THE ALLUVIAL MINERALS OF THE RIVER INDUS, WEST PAKISTAN

Rashid Ahmad Khan Tahirkheli

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THE ALLUVIAL MINERALS OF THE RIVER INDUS,

WEST PAKISTAN

Being a Thesis presented by

RASHID AHMAD KHAN TAHIRKHELI, B.Sc. (Alig).,

TO THE UNIVERSITY OF ST. ANDREWS

in application for the

DEGREE OF Ph.D.

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CERTIFICATE.

I certify that R.A. Khan Tahirkheli has been engaged in research for ten terms' at the University of St. Andrews, that he has fulfilled the conditions of Ordinary No. 16, and that he is qualified to submit the accompanying thesis in application for the degree of Doctor of Philosophy.

Supervisor.

I certify that the following thesis is based on the results of research carried out by me, that it is my own composition, and that it has not previously been presented for a higher degree.

Career.

After completing my B.Sc. degree at the Muslim University, Aligarh, India, I joined the Geological Survey of Pakistan in 1950 as Assistant Geologist. In December 1958 I was promoted to Geologist, and in December 1962 to Senior Geologist.

In 1957, I was selected to join a scientific and mountaineering expedition to the Higher Himalayas, jointly sponsored by the Kyoto University of Japan and the Punjab University of West Pakistan.

Since August 1961, I have been engaged in the study of the alluvial deposits of the Indus Valley (collected in field expeditions during 1960-61) at the University of St. Andrews.

CONTENTS

Acknowledgements.

The author wishes to thank Professor C.F. Davidson for acting as research supervisor. Part of the field investigation was carried out in collaboration with Mr. Walter Danilchik of the United States Geological Survey (attached to the Geological Survey of Pakistan), whose help is gratefully acknowledged.

The author is also indebted to the Directors of the Geological Surveys of Pakistan, the United Kingdom, and the United States, for radiometric and spectrographic analyses of some of his samples executed in the laboratories of these institutions.

The main laboratory work on the samples was carried out in the Department of Geology, University of St. Andrews, during the tenure of a Colombo Plan Scholarship for which the author extends his grateful thanks to the sponsors. Dr. E.R. Gee, retired Director of the Geological Survey of Pakistan, and Mr. Martin Lowe, a research scholar, helped in reviewing part of the manuscript. The author also acknowledges the help of the technical and secretarial staff of the Geology Department, University of St. Andrews.

ABSTRACT

The river Indus originates at an elevation of 17,000 feet on the northern flank of Kailash mountain in Tibet, and before it joins the Indian Ocean near Karachi in West Pakistan, it flows for about 2000 miles, partly in the mountainous terrain of the Himalaya and partly over the plains of Sind and the Punjab. The investigations reported upon in this thesis relate to a study of the alluvial deposits in the upper reaches of the river, along a stretch of about 500 miles between Skardu in the Great Himalayas and Kalabagh in the Outer Himalayas.

The mountains in the area studied range from 3,000 feet to over 20,000 feet in height. They can be divided into the four parallel ranges of (1) the Great Himalaya over 20,000 feet in elevation; (2) the Lesser Himalaya between 12,000 and 15,000 feet; (3) the Hazara Himalaya at 6,000 - 8,000 feet; and (4) the Outer Himalaya from 3,000 to 4,000 feet. In the greater part of this region the Indus flows through gorges with precipitous walls rising from 2,000 to 3,000 feet above the valley floor, forming perhaps the best-known example of typical antecedent drainage. For a distance of about 55 miles from Amb to Attock the valley opens out as a plain, which is locally over 12,000 feet in width, and huge accumulations of alluvial detritus have been deposited here. The gradient of the valley is high in the Great and Lesser Himalaya, where it is 29 and 17.1 feet per mile respectively. Further downstream between Amb and Attock the gradient is 6 feet per mile, and

between Attock and Kalabagh it falls to 2.7 feet per mile.

Two types of alluvial deposit have been distinguished. One is dominantly sandy and is patchy in occurrence, mantling the valley floor along the high flood mark. The other is formed of closely packed pebbles, cobbles, and boulders with interstitial sand and grit. The first is referred to as mantle sand and the second as gravel deposit. The interstitial sand in the gravel deposits tends to be darker in tinge and to contain a greater variety of minerals than the mantle sands. Minerals of high specific gravity such as gold, uraninite, tinstone, scheelite and magnetite are more frequent in the gravel deposits.

The thesis includes a description of the bed-rock geology of the area, and reports studies on the degree of sorting and the mineralogy of the gravels. Only the economic aspects of this work are reported in this abstract.

Because of accessibility, the alluvials between Attock and Amb were chosen for economic study. Here a primitive gold-washing industry exists and around 20 or 25 families are seasonably engaged in gold production. At a very rough estimate, the overall production is only 14 troy ounces per year, worth say £175. The method of mining, using a primitive sluice known as a nava. is described; and a report is given on detailed sampling tests employing a skilled gold-washer. The average yield is 1.05 grains per cubic yard of specially selected alluvium.

The valuable mineral species present in the alluvium are gold, uraninite, tinstone and scheelite. The value of the average yield of gold from selected "high-grade" alluvium is about 6d per cubic yard. From the radiometric and mineralogical assays the tenor of uraninite in the natural sands is estimated to be around 0.0002%, equivalent at full recovery to about 1d per cubic yard. The tenor of tinstone and scheelite have been estimated visually to be about 1 oz. and 0.02 oz. per cubic yard; but this estimate based on grain counts is almost certainly much too high for tinstone, since "tinning" tests using zinc and hydrochloric acid show that cassiterite is much rarer than the visual, optical, assessment. Considered overall, therefore, even the small patches of heavy mineral concentrate on which the indigenous gold industry is based have a value of contained minerals of well under one shilling per cubic yard. Since the grade of material which would have to be worked in a large-scale mechanised operation would be much lower than that of selected patches operated on manually, it is plain that there are no commercial prospects for any large-scale dredging.

Radiometric studies have been conducted on the bed-rocks traversed by the river, and also on the alluvium. The highest values encountered are, firstly, in veins of aplite, pegmatite and younger granite giving 0.03 - 0.5 mr/hr; secondly, graphitic schists usually giving 0.03 - 0.04 mr/hr, but rising in pockets to 0.08 mr/hr; and thirdly, some acid gneissose bands in the metamorphic formation giving as high as 0.15 mr/hr. When examined under ultraviolet light the last show pin-point fluorescent grains identified as zircon and (?) autunite.

The radioactive minerals encountered in the alluvials are potash, feldspar, zircon, monazite, uranothorite and uraninite. The radioactivity of the bulk alluvials throughout the region investigated ranges from 0.012 to 0.02 mr/hr, which is from 0.002 to 0.02 mr/hr higher than background. Considered overall, no significant change in the radioactivity profile has been found along the course of the river; but the greatest proportion of high values is to be found where the country rocks are the metamorphosed gneisses bearing bands of high radioactivity. This suggests that the main source of the uraninite is local, predominantly in the metamorphic rocks between Amb and Pattan, the mineral most probably occurring as disseminations of dispersed grains in these formations.

In the terrace gravel deposits uraninite is less frequent at depth than it is near the surface; and in hand-panned concentrates from the Siwalik sandstones, which represent the alluvials derived from the Himalayan crystalline rocks by the Indus-Brahma river system of Neogene times, uraninite could not be found at all. These facts suggest that detrital uraninite does not survive lithification but is removed from sandstones by intra-stratal waters permeating the rocks during the period of early to late diagenesis.

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INTRODUCTION

Preliminary Statement

The alluvial deposits of the river Indus have for many centuries formed a source of placer gold, and a gold-washing industry, conducted by methods which have changed little over the ages, remains today the means of livelihood of many families in the mountain valleys traversed by this great river. Until recent years little precise information has been available on these remotely sited activities. In 1957, however, radioactive minerals and scheelite were found in the black-sand concentrates prepared by the gold-washers, and publicity given to these discoveries resulted in many enquiries seeking factual data. These stimulated a study of the mineralogy of the alluvials, with the two-fold aim of reviewing their potentialities for large-scale commercial exploitation and of investigating the light which they shed on the geology of the unexplored crystalline rocks drained by the river in its passage through the Himalayas. A special project was created by the Geological Survey of Pakistan and the author was deputed to undertake the necessary work.

This project was begun in the latter part of 1957 and was continued up to July 1961. In its first phase, a reconnaissance survey was made of the alluvials between Attock and Amb, to produce preliminary data on the radioactivity and mineralogy of selected samples. This was followed by a detailed examination of a selected region about a mile upstream from Amb, where relatively high concentrations of heavy minerals were found. An area favoured by the gold-washers, 1000 feet long and 300 feet wide, was chosen and 30 sampling sites located on a 100-foot grid, at which channel samples were collected. The radioactivity of the sediments was measured using a scintillation counter, and a study was made of the methods of concentration employed by the gold-washers with a view to considering by-production of minerals other than gold.

In the course of these preliminary studies, an expedition was made to the Gilgit Agency together with Mr. Walter Danilchik of the United States Geological Survey, to reconnoitre the alluvials of the river Hunza, one of the major tributaries of the Indus in the Higher Himalayas. Samples were taken from widely scattered localities for mineralogical and radiometric analysis, to ascertain whether this tributary is a major source of the ore-minerals in the Indus sediments.

All these early investigations were of a local nature, being confined to a selected area in the Indus valley or to the river Hunza. The results were published from time to time by the Geological Survey of Pakistan as Administrative Reports or as Information Releases. The mineralogical and radiometric data obtained were, however, so erratic and variable that no firm conclusion could be based on them; and it was therefore decided towards the end of 1960 to embark upon a more ambitious operation, to study the mineralogy of the river Indus for a distance of 500 miles from Kalabagh in the south to Skardu in Baltistan in the north. Most of this region is tribal territory, where the inhabitants are unaccustomed to geological or any other explorers, and complex precautions had to be taken to safeguard life and property throughout the period of this pioneer reconnaissance.

Towards the end of 1960 the author was selected for a Colombo Plan Scholarship tenable for two or three years in a British University, for laboratory work on the Indus alluvials, and he was accepted as a research student by Professor C.F. Davidson at the University of St. Andrews. The following pages report the field and laboratory work accomplished.

Accessibility

The river Indus is the main drainage artery of West Pakistan. It traverses the country longitudinally and from its source on the northern flanks of Kailas mountain in Tibet, at an altitude of 17,000 feet, to its mouth in the Indian Ocean near Karachi it has a length of nearly 2,000 miles, draining a basin of some 370,000 square miles. (Fig. 1). The average breadth of the channel in the region studied is around 160-230 feet in Gilgit Agency and 800-1200 feet between Amb and Attock. The part of its course dealt with in this report begins at Skardu in the Great Himalayas, about 450 miles from its source, and continues downstream for about 500 miles to Kalabagh in the Outer Himalayas.

From Kalabagh north to Amb, for a distance of about 165 miles, the river is easily reached. Most of this sector is serviced by metalled and fair-weather roads. The sample sites at Kalabagh, Kushalgarh and Attock are also accessible by railway. Upstream from Amb, right up to Skardu, the Indus is approachable only by mule-track

INDEX MAP OF WEST PAKISTAN

SCALE

and footpath running in a zig-zag fashion along the steep slopes of the valley. At places the track is so dangerous that one follows it with trepidation. The construction of an all-weather road intended ultimately to connect with Gilgit and Skardu was in progress when the author traversed the area; to minimize the hazards of winter snow most of the road is on the slopes 2,000-3,000 feet above the river level.

A freighter air service to Gilgit and Skardu is available from Rawalpindi. This is dependent upon favourable weather and during the winter months with cloudy conditions flights may be delayed for weeks on end.

Previous Work

No studies on the Indus alluvials had been published prior to 1957. In that year a few samples of gold-washers' residues from Amb were investigated mineralogically and radiometrically by Dr. Gunter Zeschke, a UNESCO officer attached to the Department of Geology in the University of the Punjab, by Mr. D. Ostle of the Atomic Energy Division, U.K. Geological Survey, and by the author on behalf of the Geological Survey of Pakistan. The results of these studies were not then announced, but a statement on the occurrence of uranium was made by the Pakistan Atomic Energy Commission in 1958 and, according to Professor C.F. Davidson (1), this found its way into a Russian text-book (2) in the following words:

> "An announcement was made in 1958 by the Pakistan Atomic Energy Commission about the discovery of uranium mineralization in Hazara. The content of uranium is high .... in placers of the present-day river valleys. Uraninite and monazite have been found in river bed deposits, in one case over a stretch of more than 90 kilometres. The heavy concentrates from the river sands have a content of U_3O_8 reaching 16 per cent. Uraninite occurs in well-preserved crystals which contain inclusions of organic matter".

These statements are misleading in that they fail to emphasize that a high tenor of uranium was found solely in small quantities of highly-panned clean-up residues from gold-washings, quite unrepresentative of any natural occurrence. The first precise report on the radioactive placers was published by the author, in conjunction with Mr. Walter Danilchik, in 1958, as an Information Release of G.S.P. (3). It was shown that the radioactive minerals present in the sediments, in order of decreasing abundance, are zircon, monazite, uranothorite and uraninite-thorianite. Chemical analyses of 49 samples of representative material executed in the laboratories of the United States Geological Survey show 42 samples with 0.001% uranium or less and seven samples with 0.002-0.007%, the latter values relating to natural concentrates of heavy minerals. It was concluded that "the low content of uranium is surprising, considering that some of the deposits have yielded uraninite grains from their heavy mineral concentrates. Recalculating to account for the pebbles, cobbles and boulders, the overall uranium content of the gravel is on the order of 0.0007 per cent". These data were supplemented by further Information Releases of G.S.P. (4, 5) written by the author in 1960 and 1961, the substance of which is incorporated in this thesis.

Contemporaneously Dr. Zeschke publicized the uraninite of the Indus gravels in two papers in the German language (6, 7) and two in English (8, 9) the substance of which is that uraninite and scheelite have been transported downstream by the river, the uraninite for 100 miles or more and the scheelite for 1.100 miles. The view is maintained that these minerals have survived transportation over a very long period of time. These conclusions have been accepted by many writers as relevant to the conditions of formation of the gold-uranium ores of the

Witwatersrand, of which the Indus gravels are claimed by them to be an actualistic analogue. It will be shown later in this thesis that Dr. Zeschke's views are not substantiated by more detailed studies.

In 1961 the U.K. Geological Survey (Atomic Energy Division) was invited by the Atomic Energy Commission of Pakistan to make a rapid survey of the Indus alluvials, to appraise the feasibility of economic exploitation for uranium and tungsten. An aeroradiometric survey of the sediments between Kalabagh and Kabulgram was undertaken under the geological control of Mr. J.M. Miller, resulting in a confidential report GSM/AED, No. 241 (10). This report presents an Isorad map along part of the valley, and discusses the mineralogy and radiometry of concentrates collected at radioactivity "highs". On the basis of the results obtained, Mr. Miller calls for further radiometric and mineralogical exploration of the alluvials, and recommends drilling and seismic investigations at selected localities to verify the thickness of the gravels.

PHYSIOGRAPHY

The region under investigation lies between longitudes $75^{\circ}38'$ and $71^{\circ}33'$, and between latitudes $35^{\circ}18'$ and $32^{\circ}55'$. The southern limit of the area is thus about 10° north of the tropic of Cancer. Climatically, however, much of the country is tropical, although the climatic environment may vary greatly from place to place, the great mountain ranges to the north exercising a predominant influence on meteorological conditions. It is a country of the

PROFILE OF THE INDUS VALLEY IN THE AREA UNDER STUDY TOGETHER WITH LOCAL RELIEF.

highest mountains in the world, with their bases in sub-tropical valleys and their peaks in perennial ice and snow. These mountains gradually rise from around 3,000 feet in altitude at the southern limit of the region to over 20,000 feet in the north. Three parallel ranges may be distinguished, respectively known as the Great Himalayas, the Lesser Himalayas and the Outer Himalayas (11).

The Great Himalayas in the extreme north have an elevation of over 20,000 feet. The Lesser Himalayas or middle ranges have a width of about 50 miles and rise to 12000-15000 feet, and the Outer Himalayas varies in elevation between 3000-4000 feet. The local relief along the river Indus, however, suggests the presence of a fourth range, falling between the Lesser and the Outer Himalayas. This the author refers to as the Hazara Himalayas since here the Indus flows through north-western Hazara, well-known for its Palaeozoic geology. The range comprising the Hazara Himalayas varies in elevation from 6,000 to 8,000 feet; geologically it forms a distinct unit of relatively low-grade metamorphic rocks, bordered by crystalline and sedimentary groups to the north and south respectively (Fig. 2).

All these systems have distinct topographical features depending on the rock formations and their attitude to sculpturing agents. In the Outer Himalayas the Siwalik shale and sandstone is comparatively soft, and rapid weathering yields a strikingly abrupt form of topography. Great dip slopes terminating in huge steep escarpments are separated by broad longitudinal strike valleys which are dissected by numerous deep meandering ravines. The soil from the weathering of Siwalik rocks is not at all sympathetic to cultivation and hence agriculturally this area is very poor.

In the Hazara Himalayas seasonal water erosion is more active and gives rise to a varied relief. The mountains are steep with a sharp sky-line. Over 6,000 feet elevation the winter precipitation is in the form of snow, which covers the mountains during the short spell of winter months. Summer rain is monsoonal. Sub-alpine forests cover the mountains over 6,000 feet, but the rest of the region is sparsely vegetated.

The Lesser and Great Himalayas receive most of their precipitation as snow. During the winter months the snowline descends to 6,000-7,000 feet, but in the summer it recedes to 14,000 feet; which is the permanent snowline in the Himalayas. Hence ice and its melt-waters form the principal agents of erosion. Due to great variation in day and night temperatures frost-wedging is everywhere prevalent, and the peaks resemble the Matterhorn, with steep slopes and jagged heights looking as if they had been whittled by a sharp-edged knife. The steep-sided inter-montone valleys are dissected by fast-moving streams filled with boulders up to 20-25 feet in diameter (Photo 1).

The Lesser Himalayas, locally called the Indus 'Kohistan' or 'the land of mountains', receive most of their precipitation as snow in the winter months. All the peaks over 14,000 feet support neve fields. In the tributary valleys a few isolated villages depend on cultivation of the river terraces and on a timber trade based on the sporadic alpine forests.

A tributary in Lesser Himalayas with huge size boulders.

The Great Himalayas are inhabited by some of the biggest valley glaciers in the world, and the prominent mountain peaks are covered by permanent ice, the melt-waters from which feed most of the important rivers of the Indo-Pakistan sub-continent. The valleys are broad, and most of the population dwell on the river terraces which yield a good soil for grain and fruit (Photo 2). Four terraces are usually present and the two lower ones, mainly between 4000 and 6000 feet elevation, are inhabited. This part of the Himalayas is greatly favoured by mountaineering expeditions between May and September.

In its upper reaches, where the river Indus traverses the Great and Lesser Himalayas, it flows through valley gorges which are attributed to antecedent drainage (Photos 3, 4). Above the present valley floor steep walls rise abruptly for two or three thousand

Cultivated terrace along the bank
in Lesser Himalayas.

Gorge shaped Indus valley in Great
Himalayas.

A close view of the Indus river
in Great Himalayas.

feet (Photo 5). Near confluences with tributaries the valley tends to widen and lake type features are displayed. Many of the tributaries are hanging valleys with cirques displayed in their upper reaches. The gradient of the Indus valley in the Great Himalayas, between Skardu and Chilas, is 29 feet per mile. Lower down the course is less steep and between Chilas and Pattan the valley floor drops at the rate of 17.1 feet per mile.

Precipitous wall rising along the bank of the Indus in Great Himalayas.

The river Indus in the Hazara Himalayas flows through a steep-sided gorge for a distance of about 92 miles, until it emerges to the plain downstream of Amb. Between Amb and Attock the valley is old and the river has changed course many times. The gradient is low and there is little corrasion: the valley is broad, at places more than two miles in width, and a huge load of gravels and sands is deposited, covering the flood-plain to its rim. (Photo 6). In summer when the river is in spate most of the flood-plain is under water, except sand-bars which have become permanent islands with a dense growth of forest (Photo 7). In winter the floods subside and for the most part the flood-plain becomes dry. The main stream splits up into distributaries which become fordable at places, and hence in the winter months this part of the river resembles a braided channel. The gradient between Pattan and Amb where the Indus flows through mountain confines is 8.7 feet per mile. The valley floor between Amb and Attock drops at the rate of 6 feet per mile.

Huge volume of alluvials in the Indus valley upstream of Attock.

Sand-bar with thick growth of forest.

Downstream from Attock, during its course through the Outer Himalayas, the Indus again flows through a narrow gorge, with precipitous walls rising for 1000-1500 feet at an angle of from 70° to 90°. Vertical corrasion is proceeding at a tremendous rate whereever the Siwalik rocks are traversed. Alluvial deposits are sparsely distributed along the river banks, just below the great precipices. In winter sand-banks are seen in mid-stream, but in the summer floods all are submerged. Between Attock and Kalabagh, the valley floor descends at a gradient of 2.7 feet per mile.

DESCRIPTION OF THE ALLUVIALS.

The alluvial deposits of the sector of the river Indus studied in this investigation are essentially sands, pebble-beds, cobble-gravels and boulder-beds (Photo 8). On the basis of composition and mode of occurrence two main categories can be distinguished. One of these is a dominantly sandy deposit which occupies extensive patches mantling the valley floor along the high flood mark (Photo 9). The other is an assortment of closely-packed pebbles, cobbles and boulders with sand in the interstices. The first sediment is referred to as mantle sand and the second as gravel deposit.

A close view of the principal constituents of the Indus alluvials.

Vertical section of mantle sand deposit along the bank.

Mantle sand is widespread downstream from Attock. At Khushalgarh and Kalabagh most of the alluvials of the valley floor are of this nature, with only a few erratic thin patches of closely packed gravel deposit. Upstream from Attock rather less than one third of the alluvials are sand deposits. The bars in the main river-channel between Attock and Amb display both sands and gravels; most of them have become permanent islands covered by forest (Photo 10).

Sands and gravel displayed over
a sand-bar.

It is clear that these two types of alluvium were deposited under different conditions. The gravel deposits predominate where the gradient is relatively steep and where the current in flood has carried away all save the coarser debris. The mantle sand was deposited in slacker water. For the most part the sands are lenticular intercalations in the gravels, their maximum thickness rarely exceeding ten feet though one sand section 25 feet thick has been measured at Attock. Some vertical sections of the mantle sands reveal a lamination which suggests that deposition may be cyclic, a single deposit being the result of several flood cycles.

Medium to very fine sand usually predominates in the mantle sands, with angular to sub-angular grains common in the finer fractions (less than 0.25 mm.), the grains over that size being commonly sub-rounded to rounded. Wind-winnowing may give rise to patches with a dark grey tinge, enriched in black micas. Streaks of heavy-mineral concentrates are conspicuous, though usually of no great size. One can see these streaks being formed by the lapping of the waters along the banks of the river. Both black, magnetite-rich, and pinkish brown, garnet-rich, concentrations occur.

The gravel deposits normally contain less than one-third of sand and the remainder of coarse clastics. Pebble-counts reveal that 65-75% of the gravels derive from acid igneous rocks, 15-25% from intermediate-basic igneous rocks and 5-10% from metamorphic rocks. The first group includes granodiorite, granite, granite-gneiss, pegmatite and aplite, and the second diorite, dolorite, gabbro and basalt. Vein quartz, limestone and schist are most common among the metamorphic components.

Upstream from Amb the valley is narrow with a steep gradient, and the flood water has a high velocity. Here boulders 5 or 6 feet in diameter are common (Photos. 11, 12), cobble gravel predominates,

Boulder gravel in the Indus valley in Lesser Himalayas.

Boulder gravel in the Indus valley in Great Himalayas.

and pebble gravel is proportionately less abundant. Downstream from Amb the abundance of boulder gravel diminishes and at Attock this forms less than two per cent of the gravel deposits (Photo 13), the average boulders being around 2 or 2.5 feet in diameter. Cobble gravel and pebble gravel becomes correspondingly more conspicuous and most of their components attain a well-rounded form.

During flood, when the waters are charged with a heavy load, the floodplain gravels act as riffles for the finer sediments. Sands entrapped in the gravel deposits resemble the mantle sands except that they may be somewhat coarser in grain and darker in hue. In quantity and variety the tenor of heavy minerals is higher, and the species of high specific gravity such as magnetite, scheelite, uraninite and gold are more frequent in these deposits.

Sporadic distribution of boulders in
the gravel deposit at Attock.

Old river terraces are situated all along the region studied, but they are most prominent between Amb and Kalabagh. Downstream from Attock they consist mainly of sands, but upstream terrace gravels predominate, usually covered by a thick mantle of soil forming fertile, cultivated land. Chemical leaching or staining by groundwaters often leads to a pink or red colouration. The mantle sand deposits on the old river terraces appear as dunes, worked by the shifting winds. They are wholly devegetated and form waste land except where there is a high silt or clay content, when grain is cultivated once a year. Heavy mineral separations effected by rain water are often seen and one can collect a basket-full in quite a short time.

FIELD WORK

(a) Sampling of the alluvial deposits.

As already mentioned, field investigations of the Indus alluvials were begun in November 1957 and continued at intervals up to May 1961. During the first two field seasons most of the time was spent in the region between Attock and Amb. In the final field tour, which lasted longer, the sector covered ranged from Kalabagh in the south to Skardu in Baltistan to the north (Fig. 3). The stretch of alluvium sampled can conveniently be divided into three sectors, as follows.

(a). Between Kalabagh and Attock the Indus valley is narrow and alluvial deposits sparse. Sampling was carried out at Gariala, Khusulgarh and Kalabagh, respectively situated 8, 46 and 104 miles downstream from Attock. Heavy mineral deposits in substantial amounts were found in a sand-bar about two miles downstream from Kalabagh, these having a radioactivity of 1 mr/hr. By sampling this area, including the side valleys, it was hoped to ascertain whether the economic minerals derive from upstream or are fed in by tributaries.

(b). From Attock to Kabulgram many closely spaced samples were collected (Fig. 4). Most attention was paid to this sector because here the Indus, after emerging from its mountain confines, deposits most of its load over a broad valley. Consequently a huge volume of alluvials is available hereabouts, in a locality well sited for industrial exploitation.

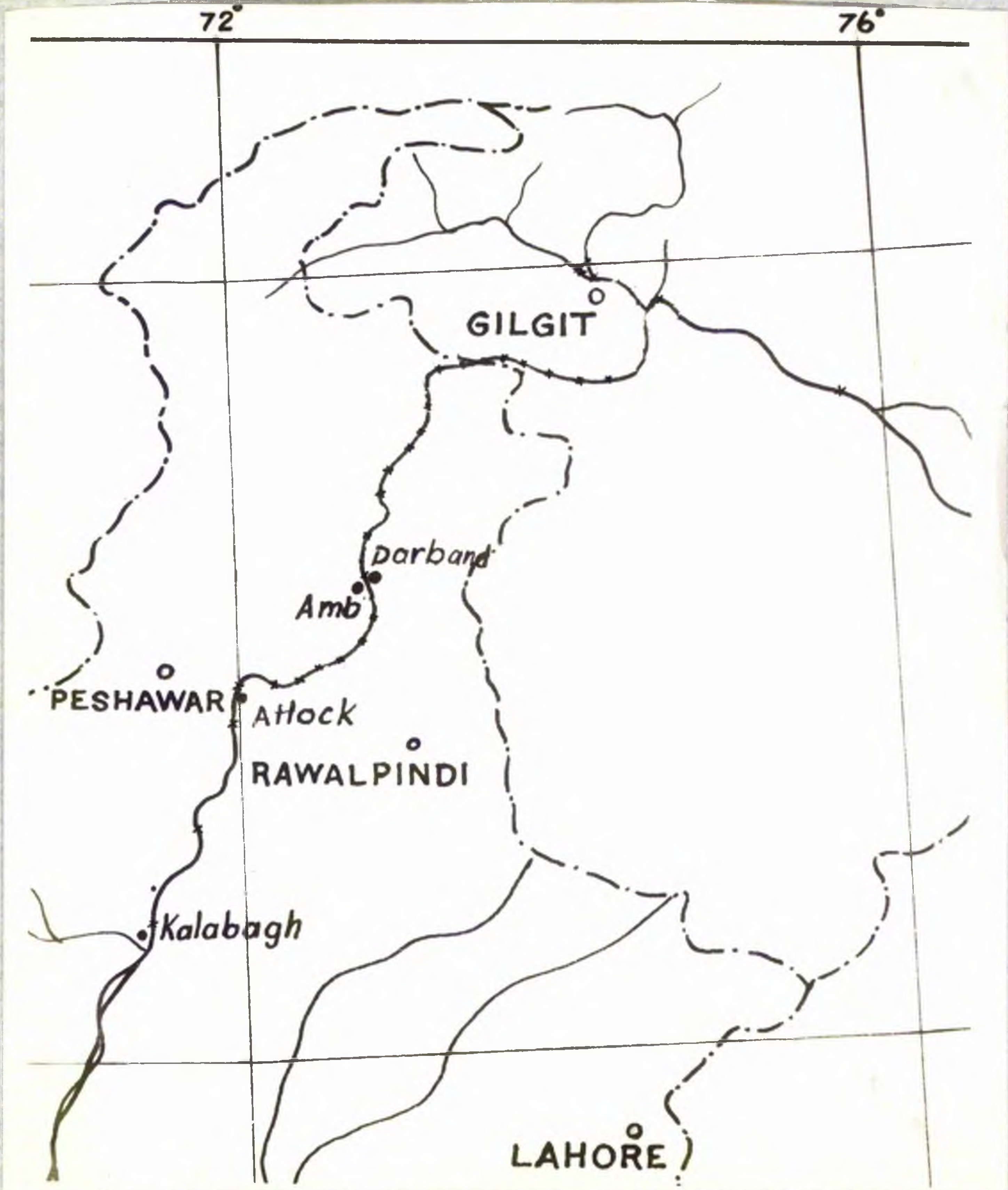


Fig. 3. Map showing approximate locations of the alluvial sampling-sites along the Indus river.

Scale
1" = 55 miles.

(c). Upstream from Kabulgram the valley is again narrow and alluvial deposits scanty. Samples were collected from the floodplain to study the distribution of scheelite, cassiterite, gold and uraninite; and the alluvials of the Gilgit, Hunza and Shigar rivers, the main tributaries of the Indus in the Higher Himalayas, were examined in greater detail.

Seven samples of old river terrace gravel were also taken between Attock and Amb, at points where the terraces are widely developed.

The sampling points were picked at random, and grab samples taken from the alluvials up to one foot from the surface. A superficial cover of clay and loam, present particularly in the terrace gravels, was removed prior to sampling. In the case of three shallow pits in flood plain alluvium dug at Attock, Guddar and Khabbal, the sand sample was obtained by channelling the five-feet deep wall of the pit. With samples from gravel deposits, preliminary sieving was carried out in the field to remove grit and pebbles.

The samples collected are of three kinds - bulk samples, hand-panned concentrates, and gold-washers' residue. The first, untreated, material has been utilized for size analysis and quantitative mineralogical study. Such material has been studied from areas (a) and (b) mentioned above as well as from the Indus at Skardu and from the Gilgit, Hunza and Shigar tributaries. The hand-panned concentrates were utilised for qualitative mineralogical analysis, and the gold-washers' residues, which are highly concentrated, have formed the main source of material for studying the scheelite, cassiterite, gold, uraninite and other rare minerals.

(b) Geological mapping.

In the reconnaissance, the rock outcrops along both sides of the valley have been mapped on quarter-inch topographical sheets (Fig. 5). This geological mapping has been confined to the immediate neighbourhood of both banks of the river. No detailed work was undertaken other than plotting the nature and disposition of the rock types encountered along the traverse route.

(c) Radiometric studies.

Both a hand-boring scintillometer and a portable field ratemeter (Geiger counter) were employed to measure the radioactivity of rocks along the traverse routes. Rock outcrops which yielded 3-4 times background were looked at in detail and at such spots closely-spaced radiometric profiles were prepared. Samples from "hot" spots were collected to examine the minerals giving rise to the radiogenic emanations.

Over the alluvials, radiometric profiles at 10-foot intervals (Fig. 18) on randomly picked sites were made, to compare the level of radioactivity at various localities and to provide data on the horizontal distribution of radioactive minerals.

LABORATORY WORK

The samples were dried, packed in cotton bags, and labelled in the field before transference to the G.S.P. headquarters at Quetta. Here the samples were again checked before being shipped to Scotland.

The laboratory operations are summarised in a flow-sheet (Fig. 6). A few experiments which did not provide adequate or satisfactory data are marked with a circle and are not described in detail in this text. First, the heavy and light minerals were separated by bromoform (sp. gr. 2.89) and, after extraction of the magnetite by a hand magnet (the amount of magnetite being weighed) representative slides of each fraction were prepared for grain-counting. On the average about 200 mineral grains were examined and identified per slide. Heavy-mineral separates from bromoform treatment were then fractionated by a Frantz isodynamic magnetic separator, the weight percentage of each fraction ascertained, and the results plotted in the form of histograms. The frequency of different mineral species in the third, fourth and fifth fractions from the Frantz separator, which contain the most varied assemblage, was determined microscopically. Scheelite grains were identified using a cold quartz tube (short wave-length) ultraviolet lamp.

Size analyses were conducted on the bulk samples and bromoform separates, using sieves of 16, 30, 60, 120 and 200 B.S.S. mesh.

According to Wentworth's classification these are designated very coarse, coarse, medium, fine, very fine, and silt sized. For the bulk samples cumulative curves were constructed to illustrate the grain-size distribution pattern, and the statistical device of quartile measures was adopted to derive significant values. The bulk samples from the mantle sand and from the gravel deposits at any one locality were treated separately. Mounted slides for microscopic study were prepared from each sieve fraction of the bromoform separates.

Radiometric assays of the crude alluvials and of the concentrates were conducted by the author in the laboratory in Pakistan. For standardization and confirmation a few samples have been analysed radiometrically by the Atomic Energy Commission of Pakistan, by the U.S. Geological Survey, and by the Geological Survey of Great Britain.

GEOLOGY.

The main purpose of plotting the geology along the traverse-route is to give additional information on the provenance of the heavy minerals and indicate the different rocks which contribute various types of these minerals. Hence more stress has been given to the lithology of the rocks, though structures and stratigraphy has been briefly described. The rocks which covered extensive stretches are discussed in more detail.

All the three main types of rocks, sedimentary, metamorphic and igneous are encountered in the area under investigation.

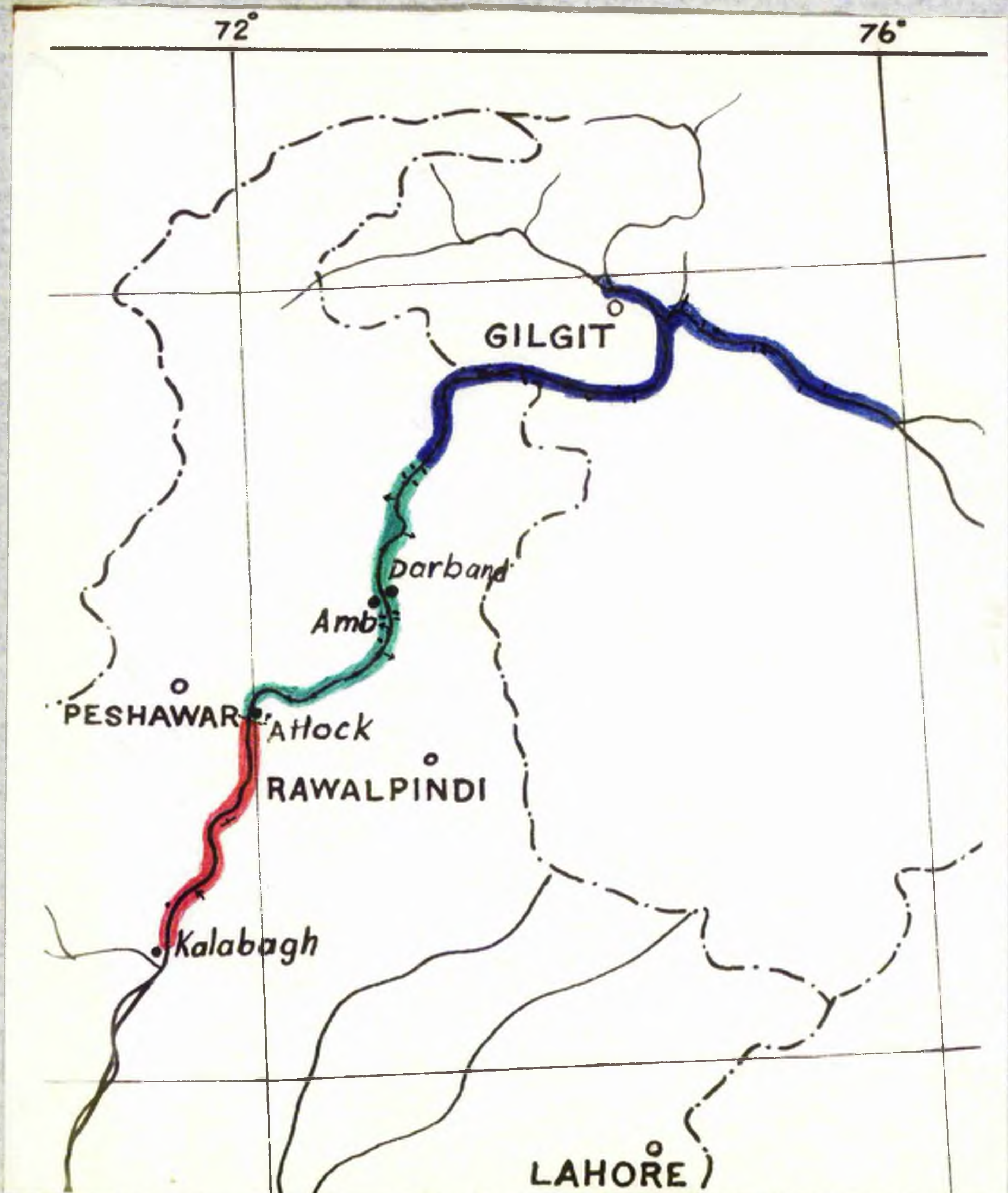
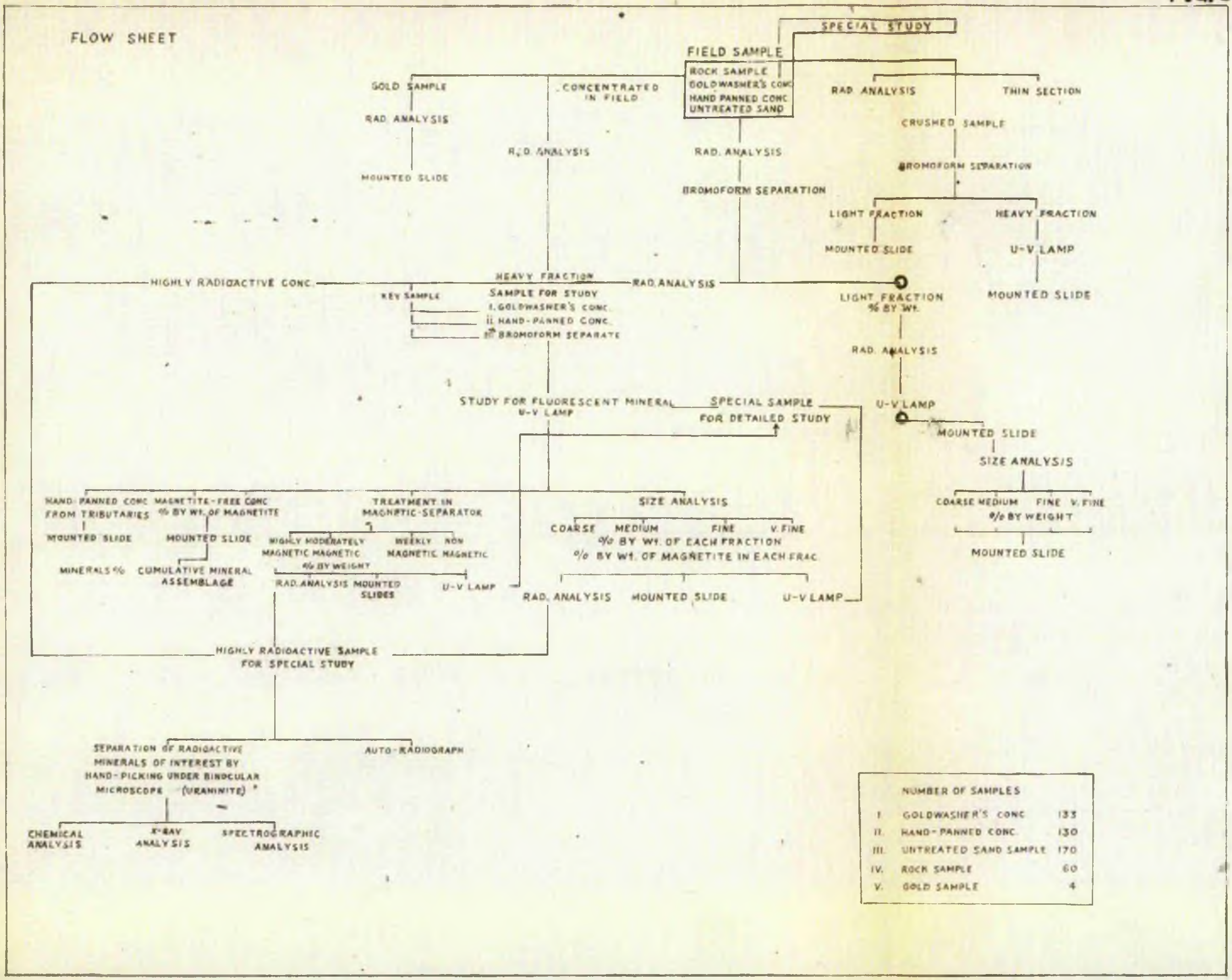


Fig. 5. Geological map of traverse-route
(Reduced from Quarter inch map)
Scale 1" = 55 miles

1. Sedimentary rock
2. Metamorphic rock
3. Igneous rock
4. Metasediment
5. Radioactive anomalies.

FIG. 6


FLOW SHEET
SPECIAL STUDY
FIELD SAMPLE
ROCK SAMPLE
GOLDWASHER'S CONC
HAND PANNED CONC
UNTREATED SAND
GOLD SAMPLE
RAD. ANALYSIS
MOUNTED SLIDE
CONCENTRATED IN FIELD
RAD. ANALYSIS
RAD. ANALYSIS
BROMOFORM SEPARATION
RAD ANALYSIS
THIN SECTION
CRUSHED SAMPLE
BROMOFORM SEPARATION
LIGHT FRACTION
HEAVY FRACTION
MOUNTED SLIDE
U-V LAMP
MOUNTED SLIDE
HIGHLY RADIOACTIVE CONC.
HEAVY FRACTION
RAD.ANALYSIS
KEY SAMPLE
SAMPLE FOR STUDY
I. GOLDWASHER'S CONC.
II. HAND-PANNED CONC.
III. BROMOFORM SEPARATE
LIGHT FRACTION
% BY WT.
RAD. ANALYSIS
U-V LAMP
MOUNTED SLIDE
SIZE ANALYSIS
COARSE MEDIUM FINE V. FINE
% BY WEIGHT
MOUNTED SLIDE
STUDY FOR FLUORESCENT MINERAL
U-V LAMP
SPECIAL SAMPLE
FOR DETAILED STUDY
HAND-PANNED CONC
FROM TRIBUTARIES
MOUNTED SLIDE
MAGNETITE-FREE CONC
% BY WT. OF MAGNETITE
MOUNTED SLIDE
MINERALS %
CUMULATIVE MINERAL
ASSEMBLAGE
TREATMENT IN
MAGNETIC-SEPARATOR
HIGHLY MODERATELY WEEKLY NON
MAGNETIC MAGNETIC MAGNETIC MAGNETIC
% BY WEIGHT
RAD.ANALYSIS MOUNTED SLIDES
U-V LAMP
SIZE ANALYSIS
COARSE MEDIUM FINE V. FINE
% BY WT. OF EACH FRACTION
% BY WT. OF MAGNETITE IN EACH FRAC
RAD. ANALYSIS
MOUNTED SLIDE
U-V LAMP
HIGHLY RADIOACTIVE SAMPLE
FOR SPECIAL STUDY
SEPARATION OF RADIOACTIVE
MINERALS OF INTEREST BY
HAND-PICKING UNDER BINOCULAR
MICROSCOPE (URANINITE) *
AUTO-RADIOGRAPH
CHEMICAL ANALYSIS
X-RAY ANALYSIS
SPECTROGRAPHIC ANALYSIS
NUMBER OF SAMPLES
I. GOLDWASHER'S CONC 133
II. HAND-PANNED CONC. 130
III. UNTREATED SAND SAMPLE 170
IV. ROCK SAMPLE 60
V. GOLD SAMPLE 4

Igneous rocks and metasediments show widespread distribution in the Lesser and Great Himalayas. Sedimentary formations are developed in the Outer Himalayas. These areas of igneous and sedimentary rocks are separated by the dominantly metamorphosed types occupying a broad belt in the Hazara Himalayas (Fig. 2).

Sedimentary formations.

From a point a few miles downstream from Attock to its exit on to the alluvial plains beyond the Salt Range at Kalabagh, the Indus river intersects a thick sequence of unaltered Tertiary and Mesozoic formations. These formations cover wide areas of the Kohat district and tribal areas West of the Indus, and extend across the Potwar plateau in Rawalpindi division to the east. At Kalabagh where the Indus cuts through the Salt Range, Mesozoic and upper Palaeozoic formations form narrow outcrops, and tectonically complex exposures of the Punjab Saline Series occur on either side of the river. The latter series is now considered to be of Cambrian/Precambrian age; in the eastern part of the Salt Range it underlies a fossiliferous Cambrian sequence (12).

This pre-Tertiary, Salt Range succession lies outside the area with which we are concerned; the description which follows will be confined to the region upstream from Kalabagh. This includes the following three stratigraphical/structural belts, each striking E-W across the region:

I./

I. The Soan Siwalik Syncline composed mainly of Upper Tertiary sediments, sandstones, clays and conglomerates, with Miocene (Murree formation) clay-shales and sandstones below. This complex syncline extends from just north of Kalabagh to near Khushalgarh.

II. The belt of steeply dipping Murree (Miocene) sandstones and shales between Khushalgarh and the Kala Chitta Range.

III. The Kala Chitta Range consisting of Mesozoic, Palaeocene and Eocene formations, mainly limestones with shales. This belt is sharply folded and complicated by a number of reverse faults. It continues West of the Indus river into the Tirah region north of Kohat.

The summarised stratigraphical/lithological succession of these areas is as follows:

Lower Pleistocene to Lower Pleiocene	Upper Siwalik 6000-9000 ft.	(Coarse boulder conglomerates, thick (earthy clays, sands, and pebbly grit (passing up into older alluvium. (Richly fossiliferous in the Siwalik hills.
Pontian to Middle Miocene	Middle Siwalik 6000-8000 ft.	(Grey and white sandstones and sand rocks (with shales and clays of pale and drab (colours. Pebbly at the top.
Middle Miocene to Tortonian	Lower Siwalik 4000-5000 ft.	(Bright red nodular shales and clays with (fewer grey sandstones and Pseudo- (conglomerates. Unfossiliferous in the (Siwalik hills.
Lower Miocene Burdigalian and Aquitonian)	Upper Murree	(Sandstones, soft, pale and coarse-grained, (with purple splintry and nodular shales (3000 ft.
	Lower Murrees	(Indurated dark sandstones, deep red and (purple coloured splintry shales, 5000 ft. (at the base the Fatehjang zone and conglomerates Upper Nari
		------------Unconformity------------
Upper Eocene	Chharat	(Nummulite shale, variegated shales, (gypseous marls and thin bedded limestone, (500-900 ft. Kirther
Middle Eocene (lutetian) to Lower Eocene (Landenian and Thanetian).	Hill limestone	(Massive well-bedded nummulitic limestone, (some shale and thin coal 200-1600 ft. (Laki and Ranikot)
		------------Unconformity------------

MESOZOIC FORMATIONS OF KALACHITTA

The Siwalik formations that cover wide areas north of Kalabagh were deposited by the ancient Indo-Brahm river system which flowed along the foothills of the Himalayas during Pleiocene times and derived most of its sediment from the Himalayan crystallines. These sediments were folded by the final upheaval of the Himalayas during Upper Pleiocene and Pleistocene times. This system skirts the Himalayan mountains for about 1600 miles with remarkable uniformity in its structural and textural behaviour, and separates the higher Himalayas from the Indo-Gangetic plain.

In West Pakistan, Siwaliks are widely distributed in the Potwar which is also the type area for these formations. Miss Elahi and Martin (13) have physiographically divided the Potwar in four main areas; the area under investigation has been distinguished as the Western Marginal area. The division of the Siwalik sequence into stages is based partly on the vertebrate fossils that they contain and partly on lithology.

Metamorphic rocks.

The metamorphic rocks of the Hazara Himalayas, between Attock and Jijal about 7 miles downstream of Pattan are represented by slate, phyllite, schist, gneisses, limestone and quartzite. The former four comprises one series and cover a wide expanse of country; quartzite occurs either as interbedded bands within the Slate series or overlies them.

The Slate series includes many lithological types, varying from place to place. Slate forms only a small percentage of the series, which embraces rocks of varying degrees of metamorphism from slaty shale to gneisses. These rocks were closely examined at three localities along the Indus Valley; at Attock, about 6 miles downstream of Amb and about 15 miles upstream of Amb.

At Attock, the section exposed in the road-cutting consists of light to dark grey slate and phyllite with thin interbedded yellowish grey limestone. About 6 miles downstream of Amb, the Slate series is composed of gneisses and schist; the former being dominant. About 15 miles upstream of Amb, phyllite and schist form the principal component whereas gneisses occur only occasionally as bands within the series. Graphitic material characterises the Slate series at certain places between Attock and Amb, and is widespread about 20 miles upstream of Amb. Previous workers named this locality the "Black Mountain" due to the extensive development of graphitic material. Sills and dykes of acid, basic and ultrabasic intrusives are frequently recorded in these rocks especially upstream of Kabulgram where acid intrusives consisting of aplite, pegmatite and younger granite are common. These intrusives increase in frequency towards the periphry of the granodiorite batholith which comes in contact with the Slate series downstream of Pattan. The rocks show intense metamorphism which resulted in change of their colour texture and composition.

The various members of the Slate series of Attock, Amb and the Black Mountains have been correlated by previous workers, on lithological, textural and structural grounds, which correlation is supported by the author's field observations. The Attock Slate series has been assigned a Pre-Cambrian age.

Quartzite and limestone associated with the Slate series is usually found overlying the latter and capping the high ridges between Attock and Turbela. The quartzite is thin-bedded, buff or brown in colour and frequently jointed. An extensive development of quartzite is noticed near Turbela which forms conspicuous ridges along the eastern bank of the river. The limestone is yellow or pale grey in colour and much weathered; caverns and fissures are very common features. Both limestone and quartzite are devoid of fossils. There are two types of quartzite and limestone; one is associated with the Slate series and occurs as interbedded bands; the other overlies the Slate series. The former are undoubtedly contemporaneous with the Slate series and is Pre-cambrian in age, whereas the latter have been designated Infra-Triassic by Middlemiss (14).

Igneous rocks.

The igneous-metamorphic contact is seen about seven miles downstream of Pattan. Igneous rocks cover large portions of the Lesser and Great Himalayas; extensive granodiorite batholith occupy over three-fourths of these areas of igneous rocks. The granodiorite batholith encountered near Pattan appears to be the south-eastern continuation of the Ladakh granodiorite previously investigated by Ivanac, Traves and King (15). The northward extension of this batholith along the Indus River is followed upstream of Chilas as far as Hanuchal. In some areas, the granodiorite merges into granite. The marginal zone towards Pattan is characterised by foliation and variation in texture and composition. The marginal facies located between Jijal and Pattan consist of dark coloured hornblende diorite which changes gradationally into the normal pale grey granodiorite. The effects of metamorphism in the granodiorite were seen all along the traverse-route, but more intense upstream of Chilas where well marked schistosity is observed.

Various acid, basic and ultrabasic intrusive bodies occur within the granodiorite mass. Acid intrusives are more frequent towards the north, upstream of Chilas, with usually regular orientation, striking north-east and dipping north-west at low angles. This phenomenon has been described by Wadia (16) as giving a misleading appearance of stratification to the south-eastern extension of the complex near Bunji. Microscopic analysis of this batholith shows it to be biotite hornblende granodiorite, medium grained, massive with granitoid texture. The mineral assemblage in order of abundance is plagioclase, quartz, biotite and hornblende. Epidote, sphene and apatite occur as accessory minerals. Some plagioclase is antiperthitic.

A granite body is noticed along the Indus between Harban and a point about six miles downstream of Chilas. This appears to have occupied a narrow belt along the Indus and the aforesaid granodiorite batholith merges with it towards the eastern and western margins. The granite is medium grained and foliated. The mineral assemblage in order of abundance is quartz, hornblende and feldspar. At places it exhibits porphyritic structure. An average feldspar measures 1.5 x .9 inches.

Meta-sediments.

Meta-sediments cover the greater portion of the Indus valley in Haramosh and upstream of Skardu. In Shigar valley, these rocks continue upstream beyond the confluence of the Basha and Braldu rivers. In Haramosh and downstream of Skardu along the river, the strike is north and northeast and the river flows transverse to the strike. In the Shigar valley, except for a few local changes in dip due to minor foldings, the general strike direction is north and northeast and conforms to that of Haramosh Range.

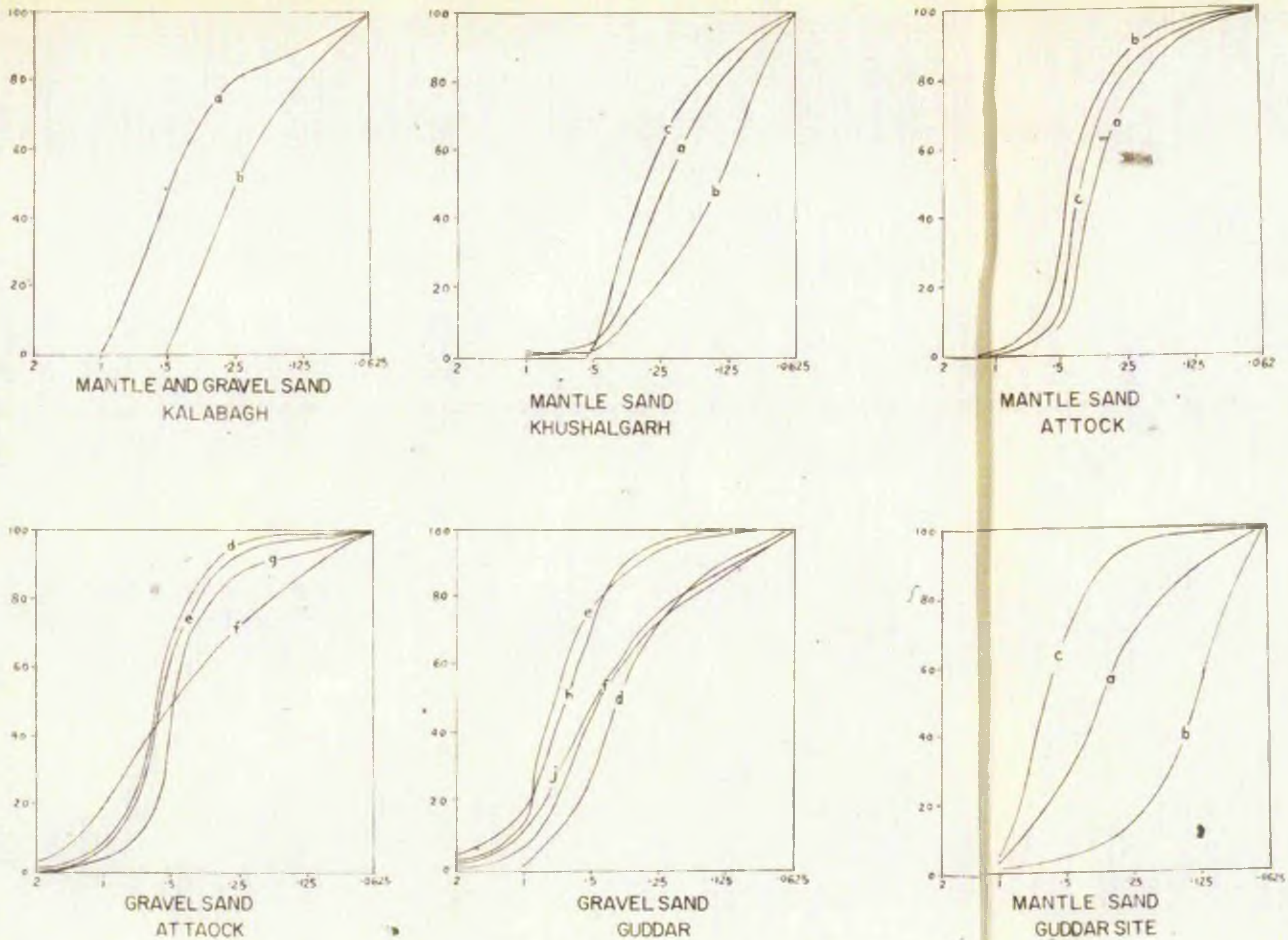
The meta-sediments consist of almost completely metamorphosed rocks belonging to more than one geological formation. In most places it has not been possible to separate and identify these formations as their original relationships have been obliterated by the intense metamorphism and tectonic disturbances. The rock types are schist, quartzite, gneisses, and recrystallized lime stone with thin cherty bands. A large number of quartz veins are also present. In the areas of mild metamorphism, the sedimentary rocks still retain their original sedimentary characters and in such localities they occur as coloured shale, slate and white and grey limestone. These formations are intruded by numerous acid, basic and ultrabasic sills and dykes.

MECHANICAL ANALYSIS.

For size analysis the samples were collected from the freshly deposited alluvials in the valley floor. Between Kalabagh and Kabulgram, samples were selected from six localities, with both the above sites inclusive. Samples from Hunza, Gilgit, Shigar tributaries and from the Indus alluvials at Skardu were also studied.

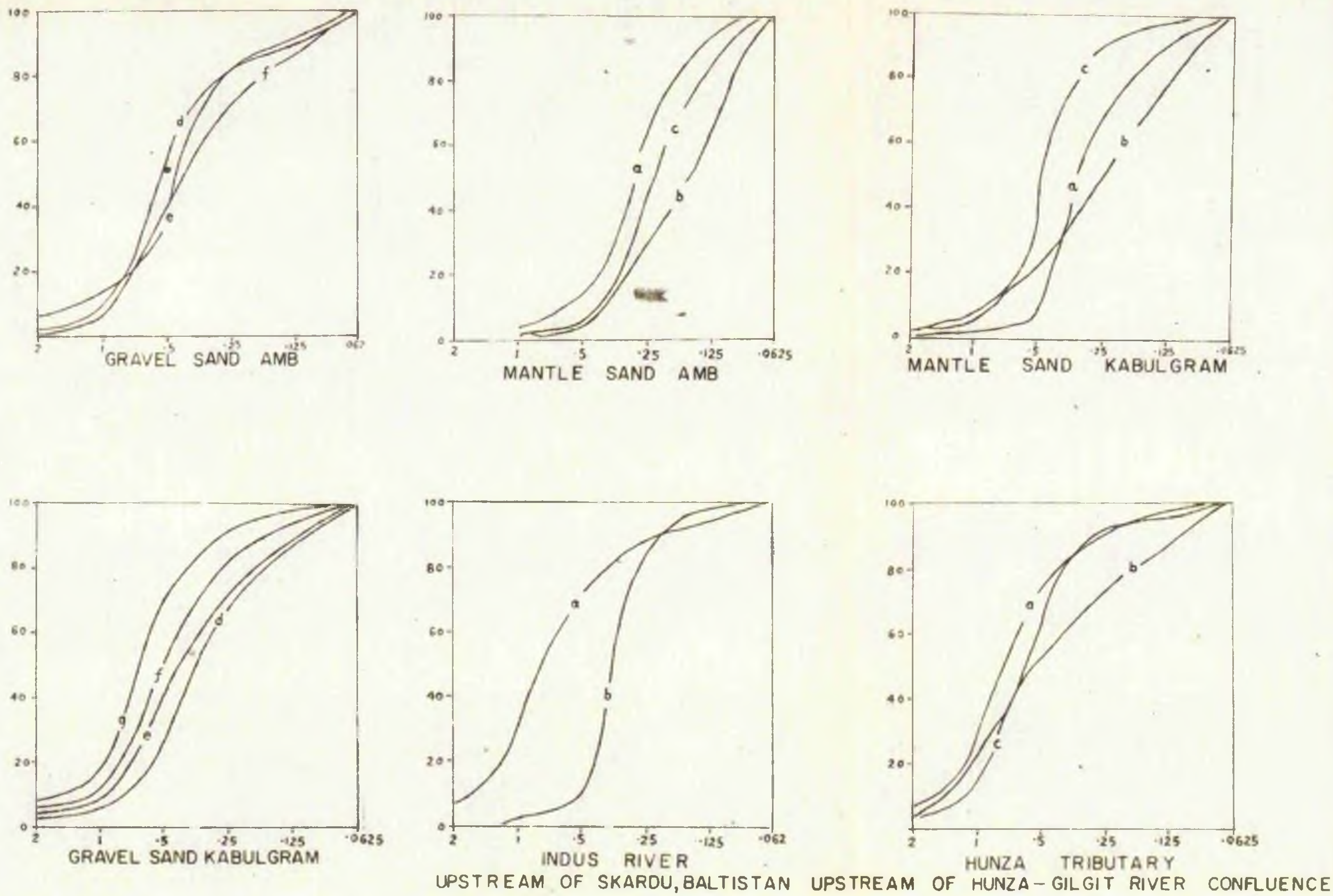
The analysis was restricted to sand-sized material between 2 and .065 mm. grade. In the laboratory the test samples were

FIG. 72



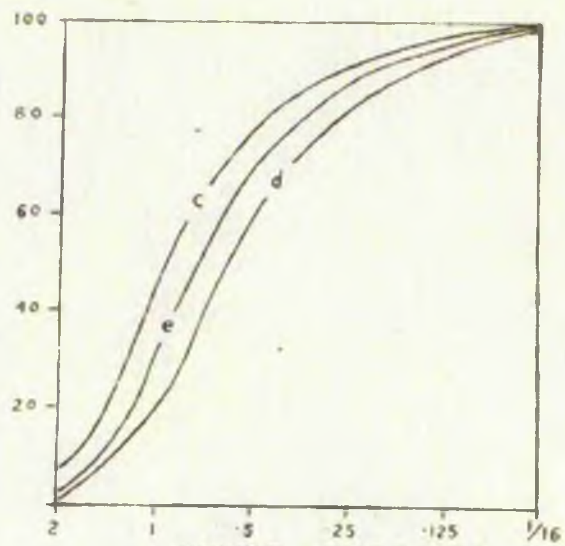
CUMULATIVE CURVES

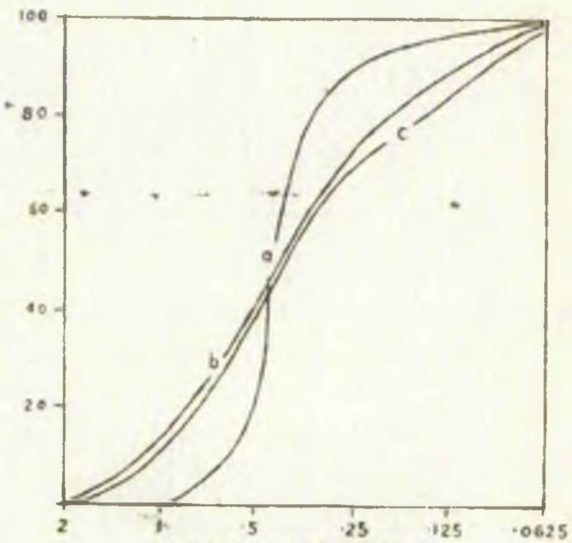
FIG. 7b



CUMULATIVE CURVES.

FIG. 7a





CUMULATIVE CURVES

separated from the field samples by cone-and-quartering. Nearly equal amounts of test samples were taken in each case and shaking was done by hand. The sieve analysis was done with test sieve screen fitted with mesh of British Standard system 410, made by Endcloth (Filter) Ltd., London. Five sieve screens of 16, 30, 60, 120 and 200 mesh were employed; according to Wentworth's grade scale these represent the following intervals.

1.	+ 16 mesh	2 mm.	very coarse sand.
2.	- 16 / + 30 mesh	1 mm.	coarse sand.
3.	- 30 / + 60 mesh	$\frac{1}{2}$ mm.	medium sand.
4.	- 60 / + 120 mesh	$\frac{1}{4}$ mm.	fine sand.
5.	- 120 / + 200 mesh	$\frac{1}{8}$ mm.	very fine sand.
6.	- 200 mesh	1/16 mm.	silt.

The samples from mantle and gravel deposits were treated separately. The sample retained in the pan below 200 mesh screen was taken as silt and no further division was attempted to evaluate the clay fraction, which forms an insignificant part in these alluvials. The amount of material retained in each sieve was weighed and proportional parts of the whole sample determined. From the weight percentage of the fractions cumulative percentages were calculated and with these data in hand, cumulative curves were constructed.

The most widely used statistical devices for comparing and describing sediments are quartile measures, median sorting co-efficient, quartile skewness and quartile kurtosis. These measures are obtained from median, 1st and 2nd quartiles, and 90 and 10 percentiles, derived from a cumulative curve. A short description of these is given below -

Md is the median parameter or a measure of the average size; 50 percent of the material is larger and 50 percent smaller than the median. Q3 and Q1 are the quartiles - that is, the size values associated with the intersection of 25 and 75 percent lines with the cumulative curves. P90 and P10 are the 90 and 10 percentiles, i.e., the size associated with the percent values respectively. The first quartile by convention refers to the diameter value which has 75 percent of the sample larger and 25 percent smaller. The third quartile diameter has 25 percent coarser and 75 percent finer than itself.

Size distribution.

The grade of the material treated to size analysis ranges between 2 and 1/16 mm. The maximum accumulation of the material is situated in three classes between ½ and ⅛ mm., which accommodate over ¾ of the material in the bulk. The remaining portion is divided among 1/16, 1 and 2 mm. classes, as arranged according to their order of abundance. The samples from mantle deposit yielded only four classes between 1 and 1/16 mm., whereas those from the gravel deposit are coarser in size and contain a varying proportion of material in 2 mm. class.

Unimodal distribution is recorded in almost all the samples from the mantle deposit, whereas gravel deposit yielded both unimodal and bimodal distribution. In the 16 samples from mantle deposits (Table 1), 11 samples have their chief modes in $\frac{1}{4}$ mm. class, 3 in 1/16 mm. and 1 each in $\frac{1}{2}$ and $\frac{1}{8}$ mm. classes. The chief modes in 7 samples contain over 50 percent of the material, in 6 over 40 and in the remaining 3 samples between 30 and 39 percent.

In the gravel deposit, out of 32 samples (Table 1) only 9 yielded bimodal distribution. The chief modes in 20 samples lie in the $\frac{1}{2}$ mm. class, 7 in $\frac{1}{4}$ mm., 4 in $\frac{1}{8}$ and 1 in 1 mm. class. Out of 9 samples, 6 have a secondary mode in 1/16 mm. class and 3 in 2 mm. class. The material retained in the chief modes is over 50 percent in 8 samples, 40 to 50 percent in 9 samples and 25 to 40 percent in 15 samples. The secondary modes retain a lesser amount of material, varying between 3 and 15 percent; a large accumulation is in those secondary modes which lie in 1/16 mm. class. In the bimodal distribution, the maximum values are 2 classes apart in 6 samples and 1 class apart in 3 samples.

<u>Average size.</u>

The average size of the sands is worked out by measuring the median diameters from various cumulative curves. The median diameter of over 60 percent of the samples from the mantle deposits falls between 0.22 and 0.35 mm. range, 25 percent between 0.4 and 0.6 and 15 percent between 0.12 and 0.22 mm. In the gravel deposit the median diameter in nearly 65 percent of the samples lie between 0.35 and 0.55 mm. range, and the rest between 0.55 and 0.9 mm. These data reveal a conspicuous coarser average size for the material collected from the gravel than mantle deposit.

So far as the three major tributaries Gilgit, Hunza and Shigar are concerned, the sands of the latter two are of a relatively higher average size of 0.63 and 0.8 mm. respectively. The average size of the material of the Gilgit tributary is 0.44 mm. which is lower than the Indus sampled at Skardu (0.58). The transportation and depositional environment of the sands of the aforementioned rivers is identical in this part of the area. The Shigar and Hunza tributaries are of coarser average size because they are smaller streams than the Gilgit, and their material has not undergone the hazards of long transportation which give textural maturity to the alluvials of the rivers Gilgit and Indus.

The average size of material from the gravel deposits at Skardu and Kabulgram is 0.58 and 0.54 mm. respectively. In other words, there is a fall of 0.04 mm. in a stretch of about 300 miles. In this part the Indus flows through a steep and narrow valley and the alluvials are transported under alpine conditions. The influx of the material from the side tributaries is also high. Downstream between Kalabagh and Kabulgram in a distance of about 200 miles, the difference in grain size widens with a net fall of 1.7 mm. The difference in average grain size in the samples from gravel deposits between the two extreme sampling-sites, i.e., Skardu and Kalabagh, a stretch of about 500 miles, is 2.1 mm.

The average grain size of mantle deposit between Kalabagh and Kabulgram has also been studied. Between Kabulgram and Amb, a distance of about 35 miles, the average size decreases from 3.3 to 2.8 mm. i.e., a net fall of 0.5 mm. But between Amb and Attock there is a progressive increase in the average grain size of the samples, both from mantle and gravel deposits. In this region the river Indus debouches on to a wide plain, and the valley gradient is nearly levelled. This change in gradient has retarded the velocity of the current, with the result that most of the load is deposited on the valley floor. The increase in average size of the alluvial material here may be attributed due to the sluggish behaviour of the stream, capable of removing the finer sediments only and resulting in the dominance of coarser grade material.

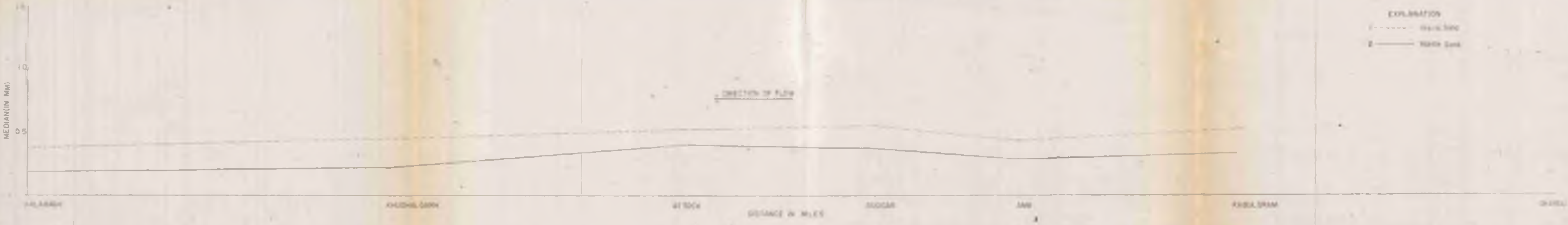
Downstream from Attock selective sorting and selective transportation again play a greater role, and cause abrupt changes in the grain size of the alluvials, here formed mainly of sand-sized material. This has resulted in a steep fall in grain size, and in a distance of about 150 miles between Attock and Kalabagh a net decrease of .16 and .22 mm. in the samples from gravel and mantle deposits are recorded respectively. Between Kalabagh and Kabulgram, the difference in average size is much the same in samples of mantle sand as it is in those of gravel deposits (Fig. 8).

"Sorting".

The geometrical quartile measure of sorting adopted by the author was first proposed by Trask (17) and eliminates the size factor and the unit of measurement. According to Trask if the coefficient of sorting is less than 2.5 the sample is well sorted, if it is greater than 4.5 the sample is poorly sorted and if it is about 3.0 the sediment has normal sorting. These values are based on the analyses of 190 samples of recent marine sediments and according to some writers they appear to be too high. Krumbein and Trisdal (18) experimented on the size analyses of crystalline rocks disintegrated in situ, and found that these have coefficients of sorting which place them within the range of Trask's well-sorted sediments. Hough and also Stetson (19), quoted by Hough (20) conducted size analysis of several marine sediments of sand grade and have reported sorting coefficient of between 1 and 2. Stetson gives 1.45 as the average.

In the samples under examination the coefficient of sorting varies between .85 and 2.3; the average of 17 and 32 samples from mantle and gravel deposits is 1.4 and 1.5 respectively. There is apparently no marked down current increase or decrease in the sorting values. The sorting values in the mantle deposits are lower than those for gravel deposit, indicating that the degree of sorting is relatively higher in most of the mantle sands. The overall result obtained from the material places the coefficient of sorting close to the average value of 1.45 obtained by Stetson.

FIG. 8



'AVERAGE' GRAIN SIZE OF THE INDUS ALLUVIALS DEDUCED BY MEASURING THE MEDIANS OF CUMULATIVE CURVES.

SCALE

KALABAGH TO KABULGRAM 1" = 10 MILES

KABULGRAM TO SKARDU 1" = [illegible] MILES

Size-sorting relationship.

Hough (21) studied the beach and near-shore sands of Cape Cod Bay and concluded, "silt and clay with diameter under 0.1 mm. are less well sorted. The sediments with diameter near 0.2 mm. are best sorted and those both coarser and finer showed less perfect sorting. Similar observation were reported by Krumbein and Aberdeen (22) in the sediments of Bataria Bay.

Inman (23) working on the size-sorting relationship has concluded that "the general relationship of sorting coefficient to median diameters appear to be similar for all water-worn environments, the difference being mainly in the degree of sorting. Sediments with median diameters near the grade of fine sand are the best sorted, sediments coarser and finer are more poorly sorted". These observations of Inman and earlier workers were further confirmed by the studies made by Griffith (24) who examined the grain size-sorting relationship in over 1200 Tertiary sediments, and attempted to express this relationship in mathematical terms.

The size-sorting relationship of the sands has been studied under the light of above mentioned observations made by the previous workers. In 44 samples studied, 3 yielded their median diameter close to 0.2 mm., 2 less than 0.2 and the rest over 0.2 mm. It is apparent from these above data that the samples under examination are not well sorted, and with the departure of average size from the expected norm (median 0.2 mm.) of well sorted sands, the sorting becomes progressively poorer.

"Symmetry".

The coefficient of geometrical quartile skewness indicates the degree of symmetry of the size distribution with respect to the median. If the skewness is unity the mode coincides with the median diameter and the distribution is symmetrical. If the skewness is greater than unity the maximum sorting of the sediments lies on the fine side of the median and the distribution is skewed towards the coarser grade size; if it is less than unity the distribution is skewed towards the fine grade size.

The skewness value determined for the sands under examination reveal that nearly 11 samples with values between 0.98 and 1.1 have got skewness close to unity. Six of these samples are from gravel and 5 from mantle deposits. All the rest have assymmetrical size distribution which are either skewed toward fine or coarser grade sizes.

Only three samples have their skewness values more than unity (1.17 to 1.4). The maximum sorting of these lies in the fine side of the median or in other words the distribution is skewed towards the coarser grade sizes. Two of these three samples are from mantle sands and one from a gravel deposit.

The rest of the 30 samples studied have their skewness values less than unity, ranging between 0.32 and 0.97. This suggests that the distribution is skewed towards the finer grade size, the median parameter being finer than the mode. From these 30 samples, 9 are from mantle deposit with their skewness values ranging from 0.71 to 0.88, and the remaining 21 are from gravel deposit with their skewness values varying from 0.32 to 0.97.

FIG. 9

DEGREE OF SYMMETRY OF SIZE DISTRIBUTION OF THE INDUS ALLUVIALS.

SCALE

KALABAGH TO KABULGRAM 1" = 10 MILES
KABULGRAM TO SKARDU 1" = 85 MILES.

Out of 17 samples from mantle deposits, 6 have relatively symmetrical distribution, 2 are skewed towards the coarser and 9 are skewed toward finer grade size. In the gravel deposits, out of 32 samples, 6 have relatively symmetrical distribution, 1 is skewed toward coarser sizes and the remaining 25 are skewed toward finer grade sizes.

Size-skewness relationship.

The correlation between size and skewness has been investigated by some previous workers. Plumby (25) who worked on the size analysis of the material of Black Hills terrace gravels, reported that skewness is the function of mean size. He plotted median against skewness in a scatter diagram and found that the samples having the largest mean size also have highly skewed distribution. That fine-grained sediments have a different relation between size and skewness was pointed out by Hough, who observed that the finer the sediment the more skewed it is. Inman has also observed the relationship between size and skewness and has shown that the finest sediments should normally be highly skewed towards the fine fraction.

In the case of the material under examination, the size-skewness relation is not very clear. There is no marked downcurrent increase or decrease in skewness. In the following table, A and B are the figures for the smallest and largest average size shown against their skewness reproduced from table 2 comparing the size-skewness relationship.

	A		B	
	Median	Skewness	Median	Skewness
1.	.13	1.08	.96	.8
2.	.13	1.01	.81	.72
3.	.19	1.4	.81	.74
4.	.24	.88	.81	.73
5.	.24	1.06	.76	.89
6.	.28	.71	.73	.74
7.	.3	.77	.6	1.1

Of the 7 samples under A, showing the smallest median diameters, 3 have symmetrical distribution, 2 are skewed toward the finer and 1 toward the coarser grade size. Under B, the largest median diameters, all the samples except 1 (no. 7) are skewed towards the finer grade size. The skewness in these samples varies from medium to high. One sample with a skewness of 1.1 has relatively symmetrical distribution. These results do not suggest any sympathetic relationship between size and skewness in the samples under examination.

"Kurtosis".

The importance of the kurtosis measure for sediments is not thoroughly understood and it has not been extensively investigated. According to Tickle (26), in normal curves kurtosis with a numerical value of .263 or less is quite common. A kurtosis greater than .263 signifies a steep curve. The kurtosis determined in this way is independent of the coarseness of the samples and the unit of measurement used. In certain practices the standard values for the kurtosis is 3.0, so that distribution curves less than 3 are flat-topped or broad while distribution curves greater than 3.0 are sharply peaked or narrow.

The kurtosis values calculated for the Indus sands are comparable to Tickell's observation, kurtosis values of 3.0 appear to be too high and also uncommon. Out of 49 samples studied, only one yielded a kurtosis value of 3.0.

In 31 out of 49 samples, the kurtosis value is over 0.2, and in the other 18 samples it is between 1.1 and 1.9. In the mantle deposit out of 17 samples, 12 have a kurtosis value over 0.2, mostly between 0.23 and 0.27. In the gravel deposits, out of 33 samples 19 gave a kurtosis value of over 0.2.

From the above data it is apparent that steep and sharply-peaked curves are fairly common in the diagrammatic representations of the Indus Sands. The samples from mantle deposits have given a greater number of such curves than the gravel deposits.

<u>Size analyses of alluvials</u>/

TABLE 1. Size analyses of alluvials

Sample No. shown in Fig.4	Sieve analyses, with cumulative percentages shown in brackets, chief and secondary modes underlined.						CURVE	LOCALITIES (G. gravel sand, M. mantle sand).
	+ 16 mesh	- 16 + 30 mesh	- 30 + 60 mesh	- 60 +120 mesh	-120 +200 mesh	-200 mesh		
1 S	-	0.8 (0.8)	45.1 (45.9)	35.1 (81.0)	7.5 (88.5)	11.5 (100)	a	KALABAGH (G)
2 S			3.5 (3.5)	44.6 (48.1)	33.1 (81.2)	18.8 (100)	b	" (M)
3 S	-	0.3 (0.3)	0.9 (1.2)	21.3 (22.5)	33.9 (56.4)	43.6 (100)	b	KHUSHALGARH (M)
4 S	-	0.2 (0.2)	4.4 (4.6)	41.6 (46.2)	36.2 (82.4)	17.6 (100)	a	" (M)
5 S	-	-	1.2 (1.2)	59.9 (61.1)	22.2 (83.3)	16.7 (100)	c	" (M)
6 S	-	0.4 (0.4)	10.2 (10.6)	71.9 (82.3)	14.9 (97.0)	3.0 (100)	c	ATTOCK (M)
7 S	-	1.8 (1.8)	26.2 (28.0)	59.6 (87.6)	10.2 (97.8)	2.2 (100)	b	" (M)
8 S	-	-	8.1 (8.1)	66.6 (74.7)	20.1 (94.8)	5.2 (100)	a	(M)
9 S	1.6 (1.6)	5.7 (7.3)	50.9 (68.2)	27.1 (95.3)	3.0 (98.3)	11.7 (100)	d	(G)
10 S	0.3 (0.3)	6.5 (6.8)	54.4 (61.2)	31.4 (92.6)	5.6 (98.2)	1.8 (100)	e	(G)
11 S	3.8 (3.8)	14.3 (18.1)	31.0 (49.1)	22.4 (71.5)	15.3 (86.8)	13.2 (100)	f	(G)
12 S	0.3 (0.3)	3.9 (4.2)	36.9 (41.1)	47.0 (88.1)	6.2 (94.3)	5.7 (100)	g	(G)
13 S	-	1.3 (1.3)	2.7 (4.0)	8.5 (12.5)	37.8 (50.3)	49.7 (100)	b	GUDDAR (M)
14 S	-	1.8 (1.8)	23.7 (25.3)	46.8 (72.3)	17.8 (90.1)	10.9 (100)	d	(G)
15 S	3.4 (3.4)	11.6 (15.0)	62.4 (77.4)	16.7 (94.1)	5.1 (99.2)	0.8 (100)	e	(G)
16 S	5.0 (5.0)	13.1 (18.1)	55.0 (73.1)	23.0 (96.1)	2.3 (98.4)	1.6 (100)	h	(G)
17 S	1.7 (1.7)	5.9 (7.6)	38.5 (46.1)	37.6 (76.1)	12.2 (88.3)	4.0 (100)	f	(G)
18 S	2.1 (2.1)	10.1 (12.2)	35.9 (48.1)	26.3 (74.4)	12.3 (86.7)	13.3 (100)	g	(G)
19 S	-	3.2 (3.2)	25.1 (28.3)	39.9 (68.2)	20.4 (88.6)	11.4 (100)	a	(M)
20 S	-	3.2 (3.2)	63.9 (67.1)	27.9 (95.0)	4.1 (99.1)	1.9 (100)	c	(M)
21 S	-	4.1 (4.1)	10.1 (14.2)	47.0 (61.2)	30.6 (91.8)	8.2 (100)	a	AMB (M)
22 S	-	1.2 (1.2)	2.7 (3.9)	24.5 (28.4)	32.7 (61.3)	38.7 (100)	b	(M)

TABLE 1. Size analyses of alluvials (contd.)

Sample No. shown in Fig.4	Sieve analyses, with cumulative percentages shown in brackets, chief and secondary modes underlined.						CURVE	LOCALITIES (G. gravel sand, M. mantle sand).	
	+ 16 mesh	- 16 + 30 mesh	- 30 + 60 mesh	- 60 +120 mesh	-120 +200 mesh	-200 mesh			
23 S	-	1.3 (1.3)	3.5 (4.8)	40.2 (45.0)	38.4 (83.4)	16.6 (100)	c		(M)
24 S	0.2 (0.2)	4.9 (5.1)	34.1 (39.2)	32.0 (71.2)	14.9 (86.1)	13.9 (100)	f		(G)
25 S	1.8 (1.8)	7.3 (9.1)	44.0 (53.1)	28.2 (81.3)	7.9 (89.2)	10.8 (100)	d		(G)
26 S	6.7 (6.7)	6.9(13.6)	39.8 (53.4)	27.7 (81.3)	9.8 (91.1)	10.1 (100)	e		(G)
27 S	1.5 (1.5)	4.9 (6.4)	14.8 (21.2)	27.9 (49.1)	30.0 (79.1)	20.9 (100)	b	KABULGRAM	(M)
28 S	0.9 (0.9)	2.2 (3.1)	3.7 (6.8)	62.2 (69.0)	21.2 (90.2)	9.8 (100)	a		(M)
29 S	1.1 (1.1)	3.3 (4.4)	30.0 (34.4)	54.8 (89.2)	8.3 (97.5)	2.5 (100)	c		(M)
30 S	3.1 (3.1)	3.0 (6.1)	20.0 (26.1)	41.4 (67.5)	20.0 (87.5)	12.5 (100)	d		(G)
31 S	4.8 (4.8)	3.3 (8.1)	34.4 (42.5)	29.3 (71.8)	17.1 (88.9)	10.9 (100)	e		(G)
32 S	7.1 (7.1)	5.1(12.2)	38.0 (50.2)	21.9 (72.1)	22.1 (94.2)	5.8 (100)	f		(G)
33 S	8.6 (8.6)	9.6(18.2)	52.7 (70.9)	21.7 (92.6)	4.8 (97.4)	2.6 (100)	g		(G)
34 S	6.1 (6.1)	22.1(28.2)	43.4 (71.6)	17.0 (88.6)	4.8 (93.4)	6.6 (100)	a	SKARDU	(G)
35 S	-	1.8 (1.8)	6.7 (8.5)	74.0 (82.5)	15.6 (98.1)	1.9 (100)	b		
36 S	6.4 (6.4)	21.7(28.1)	46.0 (74.1)	15.9 (90.0)	7.0 (97.0)	3.0 (100)	a	HUNZA TRIBUTARY	(G)
37 S	3.5 (3.5)	18.1(21.6)	29.6 (51.2)	20.6 (71.8)	15.6 (87.4)	12.6 (100)	b		(G)
38 S	1.9 (1.9)	11.2(13.1)	40.9 (52.1)	30.8 (82.9)	5.0 (87.9)	12.1 (100)	c		(G)
39 S	-	0.6 (0.6)	23.5 (24.1)	67.2 (91.3)	5.3 (96.6)	3.4 (100)	a	GILGIT TRIBUTARY	(G)
40 S	1.1 (1.1)	13.1(14.2)	26.2 (40.4)	34.0 (74.4)	15.4 (89.8)	10.2 (100)	b		(G)
41 S	.9 (.9)	10.8(11.7)	28.3 (40.0)	30.4 (70.4)	14.6 (85.0)	15.0 (100)	c		(G)
42 S	8.1 (8.1)	38.2(46.3)	31.8 (78.1)	10.7 (88.8)	9.3 (98.1)	1.9 (100)	c	SHIGAR TRIBUTARY	(G)
43 S	1.9 (1.9)	18.1(20.0)	40.0 (60.0)	23.7 (83.7)	9.7 (93.4)	7.6 (100)	d		(G)
44 S	4.1 (4.1)	28.0(32.1)	37.9 (70.0)	18.7 (88.7)	6.4 (95.1)	4.9 (100)	e		(G)

TABLE 2. Significant values derived from cumulative curves.

LOCALITY	Median (Md)	Third Quartile Q_3	First Quartile Q_1	90 - Percentile P_{90}	10 - Percentile P_{10}	"Sorting" $SO = \frac{Q_3}{Q_1}$	"Symmetry" $SK = \frac{Q_3 Q_1}{(Md)^2}$	"Peakedness" $= \frac{Q_3 - Q_1}{2(P_{90} - P_{10})}$	Type of sample G (gravel sand) M (mantle sand)
KALABAGH	0.38	0.62	0.27	0.87	0.12	1.5	1.1	0.23	G
	.19	0.34	0.15	0.44	0.095	1.5	1.4	0.27	M
KHUSHALGARH	0.23	0.34	0.16	0.43	0.11	1.4	1.04	0.3	M
	0.13	0.23	0.08	0.37	0.08	1.7	1.08	0.26	M
	0.31	0.4	0.19	0.46	0.11	1.4	0.8	3.0	M
ATTOCK	0.35	0.42	0.24	0.45	0.15	1.32	0.85	0.3	M
	0.48	0.51	0.4	0.63	0.23	1.18	0.87	0.13	M
	0.41	0.43	0.31	0.52	0.18	1.2	0.79	0.17	M
	0.60	0.75	0.45	0.88	0.35	1.2	0.92	0.29	G
	0.59	0.73	0.43	0.93	0.29	1.3	0.91	0.28	G
	0.48	0.89	0.21	0.98	0.10	2.1	0.80	0.38	G
	0.49	0.55	0.38	0.75	0.21	1.2	0.87	0.15	G
GUDDAR	0.37	0.52	0.21	0.82	0.12	1.3	0.79	0.22	M
	0.13	0.19	0.09	0.31	0.071	1.4	1.01	0.20	M
	0.62	0.81	0.46	0.93	0.34	1.3	1.2	0.29	M
	0.48	0.49	0.23	0.80	0.12	1.4	0.68	0.19	G
	0.81	0.93	0.51	1.25	0.3	1.4	0.72	0.22	G
	0.48	0.81	0.28	0.92	0.12	1.7	0.98	0.33	G
	0.60	0.80	0.50	1.5	0.37	0.85	1.10	0.13	G
	0.49	0.83	0.23	1.1	0.10	1.9	0.79	0.3	G
AMB	0.37	0.68	0.13	0.87	0.08	2.3	0.64	0.31	G

TABLE 2 CONTD.

LOCALITY	Median (Md)	Third Quartile Q_3	First Quartile Q_1	90 - Percentile P_{90}	10 - Percentile P_{10}	"Sorting" $SO = \frac{Q_3}{Q_1}$	"Symmetry" $SK = \frac{Q_3 Q_1}{(Md)^2}$	"Peakedness" $= \frac{Q_3 - Q_1}{2(P_{90}-P_{10})}$	Type of sample G (gravel sand) M (mantle sand)
AMB	0.37	0.6	0.17	0.87	0.09	1.8	0.73	0.26	G
	0.46	0.66	0.32	1.2	0.16	1.4	0.99	0.19	G
	0.41	0.67	0.15	0.93	0.09	2.1	0.58	0.30	G
	0.52	0.78	0.31	1.3	0.12	1.6	0.80	0.19	G
	0.28	0.37	0.15	0.45	0.095	1.5	0.71	0.30	M
	0.34	0.43	0.23	0.51	0.15	1.4	0.85	0.27	M
	0.24	0.34	0.15	0.44	0.095	1.5	0.88	0.27	M
KABULGRAM	0.34	0.41	0.37	0.41	0.12	1.06	1.3	0.26	M
	0.24	0.44	0.14	0.87	0.09	1.7	1.06	0.16	M
	0.46	0.56	0.37	0.85	0.23	1.1	0.98	0.15	M
	0.30	0.39	0.18	0.42	0.097	1.47	0.77	0.31	M
	0.37	0.48	0.21	0.81	0.11	1.5	0.72	0.19	G
	0.43	0.63	0.22	0.93	0.12	1.7	0.74	0.25	G
	0.50	0.82	0.34	1.1	0.16	1.5	1.1	0.25	G
	0.73	0.88	0.45	1.4	0.28	1.3	0.74	0.19	G
	0.55	0.49	0.2	0.74	0.10	1.66	0.32	0.19	G
	0.50	0.75	0.39	0.47	0.18	1.38	1.17	0.64	G
SKARDU	0.81	1.08	0.45	1.6	0.19	1.5	0.74	0.22	G
	0.35	0.41	0.28	0.46	0.19	1.2	0.93	0.26	G
HUNZA TRIBUTARY	0.76	1.08	0.48	1.8	0.15	1.5	0.89	0.18	G
	0.56	0.93	0.23	2.5	0.09	2.0	0.68	0.14	G

TABLE 2 CONTD.

LOCALITY	Median (Md)	Third Quartile Q_3	First Quartile Q_1	90 - Percentile P_{90}	10 - Percentile P_{10}	"Sorting" $SO = \frac{Q_3}{Q_1}$	"Symmetry" $SK = \frac{Q_3 Q_1}{(Md)^2}$	"Peakedness" $= \frac{Q_3 - Q_1}{2(P_{90} - P_{10})}$	Type of sample G (gravel sand) M (mantle sand)
HUNZA TRIBUTARY	0.56	0.86	0.43	1.5	0.15	1.4	1.1	0.19	G
GILGIT "	0.45	0.49	0.39	0.63	0.18	1.1	0.94	0.11	G
	0.43	0.75	0.24	1.37	0.09	1.7	0.97	0.19	G
	0.43	0.73	0.21	1.25	0.07	1.8	0.83	0.22	G
SHIGAR "	0.96	1.32	0.56	1.9	0.28	1.5	0.80	0.23	G
	0.63	0.93	0.35	1.3	0.16	1.6	0.82	0.25	G
	0.81	0.12	0.43	1.6	0.23	1.6	0.73	0.74	G

M I N E R A L O G Y

A Mineralogical Composition of the Alluvials

(a) Heavy Fraction

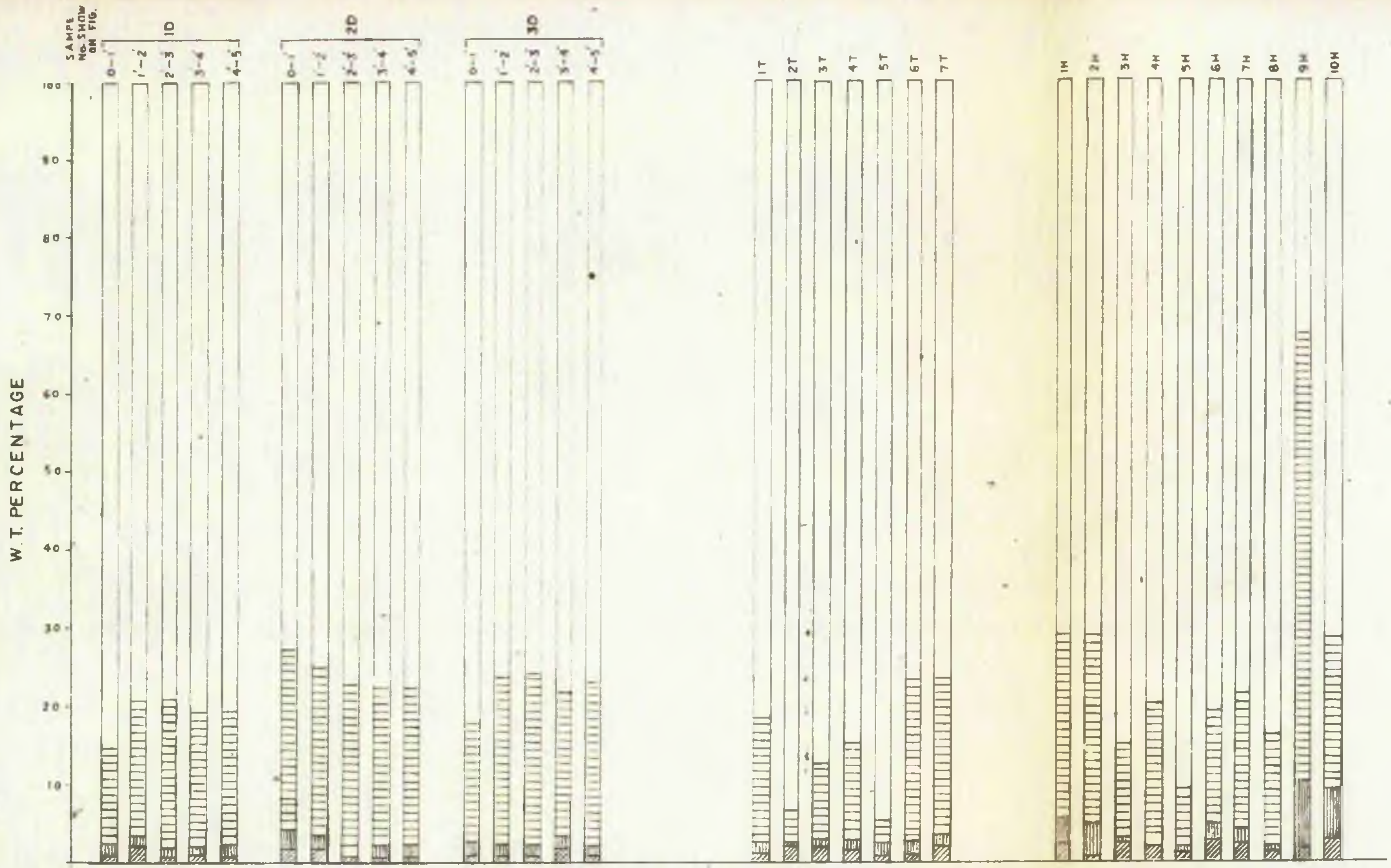
The minerals identified in the heavy suites of the Indus alluvials are magnetite, garnet, hornblende, augite, diopside, hypersthene, non-magnetic opaque minerals (pyrite, chalcopyrite, ilmenite, haematite, limonite, picotite, galena, uraninite and other species), apatite, epidote, olivine, brookite zircon, vesuvianite, muscovite, biotite, phlogopite, calcite, dolomite, cassiterite, scheelite, sillimanite, chlorite, anatase, topaz, barite, corundum, monazite, uranothorite, leucoxene and gold. The gold is extremely rare and has been found only in goldwashers' highly concentrated residues.

The percentage frequency of the different heavy minerals present in the gravel deposits and in the mantle sands is listed in Tables 3 and 4 respectively. Prior to microscopic analysis magnetite was removed by means of a hand-magnet, and the proportion established by weighing. Hence the percentage of magnetite in the heavy crops is recorded by weight, but that of all other heavy minerals was established by grain counting.

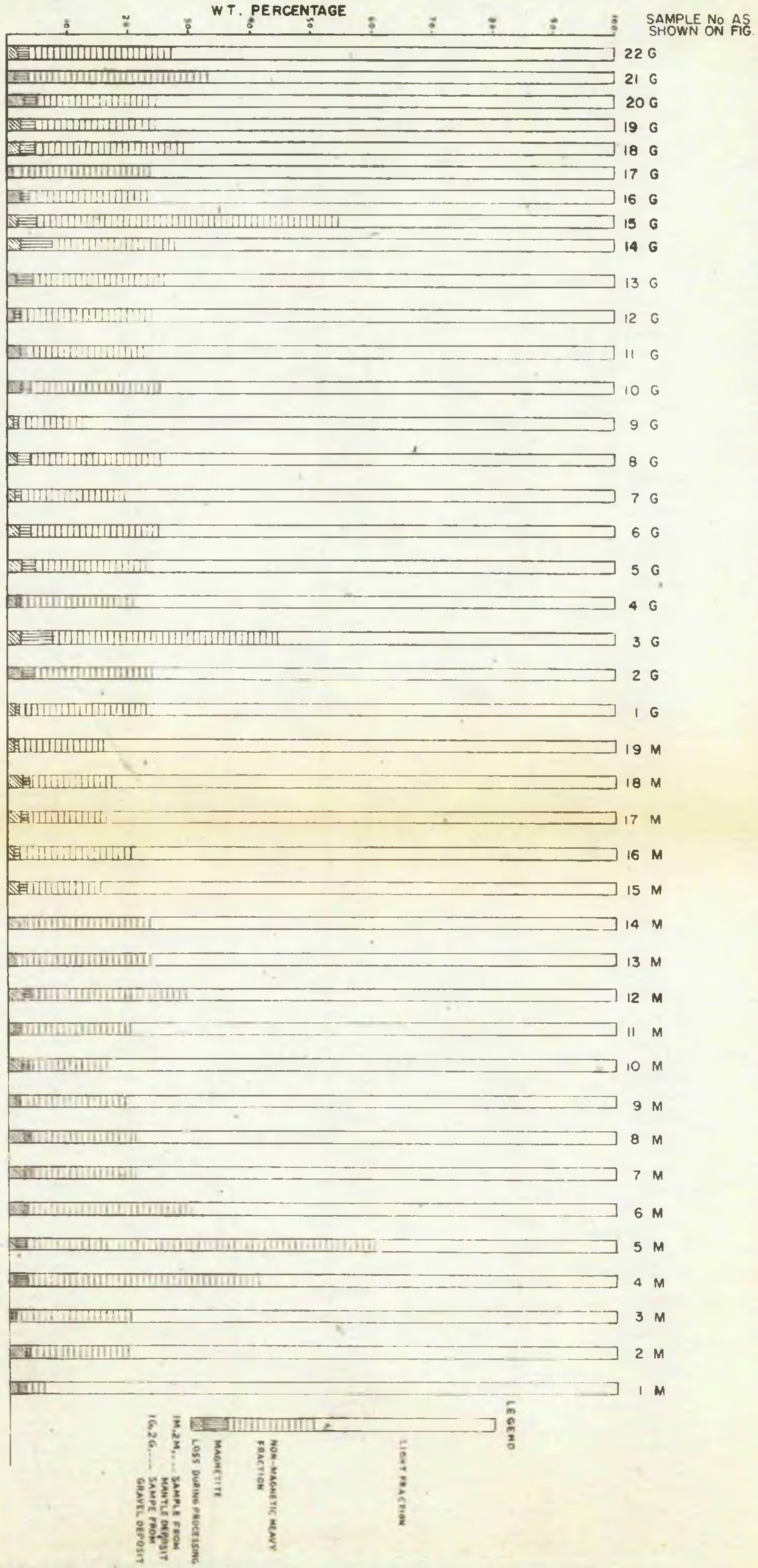
Magnetite content:

The term magnetite is used in a broad sense for all magnetic grains removable by a hand-magnet, and is thus inclusive of titanomagnetite and probably also composite opaque grains containing magnetite. Out of 18 samples of heavy mineral concentrate from mantle sands, one yielded over

FIG. 10b



VARIATION IN QUANTITY OF HEAVY (72.8) AND LIGHT FRACTIONS IN THE SAMPLES FROM SHALLOW PITS, TERRACE GRAVELS AND MAJOR TRIBUTARIES.



VARIATION IN QUANTITY OF HEAVY (72.8) AND LIGHT FRACTIONS IN THE SAMPLES FROM MANTLE AND GRAVEL DEPOSITS BETWEEN KALABAGH AND KABULGRAM

Fig. 10a

10 per cent magnetite by weight, four over 5 per cent, and the remaining 13 from 1.5 to 4.7 per cent. In 22 concentrates from gravel deposits, five yielded over 10 per cent magnetite by weight, 11 over 5 per cent, and the remaining six from 3.3 to 4.8 per cent (Fig. 10a).

Analyses of heavy mineral concentrates from the major tributaries of the Indus suggest that the tenor of magnetite is higher in Gilgit river (13%) than in the Hunza (6%) and Shigar (7%). The tenor in two samples from the Indus at Skardu averages 19 per cent (Fig. 10b). In the old river terraces magnetite forms from 5 to 11 per cent by weight of the total heavies, the highest yield coming from the terrace gravels.

Frequency distribution of non-magnetic heavy minerals between Kalabagh and Kabulgram (Fig. 11).

The composition of heavy mineral separations, 18 from mantle sands and 22 from gravel deposits, is shown in Tables 3 and 4.

Hornblende is the dominant non-magnetic species. The major supply of hornblende to the alluvials comes from upstream, and the contribution of the side tributaries is relatively meagre. The frequency varies from 20.5 to 42.5 per cent in gravel deposits and from 24.2 to 50.0 per cent in mantle sands.

Garnet is derived both from upstream and from tributaries, but unlike hornblende the main source is in the latter. Most of the side valleys upstream from Attock drain metamorphic rocks in which garnetiferous schists are abundant, with the result that garnet is a major constituent in the alluvials shed from these sources. Moreover, FIG.

DISTANCE IN MILES
VARIATIONS IN MINERAL COMPOSITION IN NON-MAGNETIC FRACTIONS OF THE INDUS ALLUVIALS

HOR. SCALE

Table 3. Frequency percentage of non-magnetic heavy minerals in the bromoform separates from gravel deposit, between Kalabagh and Kabulgram.

SAMPLE NO. AS SHOWN IN FIG 4.	APATITE	ANATASE	AUGITE	BARITE	BROOKITE	CASSITERITE	CALCITE - DOLOMITE	CORUNDUM	DIOPSIDE	EPIDOTE	GARNET	HORNBLENDE	HYPERSTHENE	KYANITE	'MICAS'	MONAZITE	OPAQUE MIN.	OPAQUE CUBE	OLIVINE	RUTILE	SCHEELITE	SILLIMANITE	STAUROLITE	TOURMALINE	TOPAZ	UNIDENTIFIED GRAINS	VESUVIANITE	ZIRCON	ZOISITE - CLINOZOISITE
1G	.6	-	2.5	-	.6	-	1.3	.6	2.6	3.2	35.6	21.5	2.3	-	1.3	.6	9.6	.6	.6	.6	-	1.9	-	-	.6	11.2	-	1.9	1.3
2G	1.9	.6	2.6	.6	1.3	.6	3.2	.6	1.9	4.5	13.0	29.0	1.9	-	7.7	1.3	4.5	.6	-	1.3	.6	3.8	.6	.6	-	12.2	-	3.2	1.9
3G	1.9	.6	1.9	.6	-	.6	5.7	-	1.3	2.5	19.4	28.5	1.3	.6	12.3	-	4.4	.6	-	.6	-	3.2	-	.6	-	10.2	-	1.9	1.3
4G	1.7	1.7	1.7	-	-	.8	2.6	.8	3.4	3.4	17.0	29.2	.8	.8	7.6	-	4.2	.8	-	.8	-	3.4	-	.8	-	15.1	-	1.7	1.7
5G	1.5	.5	1.0	-	.5	1.0	2.5	-	1.5	4.5	36.3	23.4	.5	.5	1.5	.5	5.9	2.0	-	1.0	-	2.5	.5	.5	-	8.4	.5	2.0	1.0
6G	.6	-	2.3	.6	1.2	.6	3.4	.6	1.7	4.4	18.1	32.2	.6	.6	7.2	.6	5.7	1.7	.6	.6	.6	2.3	.6	1.7	-	8.0	-	2.3	1.2
7G	1.5	.4	1.2	.4	1.5	.4	9.1	.4	.4	6.1	11.0	32.5	.8	.4	10.6	.4	8.3	.4	-	.4	-	3.9	-	.5	-	5.3	.8	1.9	1.4
8G	1.2	.4	1.6	.4	1.2	1.2	.8	.4	.8	3.3	18.3	32.5	2.1	.4	8.2	-	12.0	1.6	-	.4	-	2.5	-	.4	-	5.0	.4	4.1	.8
9G	1.1	-	2.6	-	1.4	.3	2.0	.3	.8	4.3	17.0	28.6	.3	.3	9.4	.3	15.2	.8	-	1.1	-	2.8	.3	.7	.3	4.9	-	4.8	1.4
10G	2.2	-	2.2	-	1.1	.5	1.7	-	2.2	3.5	12.5	33.3	1.1	.5	9.3	.5	9.3	.5	.5	.5	-	3.8	-	.5	1.1	8.8	.5	2.8	1.1
11G	2.2	-	2.2	-	1.6	-	7.5	.6	.6	2.7	7.5	31.2	1.6	.6	13.0	.6	8.6	.6	.6	1.1	.6	4.3	-	-	.6	5.9	-	3.7	1.1
12G	2.0	-	2.6	-	1.5	.6	1.5	.6	1.5	3.6	15.7	30.0	.6	.6	6.7	-	13.5	.6	-	.6	.6	3.6	.6	-	.6	6.2	.6	5.0	.6
13G	.5	.5	1.4	-	1.4	.5	5.2	-	.9	4.3	12.6	36.0	1.9	-	11.2	-	9.4	.5	-	.9	.5	1.9	.5	-	.5	6.1	.5	1.4	1.4
14G	.5	-	2.3	-	.8	.5	2.8	.3	1.0	4.1	25.6	29.6	1.0	.3	3.6	.3	13.3	.5	-	1.0	.3	1.3	-	.3	.3	4.9	.3	3.6	1.5
15G	.6	-	2.2	-	1.1	.6	8.3	.6	1.1	3.9	28.3	20.5	2.8	-	3.8	-	13.2	.6	-	.6	-	1.7	-	-	-	7.8	-	1.2	1.1
16G	1.5	-	1.8	.3	.9	-	5.3	.3	.6	2.6	12.3	34.5	1.5	-	11.2	.3	15.2	.6	-	.3	.3	2.0	-	.3	.3	3.2	-	3.5	1.2
17G	.4	-	1.4	-	1.8	.4	4.5	-	.4	3.8	21.4	31.0	2.7	-	7.6	-	13.0	.4	-	.4	-	1.8	.4	.4	-	5.6	-	1.8	.8
18G	1.9	-	1.5	-	.8	.4	3.8	-	.8	1.9	28.5	26.5	.4	-	4.6	.4	14.0	1.5	-	.8	-	3.8	-	-	-	3.8	-	3.8	.8
19G	1.4	-	1.9	-	1.0	.4	4.3	.3	2.3	3.3	6.6	35.5	1.4	-	12.3	.6	11.8	.6	.4	.4	.3	2.7	-	.4	.3	3.5	.3	3.1	1.3
20G	.9	-	3.9	-	.9	.5	5.8	.5	1.5	2.9	9.7	42.5	2.9	-	8.2	.5	6.8	.9	-	-	-	2.4	-	-	.9	5.3	-	1.5	1.5
21G	1.2	-	3.7	-	1.6	.8	8.1	1.6	1.2	2.8	13.2	30.6	3.7	-	3.7	.8	15.0	1.2	-	1.6	-	2.8	-	1.2	-	3.8	-	2.4	-
22G	.6	-	1.6	.4	.8	.6	4.7	-	.6	2.5	14.0	36.2	2.2	-	18.2	.4	7.8	.6	-	.4	-	2.3	-	.4	.4	4.1	-	.6	.6

garnet resists the hazards of transportation better than many minerals and due to its stability it travels relatively far: its relative abundance downstream can be attributed to this factor. It forms from 6.2 to 36.3 per cent of the non-magnetic heavies in gravel deposits and from 3.7 to 35.5 per cent in the mantle sands.

The micas comprise biotite and phlogopite, the former occurring in abundance. They derive mainly from upstream. Because of their flaky habit micas are particularly prone to selective sorting by stream and wave action and also to transportation by the wind, and so the tenor may fluctuate considerably relative to other heavy minerals. Thus four samples collected within a radius of two miles at Kabulgram, all from gravel deposits, show a relative frequency, compared to other non-magnetic heavies, of 3.7, 8.2, 12.3 and 18.2 per cent. The relative frequency in relation to other non-magnetic heavies in gravel and mantle deposits ranges from 1.3 to 14.0 and from 1.5 to 29.9 per cent respectively.

The opaque minerals form a major constituent of the non-magnetic fraction of bromoform separates. They have not all been specifically identified, but ilmenite is the principal species present. They derive both from upstream and from the side valleys. The tributaries draining schists and gneisses upstream of Attock, as well as those draining Siwalik shales and sandstones downstream from Attock, are relatively rich in opaques, both ilmenite and magnetite. There appears to be a slight downward decrease in the frequency percentage of opaque minerals. The heavy bromoform separates have a relative frequency of

TABLE 4. Frequency distribution of non-magnetic heavy minerals in the bromoform separates from mantle sand between Kalabagh and Kabulgram.

ON FIG. 4.	APATITE	ANATASE	AUGITE	BARITE	BROOKITE	CASSITERITE	CALCITE - DOLOMITE	CORUNDUM	DIOPSIDE	EPIDOTE	GARNET	HORNBLENDE	HYPERSTHENE	KYANITE	'MICAS'	MONAZITE	OPAQUE MIN.	OPAQUE CUBE	OLIVINE	RUTILE	SCHEELITE	SILLIMANITE	STAUROLITE	TOURMALINE	TOPAZ	UNIDENTIFIED GRAIN	VESUVIANITE	ZIRCON	ZOISITE - CLINOZOISITE
1 M	.7	1.5	4.5	-	2.5	.7	8.9	-	2.3	4.5	11.2	29.6	.7	-	16.8	-	8.1	.7	-	-	-	5.2	-	-	-	8.1	-	-	-
2 M	.9	.3	2.2	-	-	-	9.7	-	.7	3.2	4.8	39.0	.3	-	29.0	-	2.2	.3	-	.4	-	1.6	-	-	-	5.4	-	-	-
3 M	2.4	-	4.8	-	-	.8	4.8	.8	.8	4.8	8.9	37.0	2.4	-	1.6	-	11.8	1.6	-	-	-	3.5	-	.8	-	8.6	-	4.8	.8
4 M	-	.8	4.8	-	-	.8	3.2	.4	1.2	5.3	31.2	27.7	6.5	-	3.2	-	5.1	-	-	-	-	1.2	-	.4	-	6.4	.4	.4	-
.5 M	1.5	.5	1.0	-	.5	2.1	2.3	-	1.5	4.5	35.5	24.2	.5	.5	1.5	.5	6.1	2.1	-	1.0	-	2.5	.5	.5	-	7.1	.5	2.1	1.0
6 M	.4	-	2.1	-	1.4	1.4	16.0	.4	.7	4.2	11.5	36.2	2.1	-	5.6	-	5.6	.4	-	.4	-	2.1	-	-	-	7.0	-	1.8	.7
7 M	1.7	-	1.4	-	.3	.3	7.7	-	.9	3.7	8.2	34.2	1.2	-	17.9	-	10.2	.6	-	.3	-	2.6	-	.3	-	5.9	-	1.8	.8
8 M	.8	1.2	2.2	.3	.8	.8	5.4	.6	.8	4.1	10.2	38.9	.8	-	6.1	-	16.0	1.7	-	.3	-	2.5	.3	-	-	3.7	-	2.9	.6
9 M	.8	.5	1.1	-	.8	-	2.7	.5	.8	3.2	10.9	50.0	.8	-	13.4	.5	5.4	-	-	.2	-	1.6	-	-	.2	5.6	-	.5	.5
10 M	.3	.3	2.7	-	.7	-	1.7	-	.7	4.8	15.0	39.0	2.1	-	5.1	-	12.0	.7	-	-	-	2.7	-	-	-	9.5	-	2.7	-
11 M	.4	-	1.3	-	1.1	.4	2.8	-	.4	4.2	14.0	42.5	1.7	.4	8.6	-	5.9	.8	-	.4	-	2.8	-	.2	-	11.3	-	.4	.4
12 M	.6	1.3	2.5	-	.3	.3	4.5	.6	.6	4.5	10.6	46.0	.9	-	8.3	-	5.4	.6	-	.3	-	2.9	-	-	.3	8.6	-	.6	.3
13 M	.7	-	3.5	-	1.4	-	8.3	-	1.4	3.5	15.8	35.0	2.1	-	5.5	-	5.1	.7	-	-	-	2.1	1.4	-	-	10.7	-	2.8	-
14 M	1.1	-	1.7	-	1.7	-	7.7	-	2.1	2.4	5.9	29.1	1.4	.7	27.0	.3	9.1	-	-	.3	-	2.8	-	-	-	4.3	-	1.7	.7
15 M	.3	-	2.6	-	.8	2.0	1.4	.3	.3	6.0	22.9	38.5	.6	-	2.6	.6	10.7	.6	-	.6	.3	1.4	-	.3	-	4.3	-	2.3	.6
16 M	.8	-	3.3	-	1.8	.8	3.4	.4	.8	3.4	7.1	39.0	2.6	-	20.1	-	6.4	.8	-	.8	-	2.1	.4	.4	-	3.0	-	1.3	1.3
17 M	1.9	-	1.3	-	.6	.6	1.9	.6	-	4.5	3.7	35.0	1.9	-	29.9	-	3.9	1.3	-	-	-	3.9	-	-	.6	5.2	-	1.3	1.9
18 M	.4	-	1.4	-	1.1	.7	7.4	.7	-	4.6	6.1	39.1	.7	-	19.5	-	8.9	.7	-	.4	-	2.5	-	-	.4	3.6	-	-	1.8

non-magnetic opaques ranging from 2.2 to 16.0 per cent for mantle sands and from 4.2 to 15.2 per cent for gravel deposits.

Calcite/dolomite are recorded in almost all the bromoform separations. They are present in greatest amount in the side tributaries which traverse territory rich in carbonate rocks. Samples from mantle sand are generally richer in these minerals than are those from gravel deposits.

Epidote is prominent in all the heavy mineral separations. Between Kabulgram and Kalabagh the contribution of this mineral is drawn both from upstream and from the side valleys, but mostly from the former. Among the tributaries, those draining metamorphic rocks and old river terraces contribute a relatively higher proportion of this mineral. Frequencies of occurrence are shown in the tables.

Zircon, sillimanite, and apatite are all relatively more frequent in the heavy mineral assemblages from gravel deposits than in those from mantle sands. Apatite is the least abundant of the three species.

Among the pyroxene minerals augite, hypersthene and diopside have been identified, augite being the most and diopside the least abundant. All three are consistently present and are apparently contributed both from upstream and from the side tributaries. The fresh appearance of most of the grains suggests that their sources are nearby. The metamorphic rocks upstream from Attock and the Salt Range sediments near Kalabagh contain numerous dykes and sills of

Table 5. Frequency distribution of non-magnetic heavy minerals in the bromoform separates from shallow pits.

ON FIG. 10b.		APATITE	ANATASE	AUGITE	BARITE	BROOKITE	CASSITERITE	CALCITE - DOLOMITE	CORUNDUM	DIOPSIDE	EPIDOTE	GARNET	HORNBLENDE	HYPERSTHENE	KYANITE	'MICAS'	MONAZITE	OPAQUE MIN.	OPAQUE CUBE	OLIVINE	RUTILE	SCHEELITE	SILLIMANITE	STAUROLITE	TOURMALINE	TOPAZ	UNIDENTIFIED GRAIN	VESUVIANITE	ZIRCON	ZOISITE - CLINOZOISITE
1D	134	.5	-	2.8	-	3.7	-	3.7	1.1	.5	5.5	19.4	28.1	-	-	6.1	-	21.5	-	-	-	-	1.1	-	.5	-	1.6	1.1	2.8	
	136	-	-	5.4	-	.5	-	.5	.5	-	5.1	19.2	49.0	2.2	.5	6.2	-	5.5	-	-	.5	-	1.1	-	-	-	3.3	-	.5	
	138	.5	-	4.3	-	-	-	1.4	.5	-	5.3	18.1	48.4	1.0	.5	5.7	1.0	6.5	-	-	.5	-	1.0	-	1.0	-	1.9	-	2.4	
	140	-	-	4.6	-	1.0	-	5.1	.5	1.0	6.2	9.8	42.9	1.5	.5	9.8	-	8.5	-	-	.5	-	2.1	-	-	-	2.4	.5	1.0	2.1
2D	225	2.9	-	3.7	-	-	-	2.4	-	.5	3.4	12.8	42.8	1.0	-	8.9	-	13.8	-	1.5	.5	-	-	-	-	-	2.9	-	2.9	
	227	-	-	3.4	-	-	-	2.3	.5	.9	3.7	13.8	49.2	1.4	-	9.2	-	4.1	.9	-	.5	.5	4.6	-	.5	-	3.7	-	-	.8
	229	-	.7	3.0	-	-	-	-	-	-	2.6	12.2	55.0	.7	-	11.4	-	8.7	-	-	-	-	.4	-	-	-	4.6	-	-	.7
	233	-	-	3.3	-	.8	-	4.1	-	-	4.9	26.2	41.2	-	-	4.1	-	4.9	.8	-	.8	-	2.4	-	-	-	5.7	-	.8	
3D	164	-	.9	5.3	-	.9	-	-	-	-	5.6	17.4	35.5	5.3	-	2.6	-	15.0	-	-	-	-	7.1	-	-	-	4.4	-	-	-
	166	.6	.6	8.4	-	.6	.6	-	-	1.2	6.6	15.6	40.8	1.2	-	10.8	-	6.6	-	-	-	-	1.6	-	.6	-	2.4	.6	.6	.6
	168	-	-	4.1	-	1.4	-	.8	-	1.4	7.0	16.0	45.0	.4	-	6.0	-	14.2	-	-	.4	-	2.3	-	.4	-	1.8	-	1.8	-
	170	-	-	4.2	-	1.2	-	-	-	.6	6.0	21.0	42.5	3.0	-	3.0	-	9.5	-	-	-	-	3.0	-	.6	-	3.0	-	1.8	.6
	172	1.5	-	3.8	-	1.5	.7	-	.7	-	3.0	11.4	63.0	2.3	-	1.5	-	3.8	-	-	-	-	2.3	-	-	-	4.5	-	-	-

ultrabasic intrusives, and the tributaries draining these formations bear an influx of pyroxenes.

Frequency distribution of non-magnetic heavy minerals in pit samples from Khabbal, Guddar and Attock.

Samples collected from shallow pits, up to five feet in depth, have been examined mineralogically, and the frequency distribution of the heavy minerals present in bromoform separates is tabulated in Table 5.

In almost all these samples hornblende and garnet are dominant, together constituting over 60 per cent of the non-magnetic heavies in most of the samples. Next in importance are non-magnetic opaques, micas, epidote and sillimanite, in order of abundance. There is no significant variation in deposits up to five feet in depth.

In general calcite and dolomite are rarer in the samples from the shallow pits than in flood-plain alluvium. Opaque cubes (uraninite and/or pyrite) have been recognized only in two samples from Guddar, and not at all from Khabbal or Attock. Apatite also is rarer in these deposits. One is tempted to conclude that these minerals do not survive in the older alluvials due to intra-stratal solution, particularly at a depth of more than five feet.

Frequency distribution of non-magnetic heavy minerals in samples from the old river terraces.

Seven samples were collected from old river terraces at widely scattered localities between Amb and Attock. The frequency distribution of their non-magnetic heavy minerals is shown in table 6.

Table 6. Frequency distribution of non-magnetic heavy minerals in the bromoform separates from old river terraces.

ON FIG. 4.	APATITE	ANATASE	AUGITE	BARITE	BROOKITE	CASSITERITE	CALCITE - DOLOMITE	CORUNDUM	DIOPSIDE	EPIDOTE	GARNET	HORNBLENDE	HYPERSTHENE	KYANITE	'MICAS'	MONAZITE	OPAQUE MIN.	OPAQUE CUBE	OLIVINE	RUTILE	SCHEELITE	SILLIMANITE	STAUROLITE	TOURMALINE	TOPAZ	UNIDENTIFIED MIN.	VESUVIANITE	ZIRCON	ZOISITE - CLINOZOISITE
1 T	.6	-	3.9	-	1.3	-	1.9	-	-	5.2	8.5	51.5	1.7	-	9.2	-	5.9	.6	-	-	-	3.9	-	-	-	4.5	-	1.3	
2 T	1.1	-	3.8	-	-	-	4.5	.4	.7	4.5	9.2	40.6	1.1	.4	6.8	-	17.4	-	-	-	-	3.8	-	-	-	2.3	-	2.3	1.1
3 T	-	-	4.2	-	1.2	-	-	-	.6	6.0	21.0	42.4	3.0	-	3.0	-	9.6	-	-	-	-	3.0	-	.6	-	3.0	-	1.8	.6
4T	1.5	-	3.8	-	1.5	.7	-	.7	-	3.0	11.4	63.0	2.3	-	1.5	-	3.8	-	-	-	-	2.3	-	-	-	4.5	-	-	-
5 T	-	.9	5.3	-	.9	-	-	-	-	5.6	17.3	35.5	5.3	-	2.6	-	15.0	-	-	-	-	7.1	-	-	-	4.5	-	-	-
6 T	1.0	-	4.0	-	1.5	-	2.5	-	1.5	5.1	10.2	46.0	1.5	-	8.6	-	7.6	-	-	1.0	-	4.0	-	-	-	3.4	-	2.1	-
7 T	-	-	2.3	-	.7	-	1.9	1.1	.4	3.4	12.7	61.6	-	-	4.6	-	4.2	.7	-	-	-	1.9	-	.4	-	2.3	-	1.1	.7

Hornblende is the dominant component in the non-magnetic heavy minerals, with a frequency percentage ranging from 35.5 to 63.0. Garnet is next in abundance, forming from 8.5 to 21.0 per cent. The relative tenor of garnet in these samples is somewhat lower than that in the recent alluvials of the main channel of the rivers but conversely the content of opaque minerals is somewhat greater, the frequency in seven samples ranging from 3.8 to 17.4 per cent. Over three-quarters of these non-magnetic opaques consist of ilmenite.

The opaque cubes which are frequently recorded in the heavy crops of recently deposited alluvial samples from the flood plain are scarcer in the samples from old river terraces. Out of seven samples, only two yielded opaque cubes. Similarly calcite/dolomite are much rarer in the old alluvials of the terraces than in the modern alluvials of the floodplain.

Frequency distribution of non-magnetic heavy minerals in the Gilgit, Hunza, and Shigar tributaries, and in the River Indus at Skardu.

An examination of the heavy mineral suites from the rivers Gilgit, Hunza and Shigar is reported in table 7. Two samples from the Indus River at Skardu have also been analysed, for comparison with the alluvials downstream, between Kabulgram and Kalabagh.

Hornblende is the dominant non-magnetic heavy mineral in the three major tributaries, the frequency in the three samples from Gilgit averaging as high as 50 per cent. Garnet is next most abundant, except in the samples from Gilgit where the tenor of this mineral is relatively low. Calcite/dolomite are recorded in the samples from all three tributaries, but are not present in the Indus sample from Skardu, which

Table 7. Frequency distribution of non-magnetic heavy minerals in the bromoform separates from Gilgit, Hunza, Shigar tributaries and the Indus river at Skardu.

ON FIG. 4.	APATITE	ANATASE	AUGITE	BARITE	BROOKITE	CASSITERITE	CALCITE - DOLOMITE	CORUNDUM	DIOPSIDE	EPIDOTE	GARNET	HORNBLENDE	HYPERSTHENE	KYANITE	'MICAS'	MONAZITE	OPAQUE MIN.	OPAQUE CUBE	OLIVINE	RUTILE	SCHEELITE	SILLIMANITE	STAUROLITE	TOURMALINE	TOPAZ	UNIDENTIFIED GRAIN	VESUVIANITE	ZIRCON	ZOISITE - CLINOZOISITE
051	-	.5	2.7	-	-	1.3	2.2	.5	5.2	3.5	2.6	53.5	2.6	-	3.9	-	6.6	-	-	.5	-	1.3	-	-	-	9.5	-	1.3	1.3
052	-	-	1.2	-	.3	.6	1.8	.3	2.8	3.8	4.2	59.0	1.8	-	4.4	.5	8.0	.4	-	.3	-	3.6	-	-	-	4.2	-	2.8	-
059	.7	.4	1.1	-	.7	-	1.8	-	2.3	3.3	11.0	39.3	1.7	-	10.0	.4	6.2	-	-	.4	-	1.8	-	.4	-	7.0	.4	6.3	.8
061	-	.4	2.9	-	.7	-	1.7	-	2.1	3.7	17.4	35.5	1.2	-	9.6	-	17.4	1.7	-	.4	-	1.2	-	-	-	2.9	-	1.2	-
064	.5	-	2.1	-	-	-	1.6	1.0	4.1	4.2	10.8	40.1	1.6	-	23.5	-	3.1	-	-	.5	-	2.1	-	.1	-	4.2	.5	-	-
B 1	.6	-	3.0	-	3.0	-	5.9	.6	1.2	3.3	8.6	34.6	1.5	-	19.2	.3	7.7	.2	-	1.6	-	1.5	.6	.3	-	.9	-	4.2	1.2
B 2	1.1	-	2.6	-	1.1	.6	3.4	-	1.4	2.0	21.2	30.2	1.1	-	11.4	.6	12.8	-	-	.6	-	3.7	-	-	-	.8	-	5.1	.3
B 3	.7	-	1.9	-	.3	-	4.9	-	.9	3.3	21.0	29.5	.9	-	6.5	-	22.5	.9	-	.3	-	1.3	.9	-	-	1.6	-	2.3	.3
B 4	-	.3	1.3	-	.9	.3	-	.3	.3	4.4	28.5	39.4	2.5	.3	1.6	.3	12.3	.3	.3	1.3	-	2.2	.3	-	-	1.3	-	1.6	-
111 B	-	.5	2.2	-	1.1	1.1	-	-	1.6	5.4	19.1	45.0	1.1	1.1	1.1	-	13.4	-	-	1.1	-	2.2	-	-	.5	2.5	-	.5	.5

Table 8. Frequency distribution of minerals in the bromoform separates of light fraction (<2.89, 'float') between Kalabagh and Kabulgram.

MINERALS	sample nos. shown in Fig. 4.															
	1 L	2 L	3 L	4 L	5 L	6 L	7 L	8 L	9 L	10 L	11 L	12 L	13 L	14L	15 L	16 L
a. Quartz	46.5	59.5	60.5	40.6	48.0	49.5	35.5	40.5	47.1	29.3	56.3	50.5	53.5	51.7	56.0	57.6
b. Orthoclase	5.8	5.7	10.8	16.4	14.9	13.8	9.0	17.6	17.1	8.6	9.2	8.9	13.4	19.6	14.2	14.7
c. Plagioclase	2.5	.4	1.8	2.9	1.7	2.3	2.5	3.7	2.8	3.4	2.1	2.9	3.4	3.2	4.5	4.9
d. Microcline	-	-	-	1.1	-	-	.8	.5	-	-	-	-	.7	-	.6	.6
e. Dolomite-calcite	4.2	1.6	3.6	5.7	4.0	4.8	7.4	5.7	5.6	12.0	4.1	8.9	4.2	4.0	3.7	4.3
f. Muscovite	5.3	2.3	0.9	3.6	5.1	4.6	13.8	10.3	5.6	12.2	5.1	8.8	4.7	4.8	6.0	5.5
g. "Unidentified grains"	35.7	30.5	20.4	30.7	26.3	25.0	31.0	21.7	21.8	32.5	23.2	20.0	20.1	16.7	15.0	12.4

was collected upstream of its confluence with the river Shigar.

(b) Light fraction

For mineralogical analysis of the fraction lighter than bromoform, sixteen samples were studied from the Indus alluvials between Kabulgram and Kalabagh, eight from the Gilgit, Hunza and Shigar tributaries in the upper reaches of the Indus, and one from the Indus at Skardu. The results of this analysis are given in tables 8 and 9. The minerals identified in the light fractions are quartz, orthoclase, plagioclase, microcline, muscovite and calcite/dolomite.

Quartz is the dominant mineral in the light fractions of the alluvials, between Kabulgram and Kalabagh, the dominance being partly attributable to the decomposition of feldspar.

"Unidentified grains" come second in order of abundance in these samples, the minerals in this category being mostly weathered feldspars, particularly altered orthoclase which forms nearly three-quarters of the whole group. In order of abundance, other minerals included in this category are (?) muscovite, calcite-dolomite, plagioclase and microcline in grains not sufficiently fresh for precise determination.

Orthoclase, free from secondary alteration products, comes third in order of abundance. If the decomposed grains of orthoclase are included with the fresher ones, the tenor of this mineral in the light fraction increases by a factor of two or three

Table 9. Frequency distribution of minerals in the bromoform separates of light fraction

(< 2.89 'float')

		sample nos. shown in Fig. 4.							
	Gilgit river		Hunza river			Shigar river			Indus river (SKARDU)
MINERALS	17 L	18 L	19 L	20 L	21 L	22 L	23 L	24 L	25 L
1. Quartz	27.9	26.6	26.6	25.9	26.2	38.1	34.5	32.0	33.5
2. Orthoclase	34.1	32.1	32.6	25.5	32.5	33.5	32.5	36.5	38.2
3. Plagioclase	5.6	7.9	3.3	5.2	5.8	4.3	4.5	4.7	3.9
4. Microcline	2.8	3.9	0.8	2.2	1.9	1.7	1.8	1.6	0.9
5. Dolomite/calcite	6.3	8.9	7.5	8.2	8.6	5.2	5.4	6.3	4.9
6. Muscovite	7.7	6.9	8.3	9.7	11.6	7.7	9.8	10.2	8.8
7. "Unidentified grains"	15.4	13.7	20.9	23.3	13.4	9.5	11.5	8.7	9.8

<u>Plagioclase</u> is present in lesser amount than orthoclase but is more consistent, averaging nearly 3 per cent (range from 0.4 to 4.9 per cent) of the light minerals. <u>Microcline</u> is erratic in distribution and has been found in only five of the 16 samples taken between Kabulgram and Kalabagh.

<u>Frequency distribution of light minerals in the samples from the three major tributaries.</u>

The assemblage of light minerals in alluvials from the three tributaries in the upper reaches of the Indus is comparable to that found between Kabulgram and Kalabagh, but undecomposed feldspars are here dominant over, or equal in tenor to, the quartz, and there is a corresponding reduction in the proportion of unidentified grains. Microcline, which is a sporadic constituent in the lower sampled reaches of the river, is a consistently present ingredient in the samples from the upper tributaries. Plagioclase is also somewhat more abundant in the high-alpine tributaries than it is further downstream. The results of mineralogical analysis are given in Table 9.

B. Description of the minerals.

An account is given here of the colour, shape and size of the mineral grains, of the effect of abrasion and solution, of inclusions which are present, and of optical characteristics facilitating identification. A sketch of typical grains of the various minerals, enlarged 60 times, is reproduced in figure

Amphiboles: Common hornblende is the dominant species recorded in the non-magnetic fractions of heavy-mineral separations. Among other amphiboles, basaltic hornblende and fibrous hornblende have been recognized, but only in occasional slides. The former is more often seen in the samples from the Hunza and Gilgit rivers, and the latter, usually in a decomposed form, has been noticed in samples from the Indus river upstream at Kabulgram.

The grains of common hornblende have a wide range in size, but are most commonly between 500 and 125 microns. They are generally prismatic, elongated and flaky, with frayed and jagged edges. In colour the common hornblende may be dark green, light green or brownish green, the brownish green variety being apparently the least resistant to decay and subordinate to the other types. Uneven distribution of colour is frequent, usually with a paler tint towards the fringe of the grain. Weathered grains look blotchy, with a fibrous appearance, and give anomalous interference colours under crossed nicols. Sub-rounded to rounded grains are commoner in the coarser fractions, whereas finer grains in the 250-75 micron size-range tend to be angular and sub-angular. Inclusions are infrequent but sporadic grains contain opaque particles of ore mineral.

Garnet: Garnet is the second most important constituent of the magnetite-free heavy mineral separations. It is present in all fractions from 1000 to 75 microns, but is most abundant in the size range 500-125 microns. Both colourless and coloured (pink and red) varieties are found. Garnet occurs both in anhedral and euhedral forms, the former being most abundant, with angular, sub-angular and sub-rounded outlines. The euhedral or crystalline grains are in the habits rhomb-dodecohedron, tetragonal trisoctahedron, and combinations thereof. By attrition due to long-distance transportation these are reduced to rounded grains. The anhedral garnets are angular, sub-angular, and sub-rounded. Slight etching and reddish-brown staining is sometimes conspicuous. Inclusions are frequent, both as gas-and liquid-filled cavities and as criss-cross intersections of bands of minute needles. Opaque particles, quartz, feldspar, chlorite, apatite and hornblende have been identified as inclusions, while hypersthene and rutile are recorded more rarely.

Pyroxene: Among the pyroxene minerals augite, hypersthene and diopside have been identified, the first two being the most frequent. They are most common in grain-sizes between 500 and 125 microns. The form and habit of these minerals are essentially identical; they most commonly occur as elongated, tabular, prismatic grains but irregular outlines are not uncommon. Augite has been distinguished from diopside solely on grounds of colour; the former is colourless or pale yellow and is very often masked by secondary decomposition products, whilst the latter has a pale greenish tint and an incipient decomposition the grain takes on a hazy aspect and may also become a deeper green in shade. Opaque inclusions are not uncommon. The hypersthene can readily be singled out because of its pleochroism; a few grains show well-developed cleavage cracks with decomposition product along them, and schiller inclusions are also common.

Opaque minerals: No ore-microscope study has been made of the opaque minerals, which have not been differentiated and are placed together in the frequency tables. Magnetite is by far the most abundant species, forming more than three-quarters of the "opaques"; the name magnetite is employed for all grains attracted by an almico hand magnet and hence is likely to include titano-magnetite. In the non-magnetic fraction, ilmenite is the major constituent in most cases. The grain-size is around 250-75 microns. Chalcopyrite, pyrite, arsenopyrite, haematite, limonite, picotite, galena, uraninite and various unidentified ore minerals are also present in the opaque suites, the first two of these being more frequent in occurrence. From polished section preparations of gold-washer's residues Ramdohr (8) has also identified loellingite, native bismuth, and also maldonite, a rare gold bismuthide.

Of the opaque minerals in euhedral form, cubes and octahedra are most common, the minerals so occurring comprising magnetite, pyrite, limonite, galena, and uraninite-thorianite. The opaque cubes are placed in a separate division in the frequency tables because of the special interest attaching to the uraninite present in this form. It has been roughly estimated, visually, that around 15-20 per cent of the cubes may be uraninite, but in view of the difficulty in separating and determining minute grains around 70 microns this may be an over-estimate. Uraninite can be distinguished from fresh pyrite, but not from martitized pyrite, by the colour in reflected light. A few of the black cubes have a resinous lustre.

Epidote: Epidote is present in almost all heavy residues, but in varying proportion. It forms both colourless and light yellow-green grains, the former being most common. The coloured variety is feebly pleochroic. The mineral has a wide range in grain size but is met with most abundantly in fractions between 500 and 125 microns. Sub-rounded grains are the more common but sporadic rounded to well-rounded epidote has been encountered, and well-preserved euhedra have been met with somewhat more rarely. Gas- and liquid-filled cavities form the commoner inclusions.

Olivine: This is a very rare species in the heavy mineral assemblages and where it is met with ultrabasic or basic rocks outcrop nearby. Usually it forms anhedral grains partly masked by decomposition products.

Brookite: Not uncommon. It usually has a pale yellow colour, which in a few grains is unevenly distributed giving a blotchy appearance.

Deeply coloured spots are slightly pleochroic. Rounded to well-rounded grains are most frequent. It is typical of this mineral that the grains fail to extinguish under crossed nicols. The interference colour which they display changes from deep yellowish orange at 90 degrees to a deep green tint fringed by red-orange-yellow colours at 45 degrees. The most common inclusions are gas- and liquid-filled cavities; more rarely included particles of apatite and opaque minerals occur.

Zircon: Zircon is ubiquitous throughout the alluvials, but there is great variation in the amount present. The samples richest in zircon are from localities near to acid intrusions. In size range the mineral is confined to the fraction between 250 and 75 microns and is most frequent at 125 microns. Most grains, but not all, fluorescence in a golden-yellow colour under the short-wave ultraviolet lamp. The zircon is polyvarietal, and it can be divided into the following eight groups on the basis of colour, texture and form or habit.

1. Colourless zircon.
2. Coloured zircon.
3. Robust zircon.
4. Slender, needle-shaped, zircon.
5. Zircon with crystallographic outgrowths.
6. Dark grey or black zircon.
7. Ovoid-shaped zircons.
8. Broken, fragmental zircon.

(1) and (2). Colourless and coloured zircon embrace all the types described under (3) to (8) inclusive. In form, the mineral may range from sharp euhedra of diverse dimensions to well-worn grains devoid of any crystal faces. Crimson, yellow and red are the colours most commonly met with, the two former being most common.

(3). This type of zircon has been recorded most commonly in the samples collected upstream at Kabulgram. The length of these crystals does not greatly exceed the breadth and each grain has a dwarf robust shape. Pale yellow grains are common. Euhedra of this form are frequently met with, in some cases with slight modifications of the bipyramidal terminations. The surface of the crystals is nearly always etched to form grooves and pits, giving them an opaque appearance. A typical grain measures 180 x 140 microns. Because of the pitted surface inclusions are not apparent.

(4). Zircons of this kind occur both as subhedral and euhedral grains, both colourless and coloured. A typical crystal measures 80 by 30 microns. Inclusions are not common.

(5). Both colourless and coloured zircons may show outgrowths on the pyramid or on the prism faces, and both host crystal and the outgrowth may show well-developed forms. Inclusions are very common and comprise opaque particles, liquid with gas bubbles, apatite and very minute zircons.

(6). This variety is sporadic in distribution along the main channel of the river, but is very common in a few tributaries draining metamorphic rocks which contain bands of radioactive gneisses. The grains are greyish in colour, the shade being denser near the pyramidal terminations. The colour may be due to metamictization. Most of these crystals show little sign of abrasion and it is presumed that their source is nearby.

(7). Ovoid zircons are the tiniest form of zircon recorded in the Indus alluvials. Most of the grains have apparently attained their form by long-continued abrasion but some were doubtless shaped in an earlier cycle of erosion and sedimentation.

(8). Broken particles of zircon which retain an angular shape are referred to as fragmented when their length is less than one-third that of the normal zircon crystals. Upstream from Amb these fragmental zircons are common, but downstream the angular pieces are rounded by long transportation and ovoid grains become dominant.

In the following table an analysis is given of the proportion (per cent) of the different types of zircon at different localities between Kalabagh and Kabulgram.

Table 10. Frequency distribution of various types of zircon in the heavy residues of the Indus alluvial.

LOCATION	1.	2.	3.	4.	5.	6.	7.	8.
1. KALABAGH	14	21	-	5	-	49	11	-
2. ATTOCK	18	39	-	5	-	34	4	-
3. QAZIPUR	20	32	-	-	-	37	-	11
4. AMB	21	36	3	3	3	2	4	9
5. KABULGRAM	24	40	4	4	2	6	5	15

1. Normal colourless zircon.
2. Normal yellow, pink and crimson zircon.
3. Robust zircon.
4. Zircon with crystallographic outgrowth.
5. Dark grey or black zircon.
6. Ovoid-shaped zircon.
7. Slender, needle-shaped zircon.
8. Broken fragmental zircon.

Calcite/Dolomite. The similarity in the optical properties of these carbonates is such that a disproportionate amount of time would have to be spent, testing a multitude of grains for refractive indices or microchemically, to assess the relative proportions of the two minerals. They are therefore recorded together. Both are widely distributed throughout the alluvials. Since the approximate specific gravities are calcite 2.72, dolomite 2.85, calcite will tend to accumulate in the light fraction and dolomite in both the light and heavy fractions from bromoform separation. The minerals occur in all grain sizes. Tabular grains with a rhombohedral habit are most common, but many grains are worn and rounded and they become whiter on rounding. The minerals are usually white and they exhibit the characteristic twinkling under crossed nicols. Twinning is often conspicuous.

Vesuvianite: This is a rare mineral in the alluvials, recorded only in a very few samples. It is commonly of a green or yellowish green colour, in subangular to subrounded prismatic grains. A typical grain is subangular with its prismatic faces intact but with the two terminations worn away, of an unevenly distributed yellow-green colour with occasional vivid deep green patches. It is feebly pleochroic in light green and light yellow-green, length fast, with a uniaxial negative figure. Inclusions cannot be identified because of the colouration of the grain.

Micas: Biotite, muscovite and phlogopite are present, with biotite forming 85 per cent of the micas and muscovite being more common than phlogopite. They occur in all grain sizes but are commonest in the coarse-grained heavy fractions.

Biotite forms pale to deep brown flakes with zircons centring pleochroic haloes as the most common inclusions. The haloes in a typical grain were studied in detail. This grain is 1.4 x 1.1 mm.

Footnote on Cassiterite.

The cassiterite reported in the tabular mineralogical analyses in this thesis was identified visually, in covered preparations of heavy-mineral concentrate mounted in canada balsam. At a late stage of the investigation, after the thesis was typed, a quantitative check on the proportion of cassiterite was carried out on unmounted concentrate, using zinc dust and hydrochloric acid to give a "mirror of tin" on the surface of the tinstone grains. As a result of this experiment it has become apparent that the tenor of cassiterite is in fact much less than recorded, grains of the mineral occurring only very rarely. The difficulty of visually distinguishing tinstone from some dark zircon, rutile, sphene, and titano-niobate minerals has been emphasized by several authors and it seems likely from the results of the zinc dust test that the writer has taken occasional grains of some such minerals to be cassiterite.

in size and contains around 28 halos with diameters ranging from 9 to 48 microns. Almost all the halos contain slender zircon crystals as their kernels - but there are other inclusions of zircon in the mica which have no marked halos around them. The radioactive mineral could possibly be xenotime. In one halo about 15 major and 28 minor particle tracks could be counted, the minor tracks forming off-shoots of the major ones.

Phlogopite is of rare occurrence and is distinguished from biotite by its lighter colour and weak absorption. Muscovite is present both in the heavy and light fractions, usually in a somewhat decomposed form. It is colourless when fresh, but commonly tinted with green and white decomposition products. Inclusions of opaque particles, rutile and garnet are frequent.

Cassiterite: Brown and yellowish grains of cassiterite between 250 and 125 microns in size are of rather rare occurrence. The grains are usually rounded to subrounded, and characterised by a very high relief, a pleochroism in brown to yellow-brown and interference tints masked by the body colour.

Scheelite: This mineral is rarer than cassiterite, but appreciable number of grains can be observed in the highly concentrated gold-washers' residues with the aid of a short-wave ultraviolet lamp, when they fluoresce in a blue-white colour. In ordinary light the scheelite is of a yellow-white or pale yellow tinge. It is brittle, and fresh grains usually show uneven fractures, though subangular grains are more usual.

Apatite: Apatite is a very minor constituent of heavy concentrates, but is widespread. The grains are usually between 125 and 75 microns in size, colourless, with rounding of the prism faces and pyramidal terminations. Euhedra are rare but ovoids are common. One exceptionally long acicular crystal measured 270 x 80 microns. Liquid-filled cavities are often met with.

Sillimanite: This mineral is consistently present in colourless grains, usually subrounded to rounded in form but elongated lath-like grains are not uncommon, usually with a ragged termination. The sillimanite has a wide range in size but is commonest in the 125-75 micron fraction. Inclusions of biotite, opaque minerals, and liquid-filled cavities have been noted.

Corundum: This is a rare species, with a relative frequency in the non-magnetic heavy residues of under one per cent in almost all the samples studied. It forms colourless grains with a tabular habit and subangular to subrounded form, most commonly in the size fraction 250-125 microns.

Kyanite: Kyanite is commonly seen in the samples collected between Kalabagh and Kabulgram, to which it has been contributed from the schistose rocks upstream from Attock. It occurs in flakes and laths with subangular to subrounded form, colourless and usually fresh-looking, most commonly in the 250-125 microns size range.

Rutile: Rutile is almost ubiquitous in the non-magnetic heavy crop of the Indus alluvials, in which however its relative frequence is less than one per cent. It occurs in the size range 500-75 microns. The most common colour is foxy red but brown and yellow grains have been met with. Usually it forms subrounded to rounded grains, rarely with twinning. Due to its high relief the grain appear opaque around their margins. Some of them show slight etching marks.

Zoisite, Clinozoisite: These minerals occur as colourless grains, often tabular and of a prismatic habit, of subangular to sub-rounded form. They are commonest in the 250-125 micron size range. The grains have a high relief and exhibit interference tints in a deep blue colour, being distinguished from corundum which exhibits the same interference colour by their biaxial optical character. Clinozoisite is distinguished from zoisite by its oblique extinction. A few grains of the former mineral also show an absence of the blue interference colour.

Tourmaline: Tourmaline is consistently present. In nearly 90 per cent of the non-magnetic heavy concentrates its relative frequency is less than one per cent. It is found in all size grades but is most common between 250 and 125 microns. The commonest colours are yellowish grey, yellowish green, brownish green and pinkish brown, the first two being most frequent. The prism faces are usually intact, but terminal faces are either fractured or subrounded. Rounded grains of tourmaline have been recorded rarely.

Staurolite: It usually occurs as subrounded platy grains, usually yellow but sometimes colourless, commonly in the 125-250 micron grain size.

Monazite: Monazite is of sparse distribution in the Indus alluvials, and less than 30 per cent of the bromoform separates yielded monazite grains. It is usually rounded to well-rounded, and from colourless to pale yellow in shade, the latter being most common. It is restricted to the 75-150 micron size range. Due to their high relief, the fringe of the grains appears opaque. Some grains show a brown and green staining and possess microfractures. Radiometric study by the writer, in the laboratories of the Geological Survey of Pakistan, has shown that both the varieties have the same level of radioactivity.

Anatase: Both tabular anatase and grains with a subrounded to rounded form have been met with. Tiny zircons may be present as inclusions. The anatase is commonest in the 250-125 micron size range.

Topaz: Less than five per cent of the heavy mineral separations have yielded topaz, and where present it has a relative frequency of less than one per cent of the non-magnetic heavies. It forms colourless prismatic grains of irregular habit, sometimes sub-angular to sub-rounded, in the 125-500 micron size range.

Barite: Prismatic lath-like grains of (?) barite, with irregular and angular borders, have been tentatively identified in a very few samples.

Chlorite: A few sporadic grains have been noted both in the heavy and light fractions, distinguished by a micaceous habit, low relief, light grass green colour, and a feeble pleochroism. Chlorite is more often present as a patchy decomposition product of amphiboles and pyroxenes.

Leucoxene: Amorphous, white or coffee-coloured, leucoxene has been identified as a decomposition product of ilmenite, usually developed around the fringe of the ilmenite grains.

Xenotime: Due to its extreme rarity, xenotime has been included with zircon in the mineral frequency table. It occurs in subhedral to anhedral prismatic grains with rounded to well-rounded prisms and pyramids. The colour is usually light brown. Pleochroic grains are commonly met with.

<u>"Unidentified grains"</u>: The mineral grains which are so decomposed that they cannot readily be identified microscopically are grouped together as "unidentified grains". Most of these are secondary products after feldspar, olivine, epidote, pyroxenes, in rare cases amphiboles, and leached carbonate minerals.

Figs. 12, 12a, 12b. Typical detrital minerals of the Indus Alluvials.

(a)	1 to 1 l	Garnet
(b)	2 to 2 i	Common hornblende
(c)	3 to 3 h	Biotite, phlogopite
(d)	4a to 4 f	Augite, diopside
	4g to 4 l	Hypersthene
(e)	5a to 5 i	Calcite/dolomite
(f)	6a to 6 j	Epidote
(g)	7a to 7 k	Various types of zircon
(h)	8a to 8 j	Opaque minerals. 8i and 8j are ilmenite grains with well developed leucoxene near the fringe. 8a is an opaque cube.
(i)	9a to 9 e	Tourmaline
(j)	10a to 10 f	Rutile
(k)	11a to 11 g	Apatite
(l)	12a to 12 f	Sillimanite
(m)	13a to 13 f	Monazite
(n)	14a to 14 i	Feldspars (orthoclase and plagioclase
(o)	15a to 15 f	Muscovite
(p)	16a to 16 f	Quartz.

Fig. 12. Typical detrital minerals of the Indus Alluvials.

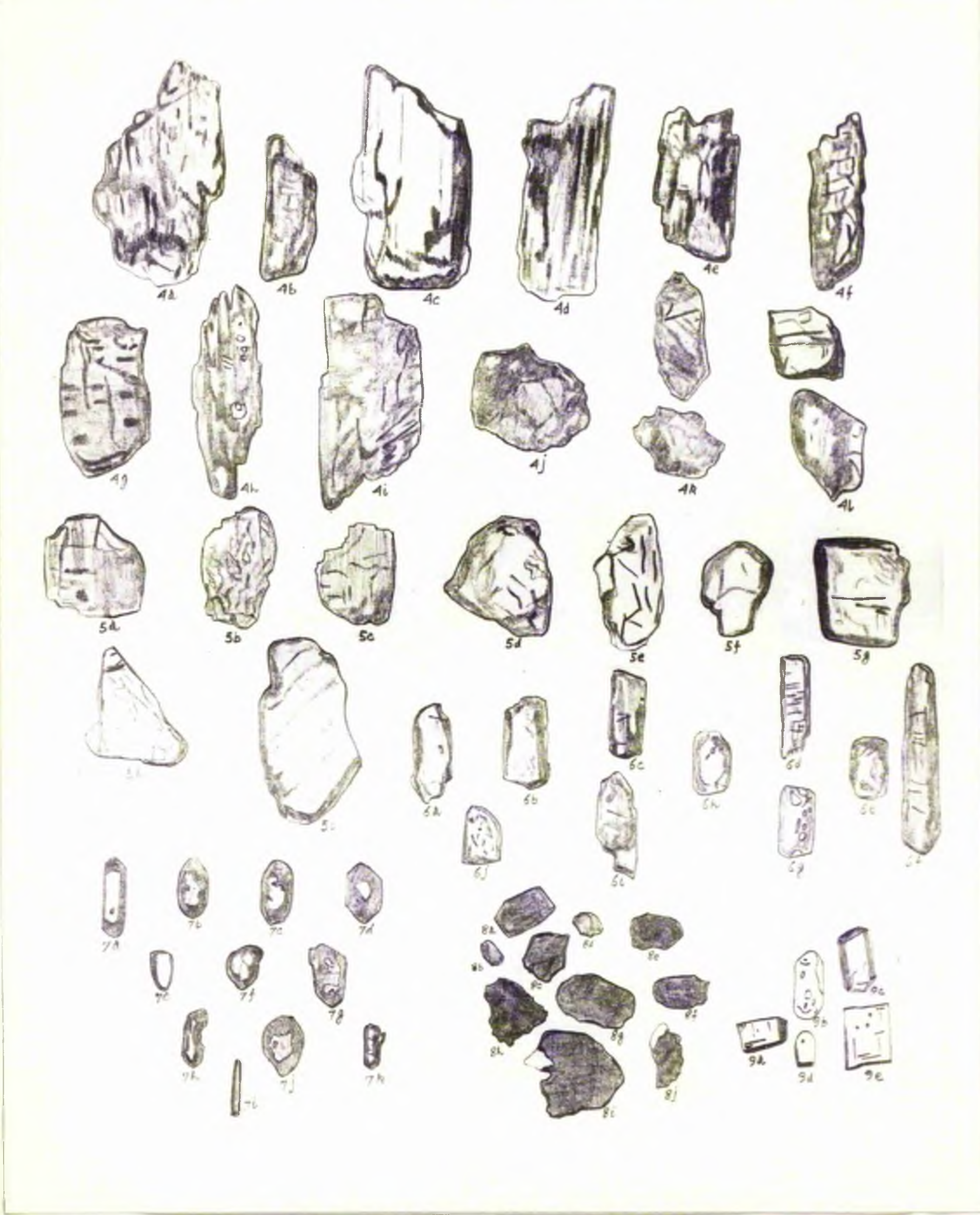


Fig. 12a. Typical detrital minerals of the Indus Alluvials.

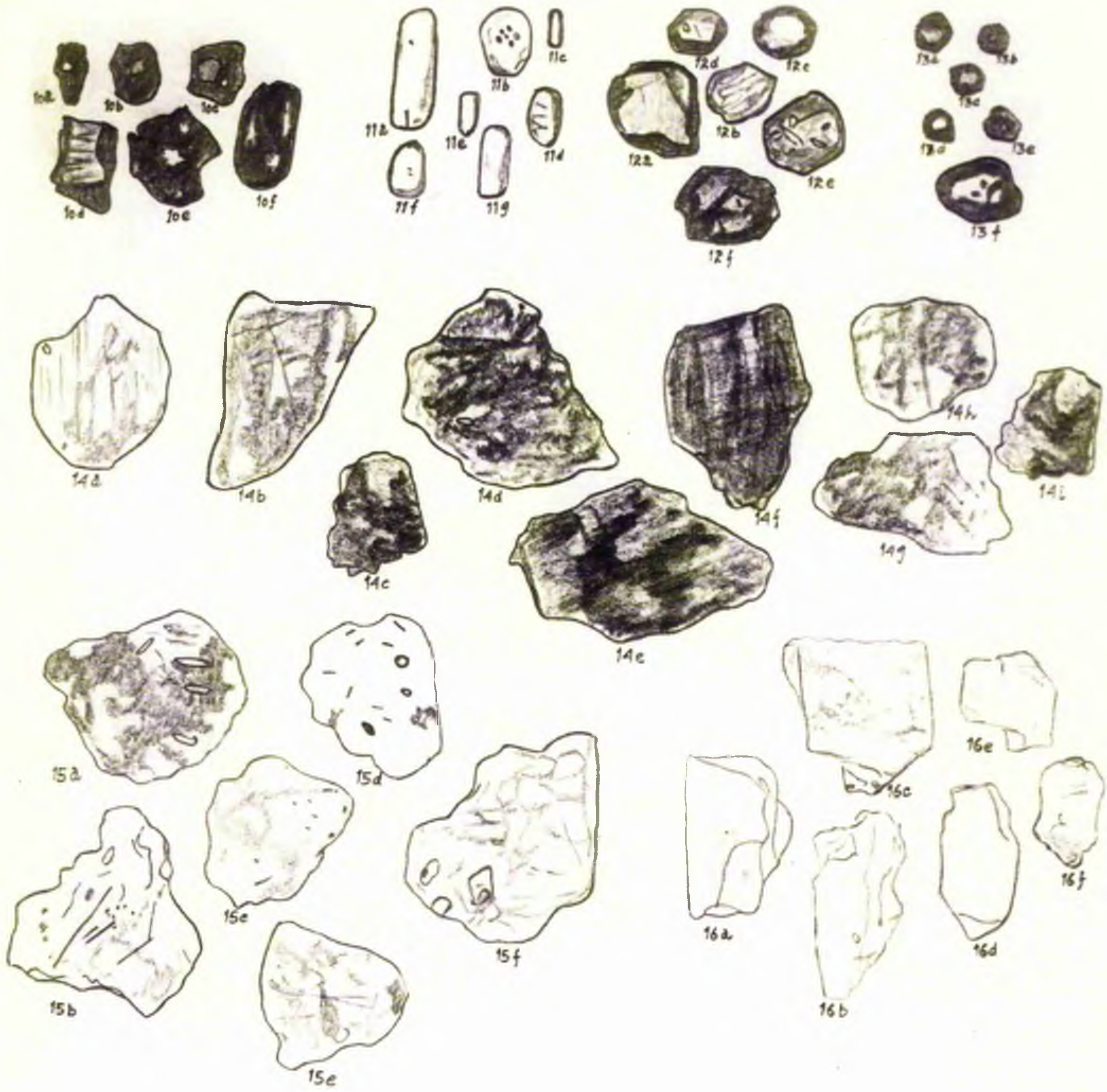


Fig. 12b. Typical detrital minerals of the Indus Alluvials.

C. Electro-Magnetic Fractionation

Twevle samples of heavy separates from bromoform, derived from nine localities between Kalabagh and Kabulgram, were selected for fractionation using a Frantz Isodynamic Electromagnetic Separator. Particulars are given in Fig. 13 and Table 14.

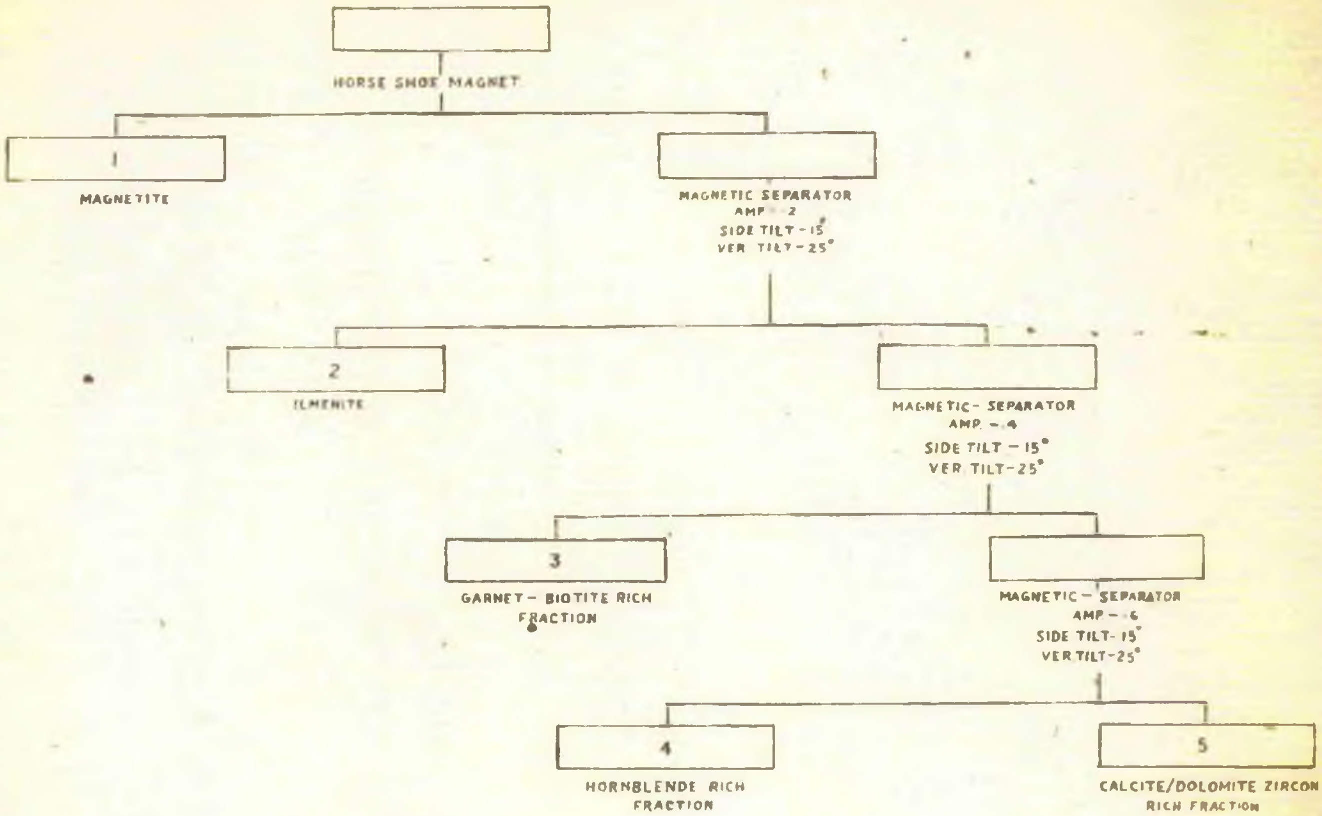
Analytical procedure:

The constituents of the heavy mineral suites vary greatly in their magnetic susceptibilities. To obtain the optimum separation of one species from another, numerous tests were made on the magnetic separator, varying the angles of slide tilt and vertical tilt and the amperage. The setting devised for the most satisfactory results is shown in the flow-sheet (Fig. 13).

Each sample was first treated in a horse-shoe magnet to remove magnetite and pyrrhotite, which clog the separator. The magnetite-free fraction was then passed through the separator running at 0.2 amperes with vertical tilt 25°, side tile 15°. This setting yielded ilmenite as the more magnetic crop. Recirculating the residue (less magnetic) at 0.4 amperes gave a garnet-biotite fraction as the more magnetic crop. The residue from this second fractionation was then re-cycled at 0.6 amperes, giving both in the upper and lower pans mixed suites of several minerals. These are discussed below.

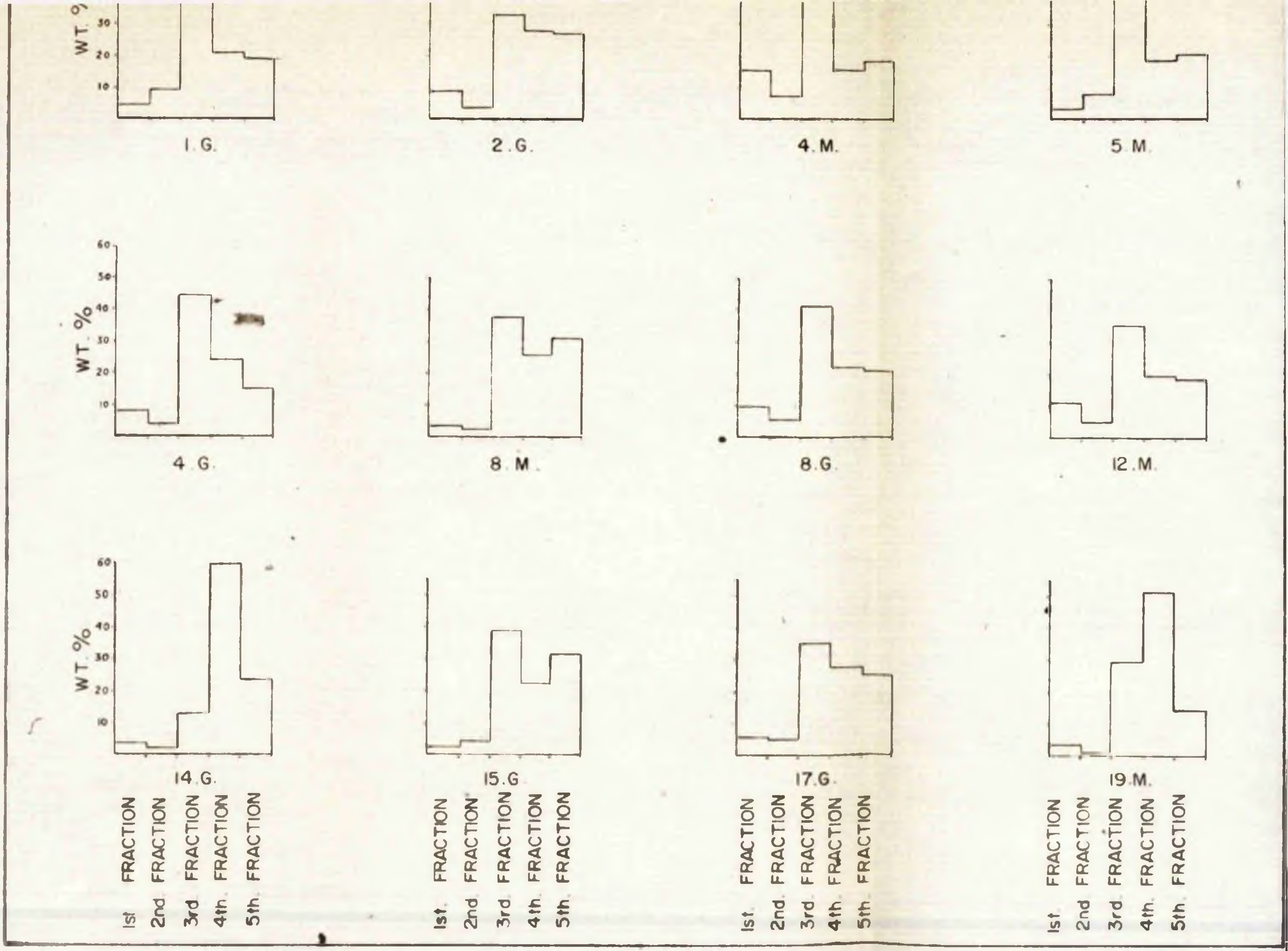
A clean-cut separation of the various minerals present was found to be impossible to obtain because of their overlap in magnetic susceptibilities. An indication of the overlap is given in the following table.

FIG.13



Electromagnetic Properties of Mineral Grains from Indus Alluvials
Frantz Isodynamic Separator

Mineral	Extraction range (amps)	Best Extraction Range (am
Garnet	0.15 - 0.7	0.2 - 0.35
Hornblende	0.30 - 0.5	
Epidote	0.40 - 0.55	
Biotite	0.25 - 0.5	0.32 - 0.40
Pyroxenes	0.2 - 0.6	0.35 - 0.5
Tourmaline	0.3 - .7	0.35 - 0.55



HISTOGRAMS SHOWING WEIGHT PERCENTAGE OF VARIOUS FRACTIONS SEPARATED BY FRANTZ ISODYNAMIC MAGNETIC SEPARATOR.

After fractionation, each magnetic separate was weighed and the percentage weight of the whole sample was calculated. The results are illustrated as histograms on Fig. 14. Microscope slides were then prepared from the successive separates and the mineral grains counted to establish their frequency distribution. The percentage frequency distribution of the minerals in the various fractions is shown in Table 11.

The first magnetic fraction consists mainly of magnetite, with rare pyrrhotite. It forms from 2.6 to 21.6 per cent of the whole. The name magnetite is used in a broad sense and includes any titano-magnetite which is attracted by a bar magnet.

The second fraction consists essentially (98%) of ilmenite which forms 0.9%-9.4% of the whole, contaminated with sporadic grains of other minerals (2%) caught up by the ilmenite.

The third fraction is usually the largest one, containing garnet, biotite, hornblende, ilmenite, and hypersthene, listed in their order of frequency. Garnet is dominant, forming from 17.5 to 75.0 per cent of the total.

The fourth fraction is sometimes the largest one. The minerals present in order of abundance are hornblende, epidote, opaque species, biotite, pyroxenes, tourmaline, garnet, anatase, corundum. Hornblende is the dominant constituent, always forming over 70 per cent. Pyrite and chalcopyrite are present among the opaque minerals.

The fifth fraction is the third largest one. Here the non-magnetic minerals report. Occurring in substantial amount, in order

11. requency distribution of heavy minerals in magnetic-separates.

N												5th FRACTION												
	DIOPSIDE	VESUVIANITE	TOURMALINE	ANATASE	GARNET	CORUNDUM	ZIRCON	APATITE	SILLIMANITE	KYANITE	ZOISITE CLINOZOISITE	CALCITE - DOLOMITE	OPAQUE MINERAL	EPIDOTE	TOURMALINE	CASSITERITE	SCHEELITE	BROOKITE	AUGITE	DIOPSIDE	RUTILE	CORUNDUM	MONAZITE
9	-	.0	2.0	.9	-	-	27.0	2.4	6.1	1.2	3.6	14.4	15.8	11.2	-	-	-	4.9	7.6	1.2	2.4	1.2	-
3	.5		.5	-	3.8	.5	18.2	3.4	17.4	-	-	36.0	-	13.4	-	-	-	4.2	5.8	-	.8	-	.8
2	-		.8	.8	-	-	2.6	3.7	21.0	-	1.2	15.0	17.5	19.0	-	2.5	1.2	3.7	6.4	-	5.0	1.2	-
2	1.1	-	-	.6	-	-	11.6	3.5	10.5	-	2.1	45.0	9.8	10.5	-	.7	-	.7	4.2	-	1.4	-	-
	2.0	[illegible]	.5	1.6	-	.5	17.9	5.5	8.8	-	1.6	51.0	5.6	3.2	-	-	-	1.6	1.6	.8	2.4	-	-
	2.6	.5	.5	-	2.1	.5	6.5	3.2	8.1	-	2.4	63.0	6.2	4.2	-	-	-	1.6	2.4	.8	1.6	-	-
	2.1	1.0	1.0	.5	1.2	1.3	21.5	4.6	6.8	-	2.3	49.0	7.6	3.0	-	-	-	.7	1.5	1.5	1.5	-	-
	1.3	.9	.4	.4	2.2	-	5.0	3.0	16.0	-	3.0	51.0	11.0	5.0	-	1.0	-	2.0	2.0	-	1.0	-	-
	1.8	.6	.6	.6	1.2	-	25.3	4.5	8.2	.9	.9	33.2	5.4	6.3	.9	1.8	-	4.5	1.8	.9	4.5	-	.9
	2.2	-	-	.6	1.7	-	15.8	3.5	11.4	.9	1.8	43.1	9.6	3.4	-	.9	-	2.6	3.5	1.7	1.7	-	-
	4.5	.7	.7	.7	-	-	3.6	3.6	8.3	1.2	4.8	44.0	10.7	7.0	-	-	-	2.4	7.2	1.2	3.6	1.2	1.2
	3.3	-	.8	-	4.9	-	3.2	4.8	6.4	-	.8	68.0	8.0	2.4	-	-	-	.8	-	2.4	1.6	1.6	-

	1st FRACT.	2nd FRACT.	3rd FRACTION									
	MAGNETITE PYRRHOTITE	ILMENITE	GARNET	ILMENITE	HYPERSTHENE	HORNBLENDE	BIOTITE		HORNBLENDE	EPIDOTE	HYPERSTHENE	
1 G	U	U	70.2	6.0	3.4	17.0	3.4		69.0	8.8	3.9	7
2 G	N	N	57.6	11.1	1.1	12.2	18.0		76.6	5.6	.8	6
4 M	D	D	52.5	6.6	-	37.0	3.3	.6	80.0	9.2	1.7	
5 M	I	I	50.1	9.2	1.4	17.3	22.0		80.0	6.3	1.6	5
4 G	F	F	49.8	4.0	2.0	19.2	25.0		78.0	6.8	.5	5
8 M	F	F	52.0	4.7	2.8	22.5	18.0		78.0	5.5	1.0	4
8 G	E	E	60.1	3.5	1.8	16.0	18.6		73.2	6.8	2.1	6
14 G	R	R	34.0	30.7	9.0	5.1	15.4	5.8	71.3	4.1	1.3	14
12 G	E	E	60.2	6.5	1.3	15.0	17.0		79.4	4.3	2.4	6
17 G	N	N	69.0	7.3	2.2	6.2	15.3		76.6	4.5	2.5	6
15 G	T	T	75.0	1.6	4.5	8.1	10.8		75.2	7.0	4.1	1
19 M	I A T E D	I A T E D	15.0	3.5	1.1	12.1	68.3		71.1	3.3	2.5	4

of abundance, are calcite/dolomite, zircon, opaque minerals, sillimanite, apatite, epidote and augite. The opaque minerals are mainly sulphides, but they also contain cubes of uraninite.

D. Heavy-Mineral Provenances.

Throughout the region described in this thesis, the Indus with its numerous tributaries drains quite a diversity of geological formations. To study the heavy mineral suites supplied by tributaries traversing different rock types, hand-panned concentrates of the alluvium were collected from many tributaries between Kalabagh and Gilgit, a distance of 375 miles. From this research it was hoped to work out the primary abode of the different mineral species in the sands and gravels. The frequency distribution of the heavy minerals in the non-magnetic fraction of these hand-panned concentrates is shown in Table 12.

It is evident from this table that most of the minerals in the alluvium are primary and derive from the crystalline rocks. There is no very apparent change in the character of the assemblages from north to south. The proportion of species supplied by sedimentary and metamorphic rocks is meagre in the upper reaches of the Indus, but downstream between Kalabagh and Kabulgram, where the Indus with its numerous tributaries flows through these formations, the contribution from such rocks is naturally higher.

Hand-panning is far from being a perfect method of making representative heavy-mineral concentrates. The lighter minerals are of course lost in this process but heavy species which are of a flaky habit are also prone to wastage, and finer-grained fractions are liable to suffer elimination. If however one takes care in draining the pan, the heaviest species such as gold and uraninite can be saved almost in their entirety. The author is well acquainted with the hand-panning procedures and numerous trials were made before embarking on this aspect of his investigations. An equal volume of bulk sample was taken in each case and all samples given similar treatment, to obtain comparable results. Despite all precautionary measures, however, there was a conspicuous loss of certain heavy minerals from the finer grades.

This loss is most marked for the fine-grained micas and amphiboles. Except in those samples where mica was initially abundant, this mineral is lost almost entirely from the hand-panned concentrates. Hornblende is not completely eliminated because of its initial greater frequency. Those minerals largely confined to the fine, very fine, or silt sized fractions, such as zircon, apatite, sillimanite, corundum, rutile, monazite, tourmaline, zoisite and clinozoisite suffered a relatively greater loss in panning operations than species like garnet, augite, diopside, hypersthene, calcite/dolomite and opaque species which, although present in part as fines, are more frequent in the coarser fractions. However, since this study is concerned with the quantitative mineral assemblages only in a very approximate fashion, losses in panning do not greatly affect the conclusions.

Before discussing the heavy mineral suites of the tributaries, it is appropriate to consider the geology of their catchment areas. From the sedimentary formation of the Siwalik sandstones and shales only one sample (01) was collected, this being from the Soan river. As discussed earlier, these rocks were deposited in Neogene times by the Indo-Brahma river system and derived most of their material from the Himalayan crystallines. Their heavy mineral suite shows a strong similarity to that of the Indus alluvials. Between points 05 and 015, both small and large tributaries have their sources in phyllites, schists and gneisses with interbedded limestone and quartzite. These tributaries traverse wide tracts of the old river terraces of the Indus before joining the main stream, and part of their load is drawn from these deposits. Between points 016 and 026 the tributaries are smaller, with their sources in metamorphic rocks which are traversed by many acid, basic and ultrabasic sills and dykes. Between points 027 and 048 the tributaries have their sources in granodiorite and granitic rocks, with occasional outcrops of metasediments. There are many intrusions of dolerite, diorite, gabbro, pegmatite, and younger granite. Over all, the most important rivers are (01) Soan river, (04 Kabul river,) (016) Siron river, (049) Gilgit river, and (060) Hunza river. Samples D1, 02 and 03 are from the old river terraces; the first was taken from terrace gravel at a depth of 80 feet in a well, and the latter two are from the Chehl tributary which drains extensive terrace deposits.

In the following discussion, mention is made only of the minerals which occur in substantial amount. The frequencies of the rarer species are given in the Table 12.

The heavy mineral suites of the tributaries which drain the metamorphic terrain and the old river terraces upstream of Attock (02 to 015) are especially rich in opaque minerals, these sometimes forming as much as 90 per cent of the panned concentrate. Next to magnetite, ilmenite fringed by well-developed leucoxene predominates. Garnet is next in abundance. Hornblende is not frequent except in the three tributaries 09, 013, 014. Augite and hypersthene are the common pyroxenes, and epidote is very common. Of the rarer minerals, zircon, calcite/dolomite, sillimanite and rutile are recorded consistently.

The tributaries between points 017 and 026 also flow through metamorphic rocks, but river terraces are not well developed here. Opaque minerals again predominate, but they are less frequent than to the south, and garnet conversely becomes more frequent. Garnetiferous mica schist is well developed here along both banks of the Indus valley, and the major contribution of the garnet to the Indus alluvials downstream comes from this area.

The heavy minerals brought in by the tributaries draining the granodiorite are characterised by opaques and hornblende as the major constituents. The average frequency of hornblende reported in the non-magnetic fractions of hand-panned concentrates is 30 per cent, but as noted above much hornblende was lost during panning. The tenor of garnet is low, except for a few tributaries (028, 031, 043, 044) which traverse bands of garnetiferous schist. In many of these tributaries (032-036, 039-041) the alluvials are significantly rich in hypersthene, and there is a slight increase in the frequency of augite and diopside.

The concentrate from the Soan river (01) is rich in opaque minerals, with magnetite dominant over ilmenite. The ratio of magnetite to the non-magnetic fraction of the hand-panned concentrate is 3:1. Downstream from Attock limestone covers wide stretches of country and many tributaries which could not be sampled bring calcite/dolomite in substantial amount to the alluvials. At Kalabagh most of the opaque minerals come from the Siwalik sandstones and shales.

The heavy residues from the Kabul river (04) show a content of garnet, suggesting that a major part of the drainage area of this tributary is underlain by metamorphic rocks.

The Siron river (016) is another large tributary with metamorphic rocks widespread in its drainage basin. Garnet is the most abundant heavy mineral in its alluvials and forms 90 per cent of the non-magnetic heavies.

The Tangir (037) and Darel (038) rivers flow close to one another, and granodiorites are more widespread in their catchment areas. Opaque minerals are abundant in both cases, and hornblende is the next most frequent mineral. Hypersthene is the commonest pyroxene.

The Gilgit (049) and Hunza (060) rivers are the major tributaries of the Indus in its upper reaches, which are fed by the perpetual ice of the Great Himalayas. The slight differences in the assemblages of the two rivers, as shown in Table 12, may be due to no more than fortuitous sampling.

Hand-panned concentrates were also collected upstream from Kabulgram to study the general spread of heavy minerals in the upper reaches of the Indus. The frequency distribution of the non-magnetic heavy minerals is shown in Table 13.

In the region above Kabulgram the Indus, with its numerous tributaries, flows through crystalline rocks with widespread grano-

TABLE 12. Frequency distribution of non-magnetic heavy minerals in the hand panned concentrates from the tributaries.

ON FIG. 4.	GARNET	HORNBLENDE	AUGITE	DIOPSIDE	HYPERSTHENE	OPAQUE MIN.	OPAQUE CUBE	EPIDOTE	OLIVINE	BROOKITE	ZIRCON	VESUVIANITE	MICAS	DOLOMITE - CALCITE	CASSITERITE	SCHEELITE	APATITE	SILLIMANITE	CORUNDUM	KYANITE	RUTILE	MONAZITE	TOURMALINE	ZOISITE CLINOZOISITE	STAUROLITE	ANATASE	TOPAZ	BARITE
01	5	1	-	-	1	8	P	1	-	-	4	1	-	1	1	-	1	1	1	-	1	1	-	1	1	-	-	-
02	5	3	2	-	1	8-	P	2	1	-	2	-	-	-	1	1	1	-	1	-	1	1	-	-	-	-	-	-
03	6-	3	2	1	1	8-	P	3	-	1	3	-	1	1	1	-	1	2	1	-	1	1	-	1	1	-	-	-
04	7-	2	2	-	1	7+	-2	-	1	3	-	1	2	1	1	1	2	1	-	1	1	1	1	1	1	-	-	-
05	7+	3	2	1	3	7-	-	4	1-	-	-	-	1	1	-	-	-	5	1-	1	1	1-	1	1	-	-	-	-
06	7+	3	2	1	3	7-	-	4	1-	-	1	-	-	1	-	-	-	1	1-	1	1	-	1	-	-	-	-	-
07	6	4	2	1	1	7+	-	5	-	1	1	-	-	1	1	-	1	1	1	1	1	1	-	1	-	-	-	-
08	5	4	2	-	1	8-	P	2	-	1	1	-	1	1	-	-	1	2	1	-	1	-	1	1	-	-	-	-
09	4	6-	1	-	1	8-	-	1	-	-	1	-	1	1	-	-	1	-	-	-	-	1	-	-	-	-	-	-
010	5	2	1	-	1	8	P	3	-	-	1	-	2	3	1	-	1	-	1	-	1	1	1	1	-	1	-	1
011	4	1	1	-	1	8	P	1	-	-	1	-	1	2	1	-	-	-	1	-	1	-	-	-	-	-	-	-
012	2	1	1	-	-	8+	-	1	-	1	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-
013	7-	6-	2	1	1	7	-	4	-	-	1	-	1	1	1	-	-	1	1	1	1	1	1	-	-	-	-	-
014	6	5	1	1	1	8-		4	-	-	1	-	-	3	1	-	1	3	-	-	1	2	1	-	-	1	-	-
015	2	1	1	1	1	8	P	2	-	-	4	-	-	2	-	-	1	2	-	-	1	1	1	-	-	-	-	1
D1	7+	2	1	1	1	7	-	3	-	1	1	-	-	1	-	-	1	1	1	1	1	1	1	1	-	1	-	-
016	8	3	2	1	2	6-	P	2	-	-	2	-	1	-	-	-	1	2	1	-	1	1	2	1	-	-	-	-
017	2	4	2	-	2	8	P	4	-	-	-	-	2	-	1	-	1	4	-	-	1	-	1	1	-	-	-	-
018	7-	2	2	-	1	7+	-	2	-	-	1	-	-	1	1	1	2	2	1	-	2	1	2	1	-	-	-	-
019 /																												

Frequency scale by Evans, Heyman and Majeed ( )

Frequency	Percent
8+	90 to 100
8	75 to 89
8-	60 to 74
7+	45 to 59
7	35 to 44
7-	28 to 34
6+	23 to 27
6	18 to 22
6-	13 to 17
5	7 to 13
4	4 to 6
3	2 to 3
2	1 to 2
1	½ to 1
1-	1 grain only per slide.
P	Present.

TABLE 12. Frequency distribution of non-magnetic heavy minerals in the hand panned concentrates from the tributaries.

ON FIG. 4.	GARNET	HORNBLENDE	AUGITE	DIOPSIDE	HYPERSTHENE	OPAQUE MIN.	OPAQUE CUBE	EPIDOTE	OLIVINE	BROOKITE	ZIRCON	VESUVIANITE	MICAS	DOLOMITE - CALCITE	CASSITERITE	SCHEELITE	APATITE	SILLIMANITE	CORUNDUM	KYANITE	RUTILE	MONAZITE	TOURMALINE	ZOISITE CLINOZOISITE	STAUROLITE	ANATASE	TOPAZ	BARITE
019	8-	2	1	1	1	6+	-	2	-	-	1	-	-	-	1	1	1	1	-	1	1	-	1	-	-	-	1	-
020	2	8	2	1	1	3	-	3	-	1	1	-	3	-	1	1	1	2	1	-	1	1	1	-	-	-	-	-
021	7+	6	2	1	2	5	-	3	-	-	-	-	-	2	1	1	1	2	-	-	1	-	-	1	-	-	-	-
022	7+	6	2	1	1	7	P	3	1-	-	1	1	-	2	1	1	1	2	1	1	1	-	-	1	-	-	-	1
023	7	5	3	2	2	6+	-	4	-	1	1	-	-	1	1	-	1	2	1	-	1	1	1	1	-	-	-	-
024	2	7+	2	1	1	7-	-	3	-	1	1	-	2	1	-	-	1	1	1	-	-	-	-	-	-	-	-	-
025	8	3	1	-	1	5	P	2	-	-	-	-	-	-	1	-	1	2	-	-	1	-	-	-	-	-	-	-
026	8-	4	2	-	1	6+	P	4	-	-	1	-	-	-	1	-	-	2	-	-	1	-	-	-	-	-	-	-
027	8	1	1	-	1	5	-	2	-	-	1	-	-	-	-	-	1	1	1	-	1	-	-	-	-	-	-	-
028	7-	7	2	1	2	6+	-	4	-	1	2	-	-	-	2	1	2	2	1	-	1	1	-	1	-	-	1	-
029	4	8-	2	2	2	5	-	4	-	-	2	-	-	-	2	-	-	2	1	-	1	-	-	1	-	1	-	-
030	1	7+	2	1	3	6+	-	3	-	1	1	-	2	-	2	-	1	1	1	-	1	2	-	1	-	-	1	-
031	6	7-	2	1	2	7	-	5	-	-	1	-	-	-	-	-	1	2	-	-	1	1	-	-	-	-	-	-
032	2	6	2	1	7	6+	-	3	-	-	1	-	-	-	-	-	1	1	-	-	2	-	-	-	-	-	-	-
033	2	7+	2	1	6+	7	-	3	-	-	1	-	-	-	1	-	-	2	-	-	-	-	-	2	-	-	1	-
034	1	7+	2	1	6+	6	P	3	-	-	2	-	-	-	-	-	1	2	-	-	1	-	1	2	-	-	-	-
035	2	5	3	1	7+	7	-	3	1	-	-	-	-	-	1	-	-	2	-	-	1	1	-	-	-	1	1	-
036	1	3	2	1	7+	7	-	2	1	-	1	-	-	-	2	-	2	-	1	-	-	1	-	-	-	-	-	-
037	2	7	2	2	3	7+	-	3	-	-	2	-	-	-	2	-	-	-	-	-	1	1	-	-	-	-	-	-
038	3	5	2	1	4	8-	-	3	-	-	2	-	-	2	1	-	1	-	-	-	1	1	-	1	-	-	-	-
039	1	5	1	1	8-	6+	-	2	-	-	-	-	-	-	1	-	1	1	-	-	-	-	-	-	-	-	-	-

TABLE 12. Frequency distribution of non-magnetic heavy minerals in the hand panned concentrates from the tributaries.

ON FIG. 4.	GARNET	HORNBLENDE	AUGITE	DIOPSIDE	HYPERSTHENE	OPAQUE MIN.	OPAQUE CUBE	EPIDOTE	OLIVINE	BROOKITE	ZIRCON	VESUVIANITE	MICAS	DOLOMITE - CALCITE	CASSITERITE	SCHEELITE	APATITE	SILLIMANITE	CORUNDUM	KYANITE	RUTILE	MONAZITE	TOURMALINE	ZOISITE CLINOZOISITE	STAUROLITE	ANATASE	TOPAZ	BARITE
040	1	3	4	3	8	3	-	3	-	-	-	-	-	-	2	-	-	-	1	-	-	1	-	-	-	1	-	-
041	3	5	3	2	6-	7+		4	-	1	1	-	-	-	2	2	2	2	1	-	1	1	-	-	-	-	1	-
042	3	2	3	2	4	8	-	4	-	-	3	-	-	-	2	-	1	2	1	-	1	1	-	1	-	-	1	-
043	7	6+	2	1	2	6	-	4	-	1	1	-	-	-	2	-	2	2	1	-	1	-	-	-	-	1	-	-
044	7+	3	2	2	1	6	-	4	-	-	4	-	-	-	1	-	3	4	-	-	2	-	-	-	-	-	-	-
045	5	6+	2	1	2	7	P	4	-	-	1	1	1	-	2	-	2	1	-	-	1	-	1	-	-	-	-	-
046	4	5	3	2	2	7-		4	1	-	5	-	4	1	1	-	3	4	-	-	2	2	1	-	-	1	1	-
047	1	3	2	2	1	8+		2	-	-	1	1	-	-	1	-	1	1	-	-	2	-	-	-	-	-	-	-
048	4	7+	3	2	2	7-	-	4	1	-	3	-	-	-	2	-	2	3	-	-	1	-	-	-	-	-	-	-
058	4	3	2	1	1	8	-	2	-	-	5	-	-	1	1	-	1	2	-	-	1	1	1	-	-	1	-	-
053	2	8-	1	2	2	6-		3	-	-	2	-	2	2	1	-	1	2	-	-	1	1	1	-	-	-	1	-
060	5	4	1	1	1	7	P	3	-	1	3	-	3	2	1	-	2	2	-	-	1	-	1	1	-	-	1	-

TABLE 13. **Frequency Distribution Upstream from Kabulgram Per Cent of Non-Magnetic Heavy Minerals in Hand-Panned Concentrate.**

ON FIG. 4.	APATITE	ANATASE	AUGITE	BARITE	BROOKITE	CASSITERITE	CALCITE - DOLOMITE	CORUNDUM	DIOPSIDE	EPIDOTE	GARNET	HORNBLENDE	HYPERSTHENE	KYANITE	MICAS	MONAZITE	OPAQUE MINERALS	OPAQUE CUBE	OLIVINE	RUTILE	SCHEELITE	SILLIMANITE	STAUROLITE	TOURMALINE	TOPAZ	UNIDENTIFIED GRAINS	VESUVIANITE	ZIRCON	ZOISITE CLINOZOISITE
1P	.7	-	.7	-	.7	-	2.1	-	.7	2.1	41.0	3.4	.7	-	.7	.7	36.2	2.1	-	.7	-	2.1	-	-	-	2.7	-	2.7	-
2P	-	-	2.4	-	.6	.6	-	-	-	1.8	31.3	3.0	.6	-	3.2	-	44.0	2.4	-	.6	-	-	-	-	-	3.0	-	6.5	-
3P	2.2	.5	2.2	-	1.7	1.7	-	-	.9	2.6	27.1	8.7	1.3	-	.5	-	35.0	1.7	-	.8	-	1.7	-	.8	-	.5	-	10.1	-
4P	.5	.5	2.1	-	1.5	-	6.1	.5	1.0	2.6	31.1	7.8	2.6	-	-	-	35.0	-	-	.5	-	1.0	-	-	-	3.1	-	4.1	-
5P	.6	-	1.7	-	.6	.6	.4	-	1.0	4.0	25.3	5.6	.6	-	-	-	21.0	2.0	-	.4	-	1.0	.6	-	-	1.6	-	3.0	-
6P	.7	-	4.5	-	-	1.3	1.9	.7	1.3	6.5	34.5	3.9	1.3	-	-	-	35.5	1.5	-	1.3	-	-	-	-	-	3.2	-	1.9	-
7P	1.0	-	3.5	-	1.0	.5	-	-	2.6	4.1	31.0	10.1	3.1	-	-	-	37.6	-	-	1.0	-	1.0	-	-	-	2.0	-	1.5	-
8P	.8	-	3.7	-	-	.8	4.4	-	2.2	.8	29.0	8.9	1.5	-	-	-	40.0	-	-	-	-	1.5	.5	-	.8	2.9	-	2.2	-
9P	-	-	3.2	-	-	-	5.6	-	3.2	4.0	32.7	5.6	3.2	-	-	.8	26.5	-	-	.8	-	1.6	-	.6	-	3.2	1.6	6.4	-
10P	1.8	-	2.8	-	1.2	.4	1.2	.4	2.5	3.4	25.0	4.3	1.5	-	.6	.4	40.5	1.2	-	.7	-	1.2	-	-	-	1.4	-	8.9	.6
11P	.9	1.8	4.0	-	1.3	-	4.0	-	1.8	4.0	21.0	5.1	1.8	-	-	-	30.7	2.7	-	.5	-	3.5	-	1.0	-	1.8	-	14.1	-
12P	-	-	2.6	-	1.7	-	1.7	-	1.7	3.1	32.9	4.3	1.3	-	-	-	30.0	3.0	-	1.3	-	1.3	-	-	-	2.1	-	13.0	-
13P	-	.4	2.3	-	.4	-	4.5	-	1.7	2.6	25.6	9.7	.8	-	.4	.8	39.1	1.7	-	.4	-	.8	-	-	-	1.4	-	7.4	-
14P	-	-	2.7	-	.3	-	1.3	-	1.6	2.2	24.0	4.3	1.4	-	-	.7	49.0	1.9	-	1.6	-	1.3	-	-	-	1.6	-	26.1	-
15P	.8	.4	3.9	-	1.4	.4	7.9	.4	1.8	6.2	28.0	11.8	1.8	-	.5	-	21.5	-	-	2.2	-	2.2	-	-	.4	2.2	.5	5.7	-
16P	.9	-	1.6	-	1.9	-	2.5	.4	0.7	3.1	27.5	5.7	.9	-	.8	.6	37.2	.4	-	2.5	-	2.8	.4	-	-	.4	.4	9.3	-

diorites, and one would therefore expect hornblende to be present in the heavy fractions to a greater extent than recorded above. As explained previously, this deficiency of hornblende is due to the imperfections of hand panning.

It will be seen that the general suite of heavy minerals recorded from the alluvials above Kabulgram is essentially the same as that recorded downstream to Kalabagh. There are local variations in the assemblages reflecting local variations in bed-rock geology, but throughout the 375 miles traversed in this investigation there are no really spectacular changes in the heavy-mineral composition of the Indus alluvium.

E. Microscopic analysis of sized fraction of bromoform-separates.

Grain size analyses are made on 7 samples of non-magnetic bromoform-separates from seven localities between Kalabagh and Kabulgram. The samples selected for this study are 1G (Kalabagh), 1M (Khushalgarh), 2G (Gariala), 5M (Attock), 9G (Qasipur), 17G (Amb) and 21G (Kabulgram).

For size analysis, sieves of 16, 30, 60, 120 and 200 mesh are employed which are adjusted according to Wentworth's grade scale to very coarse, coarse, medium, fine, very fine and silt size fractions. Weight percentage of each size fraction is calculated. The results of size analysis of non-magnetic fraction of bromoform-separates are plotted in the form of histograms. The size analysis of magnetite which is conducted on 6 samples from Amb, Qasipur, Attock and Kalabagh, is discussed separately.

To study the general characteristics of mineral assemblages in various size fractions, each mineral slide has been described elaborately. First the minerals are identified and mention is specifically made of those minerals which occur in abundance. The frequency distribution of minerals assembled in various size fractions of some of the samples from the localities mentioned above are tabulated. In the description average size and shape, physical features and optics of the more prominent mineral grains are included.

The grain form of the non-magnetic heavy minerals in various size fractions is also studied. For this study it was necessary to select those minerals which are present in all the fractions. Garnet, hornblende, biotite and opaque minerals are the ones which dominate each size fraction and combined together constitute over 90 per cent by frequency in most of the fractions. Hence these minerals are studied and frequency distribution of grain forms in various fractions from different localities are shown in tabulated results.

To study the grain form of these minerals, the grains are projected on white paper. The outlines of several grains in each sized fraction are sketched. Subsequent studies of these sketches are made by measuring the radii of the corners of the grains and the radius of the maximum inscribed circle, and by applying the formula $P = (ri/R)/N$, where P is the roundness, ri is the radii of the corners of the grain, R the radius of the maximum inscribed circle, and N the number of corners. Thus the numerical values on roundness of each grain is calculated, which according to Pettijohn (20) is adjusted as follows: for an angular grain the value is 0 to .15, subangular .16 to .25, subrounded .26 to .4, rounded 1.41 to .6 and well rounded .61 to 1.0. The frequency distribution of the grain form in various size fractions from different localities is given in Table 13. A supplementary study of the grain form is also made by projecting the grains of garnet, hornblende, biotite and opaque minerals in coarse, medium, fine, very fine and silt size fractions to compare the roundness and angularity of the grains in various size fractions.

A cursory examination is also made of the decomposition of the grains in various size fractions. The minerals which are more decomposed are specifically mentioned and their presence in various fractions is visually estimated.

Description of the slides.

1G (Kalabagh).

(Coarse fraction)

Min. identified. Biotite, "unidentified grains", hornblende, garnet, epidote and hypersthene. Biotite constitutes 40 per cent by frequency.

Description. Subrounded to rounded grains are common. A few well rounded grains of biotite are also cited. Dark brown colour in biotite is common. The "unidentified grains" occur in rounded to well rounded form and among them muscovite and augite predominate. Rounded grains of hornblende of dark green colour are present. Except for two grains, all the rest show varying degree of decomposition which affect their colour pattern. A grain of hypersthene is also cited which is partially covered with a secondary product. Opaque cleavage cracks are very conspicuous. Calcite/dolomite is also present, most of the grains occurring in rounded form and appearing cloudy.

(Medium fraction)

Min. identified. Garnet, "unidentified grains", hornblende, augite, diopside, hypersthene, biotite, epidote. Garnet and ferro-magnesian minerals constitute 23 and 27 per cent by frequency respectively.

Description. Subrounded grains are most common. Light and dark green varieties of hornblende abound. The most common form in garnet is subrounded, but a few subangular and well rounded grains are also cited. In the latter form, deep coloured garnet is the most common. Most of the garnet grains show plain faces; the few inclusions noted are opaque particles, liquid and gas-filled cavities. One grain of light coloured garnet is marked with numerous hypersthene inclusions. Common hornblende of dark green and brownish green varieties are present. Subangular to subrounded forms among hornblende are commonly noted, and the fringe of most of the grains show distorted features. Hypersthene, augite and diopside occur in increasing order of abundance. Two fresh euhedral crystals of hypersthene are marked in this slide, appearing to have their source nearby. Another grain of this mineral is located which, unlike the previous one, is completely distorted and has a "fibrous look". Augite and diopside occur in subangular to subrounded prismatic grains. Most of them are of hazy appearance.

(Fine fraction)

Min. identified. Garnet, hornblende, augite, diopside, hypersthene, "unidentified grains", opaque minerals, epidote, sillimanite, topaz, biotite, zircon, kyanite, cassiterite, olivine ?; garnet and ferromagnesian minerals constitute 37 and 23 per cent respectively.

Description. Subangular to subrounded grains are common.

Among the garnets, light and dark varieties are present, the former being abundant. Subangular grains in light coloured garnet are very common, while a few angular grains are also recorded. In the dark brown garnets, subrounded grains are most frequently met with. Most of the grains show plain faces. A dark green variety of hornblende abounds. Most of the grains appear fresh; a few show wear and tear more pronounced around the fringe of the grain. Augite and diopside are very fresh and occur in euhedral to subhedral form. Hypersthene occurs in subrounded tabular grains; Schiller's type inclusions are very prominent in most of the grains. Among the other minerals quite a number of epidotes, both in colourless and light yellowish green grains, are met with. A few euhedral to subhedral grains of a colourless variety are also cited. The most usual form of epidote grains is subrounded. Two anhedral grains of olivine are tentatively identified. These are colourless, show hazy appearance due to decomposition, contain numerous cleavage cracks, are biaxial and yield straight extinction. One grain each of zircon and opaque cubes are also identified.

(Very fine fraction).

Min. identified. Garnet, opaque minerals, hornblende, zircon, epidote, rutile, hypersthene, zoisite, cassiterite, augite, biotite, sillimanite, diopside, monazite, and apatite. Opaque minerals and garnet occur in abundance and constitute 31 and 29 per cent by frequency.

Description. Subrounded grains are most common. The most usual form among the opaque minerals is subrounded. Euhedral crystal of opaque cubes are frequently met with; most of these cubes are identified as pyrites. Light brown garnet is dominant and most of the grains are subangular to subrounded. A few rounded to well rounded grains are also cited among garnet. Hornblende is not as common as recorded in the previous slides; a few grains present have a fresher look. Augite and diopside occur in subrounded prismatic form. These grains also have a fresher look than their counterparts in the previous slides. Among the other minerals, zircon is the most common, usually occurring in subhedral grains. A colourless variety of zircon abounds in this slide. Rounded to well rounded grains of monazite are also frequently recorded.

(Silt size)

<u>Min. identified.</u> Opaque minerals, zircon, hornblende, epidote, corundum, sillimanite, garnet, augite, monazite and biotite. Opaque minerals are the major constituent, and garnet is placed second in order of abundance. Their relative frequencies are 30 and 28 per cent respectively.

<u>Description.</u> Subangular to subrounded grains are most frequently met with. Among the euhedral grains those of zircon and opaque cubes are most common. Rounded to well rounded grains of epidote, sillimanite, monazite and a few garnet are recorded. Opaque minerals with jagged and frayed borders are common.

1M (Khushalgarh)

(Coarse fraction).

Min. identified. Biotite, hornblende, garnet, calcite/dolomite, augite, "unidentified grains"; biotite constitutes over 95 per cent in the bulk.

Description. Angular to subangular grains of biotite are frequent in occurrence. Most of the biotite grains show worn features. Biotite grains with inclusions are few, the most notable ones being those of liquid and gas bubbles and zircon. Some of the zircon crystals are surrounded by "pleochroic halos". Dark green and yellowish green varieties are those most usually recorded. Most of the hornblende appears in decomposed form. A light coloured variety of garnet is present as subrounded grains.

(Medium fraction).

Min. identified. Biotite, hornblende, augite, diopside, hyperstheme, garnet, epidote, calcite/dolomite, rutile, opaque minerals, "unidentified grains". Biotite and ferromagnesian minerals occur in abundance and their relative frequencies are 68 and 22 per cent respectively.

Description. The most common form of the grains in this slide is subangular to subrounded, the latter type being dominant. The biotite and hornblende grains show more wear and tear which is most conspicuous around the fringe of the grains. The colour pattern in some of the hornblende grains is completely deteriorated, giving a "fibrous look". Among the other minerals epidote is dominant.

Subrounded to rounded grains of epidote are common.

(Fine fraction.

<u>Min. identified.</u> Hornblende, augite, diopside, hypersthene, garnet, biotite, opaque minerals, epidote, calcite/dolomite, apatite, sillimanite, corundum, "unidentified grains", rutile, zircon. The relative frequencies of ferromagnesian minerals and biotite are 31 and 19 per cent respectively.

<u>Description.</u> Subangular to subrounded grains are common. A few rounded to well rounded grains of epidote, sillimanite, and garnet are also recorded. The minerals which show varying degrees of decomposition, mostly due to abrasion, are opaque minerals, biotite and calcite/dolomite.

(Very fine fraction).

<u>Min. identified.</u> Hornblende, augite, diopside, hypersthene, garnet, apatite, monazite, biotite, opaque minerals, rutile, zircon, calcite/dolomite. Ferromagnesian and opaque minerals are dominant. Their relative frequencies are 31 and 19 per cent respectively.

<u>Description.</u> Subangular to subrounded grains are very common. A few rounded to well rounded grains are also present and minerals which occur in this form are zircon, epidote, garnet, monazite and sillimanite. Submicroscopic grains are very common.

<u>20 (Gariala).</u>

(Coarse fraction).

<u>Min. identified.</u> "Unidentified grains", biotite, muscovite, hornblende, augite, garnet, epidote; "unidentified grains" constitute over 80 per cent by frequency in the bulk.

<u>Description.</u> In this slide subrounded to rounded grains of "unidentified minerals" are very dominant. Almost all of them are completely decomposed, and most of the grains are unidentifiable. A few grains which have got clear borders are tentatively identified; the majority are muscovite, while augite and epidote come next in order of abundance. A few grains of garnet of a dark brown variety in subrounded to rounded form are recorded. The garnet grains are pitted and grooved. Subrounded to rounded grains of hornblende of a dark green variety in decomposed form are present. The grains have a fibrous appearance and yield anomalous interference colours. The biotite grains show jagged and frayed borders.

(Medium fraction).

<u>Min. identified.</u> Hornblende, garnet, biotite, "unidentified grains", epidote, hypersthene, calcite/dolomite, sillimanite, opaque minerals. "Unidentified grains" occur in abundance and garnet and ferromagnesian minerals are placed second and third in order of abundance. Their relative frequencies are 21, 19 and 17 per cent respectively.

Description. Most of the grains in this slide are subangular to subrounded. A few well rounded grains of epidote, garnet and hornblende are also recorded. Besides the "unidentified grains", biotite and hornblende show much distortion, and their colour pattern in some of the grains is also affected. Both dark and light brown varieties of garnet are present. Subrounded to rounded grains of garnet are common.

(Fine fraction).

Min. identified. Hornblende, biotite, garnet, calcite/dolomite, opaque minerals, hypersthene, augite, diopside, sillimanite, epidote, tourmaline and zircon. Garnet occurs in abundance and opaque minerals come second in order of abundance. The relative frequencies of these minerals are 33 and 21 per cent respectively.

Description. Colourless as well as deep brown coloured varieties of garnet are recorded. The colourless grains are angular to subangular and appear to have their source nearby. The coloured variety is subrounded or rounded. A few euhedral grains of light brown coloured garnet are also present. Most of the opaque minerals are subrounded, while a few sporadic rounded to well rounded grains are also cited. Irregular outlines among opaque minerals are conspicuous. As usual, biotite and hornblende show most decomposed grains. Light brown biotite and deep green hornblende are very common. Hypersthene occurs in tabular subangular to subrounded grains, most of which appear fresh. Calcite and dolomite are quite frequently met with and subangular to subrounded grains are quite common. The freshness of the grains is suggestive of their nearby source.

(Very fine fraction).

Min. identified. Hornblende, opaque minerals, biotite, garnet, zircon, monazite, rutile, epidote, tourmaline, calcite, sillimanite, apatite, dolomite, zoisite, augite and hyperethene. Ferromagnesian minerals occur in abundance and constitute 31 per cent in the bulk. Next to these, opaque minerals and garnet are the dominant minerals and their relative frequencies are 18 and 11 per cent respectively.

Description. Subrounded to rounded grains are most common. Among the rounded to well-rounded grains monasite, garnet, epidote, sillimanite, and a few opaque minerals are frequently recorded. A few euhedral grains of garnet, zircon and apatite occur.

(Silt size).

Min. identified. Hornblende, zircon, sillimanite, opaque minerals, biotite, garnet, monazite, rutile, diopside, augite, cassiterite, calcite/dolomite, apatite, tourmaline, epidote. Zircon occurs as a major constituent, nearly 18 per cent. Submicroscopic grains abound in this slide.

Description. Zircon, sillimanite and apatite are most frequently recorded. Zircon crystals with faces well preserved, are few in number. In this slide five types of zircon are distinguished:

(1). colourless zircon,

(2). coloured varieties of zircon,

(3). ovoid zircon,

(4). zircon crystals which are denser and appear dark grey or black,

(5). fragmental zircon.

Most of the well preserved crystals of zircon are colourless. Inclusions of apatite, a green mineral which may be chlorite, black spots, and gas or liquid filled cavities are most common. A few grains of sillimanite and apatite appear fresh. Opaque cubes which appear fresh, are present in this slide. Ilmenite with well developed leucoxene around the fringes of the grains is most common among the opaque group.

5M (Attock).

(Medium fraction).

Min. identified. Garnet, hornblende, hypersthene, augite, diopside, biotite, epidote, "unidentified grains", opaque minerals, cassiterite, calcite/dolomite. Garnet and ferromagnesian minerals are dominant; their relative frequencies are 33 per cent and 37 per cent respectively.

Description. A coloured variety of garnet is more frequent, light brown colour being prevalent. The grains are commonly subangular to subrounded, while angular grains are rarely recorded.

Most of the hypersthene grains in this slide appear fresh, subangular tabular grains being most common. Hornblende is of dark green and brownish green colours. Most of the hornblendes show braided features around the fringe of the grains. A few completely decomposed grains of hornblende are also located, in which the colour pattern has been affected giving a fibrous look. Augite and diopside are present in subangular to subrounded prismatic form. Several of these minerals show braided features around their borders. Among the rounded to well rounded grains, garnet, epidote, "unidentified grains", cassiterite, and a few highly decomposed grains of hornblende are prominent.

(Fine fraction).

Min. identified. Garnet, opaque minerals, hornblende, hypersthene, augite, diopside, biotite, tourmaline, calcite/dolomite, "unidentified grains", rutile, epidote and sillimanite. Garnet is the most abundant mineral, with ferromagnesian minerals next in order of abundance. Their relative frequencies are 42 and 33 per cent respectively.

Description. Subangular to subrounded grains are most common. A few rounded to well rounded grains are also recorded. A light brown variety of garnet abounds in this slide. Garnet grains are commonly subangular to subrounded in form. Garnet grains with much worn-out features are also recorded. Inclusions are not common; those present in sporadic grains are of liquid and gas filled cavities, zircon and apatite. Most of the grains of common hornblende occur in subangular form, and appear fresh. Hypersthene grains as usual are fresh and occur in subangular to subrounded tabular form. Among the opaque minerals, ilmenite with well developed leucoxene shows more wear and tear, which is well pronounced around the fringe of the grains. The number of rounded to well rounded grains is greater than in the previous slide. Cassiterite, epidote, garnet and sillimanite, are the common minerals which usually occur in this form.

(Very fine).

Min. identified. Garnet, opaque minerals, hornblende, augite, diopside, hypersthene, biotite, rutile, corundum, calcite/dolomite, epidote, sillimanite, apatite, zoisite and zircon. Garnet and opaque minerals occur in abundance. Their relative frequencies are 31 and 28 per cent respectively.

Description. Subangular grains are very common. Among the garnet grains, colourless and light coloured varieties are most usually met with. Opaque minerals show more wear and tear by abrasion. A few opaque cubes are also recorded which show polished and smooth edges. Most of the cubes are identified as pyrites. Dark green and brownish green hornblende are common, which occur in angular to subangular form. Most of the grains appear fresh. Hypersthene gives a fresher look than augite and diopside. Euhedral grains of garnet, zircon and apatite are recorded.

(Silt size).

Min. identified. Opaque minerals, garnet, hornblende, hypersthene, augite, diopside, zircon, epidote, sillimanite, apatite, biotite, monazite, tourmaline and rutile.

Description. Subangular to subrounded grains are very common. Several rounded to well rounded grains are also recorded and the minerals which constitute these grains are opaque minerals, garnet, epidote, apatite, zircon, sillimanite and monazite. Euhedral grains of opaque cubes and zircon also occur.

9G (Gazipur)

(Coarse fraction).

Min. identified. Garnet, hornblende, augite, biotite, epidote, "unidentified grains", and sillimanite. Garnet occurs in abundance and constitutes 31 per cent in the bulk.

Description. Subrounded to rounded grains are very common. The coloured variety of garnet with pitted and grooved faces is more often seen. Most of the garnet grains are rounded to well rounded. Inclusions are very common and some of the garnet grains show brown staining. A deep green variety of common hornblende is more frequent in occurrence. Most of the hornblendes show scars of abrasion which affected the fringe of the grains. Deep brown biotite in subrounded to rounded grains is common. The colour in most of the grains is deep in the centre and becomes lighter towards the borders. Most of the biotite grains show frayed borders. The few well marked inclusions are "pleochroic haloes" and zircon.

(Medium fraction).

Min. identified. Garnet, biotite, hornblende, calcite/dolomite, epidote, augite, opaque minerals, "unidentified grains", hypersthene. Garnet and biotite combined together constitute 31 per cent. The relative frequencies of ferromagnesian minerals and "unidentified grains" are 19 and 24 per cent respectively.

Description. Subangular to subrounded grains are common. A few rounded to well rounded grains are also recorded. A dark brown variety of garnet is most prevalent; it has been discussed in the previous slide. A few light brown coloured garnets are also located which are more angular in form with very few inclusions. The light coloured garnet appears to have its source nearby. Dark green and yellowish green are the common colours in the hornblende. The number of fresh and intact grains of hornblende is quite high in this slide. Hypersthene is present in subrounded tabular grains and has a fresher appearance than the augite. Schiller's type inclusions are prominent in most of the grains. Colourless to pale yellowish grains of augite with irregular borders are encountered. Most of the grains appear partially cloudy due to decomposition. Epidote is quite common among the other minerals, usually in subrounded form. A few grains of epidote give a cloudy appearance.

(Fine fraction).

Min. identified. Garnet, hornblende, hypersthene, biotite, opaque minerals, tourmaline, zircon, calcite/dolomite, epidote, apatite, augite, rutile, cassiterite, "unidentified grains". The ferromagnesian minerals and garnet occur in abundance with relative frequencies of 13 and 19 per cent respectively.

Description. Subangular to subrounded grains are dominant. A few grains of epidote, sillimanite, garnet and cassiterite are recorded in rounded to well rounded form. Dark green and brownish green varieties of hornblende are prevalent; the latter appear to be more prone to decomposition. Hypersthene occurs as subrounded tabular grains, most of them appearing fresh. Augite is rare in this slide: the few grains recorded are lath-shaped and prismatic, with distorted borders. Light brown garnet is more frequent and occurs in subrounded grains. A few euhedral crystals of garnet are also recorded. Light brown biotite is common; it occurs in subangular to subrounded grains with frayed borders. Inclusions are recorded in sporadic grains. Subrounded grains of epidote are frequent. Colourless as well as light yellowish coloured epidotes are present, the former being dominant. The colourless variety of epidote usually exhibits plain surfaces with sporadic inclusions. Light yellowish epidote contains swarms of inclusions, gas and liquid-filled cavities and zircon being the most common. One well-preserved opaque cube is also present.

(Very fine fraction).

Min. identified. Garnet, hornblende, biotite, opaque minerals, zircon, monazite, epidote, hypersthene, augite, zoisite, calcite/dolomite, tourmaline, apatite, and sillimanite. Ferromagnesian and opaque minerals occur as major constituents with their relative frequencies of 32 and 21 per cent respectively.

Description. Subangular to subrounded grains are dominant. A few grains of apatite, biotite, and garnet are found to occur in rounded to well rounded form. A grain of monazite occurs in well rounded form. The grain under examination is .075 x .06 mm. and gives a light yellow tinge. Well marked inclusions are gas and liquid filled cavities, and a long thin crystal of apatite. This grain shows microfracture developed around a corner, which divides the crystal in two parts. Tourmaline occurs as a long subhedral prismatic crystal with an unevenly fractured end. Its colour is light yellowish brown and it contains numerous inclusions; among those identified are opaque particles, zircon, apatite and anatase (?).

(Silt size).

Min. identified. Opaque minerals, hornblende, zircon, sillimanite, monazite, biotite, epidote, apatite, rutile, hypersthene, zoisite, augite. Ferromagnesian and opaque minerals abound in this slide and their frequency percentages are 21 and 19 respectively.

Description. Subangular to subrounded grains are dominant. Among the rounded to well rounded grains, monasite, sillimanite, epidote, and opaque minerals occur, the former two being more frequent. A few grains of zircon, apatite, garnet and opaque cubes occur as euhedral crystals.

17G (Amb).

(Coarse fraction).

Min. identified. Biotite, "unidentified grains", hornblende, hypersthene, calcite/dolomite, epidote. In this slide "unidentified grains" predominate, constituting 61 per cent by frequency. Biotite and ferromagnesian minerals are next in order of abundance, their relative frequencies being 12 and 10 per cent respectively.

Description. Subrounded to rounded grains are common. Quite a number of well rounded grains are found in this slide. Rounded to well rounded grains of dark brown garnet with pitted and grooved surfaces are recorded. Hornblende is of dark green variety and most of the grains are distorted. Dark brown biotite also shows the most wear and tear around the fringe of the grains. A grain of hypersthene in well rounded form is cited. On the whole, almost all the grains show evidence of decomposition mostly due to abrasion; the most affected minerals are hornblende and biotite.

(Medium fraction).

Min. identified. Garnet, hornblende, augite, diopside, "unidentified grains", epidote, calcite/dolomite and hypersthene. Ferromagnesian minerals and "unidentified grains" occur in abundance; their relative frequencies are 28 and 20 per cent respectively.

Description. Subangular to subrounded grains are dominant in this slide. Dark green hornblende is the most common of the ferromagnesian minerals. It usually has a fresher look and the borders of the grains in most cases are found to be intact, as is also the case with the augite and diopside. Hypersthene occurs in subrounded to rounded grains. A few badly decomposed grains of hypersthene are also recorded, usually covered with a secondary decomposition product. Among the garnet grains a light coloured variety is common. The garnet grains are usually subangular and most of them are devoid of inclusions. The biotite is of a dark brown variety and sporadic grains show inclusions of zircon and "pleochroic halos". Calcite and dolomite are frequently recorded in this slide; the majority of the grains appear fresh.

(Fine fraction).

Min. identified. Garnet, hornblende, augite, diopside, hypersthene, biotite, tourmaline, epidote, rutile, opaque minerals, calcite/dolomite, cassiterite, sillimanite, apatite, "unidentified grains" and zoisite. Garnet and ferromagnesian minerals occur in abundance and their frequency percentages are 40 and 28 respectively.

Description. Colourless and light to deep brown garnets are present. Subangular grains among garnet are most common; the colourless variety usually occurs in this form. Deep brown garnet usually contains spots of brown staining and pitted and grooved features are common. Its subrounded to rounded form suggests that it is derived from a distant source. Among hornblende, dark green and brownish green varieties predominate. The grains of the latter show greater wear and tear around the fringe. Augite and diopside occur as subangular to subrounded prismatic grains; the majority are fresh. Irregular and sharp borders are common in most of these grains. Among the opaque minerals, ilmenite predominates and is easily recognised by the development of leucoxene around the fringe. Sharp angular as well as rounded grains are recorded among the opaque minerals. Jagged borders are noted in the few grains.

(Very fine fraction).

Min. identified. Opaque minerals, hornblende, hypersthene, epidote, zircon, garnet, biotite, calcite/dolomite, apatite, sillimanite, rutile, monazite, corundum and zoisite. Opaque minerals and garnet occur in abundance with relative frequencies of 30 and 21 per cent respectively.

<u>Description.</u> Subangular to subrounded grains are dominant over this slide. Euhedral grains of zircon, opaque cubes, calcite and dolomite are recorded. A number of rounded to well rounded grains of monazite, garnet and epidote occur.

(Silt size fraction).

<u>Min. identified.</u> Hornblende, augite, opaque minerals, sillimanite, zircon, monazite, garnet, tourmaline, hypersthene, calcite/dolomite, biotite. Opaque and ferromagnesian minerals are the major constituents; their relative frequencies are 20 and 29 per cent respectively.

<u>Description.</u> Angular to subangular grains are common in this slide; the former being dominant. Among the euhedral grains a few crystals of zircon, calcite/dolomite and opaque cubes are prominent. Opaque minerals are most often seen in angular form, but rounded grains with braided corners are not uncommon. Angular grains of hornblende of light and dark green colour are present. The hornblende grains appear fresh; the fringes of the grains are usually found to be intact.

<u>21G (Kabulgram)</u>.

(Coarse fraction).

<u>Min. identified.</u> "Unidentified grains", biotite, hornblende, hypersthene, epidote, augite, diopside, garnet and calcite/dolomite.

"Unidentified grains" occur in abundance and constitute 47 per cent by frequency. Ferromagnesians are the next abundant minerals and their frequency is 21 per cent.

<u>Description.</u> Subrounded grains are more frequently recorded, but rounded to well rounded grains are not uncommon. Decomposed grains of muscovite predominate among "unidentified grains". Other minerals tentatively identified in this group are olivine and pyroxene. Dark green and brownish green are the common colours of the hornblendes, both varieties show varying degrees of decomposition which in some of the grains has also affected the colour pattern. Two grains of hypersthene are identified: one in subangular tabular form and the other as a subrounded lath-like grain. The former is partially decomposed, with secondary products along the cleavage cracks. Schiller's inclusions are well marked in both of these grains. The augite is of a light yellowish green colour; subangular tabular grains are common. Most of the grains are hazy in appearance. A grain of diopside has also been recognised; this is fresher than the augite. A deep brown variety of garnet is recorded; subrounded to rounded grains are common. Pitted and grooved features are conspicuous in most of the garnet grains. Subrounded to rounded grains of dark brown biotite are present; most of the grains show braided features around their fringes.

(Medium fraction).

Min. identified. Garnet, hornblende, "unidentified grains", epidote, biotite, hypersthene, calcite/dolomite, augite, opaque minerals. Garnet occurs in abundance and constitutes 30 per cent by frequency, whereas ferromagnesian minerals are placed second in order of abundance with relative frequency of 28 per cent.

Description. Subangular to subrounded grains are common, the latter being abundant. Common hornblende of dark green and brownish green colours is recorded. Most of the grains are decomposed, the latter type appearing to have suffered more. Among the pyroxene minerals, hypersthene is very prominent. It occurs in subangular to subrounded tabular form. There are two types of hypersthene: firstly, those with well marked Schiller's inclusions and cleavage cracks, which contain well developed secondary decomposition products pronounced along the cleavage cracks; secondly, a type which is usually fresh and more angular in form. Schiller's type inclusions and cracks are not very conspicuous in this type. From the wear and tear and other general features, it appears that the latter type is included in the alluvials from a nearby source. Calcite/dolomite grains are quite frequent in occurrence and angular to subangular grains are commonly recorded among them.

(Fine fraction).

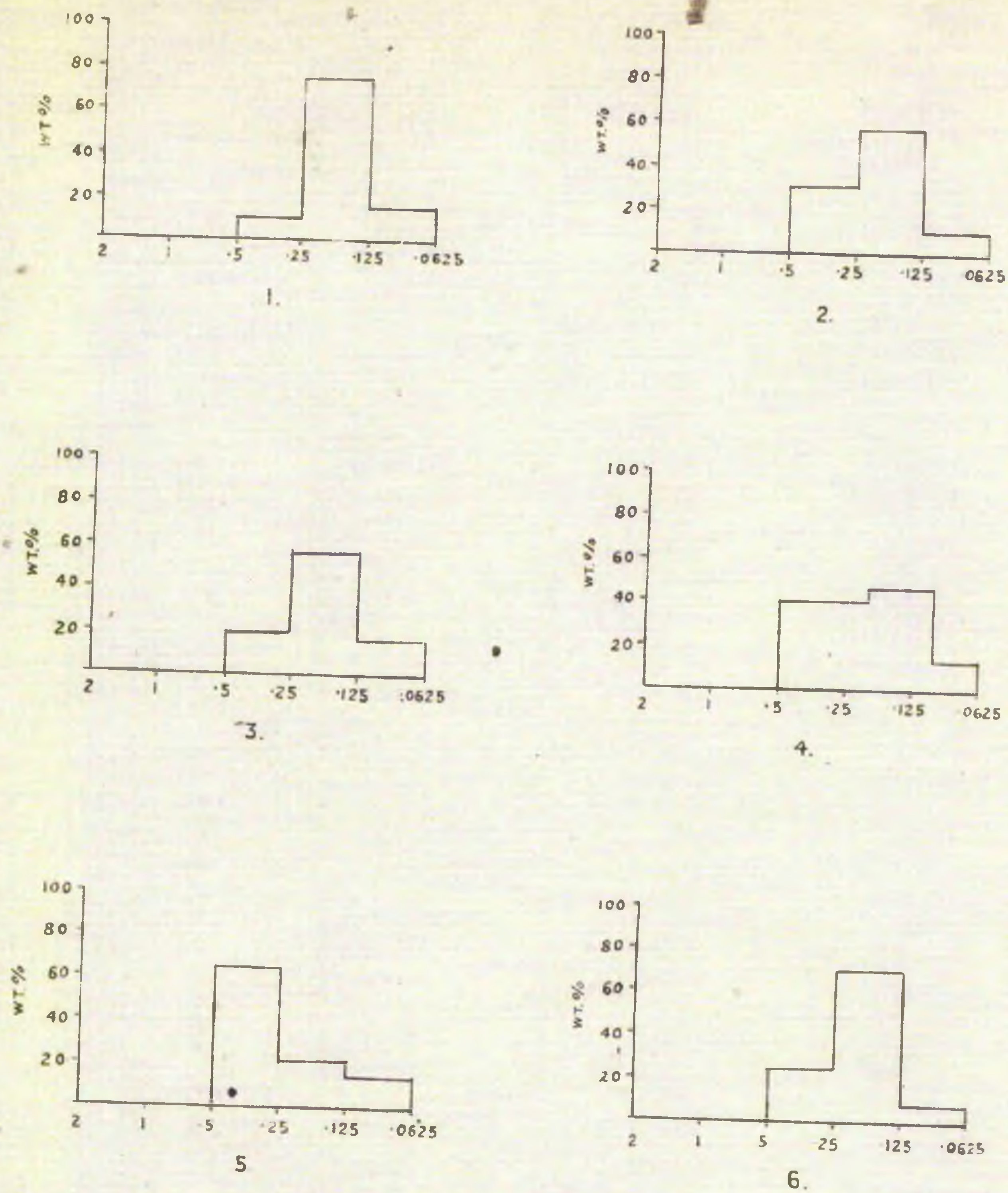
Min. identified. Garnet, hornblende, augite, diopside, hypersthene, calcite/dolomite, epidote, sillimanite, "unidentified grains" and clinozoisite. Ferromagnesian minerals and garnet occur in abundance; their relative frequencies are 38 and 21 per cent respectively.

Description. Subangular to subrounded grains are common; the former is abundant. Common hornblende of dark green colour is present. Most of the grains of hornblende are fresh. Augite and diopside occur in subangular prismatic forms, the former being more decomposed. Irregular and jagged fringes are commonly marked in these minerals. Light brown garnet predominates. It is angular to subangular in form and a few grains are worn. The number of "unidentified grains" over this slide are very few. Those which could be tentatively identified are muscovite, olivine and augite. Among the other minerals, epidote and calcite/dolomite are very prominent. Epidote usually occurs in subrounded grains, but a few well preserved euhedral grains are also recorded. An epidote grain which occurs as a euhedral crystal measured .06 x .03 mm. Calcite and dolomite grains are also fresh; a few euhedral grains occur among them. Biotite is of a dark brown colour, the subrounded form being most common. Biotite shows varying degrees of wear and tear which is more pronounced around the fringes of the grains.

(Silt size fraction).

Min. identified. Hornblende, augite, diopside, hypersthene, biotite, garnet, epidote, opaque minerals, zircon, sillimanite, rutile, apatite, calcite/dolomite, zoisite, corundum, and monazite. Ferromagnesian and opaque minerals occur in abundance; their relative frequencies are 32 and 21 per cent respectively.

Description. Angular to subangular grains are commonly recorded. A few rounded to well rounded grains are also present; monazite, sillimanite, garnet and epidote occur in this form. Zircon, opaque cubes and apatite yielded a few euhedral grains. Hornblende and biotite are fresher than in the previous slides. In this slide, unidentifiable submicroscopic grains are very abundant.



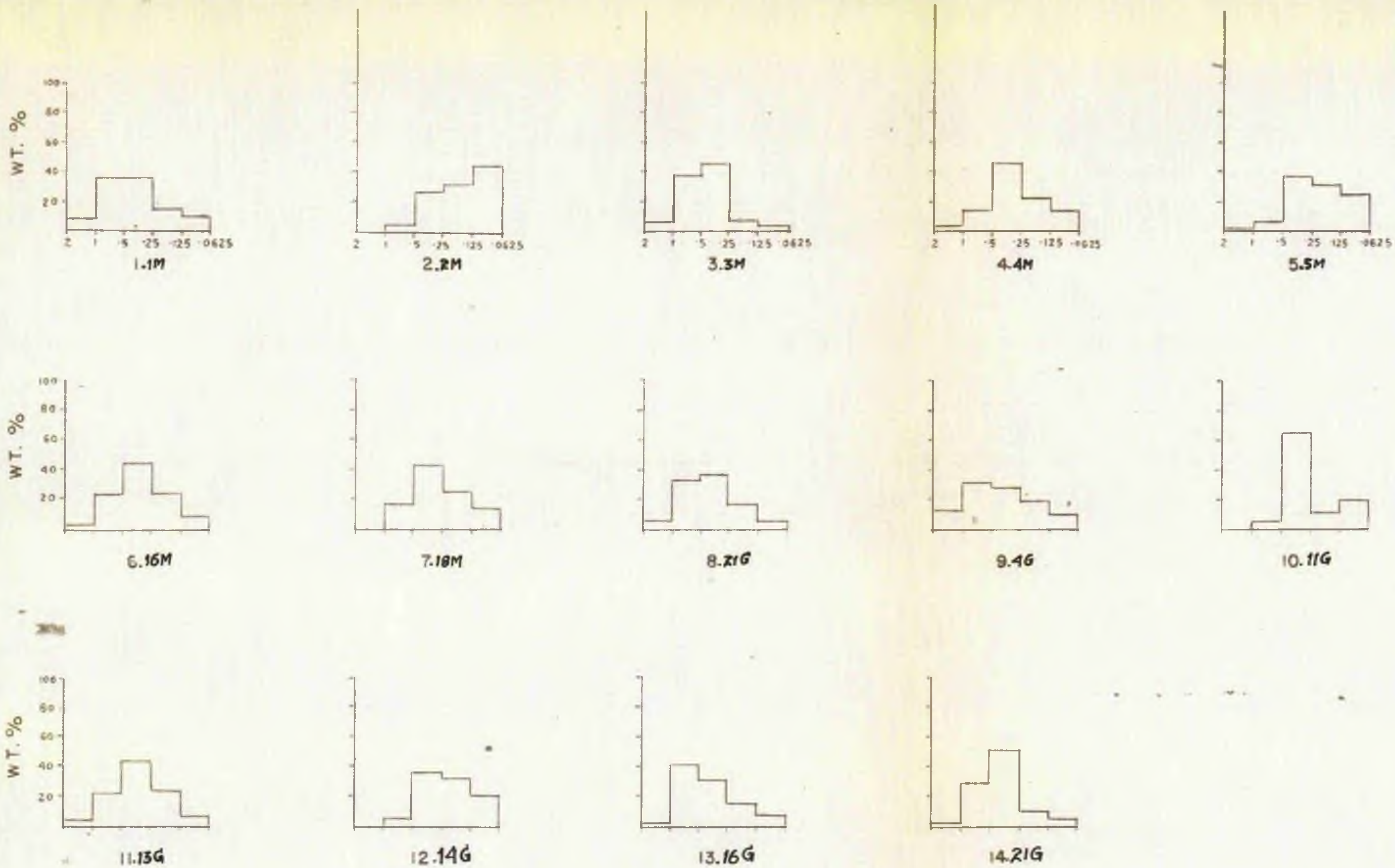
HISTOGRAMS OF MAGNETITE

Grain size.

Magnetite samples from Amb, Qasipur, Attock and Kalabagh were examined to study their grain size range at these localities, which lie between Kalabagh and Kabulgram. The result of these size analyses is shown in the form of histograms in Fig. 15. The general charactersitics of size range of magnetite indicate that the assemblage is confined to three fractions alone, i.e. fine, very fine and silt size; the former two fractions include the greatest amount of the magnetite. At Amb, two samples of magnetite, one from gravel and the other from mantle sand, were sieved to determine the difference in their size range. The sample from the mantle sand yielded the highest proportion of magnetite in the very fine fraction; next in order of abundance are silt size and fine fractions. Similarly, at Kalabagh, magnetite from two samples, one from handpanned concentrate from gravel sand and the other from naturally concentrated heavy residue, were examined to find the difference between their size ranges. The size range of these samples varies considerably. In the former, the maximum accumulation of magnetite is in the very fine fraction, whereas fine and silt size fractions are placed second and third. In the latter, the grain size shifts to the fine fraction, which includes the highest amount of magnetite; next in order of abundance are very fine and silt size fractions.

The size analyses of the non-magnetic fractions from various localities are shown in Fig. 16. It is seen from the histograms that

FIG. 16



HISTOGRAMS OF NON-MAGNETIC FRACTIONS OF BROMOFORM-SEPARATES.

no material is left in the very coarse fraction. In the concentrates from mantle sand, less than 50 per cent of the samples in the coarse grade contain material ranging from 1.9 to 5.6 per cent. In the concentrates from gravel sands, almost all of the samples in the coarse grade contain varying proportions of material which range from 1.1 to 11.7 per cent. Most of the samples from mantle sand downstream of Attock are devoid of coarse grade material. The maximum accumulation of material is in the last four fractions, i.e. medium, fine, very fine and silt size which includes more than 90 per cent of the material. Among these four fractions, the fine size represents the highest proportion, which in most of the samples averages over 30 per cent. Very fine, silt size and medium fractions retain the remaining portion of the material in that order of abundance.

The percentage of very fine and silt size fractions averaged in two samples at Kabulgram is 49.4, which among the samples examined is placed second in order of abundance in retaining these fractions in the area under study. At Amb, Qasipur and Attock the percentage of very fine and silt size fractions varies from 22.8 to 31.1; being 22.8 at Amb, 31.1 at Qasipur and 29.8 at Attock. This shows that in a stretch of about 85 miles between Kabulgram and Attock, there appears to be no progressive decrease in average size of the grains. At Kabulgram, very fine and silt size fractions retain more material than downstream at Attock.

At Gariala and Khushalgarh, downstream of Attock, the samples showed a well-marked decrease in average size where 69.6 and 40.5 per cent of material is retained in very fine and silt size fractions. These two localities are 8 and 46 miles downstream of Attock respectively. Further downstream, in one sample at Kalabagh only 17.8 per cent of the material is retained in very fine and silt size fractions.

From the above results, it is apparent that in a stretch of about 200 miles between Kalabagh and Kabulgram there is no systematic decrease in the average grain size of the heavy minerals. Sharp decreases in average size occur in two localities, Gariala and Khushalgarh, but at Kalabagh this decline in average size is again checked and the retention of material in the very fine and silt size is much less than in the previous two localities. Similarly, in the sample from Kabulgram, very fine and silt size fractions accommodate more material than in the samples from Amb, Qasipur and Attock, which are 35, 66 and 90 miles downstream of Kabulgram. There are two main factors which usually affect the grain size of stream alluvials and these appear to have a direct bearing in the area studied. First, there is contamination due to influx of material from side tributaries. Numerous large and small tributaries join the Indus river in this part of the area, and the Braldu river 10 miles upstream of Amb, the Siron river a mile upstream of Turbela, the Kabul river 2 miles upstream of Attock, the Haro river 2 miles downstream of Gariala and the Soan river (about 14 miles upstream of Kalabagh) in particular contribute substantial amounts of material in their alluvials. This fresh supply of material replenishes the medium and fine fractions and compensates for the losses resulting from grinding and abrasion during transportation. The second factor which is much more important is the conditions under which the samples were collected. Due to the selective abrasion and transportation which is a common function of rivers, it is possible that the sampling was carried out in apparently similar beds and may have a different range of grain sizes.

Mineral assemblages.

After going through the frequency table showing the distribution of non-magnetic heavy minerals in various size fractions, it is easy to delineate a mineral assemblage boundary between coarse and medium fractions on the one hand, and fine, very fine and silt size fractions on the other. In the former two fractions, a limited number of mineral species are recorded: garnet, hornblende, micas, calcite/dolomite, opaque minerals, epidote, augite and hyperathene are the common minerals which in most cases predominate in these fractions. The former three minerals in the coarse and medium fractions of most of the samples constitute over 90 per cent.

...ls in various size-fractions.

	DOLOMITE - CALCITE	CASSITERITE	SCHEELITE	APATITE	SILLIMANITE	CORUNDUM	KYANITE	RUTILE	MONAZITE	TOURMALINE	ZOISITE CLINOZOISITE	STAUROLITE	ANATASE	TOPAZ	BARITE
.8	16.6														
.5	2.3	-	-	-	-	.8									
.0	9.6	-	-	-	-	-	.6	.6	-	-	-	1.2			
.0	10.2	-	-	1.0	2.6	1.0	-	.5	.5	.5	-	-	-	-	.
.2	11.0	-	-	.7	2.1	.7	-	1.4	.7						
.2	3.5														
.5	6.8	-	-	.4	1.2	.4	-	-	-	.4	-	-	.4		
-	5.3	-	-	.4	2.2	.4	.4	.8	-	.8					
.2	4.3	-	-	.6	1.6	-	-	-	.8	.4	.4				
.3	2.0														
.0	4.6														
.0	3.9	-	-	.6	2.3	-	-	.6	-	1.1	.6				
.5	9.6	-	-	.7	2.2	.4	-	.7	.4	.4	.7				
.4	14.7	-	-	3.4	4.5	1.1	-	1.2							
.1	2.0														
.5	-	-	-	4.6											
.5	2.5														
.4	9.6	-	-	.4	2.5	-	.4	-	-	1.0	.7				
.5	8.9														
.1	7.9	-	-	-	-	1.1	-	-	-	-	1.1	-	1.1		
.2	2.2	-	-	.7	2.3										
.8	4.8	-	-	.4	3.2	-	-	.8	.4	-	.8				
.2	38.5	-	-	-	5.0	-	-	2.5							

TABLE 14. Frequency distribution of non-magnetic heav

	GARNET	HORNBLENDE	AUGITE	DIOPSIDE	HYPERSTHENE	OPAQUE MIN.	OPAQUE CUBE	EPIDOTE	OLIVINE	BROOKITE	ZIRCON
TTOCK											
Coarse	4.4	63.5	3.3	-	1.1	1.1	-	2.2	-	-	-
Medium	37.0	31.5	2.3	.8	3.2	-	-	.8	-	.8	-
Fine	13.0	34.5	2.3	.6	1.7	3.8	-	2.8	-	2.3	-
Very Fine	6.1	47.0	3.5	.5	.9	9.1	.5	6.1	-	.5	-
Silt	9.6	35.3	2.7	.7	1.3	18.6	1.4	4.[illegible]	-	-	4.8
AZIPUR											
Medium	37.5	26.5	5.3	.9	7.9	.9	-	4.3	-	-	-
Fine	35.0	33.5	4.3	1.6	2.7	3.1	-	5.5	-	.8	-
Very Fine	31.0	22.5	2.6	.4	.8	22.0	1.6	5.8	-	1.8	.8
Silt	17.7	15.4	1.2	-	.8	45.0	.8	4.3	-	.4	5.1
B											
Coarse	7.3	46.7	3.0	2.1	1.3	2.3	-	1.0	-	-	-
Medium	5.5	59.0	3.3	1.1	2.2	2.2	-	-	-	1.1	-
Fine	32.0	34.5	3.1	-	2.3	3.9	-	4.1	-	-	-
Very Fine	16.0	36.5	2.5	.4	1.1	15.0	1.1	3.3	-	.7	5.4
Silt	7.9	21.5	3.4	.6	2.2	23.5	-	5.7	-	1.1	5.7
B											
Medium	3.1	4.6	1.3	-	1.2	-	-	1.7	-	-	-
Fine	3.0	14.7	3.1	.8	3.1	-	-	3.1	-	-	3.1
Very Fine	5.6	39.0	3.7	1.2	-	1.2	-	3.1	-	1.2	-
Silt	5.7	36.2	2.5	1.0	1.0	13.6	.7	3.9	-	.7	.7
BULGRAM											
Coarse	1.1	5.5	2.2	1.3	6.6	6.6	-	3.3	-	-	-
Medium	13.6	36.5	6.8	2.3	5.7	2.5	-	6.8	-	3.4	-
Fine	25.5	39.4	4.5	.7	5.3	11.2	.7	3.8	-	1.5	-
Very Fine	25.6	17.3	1.6	-	1.6	34.0	1.6	2.7	-	.4	4.0
Silt	5.0	12.5	6.3	-	2.5	13.7	2.5	1.6	-	1.2	7.5

In the fine, very fine and silt size fractions on the other hand, the highest number of mineral species are recorded and the percentages of the minerals among these fractions varies from sample to sample. The minerals mentioned above in coarse and medium fractions still abound in the finer fractions and constitute over 95 per cent. In addition, there are other minerals which are exclusively recorded in the fine, very fine and silt size fractions. These are zircon, sillimanite, apatite, brookite, corundum and a few others shown in the frequency tables; the combined relative frequency of all these minerals constitutes less than 10 per cent of bulk in these fractions. These minerals apparently have little effect on the percentages of the total mineral assemblages of these fractions, but they certainly distinguish the mineral constitution of the fine, very fine and silt size fractions from those of the coarse and medium fractions. Opaque minerals are not a very common ingredient of the coarse and medium fractions and in a few samples these minerals are not encountered. Among the opaque minerals, most of the species are found in the fine, very fine and silt size fractions and sporadic grains of ilmenite are usually retained in the coarse and medium fractions.

Grain form.

On the basis of grain form, a tentative division is possible between coarse and medium fractions on the one hand, and fine, very fine and silt size fractions on the other. In the former, roundness

TABLE 15. **Frequency distribution of grain form in size fractions of the samples collected from various localities from the Indus Alluvials.**

		0. - 0.15				0.15 - 0.25				0.25 - 0.4				0.41 - 0.6				0.61 - 1.0			
LOCATION	SIZE RANGE	HORN.	OPQ.	GNT.	BIOT.	HORN.	OPQ.	GNT.	BIOT.	HORN.	OPQ.	GNT.	BIOT.	HORN.	OPQ.	GNT.	BIOT.	HORN.	OPQ.	GNT.	BIOT.
KABULGRAM	COARSE	-	-	-	-	10.4	-	5.0	-	23.3	8.3	6.6	-	23.3	-	3.3	6.6	13.2	-	-	-
	MEDIUM	6.6	-	2.2	4.3	11.1	2.2	4.3	8.6	22.3	-	-	6.6	15.4	2.2	2.2	3.2	4.4	4.4	-	-
	FINE	8.2	-	-	2.0	36.0	-	8.0	6.0	20.0	-	8.0	6.0	2.0	-	2.0	-	-	-	-	-
	VERY FINE	9.7	-	3.6	2.4	15.1	7.6	7.6	7.6	19.4	3.6	7.6	6.1	4.9	2.4	1.2	1.2	-	-	-	-
AMB	COARSE	-	-	-	-	6.0	-	6.0	4.0	24.0	-	16.0	12.0	8.0	2.0	4.0	14.0	-	-	-	4.0
	MEDIUM	3.5	-	-	2.2	-	4.5	13.2	8.9	-	11.1	15.5	23.2	-	6.7	4.5	4.5	-	-	2.2	-
	FINE	4.6	-	6.2	4.6	10.5	4.6	6.6	15.1	9.1	7.7	12.3	9.5	-	3.1	3.5	3.1	-	-	-	-
	VERY FINE	11.6	3.3	-	3.3	20.1	6.6	2.0	11.6	15.0	11.6	-	8.3	1.6	5.0	-	-	-	-	-	-
	SILT	11.0	1.4	2.8	2.8	25.6	9.8	5.8	4.3	9.8	9.7	2.8	5.8	4.2	4.2	-	-	-	-	-	-
QAZIPUR	COARSE	-	-	1.6	3.2	-	-	1.6	11.4	16.2	8.1	3.2	17.8	13.0	4.8	3.1	6.4	-	-	4.8	4.8
	MEDIUM	2.8	-	-	-	7.6	-	6.2	18.6	16.7	1.5	12.4	16.7	4.7	3.0	-	4.6	-	3.1	-	3.1
	FINE	-	-	2.3	-	9.6	5.3	3.2	9.6	26.5	11.6	9.6	13.8	3.2	2.1	2.1	-	-	-	1.1	-
	VERY FINE	11.0	-	3.1	2.1	24.6	1.0	9.6	9.6	14.4	4.1	6.2	4.1	3.1	4.1	1.0	1.0	-	-	1.0	-
	SILT	13.6	6.9	6.9	4.6	17.0	9.1	-	11.4	9.1	7.9	7.9	4.5	-	1.1	.-	-	-	-	-	-
ATTOCK	COARSE	-	-	-	-	4.2	-	-	2.2	23.7	13.6	-	15.2	13.1	4.2	-	8.4	4.2	4.2	2.2	4.8
	MEDIUM	-	-	-	-	4.2	-	11.2	9.6	17.6	8.0	19.2	14.4	4.7	4.7	3.2	3.2	-	-	-	-
	FINE	-	-	6.6	3.7	6.1	-	18.4	14.8	18.4	2.4	12.4	13.6	-	1.2	-	2.4	-	-	-	-
	VERY FINE	7.9	.8	4.3	1.4	34.5	4.3	8.6	15.2	11.6	2.2	5.0	1.4	.7	1.4	-	-	-	-	.7	-
	SILT	9.3	7.7	8.4	8.9	10.1	4.8	7.8	11.5	6.7	4.3	4.4	17.1	-	-	-	-	-	-	-	-

TABLE 15 CONTINUED....

		0 - 0.15				0.15 - 0.25				0.25 - 0.4				0.41 - 0.6				0.61 - 1.0			
LOCATION	SIZE RANGE	HORN.	OPQ.	GNT.	BIOT.	HORN.	OPQ.	GNT.	BIOT.	HORN.	OPQ.	GNT.	BIOT.	HORN.	OPQ.	GNT.	BIOT.	HORN.	OPQ.	GNT.	BIOT.
KHUSHALGARH	COARSE	-	-	-	-	-	-	2.8	8.7	8.6	1.7	3.4	39.1	6.8	5.1	-	23.8	-	-	-	-
	MEDIUM	-	-	-	-	9.9	1.0	.9	50.0	7.4	-	.9	16.2	4.5	.9	.9	7.4	-	-	-	-
	FINE	7.8	2.0	2.6	9.4	23.0	1.3	3.3	19.8	13.3	3.9	3.9	5.3	1.3	.7	-	2.6	-	-	-	-
	VERY FINE	20.7	4.9	10.8	7.9	18.6	6.9	6.9	.9	9.8	7.8	2.9	-	-	1.9	-	-	-	-	-	-
	SILT	15.3	5.8	8.0	8.8	13.2	8.0	9.5	10.2	5.8	8.8	4.4	2.2	-	-	-	-	-	-	-	-
KALABAGH	COARSE	-	-	2.2	-	3.2	-	2.2	-	19.8	-	6.6	30.8	2.2	4.4	-	13.2	2.2	2.2	2.2	8.8
	MEDIUM	-	-	3.3	-	11.0	-	5.1	-	40.3	5.1	5.1	7.7	11.3	3.2	1.1	-	3.3	3.2	-	-
	FINE	6.1	-	11.2	3.3	23.5	4.1	10.1	4.1	11.2	4.1	11.2	4.1	2.0	4.0	1.0	-	-	-	-	-
	VERY FINE	6.4	5.0	7.8	2.0	20.0	10.0	10.8	10.0	4.3	9.6	2.8	2.8	-	5.0	.7	-	-	2.1	.7	-
	SILT	11.4	6.3	15.2	7.6	7.6	3.8	22.6	5.0	3.8	2.5	10.4	3.8	-	-	-	-	-	-	-	-
INDUS AT SKARDU	COARSE	-	-	-	-	-	-	4.0	-	32.0	12.0	8.0	8.0	16.0	4.0	4.0	-	4.0	4.0	-	4.0
	MEDIUM	-	-	-	-	8.5	-	6.0	8.4	23.5	11.7	14.7	5.8	1.3	5.9	9.0	2.9	-	-	2.9	-
	FINE	10.4	-	7.8	-	26.0	5.2	7.6	2.6	14.3	5.4	11.7	2.6	1.3	1.3	3.9	-	-	-	-	-
	VERY FINE	12.4	16.6	4.3	2.1	12.4	9.3	14.6	-	4.1	8.4	9.6	2.1	-	3.1	-	-	-	1.0	-	-
	SILT	17.4	8.5	12.5	6.4	11.2	6.4	13.8	3.7	3.7	3.7	7.5	1.2	-	2.5	2.5	-	-	1.2	-	-

in the grain is more pronounced, whereas in the latter angularity is well preserved. In fig. 17, outlines of grains in various size fractions are illustrated to show these characteristics. A cursory examination of these outlines will throw some light on the behaviour of the grains in the various size fractions.

In silt size fractions, angularity in the grains is well preserved. The grains appear fresh, as if they have been recently derived from their parent rocks. The reshaping of the grains due to hazards of transportation is not vividly marked. The edges of the grains appear straighter, with sharp angular zig-zag corners. In the very fine fraction, the grains still preserve the same shape but slight modifications have been imparted to the angular corners which have become slightly rounded. The undulatory features around the fringe of the grains are slightly broadened. In the fine fraction, the undulation around the fringe becomes broader and rounded, and the grains appear to have attained an intermediate position between angular and rounded form, the latter being immature in development.

In the medium fraction, the grains appear to have completely shed their angularity. The undulations around the fringe of the grains have further widened and become rounded. In the coarse fraction angularity has disappeared and undulations around the edges of the grains have further widened so that they have become completely rounded.

The frequency distribution of grain form in the various size fractions is given in Table 15. The grain form of hornblende, garnet,

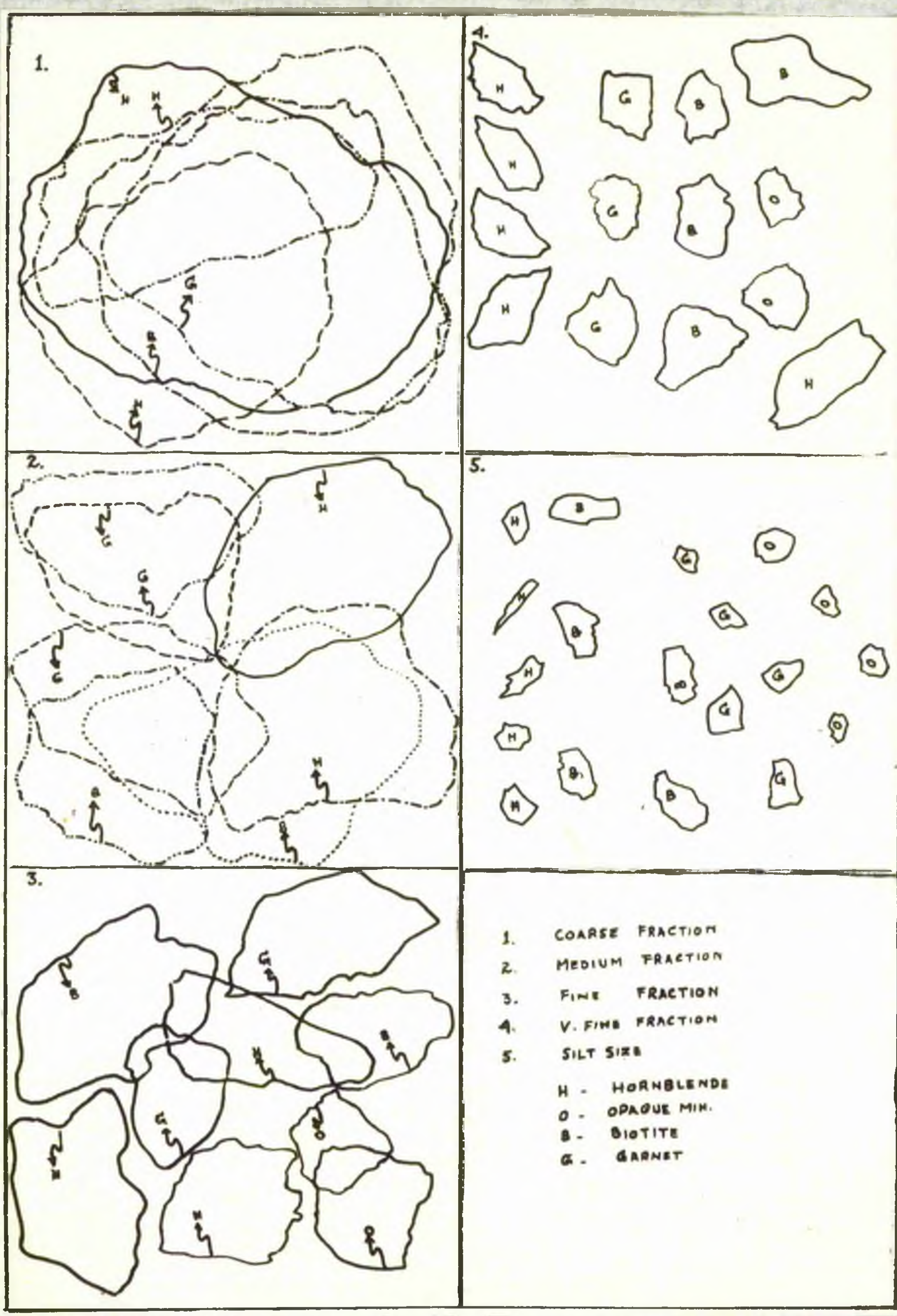


Fig. 17. Photograph of the enlarged mineral grains in various size fractions.

biotite and opaque minerals has been studied in each fraction. Subangular and subrounded grains are common in each of the size fractions. Angular grains are rarer in the coarse and medium fractions, whereas they occur in quantity in the fine, very fine and silt size fractions. Rounded to well rounded grains are very common in the coarse and medium fractions. In the fine, very fine and silt size fractions, rounded grains show a slight decline in frequency percentage, whereas well rounded grains become extremely rare.

In the coarse fractions, subrounded grains predominate. Next in order of abundance are rounded, well rounded and subangular grains. The increase in relative frequency of rounded and well rounded grains is recorded at Attock and downstream. The main characteristic of the grain form in the coarse fraction is that the rounded and well rounded grains are very prominent and constitute a substantial percentage in the bulk. The relative frequency of angular grains decreases; they constitute an insignificant part in most of the samples.

To some extent, the medium fractions show grain form characteristics similar to those recorded in the coarse fractions, except for a slight increase in the number of angular grains. The relative frequency of rounded and well rounded grains also diminishes. Subrounded grains as usual occur in abundance and subangular grains are placed second in order of abundance.

The fine fraction is quite distinct in grain form. Angular grains are present in almost all the samples, whereas well rounded grains have become extremely rare; out of seven samples, only one sample at Qazipur yielded well rounded grains with a relative frequency of 1.1 per cent. Subrounded grains are abundant, while subangular, angular and rounded grains are placed next in increasing order of abundance.

Except for minor fluctuations in the percentage of the grains in various forms, the grain form characteristic of the very fine fraction are similar to those of the fine fraction. It appears that in the very fine fraction, angular grains increase in number and subangular grains become most abundant. Next in order of abundance are subrounded, angular and rounded grains. Well rounded grains are encountered only in three samples from Qazipur, Attock and Kalabagh.

In the silt size fraction the relative frequency of angular grains again increases. Angular, subangular, subrounded, rounded and well rounded grains occur as arranged according to their order of abundance. Well rounded grains become extremely rare and rounded grains also show a sharp fall in frequency.

Decomposition by abrasion and solution.

The term "unidentified grains" is applied to those mineral grains which are devoid of microscopic properties. They are opaque in ordinary light and appear cloudy under crossed nicols. A few grains which are clear and intact around their fringes were tentatively identified.

The minerals encountered in this form are calcite/dolomite, muscovite, feldspars, olivine, augite, diopside, epidote, hypersthene and, in very rare cases, hornblende. These minerals are more prone to decomposition by solution: usually secondary products conceal the mineral grains. The effect of abrasion further deteriorates the grain by producing jagged and frayed features around the fringe. Flaky grains, such as micas and hornblende, have suffered most and distorted features produced by abrasive action are commonly noted in these mineral grains. The stable minerals resist this deterioration but yield to rounding. Hence the amount of abrasion in the case of the stable minerals, such as cassiterite, scheelite, garnet, zircon, monazite, staurolite, sillimanite and tourmaline, is indicated by the degree of roundness imparted to the grains.

Regarding the distribution of decomposed grains in the various size fractions, it has been noted that the percentage is high in the coarse and medium fractions. Fine, very fine and silt size fractions show minimum numbers of decomposed grains. In the light fractions muscovite and feldspars are most affected.

ECONOMIC GEOLOGY

Introduction.

In reviewing the economic geology of the alluvials, it is convenient to split up the investigated 500-mile stretch of the Indus into three parts: (a) upstream from Amb, including the major tributaries of Gilgit, Hunza and Shigar; (b) between Amb and Attock; and (c) downstream from Attock.

Upstream from Amb the valley is narrow and the development of alluvials, forming thin stringers along the river banks, is insufficient to support any large-scale mining operation. The Gilgit, Hunza and Shigar tributaries contain extensive alluvial deposits which may possess an interesting amount of economic minerals, but the regions in question are so remote, and have such poor communications, that there is no attraction for commercial development. Again, weather conditions in these areas over 5,000-6,000 feet in elevation are unfavourable to mining. For these reasons no further consideration is given to the alluvials in the major tributaries.

After emerging from the mountain confines the Indus gradually starts to widen its valley downstream from Amb. A great accumulation of alluvial deposits is situated in this region, where the valley at places is from 2 to 2½ miles across. Numerous sand-bars have here become permanent islands in the river. This area is readily accessible both by metalled and fair-weather roads and by rail, the rail-head at Haripur being only twelve miles off and that at Attock still closer, on the bank of the river. Most of the villages here are electrified, and cheap electric power could be made available for mining. These various factors make a placer-mining project between Amb and Attock much more attractive, and it is therefore to this sector of the alluvials that most attention has been given.

Downstream from Attock, the Indus again flows through a narrow valley as far as Kalabagh, where it debouches on to a wide plain. The region downstream from Kalabagh is not included in the present study. Natural concentrations of heavy minerals are known to occur here, and there are vast accumulations of alluvials which are readily accessible. But, as this region is far downstream from the source provinces of the economic minerals compared to the placers between Amb and Attock, the tenor of these minerals is likely to be lower than at the latter locality. Only if mining operations between Amb and Attock should prove payable would the alluvials downstream from Kalabagh merit detailed study.

Between Amb and Attock the river runs for about 55 miles, from Amb to Turbela, about 15 miles, the width of the valley ranges from 1,000 to 8,000 feet. Downstream from Turbela the valley gradually widens and at a point 8 miles before Attock its extent is over 12,000 feet.

Some data on the thickness of the alluvials are available for one site about 6 miles downstream from Turbela, where exploratory bore-holes were drilled in connexion with the Turbela dam. The maximum thickness of alluvium recorded was 400 feet, and many holes from 100 to 150 feet were drilled. Bedrock was not reached in many boreholes because of the difficulties of drilling through boulder-bed gravels, but it is certain that the alluvials are here more than 150 feet thick.

The weather conditions in the Amb-Attock stretch of alluvium are favourable for dredging, though operations might have to be suspended for about 3 months annually (May to August) when the river is in spate.

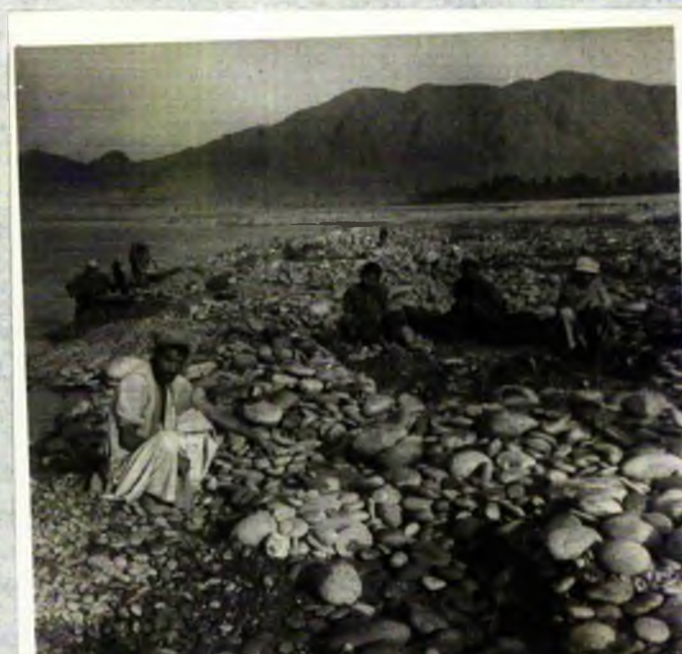
The Gold-Washing Industry.

The alluvial deposits between Amb and Attock have been worked for gold in a primitive manner for many generations, but no description of the industry has yet been published. At a very rough estimate, maybe around 20 or 25 families of workers are now engaged seasonally in the industry and the overall production of gold, which can only be guessed at, may be around 14 troy ounces. At British prices this would have a value of around £175 per annum. Gold is at a premium price in Pakistan.

Dr. Zeschke (8) records that some ancient gold ornaments reputedly of Indus provenance are radioactive due to uraninite being associated with the gold; but Professor Davidson (in discussion of Zeschke's paper) has commented that uraninite-thorianite is present in the final concentrates from gold-washing in many parts of Asia.

Goldwashers' tools and the way he operates them.

Goldwasher is busy in separation of heavy residues from measured volume of bulk sand.



Goldwashers' helpers (family members) who help him in scraping the bulk sand from the gravels.

The Indus gold-washing is carried out on a specially designed sluice or table called a nava (photo. 14). This is made locally of seesam wood which takes a good polish and which is available in this region. The length of a typical nava is 62 inches, its top, 22 inches, is wider than the bottom, 8 inches. The floor is raised near the head, where it has a drop of 3 in 13 inches, and the two sides and head are enclosed by a 5½-inch high rim. In operation, the gold-washer fixes the nava so that the head is raised to an angle of 10°-15° with the horizontal; and feeds sand and water on to it so that the lighter particles are washed away and the heavies retained.

Gold-washing is done in three stages. In the first stage, the grit and pebbles are removed from crude sand by screening. In stage II, the heavy minerals are concentrated by washing the crude sand, to give a bulk concentrate. (In this process all of the light minerals and a great deal of the ferromagnesian content is removed). In stage III, the bulk concentrate is washed and much reduced to give a final concentrate formed largely of the species of very high specific gravity. The gold is extracted by amalgamation from this highly panned concentrate and what is left is referred to as gold-washers' residue. Very roughly the ratio crude:bulk: final may be of the general order 1200:300:1.

The crude alluvium selected by the gold-washer is usually from the floodplain gravel deposit. Mantle sands contain gold only where there are lenses of heavy-mineral concentrates. Before

TABLE 16. Yield of Gold from measured volume of bulk sands.

	CRUDE ALLUVIUM IN CUBIC FEET.	VOLUME OF GRIT AND PEBBLES IN CUBIC FEET.	VOLUME OF BULK CONC. IN CUBIC FEET.	WT. OF FINAL CONCENTRATE IN LBS.	YIELD OF GOL IN GRAINS.
1.	25	$1\frac{2}{3}$	6	$3\frac{1}{2}$	
2.	50	3	8	$8\frac{1}{2}$	.3620
3.	50	$1\frac{1}{2}$	10	10	
4.	50	$4\frac{2}{3}$	12	7	
5.	50	$4\frac{1}{2}$	12	$5\frac{1}{2}$	
6.	50	$3\frac{1}{4}$	12	6	0.4857
7.	50	$5\frac{1}{2}$	12	4	
8.	50	5	12	7	
9.	50	6	16	8	0.2819
10.	60	5	12	6	.1315
11.	60	4	12	6	.1095

TABLE 17. **COMPOSITION OF GOLDWASHER'S RESIDUE.**

					VARIOUS MINERALS IN COMPOSITED SAMPLES OF HEAVY NON-MAGNETIC FRACTION.														
SAMPLE BO. SHOWN IN FIG. 4.	BULK SAND	GOLDWASHERS' CONC. IN OUNCES.	MAGNETITE	NON-MAGNETIC FRACTION	APATITE SILLIMANITE	BROOKITE - RUTILE	CASSITERITE	EPIDOTE ZOISITE CLINOZOISITE	GARNET	HORNBLENDE	HYPERSTHENE AUGITE DIOPSIDE.	'MICAS'	MONAZITE	OPAQUE MINERALS	SCHEELITE	TOURMALINE TOPAZ, ANATASE, STAUROLITE.	ZIRCON	DOLOMITE - CALCITE	OTHER MINERALS
1W	80 Lbs.	1.5	28.7	71.3															
2W	"	2.3	39.2	60.8	.72	.31	.4	3.3	33.1	4.2	2.5	.9	.3	47.4	.1	.5	4.2	.43	1.6
3W	"	2.0	41.6	58.4															
4W	"	4.0	49.3	50.7															
5W	"	8.0	68.3	31.7															
6W	"	6.0	58.0	42.0															
7W	"	6.5	79.1	20.9	.92	.47	.57	4.2	34.6	4.9	2.8	1.4	.37	42.3	.21	.6	3.2	.8	2.7
8W	"	6.0	71.9	28.1															
9W	"	3.0	68.4	31.6															
10W	"	2.5	74.8	25.2															
11W	"	11.0	73.2	26.8															
12W	"	4.5	69.5	30.5															
13W	"	1.3	47.9	52.1	.85	.28	.49	3.9	36.7	3.6	5.7	1.0	.41	40.3	.22	.8	3.8	.39	2.6
14W	"	3.5	72.3	27.7															
15W	"	3.2	60.5	39.9															
16W	"	4.0	59.0	41.0															
17W	"	4.0	66.3	33.7															

TABLE 18. Composition of Natural accumulates from between Kalabagh and Kabulgram.

SAMPLE NO. SHOWN ON FIG. 4.	LIGHT FRACTION 'FLOAT' $<$ 2.89	HEAVY NON-MAGNETIC FRACTION $>$ 2.89	MAGNETITE	LOSS DURING OPERATION	VARIOUS MINERALS IN COMPOSITED SAMPLES OF HEAVY NON-MAGNETIC FRACTION.														
					APATITE SILLIMANITE	BROOKITE	CASSITERITE	CALCITE - DOLOMITE	EPIDOTE ZOISITE CLINOZOISITE	GARNET	HORNBLENDE	HYPERSTHENE, AUSITE, DIOPSIDE.	'MICAS'	MONAZITE	OPAQUE MINERALS	RUTILE, TOURMALINE, CORUNDUM, ANATASE.	SCHEELITE	ZIRCON	OTHER MINERALS
1 NC	13.8	58.4	26.5	1.3	.65	.22	1.1	3.3	2.4	17.7	4.6	2.04	.04	3.04	52.4	.4.3	0.7	4.9	2.6
2 NC	18.8	56.7	23.1	3.1	.38	.16	1.7	2.8	2.8	29.1	7.2	3.1	1.26	2.2	40.1	3.1	0.4	3.1	1.9
3 NC	21.1	50.3	24.9	2.7	.3	.26	1.4	2.0	3.2	14.8	9.1	4.8	2.4	2.7	48.8	3.8	.5	3.4	3.5
4 NC	11.3	71.1	15.7	1.9	.18	.11	1.1	1.7	2.1	60.2	7.6	1.8	1.0	0.8	18.4	.9	.3	2.1	1.7
5 NC	4.9	64.3	29.6	1.2	.4	.08	.9	2.1	3.8	19.1	4.1	1.1	1.3	2.2	55.1	2.6	.45	3.1	3.6

beginning operations the gold-washer usually spends some time searching for pay-streaks where the yield of gold is high. Using a small wooden pan, he washes handfuls of alluvium at likely sites and from the results of these trials he marks the spots where his co-workers will scrape together the crude auriferous sand. Sands in the terrace gravels also contain gold, but the gold-washer pays little or no attention to these deposits because they are mostly covered with overburden and pay-streaks cannot be located without major stripping operations.

In the gravel deposit, only the top two to 15 inches of sand is scraped from the surface and usually only the fresh sands deposited during the last flood are collected. For a single wash on the nava, between four and five cubic feet of sand is scraped together; and in a 6-8 hour day, a gold-washer treats from 32 to 42 cubic feet of sand.

The gold-washer is normally assisted by two men (photograph 14) who help him to scrape together auriferous sand and transport this from the gravel to the nava. The main operation, the handling of the nava, is one demanding long experience. His co-workers are usually members of his own family (photograph 15) but a few washers employ one or two labourers who are paid between Rs. 1/8 and 2/- (2s. 6d. to 3s.) per day. The goldwasher's daily income is from Rs. 4/- to 6/- (i.e. 6s. 0d. to 9s. 0d.), from which he must pay his labourers. Obviously income fluctuates. At the start of a season, after the recession of the floods, sites can be found where the yield of gold is relatively high, and at this time the daily earnings may rise to Rs. 10/- to 15/- per day (15s. 0d. to 22s. 6d.). But such days are few and only bonanzas pay this much.

The technique of the gold-washer is crude and, since the gold occurs as fine dust as well as flakes, it is likely that a substantial amount is not recovered. In the writer's opinion nearly a third of the gold present is lost in each wash. With the co-operation of an experienced gold-washer the writer has made a quantitative study of the yield of gold, beginning with measured volumes of picked alluvium. The results are shown in the following table. The average yield of the eleven samples is approximately 0.068 gm. = 1.05 grains per cubic yard of selected alluvium.

An estimate of the composition by weight of the major constituents in the gold-washers' residues is given, for record purposes, in table 17.

In addition to the studies made of these gold-washers' concentrates, a quantitative mineralogical examination has been carried out on the natural heavy mineral accumulates found in the region. These concentrates or pay-streaks form black or pink skims up to some tens of feet in length; but they are very thin indeed, practically immeasurable in the field. Five composited samples of this natural high-grade were collected between Kalabagh and Kabulgram. These natural concentrations form an altogether insignificant part of the alluvials distributed in the flood plain and not a single one of them merits consideration for large-scale mining because of insufficient material. Because of the thinness of these streaks it proved impossible to collect the heavy minerals free from the underlying light sands. Nevertheless, it is apparent that in the heavy mineral fraction of the material collected, hornblende and micas very rarely exceed 10 per cent by weight (i.e. they form a smaller proportion of the total heavies than in the normal sands and gravels) whereas the non-magnetic opaque minerals combined with garnet together constitute over 65 per cent of most samples. Heavy species such as zircon, monazite, brookite, rutile, sillimanite and apatite are particularly abundant in the skims of this kind. The composition of the five samples is given in Table 18 . The ratio of light to heavy minerals is approximately 1:4, the tenor of heavies ranging from 76.2 to 93.9 per cent.

For comparison with the natural accumulates, it is relevant that the ratio of light to heavy minerals in randomly picked samples from the flood-plain is about 4:1, the range of heavies in ten composited samples being from 10.3 to 36.1 per cent, averaging 20.5 per cent. The tenor of heavy minerals in random samples from the sands of the terrace gravels is somewhat less, ranging from 4.5 to 23.3 per cent, averaging (over 7 samples) only 13.7 per cent. Particulars are given in Tables 19 and 20.

In the ten composited samples from the flood plain, the yield of heavy minerals varies from 154 to 540 lbs. per cubic yard. The tenor of magnetite and non-magnetic heavy minerals ranges from 6 to 36 and from 148 to 504 lbs. per cubic yard respectively, averaging 19.19 lb./c. yd. for magnetite and 278 lb./c. yd. for non-magnetic heavies. The lowest yield is at Khusulgarh and the highest yield at Attock.

In the seven samples of sand from terrace gravels, the tenor of heavies ranges from 68 to 373 lbs. per cubic yard, of which magnetite accounts for 15-201 lbs. per cubic yard. Particulars are given in table 21.

TABLE 19. COMPOSITION OF FLOOD PLAIN ALLUVIALS FROM BETWEEN KALABAGH AND KABULGRAM.

SAMPLE NO. FIG. 4.	LIGHT FRACTION 'FLOAT' (<2.89)	HEAVY FRACTION (NON-MAGNETIC) 72.89	MAGNETITE	LOSS DURING OPERATION	VARIOUS MINERALS IN COMPOSITE SAMPLES OF NON-MAGNETIC HEAVY FRACTION (72.89).														
					APATITE SILLIMANITE	BROOKITE	CASSITERITE	CALCITE - DOLOMITE	EPIDOTE, ZOISITE CLINOZOISITE	GARNET	HORNBLENDE	HYPERSTHENE AUGITE, DIOPSIDE.	'MICAS'	MONAZITE	OPAQUE MINERALS	RUTILE, CORUNDUM, TOURMALINE ANATASE, VESUVIANITE, KYANITE	SCHEELITE	ZIRCON	OTHER MINERALS.
1G	77.5	20.0	1.0	1.5															
1M, 2M.	88.6	9.9	.4	3.1	.04	.02	.001	17.1	2.2	26.5	16.6	6.0	22.5	.001	3.7	1.1	.001	0.8	4.1
2G, 3M.	78.4	18.8	1.2	1.6															
3G, 4G, 5G, 4M, 5M.	62.1	33.7	2.4	1.8															
					.03	.01	.001	15.4	2.3	36.0	13.1	7.7	18.6	.002	3.3	1.2	.001	1.2	1.1
6G, 6M, 7M, 8M.	78.1	16.8	1.2	3.9															
10G, 11G, 12G, 13G, 9M, 10M, 11M.	78.7	17.2	1.0	3.1															
					.09	.01	.001	9.6	2.1	29.3	28.8	5.8	16.1	.001	3.8	1.7	.001	1.1	1.5
7G, 8G, 9G, 9M, 10M.	81.2	16.3	1.2	1.3															
14G, 15G, 12M, 13M, 14M.	74.3	21.4	1.9	2.4															
16G, 17G, 18G, 15M, 16M, 17M.	78.4	17.9	1.4	2.3															
					.08	.01	.0009	3.5	1.17	17.3	45.0	5.02	18.0	.001	4.0	1.5	.001	1.7	1.9
19G, 20G, 21G, 22G, 18M, 19M.	76.7	19.8	1.6	1.9															

TABLE 20. COMPOSITION OF SANDS IN THE TERRACE GRAVELS FROM BETWEEN ATTOCK AND AMB.

VARIOUS MINERALS IN COMPOSITE SAMPLES OF HEAVY NON-MAGNETIC FRACTION 72.89

SAMPLE NO. ON FIG. 4.	LIGHT FRACTION 'FLOAT' (<2.89)	HEAVY NON-MAGNETIC FRACTION >2.89	MAGNETITE	LOSS DURING OPERATION	APATITE SILLIMANITE	BROOKITE	CASSITERITE	CALCITE - DOLOMITE	EPIDOTE ZOISITE CLINOZOISITE	GARNET	HORNBLENDE	HYPERSTHENE AUGITE DIOPSIDE	'MICAS'	MONAZITE	OPAQUE MINERALS	RUTILE CORUNDUM TOURMALINE ANATASE	SCHEELITE	ZIRCON	OTHER MINERALS
1T	81.7	16.0	1.1	1.2	.09	.002	.001	3.2	3.8	13.7	56.9	4.6	8.9	-	3.9	.002	-	-	4.9
2T	93.7	4.2	0.3	2.1															
3T	87.2	10.2	.8	2.0															
4T	84.8	12.5	1.2	1.5	.07	.001	-	-	4.8	16.2	58.8	4.2	6.8	-	4.9	.004	-	1.2	3.0
5T	94.8	4.5	.2	.5															
6T	75.7	21.7	1.6	1.0	.04	-	-	1.8	3.4	14.6	59.3	3.2	7.7	-	3.7	.007	-	1.9	4.2
7T	76.2	20.0	1.6	2.2															

TABLE 21. HEAVY MINERALS PER CUBIC YARD OF SANDS.

A. Flood plain.

Sample no. shown in Fig. 4.	Light fraction	Magnetite	non-magnetic heavy minerals.
1G	1162	15	300
1M, 2M.	1329	6	148
2G, 3M.	1176	18	282
3G, 4G, 5G, 4M, 5M.	930	36	504
6G, 6M, 7M, 8M.	1170	18	252
10G, 11G, 12G, 13G, 9M, 10M, 11M.	1179	15	258
7G, 8G, 9G, 10M.	1218	18	244
14G, 15G, 12M, 13M, 14M.	1101	28	321
16G, 17G, 18G, 15M, 16M, 17M.	1176	21	267
19M, 20G, 21G, 22G, 18M, 19M.	1149	24	297

B. Terrace gravels.

Sample no. shown in Fig. 4.	Light minerals	Magnetite	non-magnetic heavy minerals
1T	1296	16	256
2T	1488	4.8	64
3T	1392	12.8	160
4T	1344	19.2	192
5T	1504	3.2	72
6T	1200	25.6	347
7T	1216	25.6	320

TABLE 22. HEAVY MINERAL CONCENTRATES (NON-MAGNETIC 72.89) EXPRESSED IN LBS/cu. yd.

LOCALITY	APATITE SILLIMANITE	BROOKITE	CASSITERITE	CALCITE - DOLOMITE	EPIDOTE ZOISITE CLINOZOISITE	GARNET	HORNBLENDE	HYPERSTHENE AUGITE DIOPSIDE	'MICAS'	MONAZITE	OPAQUE MINERALS	RUTILE TOURMALINE CORUNDUM ANATASE KYANITE	SCHEELITE	URANINITE	ZIRCON
1. KABULGRAM.	2.1	1.1	.7	9.0	8.3	14.2	142.4	28.3	66.0	.6	12.7	2.3	.2	.4	7.8
2. AMB.	1.9	.5	.85	13.0	2.9	26.7	131.3	13.0	64.0	.3	8.3	2.7	.4	.47	5.7
3. QAZIPUR.	1.7	.8	.9	12.4	6.9	64.2	108.4	18.2	18.3	.3	16.3	3.1	.35	.5	4.7
4. ATTOCK.	1.4	1.4	1.1	86.0	11.1	180.0	90.0	12.7	88.2	.34	15.4	2.6	.31	.41	6.4

Four composited samples of the non-magnetic heavy minerals from the flood-plain deposits of Kabulgram, Amb, Qazipur and Attock, referred to in the preceding table, have been examined and an attempt made to calculate their composition in terms of pounds of mineral per cubic yard of concentrate. The results are listed in Table 22.

Taking the two preceding tables together, it can be calculated that the tenor of uraninite in the crude alluvials is around 0.03-0.05 lbs. per cubic yard. This result is undoubtedly an overestimate since it is much in excess of values obtained from radiometric surveys in the field and laboratory, and from chemical analyses of selected samples. The difficulty arises from the difficulty, in quantitative mineralogical analyses, of distinguishing uraninite from minute opaque cubes of martitized pyrite.

Size analyses of bromoform separates illustrated in figure 14 show that most of the valuable minerals in the alluvials are concentrated in the fractions of finer mesh. Uraninite, monazite, gold and apatite are confined to the very fine and silt-sized grades, while zircon, rutile, scheelite, cassiterite, corundum and sillimanite occur not only in these fractions but also in considerable amount in the fine-sized grades. Garnet and opaque minerals are distributed in all the fractions (Table 15).

A semiquantitative spectrographic analysis of two samples of gold-washers' final residues was carried out, on samples submitted by the writer, in the laboratories of the United States Geological Survey. Results are given below.

TABLE 23. Semi-quantitative spectrographic analyses of gold-washers' residues

Elements	Hunza river	Indus river
Silicon	1.5	1.5
Aluminum	0.3	0.7
Iron	10	10
Magnesium	0.3	0.15
Calcium	0.07	0.07
Sodium	0.7	0.015
Potassium	0.3	0.007
Titanium	1.5	3
Manganese	0.7	0.7
Silver	0.0007	0.0003
Arsenic	1.5	3
Boron	0	0
Barium	0.001	0.007
Beryllium	0	0
Bismuth	0.07	0.003
Cerium	0.07	0.03
Cobalt	0.003	0.003
Chromium	0.007	0.015
Copper	0.003	0.007
Dysprosium	0.007	0.007
Erbium	0.003	0.003
Europium	0.0015	0.0015
Gallium	0	0

TABLE 23 CONTINUED............

Elements	Hunza river	Indus river
Gadolinium	0.015	0.07
Hafnium	0.003	0.007
Holmium	0.0015	0.0015
Lanthanum	0.07	0.15
Molybdenum	0.0007	0.0015
Neodymium	0.03	0.15
Niobium	0.03	0.03
Nickel	0.07	0.07
Lead	0.03	0.03
Praseodymium	0.015	0.03
Scandium	0.003	0.007
Tin	0.03	0.03
Strontium	0.0003	0.0003
Samarium	0.015	0.015
Thorium	0.7	0.7
Uranium	10	3
Vanadium	0.015	0.03
Tungsten	0.07	0.07
Yttrium	0.03	0.03
Ytterbium	0.003	0.003
Zirconium	3.	7.

Economics of Gold Washing

The success of a large-scale mining operation in these alluvials must depend almost wholly on the tenor of gold, uraninite, tinstone and scheelite, which are the only high-value minerals present. It has been shown that the average yield of gold in eleven samples treated by an experienced gold-washer is 1.05 grains per cubic yard. At a price of £12.10s. per fine ounce of gold, this equates to about 6½d. per cubic yard. This is, however, the yield from specially selected beds of sand, naturally enriched in heavy minerals; and since a dredge must work all the alluvium, without special selection, the yield by dredging would for this reason be very much less than that from selective mining. Even if we assume that the manual operation of the gold-washer is so inefficient as to lose half the gold, and that mechanized working would be more efficient, it must be admitted that the yield from dredging, taking all sand and gravel as it came, would be very much less than 6d per cubic yard. This is well under half the poorest recovery obtained from commercial dredging operations elsewhere (e.g., Gold Coast, New Zealand) which according to Skinner's Mining Yearbook demand an overall recovery of 2-2½ grains per cubic yard to be payable - i.e., minimum overall costs are about 1s. 1d to 1s. 4d per cubic yard treated.

From radiometric and mineralogical assays it appears that a ton of the gold-washers' final concentrates evidently contains from 2 to 5 lb. uraninite. Assuming that because of its high density most of the uraninite is retained in these concentrates, the content of uraninite in the parent crude sand must be around 1/1200 of this amount, say around 0.0002%, a figure which is in keeping with the radiometric surveys when the thorium from monazite and the radioactivity of zircon are taken into account. Taking the current price of uranium oxide at 35s. per lb. and assuming that half of this represents the costs of treatment after mining, then the value of the recoverable uraninite in the alluvium selected by the gold-washers is only about one penny per cubic yard. This is the tenor in small local placers specially chosen for their high grade. The tenor in the alluvials considered over all must be very much less than this.

RADIOMETRIC INVESTIGATIONS

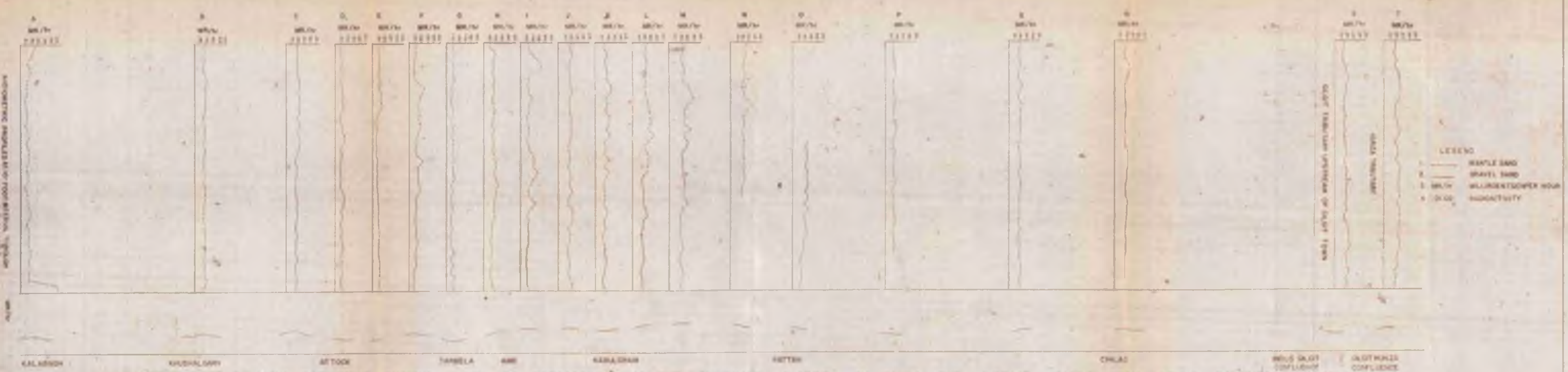
A. Rock Outcrops

The radioactivity of the rock outcrops along the traverse route was measured by means of a portable field ratemeter, and those rocks which had a radioactivity three or four times the background value, or more, were examined in detail and the results plotted on the accompanying map (Figure 18). The background readings ranged from 0.005 to 0.014 mr/hr, the higher values being met with where granitic and gneissic rocks are exposed, and over the alluvials.

Downstream from Attock the sedimentary rocks have an overall low radioactivity, too insignificant to merit plotting on the map. The limestone gave the lowest readings, from 0.002 to 0.005 mr/hr, and the shale and sandstone formations gave from 0.01 to 0.02 mr/hr. These rocks contain occasional concretions which are relatively "hot" and give higher readings when the counter is placed over them.

The metamorphic rocks upstream from Attock contain more radioactive zones, locally emitting as much as 0.15 mr/hr. The principal components of this formation are slaty shale, slate, phyllite, schist, various gneisses, quartzite and limestone. Irregular patches of graphitic material are locally present. The quartzite and limestone do not emit any measure of radiation detectable in the field with the equipment available. The radioactivity over slaty shale, slate and phyllite ranged from 0.01 to 0.025 mr/hr, and that over schistose rocks was slightly

FIG. 10



RADIOMETRIC PROFILE - ALONG THE INDUS, SHOWING LEVEL OF RADIOACTIVITY OF THE ALLUVIALS, PLOTTED BY TAKING THE AVERAGE READING FROM VARIOUS RADIOMETRIC PROFILES (A to T) higher at between 0.03 and 0.04 mr/hr. The highest radioactivity is found in the gneisses, ranging in bands from 0.04 to, exceptionally, 0.15 mr/hr. Over the pockets of graphitic schist the intensity is usually higher than over the surrounding rocks, the common values being 0.03 to 0.04 mr/hr but rising to 0.08 mr/hr in a few lenticles.

The more radioactive metamorphic rocks have a widespread distribution about 6 miles downstream from Amb and upstream from Kabulgram. In the former area the gneiss outcrops emit between 0.04 and 0.08 mr/hr, and in the latter the radioactivity ranges from 0.04 to 0.15 mr/hr. The graphitic pockets with higher radioactivity are found between Tarbela and Amb, along the western bank of the river.

Near the contact with the granodiorite batholith numerous acid veins rich in potash feldspar invade the contact metamorphosed schists and gneisses. Due perhaps in part to potash, the general radioactivity of these rocks is higher than in their counterparts downstream. Gneissose bands with a radioactivity of 0.1 mr/hr have been frequently recorded, and the acid veins show from 0.03 to 0.05 mr/hr. In the radioactive gneisses, when examined in the laboratory under a short-wave ultraviolet lamp, fluorescent spots are visible. These are of two kinds, golden yellow fluorescing grains identified as zircon and minute greenish yellow grains tentatively identified as autunite but possibly uranophane or zippeite. Rocks in which these yellow-green fluorescing grains are more frequent have a higher radioactivity.

The granodiorite batholith which covers a great part of the area under investigation has a low radioactivity, not far above a "background" reading. The acid intrusions of younger granite, pegmatite and aplite which are frequently encountered are more radioactive, giving values of from 0.03 to 0.05 mr/hr. Many chip samples were taken from these rocks to study the source of the radioactivity, and both monazite and zircon were identified. It is believed that these formations are the source of the uraninite in the alluvials, but so far no success has been achieved in attempts to locate the mineral _in situ_. If uraninite does occur in these granites, pegmatites or aplites, the level of radioactivity suggests that the mineral is sparsely disseminated.

The intensity of radioactivity in the lower grade metasediments is not as great as in the higher grade metamorphic rocks. The former are traversed by numerous aplite and pegmatite veins. The radioactivity ranges from 0.02 to 0.05 mr/hr, the various schists giving readings of 0.02-0.025 and the gneisses 0.035-0.05 mr/hr. A few pegmatite veins reached as high as 0.08 mr/hr, this being the maximum radioactivity encountered in these rocks.

B. Alluvials

Alluvial deposits from the tributaries of the Indus in the area under examination were examined radiometrically in an attempt to locate the source of the uraninite and other radioactive minerals.

Alluvials were collected upstream of their confluence with the Indus, and where these had a radioactivity of three to four times the background they were panned, and the concentrates retained for laboratory study. A radiometric analysis of 26 samples of these panned concentrates from the side tributaries was kindly carried out for the writer by the Atomic Energy Division of the Geological Survey of Great Britain, by courtesy of the Director and Mr. S.H.U. Bowie. The results are as follows.(Table 24)

The localities for these 24 samples are as follows -

01 (Soan river downstream of Attock),

02 (Old river terrace near Attock),

030 to 048 (tributaries traversing granodiorite batholith and granite),

052 to 057 (Gilgit river upstream of Gilgit town),

064 to 066 (Hunza river upstream of its confluence with Gilgit river),

D_1 (old terrace gravel in a pit at 80 feet depth from the surface).

Radiometric profiles with determinations at 10-foot intervals were measured over the floodplain alluvials of the Indus and its two major tributaries the Gilgit and the Hunza, at randomly picked spots. These profiles, recorded in Figure 6, provide data on the horizontal distribution of radioactive minerals and on the level of radioactivity along the river.

From the radiometric profiles A to T, it is apparent that the

TABLE 24. Radiometric Analysis by Mica End-Window Assay (Geological Survey of Great Britain)

	Sample no.	$\% eU_3O_8$
1.	01	0.013
2.	02	.0054
3.	04	.022
4.	012	.0029
5.	016	.0091
6.	017	.0042
7.	018	.047
8.	022	.025
9.	024	.0049
10.	026	.017
11.	030	.0076
12.	031	.0007
13.	036	.002
14.	038	.055
15.	041	.0023
16.	042	.015
17.	046	0.28
18.	047	0.0027
19.	048	0.10
20.	052	0.17
21.	057	0.18
22.	064	0.095
23.	066	0.094
24.	D1	.0082

overall level of radioactivity in the bulk alluvials ranges from 0.012 to 0.02 mr/hr, which is 0.002-0.008 mr/hr more than background. This low radioactivity is from sands which do not exhibit natural heavy mineral accumulations and a substantial proportion of the radiation may be from potash feldspar which is present in appreciable amount in the sands. Natural concentrations of heavy minerals in the form of thin streaks and surficial skims are more active, ranging from 0.02 to 0.06 mr/hr. Skims with a high level of radioactivity are most common over the mantle sands. The maximum radioactivity measured over this type of concentrate was 1.0 mr/hr, on an island about 2 miles downstream from Kalabagh. This forms the most radioactive natural accumulation yet encountered in the Indus alluvials. Thus from the radiometric profiles it is apparent that the horizontal distribution of radioactive minerals is quite erratic and higher values are restricted to sporadic spots where natural concentrations of heavy minerals occur.

The radioactive profiles I to O, i.e., from Amb upstream to Pattan, show a somewhat higher proportion of anomalies, which may be accounted for by the more frequent occurrence here of natural heavy concentrates relatively rich in radioactive species. This part of the Indus valley is bordered by metamorphic rocks cut by numerous acid veins of aplite, pegmatite, and younger granite which, as already shown, have a higher than normal radioactivity. Moreover the contact of the metamorphic rocks and the granodiorite batholith is about 7 miles downstream from Pattan. This contact zone, 6 to 8 miles wide, consists of highly metamorphosed rocks frequently traversed by acid intrusives. Gneisses here have a radioactivity of up to 0.15 mr/hr, the highest encountered in bedrock in the Indus valley. This zone is the only one found where a measurable increase in the radioactivity of the alluvials is accompanied by a comparable increase in that of the flanking bedrock. Further upstream, where granodiorite rocks flank the Indus, the level of bedrock radioactivity is lower, as is the case also with the alluvials. These facts suggest that the alluvial uraninite is most probably derived from bedrock bordering the Indus between Pattan and Amb. (Downstream from Amb, the metamorphic formations are intruded by sills and dykes of basic-ultrabasic rock but the acid veins gradually disappear). Another conclusion which can be tentatively deduced from this field evidence is that, if the gneisses and acid veins are the source of the uraninite, then considering the generally low level of radioactivity it is likely that the mineral occurs as sparsely disseminated grains in the rocks and is unlikely to be concentrated into a commercially exploitable deposit.

So far as the two major tributaries are concerned, the level of radioactivity along the Hunza, where a considerable part of the alluvials emit over 0.02 mr/hr, is a shade higher than along the Gilgit, where the values remain below 0.02 mr/hr. In laboratory studies, uraninite was found to be more frequent in the Hunza alluvials than from those in the Gilgit.

Radiometric and chemical assays of bulk sand concentrates collected from the Indus, the Hunza and the Gilgit, made for the writer in the laboratories of the United States Geological Survey and of the Geological Survey of Pakistan, are listed in the following tables.

TABLE 25. Samples of Indus Sand from Amb Village (34°07'N., 72°49'E.)
Hazara District, Pakistan.

Analysed by United States Geological Survey.

Sample No.	Lab. No.	% U.	% Eq. U.
AMB 36/3	154182	.001	.001
AMB 36/6	154183	.001	.001
AMB 36/9	154184	.001	.001
AMB 21	154185	.001	.002
AMB 13	154186	.002	.002
AMB 22	154187	.001	.002
AMB 162	154188	.001	.001
AMB 12	154189	.002	.003
AMB 11	154190	.001	.002
AMB 161	154191	.001	.002
AMB 23	154192	.001	.001
AMB 163	154193	.001	.002
AMB 411	154194	.001	.002
AMB 311	154195	.001	.003
AMB 234	154196	.001	.003
AMB 25	154197	.007	.007

TABLE 26. Samples of untreated Indus Sand from Attock

Chemical Analyses by Geological Survey of Pakistan

(Analyst: M. A. Wahid).

No.	
AU3	Uranium less than 0.001%
A10	Uranium less than 0.001%
A1	Uranium less than 0.001%
AU1	Uranium less than 0.001%
A7	Uranium equal to 0.003%
A6	Uranium less than 0.001%
A70	Uranium less than 0.001%
AB5	Uranium less than 0.001%
A2	Uranium less than 0.001%.

TABLE 27. Samples of Indus Sand from Amb and Ghazi (Hazara)

Chemical Analyses by Geological Survey of Pakistan

(Analyst: M.A. Wahid).

No.	
AMB 36/1	Uranium less than 0.001%
AMB 36/9	Uranium less than 0.001%
AMB 36/10	Uranium less than 0.001%
AMB 36/1	Uranium less than 0.001%
GHAZI 75	Uranium less than 0.001%.

TABLE 28. Goldwashers' Concentrates from Indus Valley

Radiometric and Chemical Analyses by Geological Survey of Pakistan

(Analysts: Aziz Ahmed Khan & Aminul Islam)

Locality	Radioactivity in Equivalent U_3O_8	Chemical analyses for Thorium
AMB	0.110 ± 0.005	0.019
AMB	4.570 ± 0.031	0.394
TARBELA	1.480 ± 0.017	0.548
TARBELA	0.210 ± 0.006	0.132
TARBELA	0.260 ± 0.007	0.093
GHAZI	1.820 ± 0.019	0.241
GHAZI	0.210 ± 0.006	0.030
GHAZI	0.210 ± 0.007	0.21
QAZIPUR	0.060 ± 0.004	0.010
QAZIPUR	0.050 ± 0.003	0.0150
QAZIPUR	0.490 ± 0.010	0.218
ATTOCK	1.240 ± 0.016	0.341
ATTOCK	0.210 ± 0.006	0.030
ATTOCK	0.080 ± 0.005	0.010

THE RADIOACTIVE MINERALS OF THE ALLUVIALS.

The minerals responsible for the radioactivity of the alluvials, listed in order of abundance, are potash feldspar, zircon, monazite, uraninite and uranothorite. One other opaque species was found to affect a nuclear emulsion plate but could not be identified specifically under the microscope. This latter mineral is recorded more frequently in final concentrates from the Gilgit and Hunza tributaries. This may be a refractory uraniferous compound.

Since 100 per cent K_2O has a gamma-beta radioactivity equal to no more than about 0.0007 per cent U_3O_8, the contribution of radioactivity from potash feldspar is obviously small. In the heavy concentrates zircon is a ubiquitous species and since radiometric studies show that most of the zircon is radioactive, it can be accepted that much of the radioactivity derives from zircon.

Monazite is next in order of abundance. It usually occurs in substantial amounts in the natural heavy accumulations. There are two varieties, one forming colourless grains and the other, more abundant, being of a pale yellow shade. Radiometric studies show that both types have the same level of radioactivity.

Uranothorite has been found sporadically only in the highly concentrated final residues from gold-washing operations. Usually it occurs as small tetragonal prisms with pyramidal terminations, resembling zircon. It is most commonly of a greenish-black or brown colour.

Uraninite also has been found solely in the gold-washers' final residues, but it is more frequent than uranothorite. Since 1957 the Indus uraninite has been much publicised in the writings of Dr. Zeschke and Professor Ramdohr, who have made analogies between the distribution of this mineral in the river alluvium and its occurrence in the bankets of the Witwatersrand. The writer worked with Dr. Zeschke on this problem in Pakistan during 1957-58, and most of the samples described by the latter, particularly those from the upper reaches of the Indus at Chilas and Gilgit, were collected in the course of the writer's field-work. From studies continued independently by the author the following facts have come to light.

1. Uraninite and gold assemble together in the gold-washers' residues, but there is no sympathetic or genetic relationship between the two minerals. In the floodplain alluvials the two minerals may occur side by side, but their sources appear to be quite different. This was confirmed by studies on the side tributaries. One small tributary in the Gilgit agency, locally named Bagrot Gah, contains gold in its alluvials. The writer conducted a gold-washer's operation and confirmed the existence of gold. No uraninite could be identified in the final residues and subsequent radiometric examination of a highly panned sample showed a radioactivity of only 0.0027 per cent eU_3O_8. This sample, however, was found to be quite rich in sulphide minerals and besides pyrite and chalcopyrite considerable detrital arsenopyrite was identified.

2. It has been stated by Dr. Zeschke that the gold originating from the Indus is invariably radioactive. It is difficult to see how this can be so, since the gold is separated by amalgamation and then distilling off the mercury; but it is possible that grains of uraninite might contaminate the gold. The author, however, has carried out radiometric tests on gold samples from different localities and in no case were they found to be radioactive. Apparently if the gold is washed well after separation, as is confirmed by the author's pannings, no radioactivity is encountered. To test this issue further, ancient gold coins and ornaments of the Budhist civilisation about 3000 years ago, now in the Taxilo museum, were examined by scintillometer and none was found to be radioactive. The gold of these coins and ornaments is commonly believed to be of Indus origin.

3. Hand-picked uraninite from the Indus river has been chemically analysed in the laboratories of the Geological Survey of Pakistan, and found to contain from 6 to 8 per cent thorium oxide. This result has been confirmed by the Geological Survey of Great Britain (Atomic Energy Division) who report 6 per cent ThO_2.

4. In size range, uraninite grains are most frequent in the very fine (⅛ mm.) and silt-size (1/16 mm.) fractions. There is no difference between the size of the detrital uraninite from Amb and that

from Chilas and Gilgit in the upper reaches of the Indus, and Dr. Zeschke's contrary reports suggesting an alluvial fractionation according to grain-size are not confirmed.

5. Uraninite has been recognised only as well-formed cubes and more rarely as octahedra, always of minute size. No etching or solution effects on these grains were observed.

6. Uraninite is not confined to the Indus alluvials above Attock but it has been recognised as far downstream as Kalabagh.

7. To study the problem of survival of detrital uraninite, highly-panned concentrates of heavy minerals were made from alluvials derived from the Siwalik shale and sandstone formations. These sediments were deposited by the ancient Indo-Brahm river system which flowed along the foothills of the Himalayas during upper Pliocene and Pleistocene times. The heavy mineral suites obtained in this way were found to be similar to those from the modern floodplain deposits, and contain gold; but no trace of uraninite was found. Moreover the river terraces exposed along the banks of the Indus, a few hundred years old, have been explored for uraninite by investigation of heavy concentrates. These deposits are still loosely packed and unlithified. In the pannings from this source uraninite is at best rarer than in the modern alluvials, and most of the samples did not yield a single grain

of the mineral. It is therefore plain that although detrital uraninite occurs in these alluvials, it does not survive for any length of time (geologically speaking). Its long transportation in the floodplain of the Indus may be attributed to the very cold temperature of the river water, derived from numerous tributaries which have their source in melting ice-fields. Transportation takes place principally during the flood season when the river is turbulent and has a high velocity, and Dr. Zeschke's claims that the mineral has survived for 150,000 years cannot be supported.

8. A radiometric profile has been drawn for the course of the Indus, based upon the average radioactivity of local radiometric profiles at sites along its banks. This indicates that there is no noteworthy upstream increase in the level of radioactivity in the alluvials. Apparently, therefore, there is no single major source of the uraninite found in these alluvials, and it is most likely that the mineral has its primary distribution as sparsely disseminated grains in widely distributed source rocks. In earlier pages the writer has tried to delineate the regions which may be a source of uraninite upstream from Amb; but more work is needed, particularly in the tributaries of the Indus, before any firm conclusion about the precise source of the mineral can be reached.

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