**15**	17	46	No visible copper mineral.

Table H2. Concentrations of selected elements (in parts per million) determined by geochemical analyses of reconnaissance samples from the Potwar Plateau area, northern Pakistan.—Continued

Sample number	Field number	Geology: Host or source[1]	Geology: Rock analyzed	Ag (2)	As (10)	Cu (40)	Hg (15)/0.1[2]	Pb (50)	Zn (50)	Remarks
61	13	Cambrian and Permian formations.	Alluvium	<2	<5	12	13	18	**55**	
62	22	Warchha Sandstone	do.	<2	<5	27	10	19	**73**	No visible copper mineral.
63	17	Patala Formation	Coaly shale	<2	<5	16	**21**	12	18	Contains pyrite.
64	18	Warchha Sandstone	Alluvium	<2	<5	25	13	16	30	Do.
65	21	Permian formations	do.	<2	<5	13	4	15	25	
66	20	Patala Formation	Coaly shale	<2	**78**	6	**61**	**2592**	**92**	Do.
67	14	Warchha Sandstone	Alluvium	<2	<5	15	**15**	19	30	No visible copper mineral, coal area.
68	15	do.	do.	<2	<5	14	13	18	27	No visible copper mineral.
69	16	do.	do.	<2	<5	11	10	17	29	Do.
70	10	do.	do.	<2	<5	13	6	20	31	Do.
71	7	do.	do.	**2**	<5	14	8	18	40	Do.
72	8	do.	do.	<2	<5	12	13	13	27	Do.
73	6	Datta Formation	Ferruginous sandstone.	<2	<5	25	10	21	**210**	

[1]Includes some formation names of informal or local usage.

[2]Samples having reported values <1 ppm Hg were probably analyzed in a different way than the others; details of methods are not available. A separate anomaly threshold of 0.1 ppm is used for these analyses.

Appendix H1. Definition of Levels of Mineral Resource Potential and Certainty of Assessment

Definitions of Mineral Resource Potential

LOW mineral resource potential is assigned to areas where geologic, geochemical, and geophysical characteristics define a geologic environment in which the existence of resources is unlikely. This broad category embraces areas with dispersed but insignificantly mineralized rock as well as areas with few or no indications of having been mineralized.

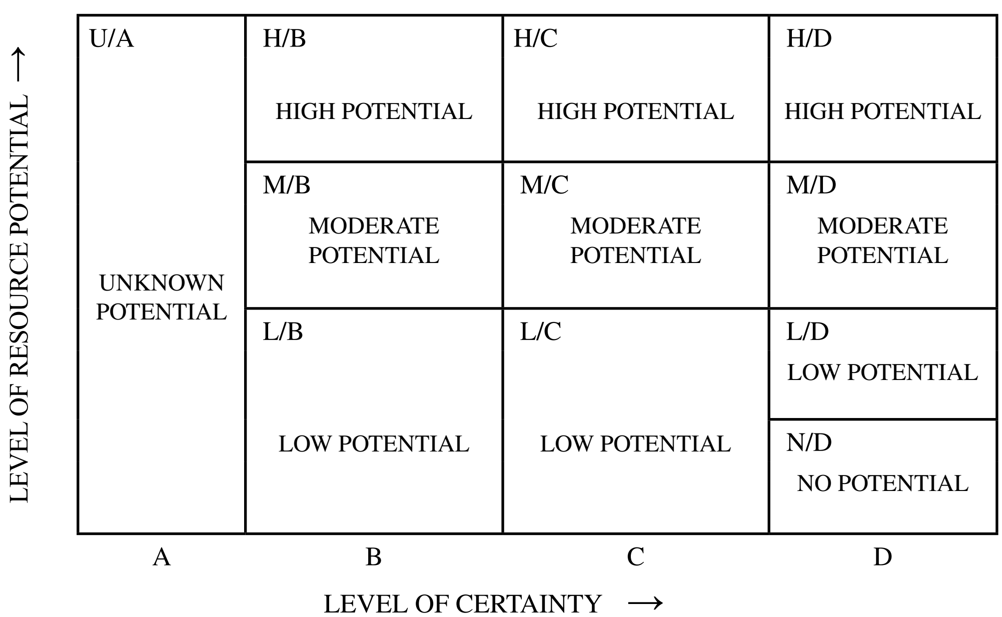
MODERATE mineral resource potential is assigned to areas where geologic, geochemical, and geophysical characteristics indicate a geologic environment favorable for resource occurrence, where interpretations of data indicate a reasonable likelihood of resource accumulation, and (or) where an application of mineral-deposit models indicates favorable ground for the specified type(s) of deposits.

HIGH mineral resource potential is assigned to areas where geologic, geochemical, and geophysical characteristics indicate a geologic environment favorable for resource occurrence, where interpretations of data indicate a high degree of likelihood for resource accumulation, where data support mineral-deposit models indicating presence of resources, and where evidence indicates that mineral concentration has taken place. Assignment of high resource potential to an area requires some positive knowledge that mineral-forming processes have been active in at least part of the area.

UNKNOWN mineral resource potential is assigned to areas where information is inadequate to assign low, moderate, or high levels of resource potential.

NO mineral resource potential is a category reserved for a specific type of resource in a well-defined area.

Levels of Certainty



A. Available information is not adequate for determination of the level of mineral resource potential.
B. Available information suggests the level of mineral resource potential.
C. Available information gives a good indication of the level of mineral resource potential.
D. Available information clearly defines the level of mineral resource potential.

Abstracted with minor modifications from:

Taylor, R.B., and Steven, T.A., 1983, Definition of mineral resource potential: Economic Geology, v. 78, no. 6, p. 1268–1270.

Taylor, R.B., Stoneman, R.J., and Marsh, S.P., 1984, An assessment of the mineral resource potential of the San Isabel National Forest, south-central Colorado: U.S. Geological Survey Bulletin 1638, p. 40–42.

Goudarzi, G.H., compiler, 1984, Guide to preparation of mineral survey reports on public lands: U.S. Geological Survey Open-File Report 84–0787, p. 7, 8.