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CONTENTS

GEOLOGY OF THE CANIZAR DEL OLIVAR AREA, MONTALBAN, SPAIN

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Abstract :—*On the basis of newly collected field data and the interpretation of the aerial photographs, the previous geological map of the Canizar del Olivar area has been improved on a scale of 1 : 18,000 over a previous scale of 1 : 50,000 and the stratigraphy is revised. Furthermore, some structural elements are also identified.*

INTRODUCTION

Geological studies of the Canizar del Olivar area (Fig. 1) were carried out in May-June, 1994, to prepare a detailed geological map on a much larger scale (1 : 18,000) against a previous mapping of 1 : 50,000 for revision of the stratigraphy and the structural framework on the basis of interpretation of the aerial photographs and field data.

A number of geologists especially from the International Institute For Aerospace Survey and Earth Sciences (ITC), the Netherlands, have worked in this area in the past (Mekel and Meer Mohr, 1971; Mekel, 1976; Ginkel and Mekel, 1981; Meer Mohr, 1983; Beekman and Meer Mohr, 1986). This paper describes the geology of the Canizar del Olivar area alongwith an improved geological map (Fig. 2). Stratigraphic terminology has been adopted after Ginkel (1981). The succession is exposed from Triassic to Quaternary (Ginkel and Mekel, 1981).

STRATIGRAPHY

Following is the stratigraphic succession exposed in the mapped area (Fig. 3).

Quaternary
Alluvial Deposits
——Unconformity——

Tertiary
TORRECILLA GROUP
——Unconformity——
Late Cretaceous
Guadalope Marl
Canadilla Formation

——Unconformity——

Early Cretaceous
ALIAGA GROUP
Utrillas Formation
Palomar Formation
——Unconformity——

Early Jurassic-Middle Triassic
OLIETE GROUP
Martin Limestone

MONTALBAN GROUP
Cantalera Dolomite
——Unconformity——
Monforte Marl
La Hoz Dolomite
(Base not exposed)

MONTALBAN GROUP

This group comprises four formations namely the La Hoz Dolomite (R2), the Montforte Marl (R3), the Zarza Dolomite (J1) and the Cantalera

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Dolomite (J2). The Zarza Dolomite (J1) is missing in the area. The rocks of this group were deposited in transitional (lagoons, tidal flats) and restricted shallow marine environments under hot and arid conditions.

MIDDLE TRIASSIC
La Hoz Dolomite (R2)

The formation mainly consists of well bedded dolomite with shale and argillaceous limestone at the top. The dolomite is light to medium gray, thin to medium bedded and micritic with wavy bedding planes. It contains horizontal worm burrows. The shale is greenish gray, silty and fissile. The upper contact with the Montforte Marl is conformable. Fossils are rare in this formation. Age is Middle Triassic. Its photo tone is light to dark gray.

LATE TRIASSIC
Montforte Marl (R3)

The formation consists of red, gray gypsiferous clay and marl with minor siltstone. It is mainly exposed near Canizar del Olivar forming an anticlinal structure. The lower contact with the La Hoz Dolomite (R2) is conformable and the upper contact with the Cantalera Dolomite (J2) is unconformable but near Canizar del Olivar its lower contact with the Palomar Formation (K2) is faulted. No fossils are found in the area. Age is Late Triassic. Its photo tone varies from light to dark gray and is smooth textured.

EARLY JURASSIC
Cantalera Dolomite (J2)

The formation mainly consists of dolomite. It is medium gray, yellowish brown to reddish brown, brecciated, recrystallized and massive. The lower contact with the Montforte Marl (R3) is unconformable. The upper contact with the Martin Limestone (J3) is conformable and with the Palomar Formation (K2) and the Utrillas Formation (K3) is unconformable but, at places, it is fault-

ed with the Martin limestone (J3) and the Palomar Formation (K2). Fossils are rare. Age is Early Jurassic. It gives light gray photo tone without cultivation.

OLIETE GROUP

This group consists of seven formations but but only lowermost Martin Limestone (J3) is exposed. The rocks were deposited in open marine, shallow shelf environments.

Martin Limestone (J3)

This formation consists of well bedded limestone. It is light gray, thin to medium bedded and micritic with wavy bedding planes. The lower contact with the Cantalera Dolomite (J2) is conformable and the upper contact with the Palomar Formation (K2) and the Utrillas Formation (K3) is unconformable but, at places, its lower contact with the Palomar Formation (K2) and upper contact with the Cantalera Dolomite (J2) is faulted. Only some shell fragments and bivalves are present. Age is Early Jurassic. It shows medium gray photo tone without cultivation.

EARLY CRETACEOUS
ALIAGA GROUP

This group consists of three formations, namely, the Parras (K1), the Palomar (K2) and the Utrillas (K3) but the Parras Formation (K1) is missing in the area. It was deposited in shallow marine, transitional (beach, estuarine) and continental environments.

Palomar Formation (K2)

The formation consists of alternating beds of limestone and marl. The limestone is gray to yellowish gray, medium bedded, sandy and marly. It is rich in fossils especially orbitolinids and some echinoids near the base. Near the contact with the Utrillas Formation (K3) in the northwest of Canizar del Olivar, the upper part contains oyster beds alongwith other fauna. The lower contact

with the Cantalera Dolomite (J2) and the Martin Limestone (J3) is unconformable but in the north-west of Canizar del Olivar, it displays normal fault contact relationship with the Montforte Marl (R3). The upper contact with the Utrillas Formation (K3) is conformable except in the south where it is thrusted by the Martin Limestone (J3) and the Cantalera Dolomite (J2). The formation is richly fossiliferous and its age is considered as Early Cretaceous. On aerial photographs its tone is medium to dark gray.

Utrillas Formation (K3)

The formation consists of variegated sand-stone, clay, siltstone and shale. The lower part mainly covered by vegetation is probably shale and marl. In the upper part sandstone, clay, siltstone and silty shale predominate. The sandstone is white, red, yellow to purple, massive, fine to medium grained, micaceous, cross-bedded and contains iron concretions. It is followed by white massive clay with siltstone interbeds at intervals. The siltstone is yellowish gray while silty shale is yellow-wish green. The lower contact with the Martin Limestone (J3) and the Cantalera Dolomite (J2) is unconformable whereas its upper contact with the Canadilla Formation (K4) is conformable and is placed where first limestone bed appears. No significant fossil was found. Age is Early Creta-ceous. Its photo tone is light to medium gray with cultivation in valleys and slopes.

LATE CRETACEOUS
Canadilla Formation (K4)

The formation consists of limestone, dolomite and marl. During present study this formation is also subdivided into two units (K4-1 and K4-2) like other areas.

Unit K4-1

This is a unit of interbedded gray limestone and marl. The limestone is thinly bedded, dolo-mitized and fossiliferous.

Unit K4-2

This unit consists of gray to yellow, thick bedded to massive limestone. It is brecciated and contains fossils.

The lower and upper contacts with the Utrillas Formation (K3) and the Guadalope Marl (K5) are conformable respectively. The age is Late Cretaceous. Sedimentation took place in transi-tional shallow marine depositional environments. It gives light to medium gray photo tone.

Guadalope Marl (K5)

The formation is consisted of dark red marl and marly limestone mainly covered with vegeta-tion and is restricted to the core of the synclinal structure. The lower contact with the Canadilla Formation (K4) is conformable. Age is Late Cretaceous. Photo tone is medium gray.

TERTIARY
TORRECILLA GROUP(T)

The undifferentiated Torrecilla Group consists of red and yellowish brown conglomerate, sand, stone, shale and marl. It is mainly covered with vegetation and is exposed in the southeastern corner of the area. Its lower contact with the Palomar Formation (K2) and the Cantalera Dolomite (J2) is unconformable. Age is Oligocene to Miocene. The rocks were deposited in continental environ-ments. The photo tone is dark gray.

QUATERNARY (Q)
Alluvial Deposits

This comprises unconsolidated fine to coarse clastics showing cultivation pattern. Age is recent. It gives light to dark gray photo tone.

STRUCTURAL GEOLOGY

The study area is located in the northeast of the Penarroyas Monocline forming the northeast flank of the Montalban High. The main structural trends are E-W directions in the area. The impor-

tant structural elements are as follows :

Thrust Faults

The thrust faults shaping the structural frame of the area range from Early Jurassic to Early Cretaceou. Oldest thrust fault is developed between Cantalera Dolomite (J2) and Martin Limestone (J3) along which Cantalera Dolomite (J2) thrusts on to Martin Limestone (J3) from south to north with a north wardconvex E-W fault zone (Fig. 4a).

The second major thrust is developed in the central part of the area between Martin Limestone (at places, Cantalera Dolomite) and Palomar Formation (K2) where Early Jurassic Martin Limestone (at places, Early Jurassic Cantalera Dolomite) thrusts on to Early Cretaceous Palomar Formation from south to north with a northward convex E-W curvilinear fault zone.

Normal Faults

The straight to curvilinear normal faults are observed having some lateral off-sets. These are oriented N-S, E-W, NW-SE and NE-SW. They are mainly developed within the Cretaceous units. In the south of Canizar del Olivar, a normal curvilinear fault running NE-SW direction uplifted the southern block. Movements of N-S faults are probably mainly vertical and eastern block upthrown.

Folds

There are two main fold structures in the area. They are generally singly to doubly plunging anticlines and synclines with their fold axes oriented approximately E-W direction. In the south of Canizar del Olivar the Montforte Marl (R3) is in

the core of h the anticline with its axis trend oriented E-W direction with Jurassic and Cretaceous units at its flanks.

In the southern part of the area the resistant Late Cretaceous Canadilla Formation (K4) which rests on the top of Utrillas Formation (K3) forms an asymmetrical syncline with E-W axis trend containing some Late Cretaceous Guadalope Marl (K5) in the core (Figs. 4b). Minor other fold struructures are also observed especially near the fault zones with different orientation of fold axes (Fig. 5a) Some intraformational microfolding is also found in the Utrillas Formation (Fig. 5b).

CONCLUSIONS

1. The Lower Cretaceous Palomar Formation has been traced in some new places.
2. The Upper Cretaceous Canadilla Formation (K4) has been subdivided into two members on the basis of lithology as is the case in other areas.
3. The Upper Cretaceous Guadalope Marl (K5) is newly identified.
4. A thrust fault has been traced between the Martin Limestone (at places, Cantalera Dolomite) and the Palomar Formation.

ACKNOWLEDGEMENTS

Fig. 1. Location Map of the Canizar Del Olivar Area.

FIG. 2A. GEOLOGICAL MAP OF THE
CANIZAR DEL OLIVAR AREA
ON REVISED SCALE.

LEGEND

Q	Alluvial deposits.
T	Torracito Group
Ks	Guadalope Marl
K4-2 / K4-1	Cañadilla Formation
K3	Fm. Blas Formation.
K2	Polomar Formation
J5	MorHe Limestone
J2	Cantalero Dolomite
R3	Mantfona Marl
R2	La Hoz Dolomite

Unconformity
Dips
Stratigraphic boundary
Fault
Thrust Fault
Anticline
Syncline

Scale
0   300   600m

FIG. 2B. CROSS SECTION ALONG A–B LINE.

SYSTEM	SERIES	GROUP	FORMATION	LITHOLOGY	DESCRIPTION	ENVIRONMENTS
TERTIARY		TORRECILLA	T		Red and yellowish brown conglomerate, sandstone shale and marl	Continental
CRETACEOUS	LATE	ALIAGA	K5		Dark red marl and marly limestone	Transitional
			K4		Gray to yellowish gray, thick bedded to massive, brecciated and fossiliferous, limestone.	Shallow marine
					Limestone and marl interbeds. Limestone: gray, thin to medium bedded.	Transitional
	EARLY		K3		Yellowish green silty shale. Yellowish gray siltstone. White massive clay with siltstone intercolations. Sandstone; Variegated, fine to medium grained micacaceous, cross bedded.	Continental
			K2		Shale (covered) Limestone and marl interbeds. Limestone: Yellowish gray, medium bedded, fossiliferous.	Transitional
JURASSIC	EARLY	OLETE	J3		Medium gray, thin to medium bedded, micritic fossiliferous limestone.	Shallow marine
		BAN	J2		Gray to yellowish brown, massive brecciated and recrystallized dolomite.	Shallow marine
TRIASSIC	LATE	MONTA	R5		Red, gray gypsiferous clay and marl with minor siltstone.	Transitional
	MIDDLE		R2		Light to medium gray, thin to medium bedded, micritic dolomite with shale and argillaceous limestone in upper part, wavy bedding plans	Shallow marine

(Not to scale)

Fig. 3. Stratigraphic column in izar Dil Olivar area.

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FIG. 4a. SCHEMATIC SKETCH OF MESOZOIC ROCKS (SECTION LINE 1 IN FIG. 1.)

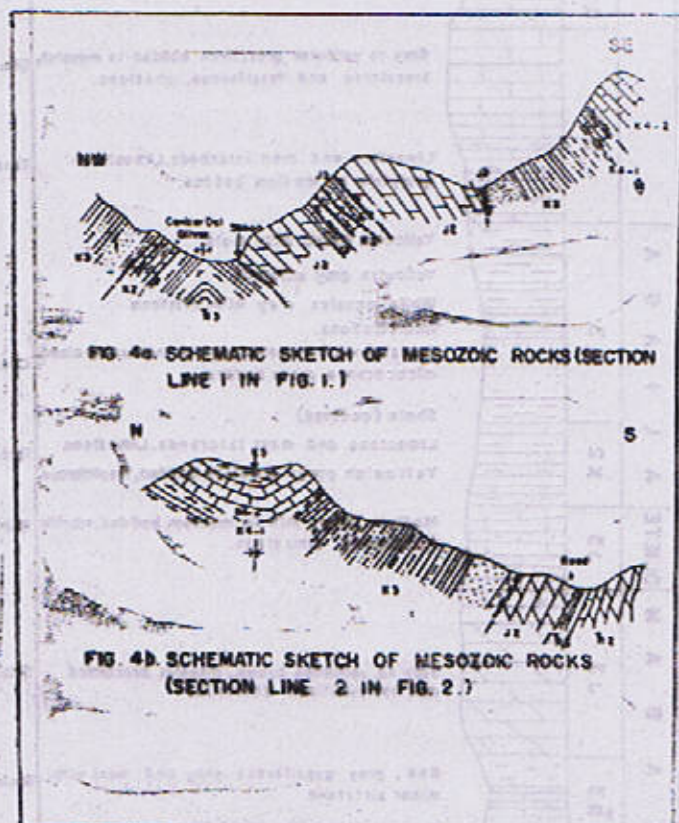FIG. 4b. SCHEMATIC SKETCH OF MESOZOIC ROCKS (SECTION LINE 2 IN FIG. 2.)

Fig. 5 a.   Gentle folding in Canadilla formation (K 4).

Fig. 5 b.   Intrafornational Microfolding in Utrillas Formation (K 3).

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CHEMISTRY OF THE MONSOON PRECIPITATION FROM LAHORE, PAKISTAN

By

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Abstract :— *Rain water samples were collected from Lahore, Pakistan during the monsoon season for the years 1993, 1994 and 1995 to analyze for sea-dominated cations, such as Na, K and Mg. The weight ratio of Na/K has been used to identify the pulses of the sea storms/hurricanes. The EF (sea) for K as a function of Na concentration in the rain water samples, shows the non-enriched element behaviour entirely of sea origin, while EF (sea) for Mg shows a slightly enriched element behaviour for some samples pointing out a non-oceanic source which is most probably through anthropogenic activities.*

INTRODUCTION

Global atmospheric chemistry is often perturbed by the anthropogenic activities in the form of pulses. These pulses can be identified in the rain water. The monsoon system in Indo-Pak region is the major system responsible for rainfall. It covers the Indo-Pak subcontinent and a part of the Far-east Asia.

In this paper the chemistry of rain water samples of monsoon has been presented. The main objectives of the study were (a) to asses and identify the anthropogenic pulses recorded in the form of changed chemistry of rain water in the region, (b) to differentiate between the chemistry of various dissolved elements of two contrasting seasons, i.e., winter and summer, (c) to study the input sources responsible for introducing the material into the atmosphere of the region.

MATERIAL AND METHODS

Series of rain water samples were collected in the successive rainfalls during monsoon season for the years 1993, 1994, 1995. Rain water samples were collected from the top (first floor) of author's residence at Gulberg, Lahore, Pakistan (at a fixed point) in plastic bottles (400ml capacity) with the help of glass funnel (4" diameter) so that a representative homogeneous sample of one rain spell was obtained. The sampling site was kept at 5 feet above from its surrounding to avoid any contamination. These samples were analyzed for Na and K by Flamephotometer, Mg by Atomic Absorption Spectrometer and pH by digital pH Meter.

RESULTS AND DISCUSSION

The data for Na, K, Mg and pH of the rain water samples of three successive years along with their averages is given in Table 1. It can be seen from Table 1 that the data for both individual and average cationic concentrations of rain water samples of the monsoon gives little information, i.e., what is happening in this region. This may be because of the variable quantity of the rain water which certainly disturbs the input signals in the

atmosphere,. For example, a greater volume of rain water would dilute the signals and vice versa. However, it is important to know that the use of elemental ratios is the only solution for such type of data where the ratio of elements remains the same, regardless of the varying amount of rain water. A variation in the elemental ratios would therefore indicate any perturbation in the background signals. Therefore, in the this paper, only the elemental ratios will be discussed for the better interpretation of what is happening in the region?

According to the Encyclopaedia Britannica (1986), the monsoon system is described as the difference of temperature over land and sea, and the southwest wind is a diverted southeast wind from the south of Indian ocean which after some 4,000 miles journey is highly charged with water vapour and on reaching the north of India is caught in the box-like arrangement of the Himalayan belt. Chester (1990) described this system as the alteration of westerly winds which in this season converts to monsoon system. Ruddiman and Kutzbach (1991) explained this system as the result of sun heat at high plateaus in summer, which in turn rapidly warm the thin overlying atmosphere and produce low pressure. The process ultimately leads to the seasonal monsoon rains in Asia. The air in the lower atmosphere swirls anticlockwise toward and around the plateau in summer. However, in winter the process reverses.

From above, it is clear that this wind system develops in summer (from July to November) when the loaded winds from the Arabian sea and Indian ocean rises and travel towards the low pressure regions, i.e., the great Himalayas, causing heavy rainfall in the region in a periodic fashion. Another important point which can be concluded from this discussion is that *No Himalayas No Monsoon.*

Simpson (1921) classified the Indian Monsoon System into two categories, i.e., (a) a Bad monsoons when the Indo-Pak subcontinent receives less rainfall, (b) a Good monsoon, when the Indo-Pak subcontinent receives a sufficient rainfall. It appears from Table 1 that the monsoon season for the years 1993 and 1994 are not good monsoon seasons due to less precipitation recorded. However, the monsoon 1995 is a good monsoon year with plenty of rainfall causing lots of floods in various parts of Asia.

The troposphere is a reservoir in which elements are present in particulates, gaseous and liquid forms. These elements in the atmosphere are introduced mainly through the direct formation of particles (e.g., during crustal weathering, sea salt generation, volcanic emissions) and the indirect formation of particles in the atmosphere itself by chemical reactions and by the condensation of gases and vapours (Chester, 1990). A part of these elements is then removed from atmosphere through the process of precipitation of water vapours in the form of droplets, eventually the rainfall.

The ratios of crust or sea dominated elements are often used to identify the pulses of various atmospheric inputs. Chester (1990) pointed out that the K and Mg in the world aerosols have a predominantly oceanic source. Na ion is a major Cation specie in sea water. Therefore, the Na/element ratio can be used to study the variation in the samples of each successive rainfall. For this purpose, variation of Na/K is plotted in Figure 1. From this figure, two pulses of sea storms or hurricane can be observed having high Na/K ratios during the monsoon-1993 and monsoon-1994. In these particular spells, the monsoon system is very much perturbed by the sea salt formation during hurricanes or sea storms. However, the average Na/K for the rest of the rain water samples for Good and Bad monsoon is less than 10. The average Na/K (values are ug/ml) of sea water is 25.

It may be therefore concluded that a few rain spells of monsoon had likely to receive a direct sea salt concentration from sea storms or hurricanes which have been transported to land having higher Na/K ratios.

The K and Mg in the world aerosols have purely oceanic source as explained earlier. Therefore, to see the effect of other than oceanic source for Mg and K one can make use of Enrichment Factor (EF) for K and Mg with respect to sea as explained by Chester (1990) for aerosols. In this method, the elemental ratio remains almost the same in a system as initially present in the source input, i.e., sea water or earth's crust. Any EF (sea) value ≤ 10 is described as Non-enriched elements, i.e., those elements have predominantly oceanic source while the samples having EF (sea) values greater than 10 are described as Enriched elements, i.e., these samples have oceanic as well as non-oceanic sources. The rain water is the result of evaporation of sea water on first hand and then travels a long distance before it condenses and falls on the lands/oceans. Therefore, the average elemental concentrations of sea water can be taken for calculations of EF (sea) for various elements to discriminate from non-oceanic input sources. The average chemical composition of sea water from Wilson (1975) has been used for calculations. The formula for EF (sea) for an element 'X' is as follows :

$$EF \text{ (sea) for } X = \frac{\dfrac{\text{Conc. of X in rain water}}{\text{Conc. of Na in rain water}}}{\dfrac{\text{Conc. of X in Ocean}}{\text{Conc. of Na in Ocean}}}$$

The EF (sea) for both K and Mg is plotted in Figure 2. The values of EF (sea) for Mg and K along with their averages are given in Table 1. It can be seen from Figure 2 that EF (sea) for K in almost all samples is less than 10 which is a non-enriched zone where all the samples have predo-

minantly oceanic input source. No other than oceanic input source for K is visible in the diagram. On the other hand EF (sea) for Mg shows relatively hgher values than 10 therefore entering into the Enriched zone indicating predominantly oceanic source slightly perturbed by non-oceanic sources. The non-oceanic input sources of Mg could be the volcanic emission or anthropogenic activities. However, the addition of Mg ions into the atmosphere due to anthropogenic activities is more probable.

It may be concluded from above that the introduction of K into the atmosphere of Asia is predominantly of oceanic origin during evaporation or sea salt formations. In contrast, Mg shows a relatively enriched element behaviour. The input of Mg into the Indo-Pak atmosphere is predominantly oceanic source slightly perturbed by non-oceanic sources.

The average values of EF (sea) for Mg for the monsoon-1993, monsoon-1994, winter-1995 and monsoon-1995 are given in Table 1. It can be seen from this Table that the average EF (sea) shows a decreasing trend from Bad monsoon to Good monsoon. This shows that in Bad monsoon the Mg concentration keeps on adding into the atmosphere from non-oceanic sources which got fewer chances to be removed from the atmosphere due to less rainfall.

It is therefore clear that a Good monsoon is a blessing for Asia which certainly reduces the certainties of air pollution of the region. A Bad monsoon means a Bad atmosphere for Asia.

CONCLUSIONS

The Himalayas are the only major cause of the development of Monsoon System in the region. The winds swirl in anticlockwise in summer and clockwise in winter causing rainfall in the region in a periodic fashion. Heavy rainfalls and floods are the characteristic features of a Good Monsoon, while lesser rainfall is observed in Bad monsoon

The monsoon season for the years 1993 and 1994 are not good monsoon season as there is less rainfall reported. However, the year 1995 is a good monsoon yaear with plenty of rainfall causing lots of floods in various parts of Asia.

A few pulses of sea storms or hurricanes can be identified from the chemistry of rain water samples having relatively higher Na/K ratios. The EF (sea) for K as a function of Na concentrations in the rain water samples shows the non-enriched element behaviour predominantly of oceanic origin while EF (sea) for Mg shows slightly enriched element behaviour indicating predominantly oceanic behaviour perturbed by non-oceanic sources.

A good monsoon is a blessing for Asia which certainly reduces the certainties of air pollution of the region. A Bad monsoon means a Bad atmosphere for Asia.

TABLE 1.

Chemical variation of sea dominated cations in the samples of monsoon rain collected from Lahore, Pakistan (units ; ug/ml.)

Dates	pH	Na	K	Mg	Na/K	Mg/Na	K E.F.K. 5:0	F.F.MF 15:0
Monsoon-1993								
80-Jul-94	7.46	2.8	1.20	2.51	2.33	0.63	11.37	7.48
09-Jul-94	7.02	2.2	0.70	3.82	3.14	1.32	8.59	14.50
16-Jul-94	7.36	0.5	0.10	1.33	5.00	2.22	8.40	22.50
21-Jul-93	7.62	1.7	0.35	2.77	4.86	1.35	5.56	13.60
23-Jul-93	7.90	4.3	0.30	6.59	14.33	1.43	1.88	12.80
31-Jul-93	7.22	5.9	1.00	5.53	5.90	0.80	4.57	7.83
13-Sep-93	7.21	2.5	0.45	3.58	5.56	1.21	4.86	11.96
Average	7.40	2.8	0.59	3.73	5.87	1.28	6.06	12.91
Monsoon—1994								
31-Jul-94	7.21	1.3	0.25	1.76	5.20	1.14	5.19	11.30
24-Aug-94	7.08	2.3	0.50	2.42	4.60	0.86	5.87	8.78
24-Aug-94	7.32	1.0	0.05	0.99	20.00	0.94	1.35	8.27
03-Sep-94	7.01	4.1	0.55	2.17	7.45	0.47	3.62	4.42
04-Sep-94	7.19	1.5	0.15	0.70	10.00	0.42	2.70	3.90
Average	7.16	2.0	0.30	1.61	9.45	0.77	3.75	7.33

Winter—1995

Date								
27-Dec-94	6.79	5.8	0.85	5 98	6.82	0.09	3.96	8.61
08-Jan-95	6.90	4.5	0.60	3 76	9.00	0.75	3.00	6.98
14-Jan-95	6.89	2.4	0.35	2 89	6.86	1.05	3.94	10.05
12-Feb-95	6.85	4.5	0.55	4.37	8.18	0.87	3.30	8.11
27-Feb-95	7.06	1.1	0.25	2.36	4.40	1.75	6.13	17.91
Average	6.90	3.7	0.50	3.87	7.05	1.06	4.07	10.33

Monsoon—1995

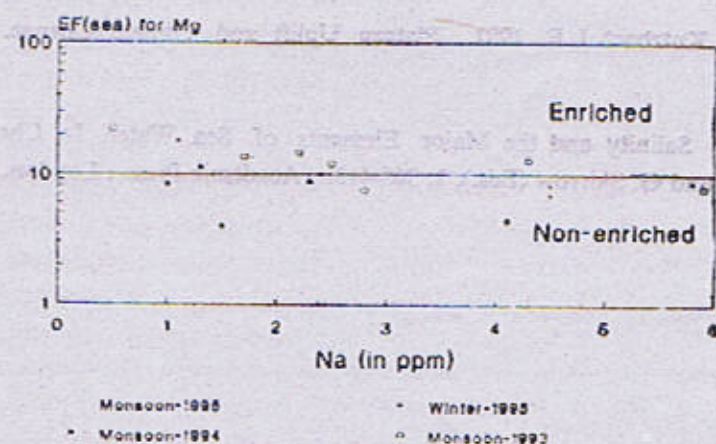| Date								
22-Jun-95	7.61	3.0	0.60	1.29	5.00	0.36	5.40	3.59
15-Jul-95	8.91	2.7	0.60	0.75	4.50	0.23	6.00	2.32
23-Jul-95	7.44	1.1	0.30	1.31	3.67	0.94	7.36	9.94
24-Jul-59	7.44	1.4	0.35	0.54	4.00	0.31	6.75	3.22
27-Jul-95	7.66	0.8	0.20	0.67	4.00	0.76	6.75	6.99
28-Jul-95	7.57	0.8	0.20	0.97	0.00	4.97	6.57	10.12
01-Aug-95	7.18	2.6	0.50	1.47	5.20	0.47	5.19	4.72
04-Aug-95	7.44	1.3	0.20	0.34	6.50	0.23	4.15	2.18
05-Aug-95	7.70	0.5	0.10	0.40	5.00	0.67	5.40	6.68
06-Aug-95	7.91	2.3	0.10	0.10	3.00	0.25	9.00	2.78
10-Aug-95	7.45	4.5	0.60	1.18	7.50	0.23	3.60	2.19
14-Aug-95	7.57	4.0	0.70	2.89	5.71	0.61	4.72	6.03
18-Aug-95	7.72	4.1	1.00	3.62	4.10	0.71	6.58	7.37
21-Aug-95	8.36	1.2	0.30	1.04	4.00	0.69	6.75	7.24
24-Aug-95	8.72	4.0	0.85	1.35	4.71	0.28	5.74	2.82
06-Sep-95	7.73	4.8	1.10	5.14	4.36	0.87	6.19	8.94
Average	7.78	2.3	0.48	1.44	4.70	0.53	6.02	5.45

Variation in Na/K Ratios in Monsoon Precipitation
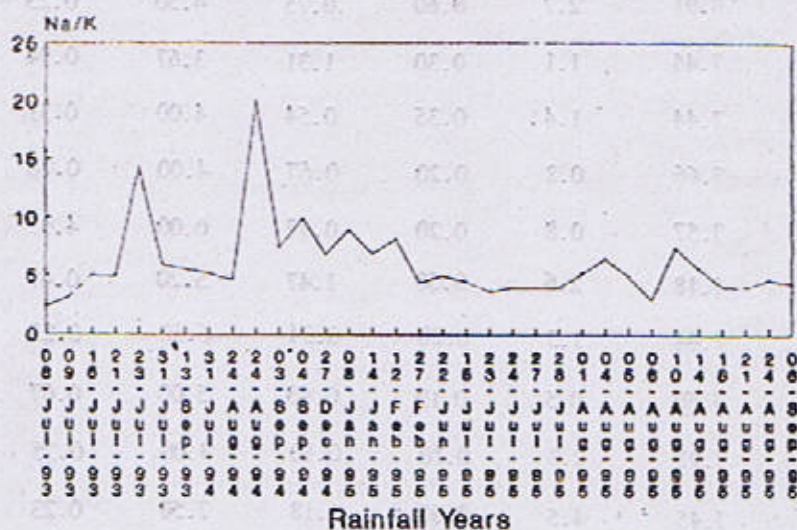
Fig. 1.   Variation of Na/K ratio in the samples of monsoon rain
collected from Lahore, Pakistan (units ; Na and K in ug/ml).

(a)
Variation of EF(sea) for Mg in the samples of Monsoon rain

EF(sea) for Mg

Enriched

Non-enriched

Na (in ppm)

Monsoon-1995 · Winter-1995
· Monsoon-1994 ○ Monsoon-1993

(b)
Variation of EF(sea) for K in the samples of Monsoon rain

EF(sea) for K

Enriched

Non-enriched

Na (in ppm)

Monsoon-1995 · Winter-1995
· Monsoon-1994 ○ Monsoon-1993
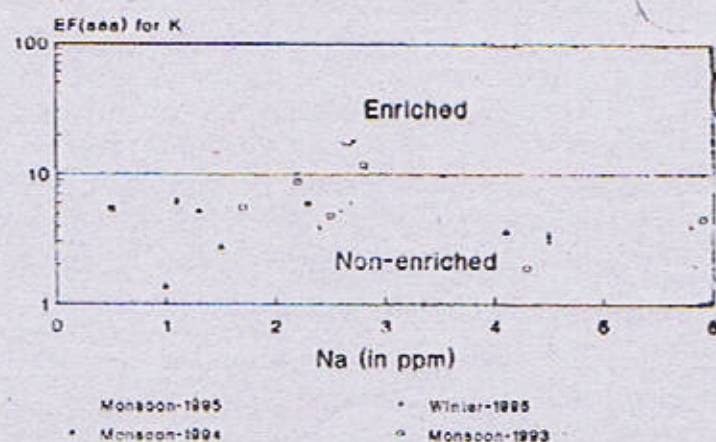
Fig. 2. Distribution of EF (sea) as a function of Na concentration in the rain water samples of monsoon. (a) Variation of EF (sea) for Mg. (b) variation of EF (sea) for K.

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DIAGENESIS AND DIAGENETIC PROCESSES—A REVIEW

By

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Abstract :— *Weathering is a common phenomenon occurring on the continental crust and is the main cause for the change in rocks present on earth's crust through weathering processes while diagenesis occurs in the marine sediments and brings about the changes in the marine sediments through diagenetic processes. Early diagenesis occurs immediately after the deposition of sediments, whilst late diagenesis occurs over a longer period of time. Three main diagenetic processes have been identified in marine sediments. Among them chemical and biological diagenetic processes seem to dominate in the marine environment and hence, are the major contributors in controlling the geochemical cycles of the elements.*

INTRODUCTION

Diagenesis is the sum total of all processes occurring after the deposition of sediments in water, which change or tend to change the genetics of the sediments. On the basis of chronology, it is divided into two major groups; Early diagnesis and Late diagenesis. Early diagenesis occurs immediately after the deposition of sediments and is mostly confined to a few hundred meters in depth, whilst late diagenesis occurs over a longer period of time and is mainly confined to the bottom layers of sediments. In early diagenesis, the chemical processes exceed the physical processes. Conversely, in late diagenesis the physical processes exceed the chemical processes. On the basis of processes, one can divide them into three categories ; chemical diagenesis, physical diagenesis and biological diagenesis.

Chemical diagenesis occurs due to the chemical processes which changes the chemistry of the sediments and physical diagenesis occurs due to the physical processes which bring about physical changes in the sediments. Similar is true for biological diagenesis. A schematic presentation of this classification is given as follows :

Diagenesis
- Early Diagenesis → Chemical diagenesis / Physical diagenesis / Biological diagenesis
- Late Diagenesis → Chemical diagenesis / Physical diagenesis / Biological diagenesis
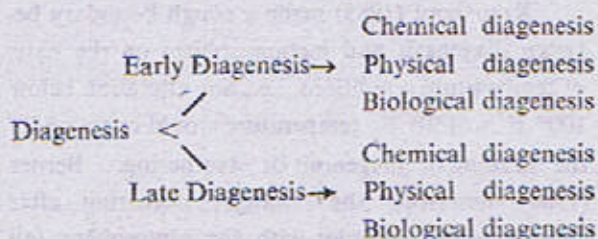
In both the main groups, the processes are the same, but different in their intensities. By using these processes, one can mark off the sedimentary environments. Such an attempt is made by Berner (1981). He used the oxidation, reduction properties of sediments as manifested by the concentrations of dissolved oxygen and sulphide. His new geochemical classification of sedimentary environment is given in Table 1.

No doubt, this new geochemical classification is a new contribution in chemical sedimentology and chelaimed that his new classification

can be applied to the continental, coastal, hemipelagic as well a pelagic sediments. However, the major problem with this kind of classification is that it is purely based on petrographic work and cannot be applied to the modern unconsolidated deep sea sediments due to its very fine grained texture. The second drawback is that the sediments must originally contain sufficient iron and manganese unless it will cause problems, as he mentioned in his paper. Inspite of these problems, this new geochemical classification of sedimentary environment can be taken as a basis for solving the mystery of diagenetic problems. But quite often I will also use a broad classification of sedimentary environments as :

$$Oxic \longleftrightarrow Suboxic \longleftrightarrow Anoxic$$

There always exists a gradational boundaries between weathering, diagenesis and metamorphism, i.e.,

$$Weathering \leqslant - \geqslant Diagenesis \leqslant - \geqslant Metamorphism$$

Krauskopf (1985) made a rough boundary between diagenesis and metamorphism on the basis of temperature conditions, i.e., any alteration below 100° F to 150° F temperature would come under the heading of diagenesis or weathering. Berner (1980) described the changes occurring after contact of the particles with the atmospheric fall under the heading of weathering. Therefore, in our case all alteration occurring in the upper layer of marine sediments fall under the heading of diagenesis or more accurately early diagenesis. The active oceanic ridges, vents and some hydrothermal activities are exceptional. In the following paras, the diagenetic processes have been discussed with respect to different sedimentary environments.

DIAGENETIC PROCESSES

As soon as the sediments finish their global journey and want to take rest at the bottom of the oceans, they are attacked by different diagenetic processes, which continue in the rest of their lives and try to change their genetic. These not only alter the major composition of sediment but also invite trace elements as guests from overlying sea water and from interstitial water at depth. These processes usually occur side by side, however, their intensities vary in space and time. These diagenetic processes may be divided into physical, chemical, biological and radioactive processes.

DIAGENETIC PHYSICAL PROCESSES

These important diagenetic processes brnig about physical changes in the marine sediments after burial. The effects of these processes are small in early diagenesis. However, a tiny change in some physical processes may cause a great change in the nature of sediments. The degree of their intensities has a direct relation with depth. The greater the depth the more intense physical processes are.

At greater depth these diagenetic physical processes grade into metamorphism. But we are only concerned with a few hundred meters depth of early diagenetic zone. Among diagenetic physical processes the most important are, compaction and diffusion.

Compaction

Compaction is a broad term and is applied to any process in which a substance is compressed under compressional stresses which may external or internal. In our case, the be sediments are mainly compressed by the force of gravity which, in turn, is a weight of overlying sediments and water column. Intermolecular forces are said to be the internal forces which also contribute its effects in compaction. As a result, the particles get closer and closer to make a more compact structure by expelling pore water. The flushed pore water then moves towards the least pressure area, i.e., laterally or vertically up-

ward. In compaction, three phenomena are usually taken into account, i.e., porosity permeability, and cementation.

Porosity

Porosity is defined as the total number of voids present in the sample. It is usually expressed in percentage, as follows :

$$\% \ \phi = \frac{\text{Total number of voids}}{\text{Total volume of the sample}} \times 100$$

Porosity has an inverse relation with compaction and depth. Therefore, sea surface sediments have a maximum porosity due to minimum compaction. Keller (1970) suggested that certain properties such as water contents of over 500%, porosities of 70-80%, liquid limits of 250 and liquidity indices of 3,000 are more or less unique to all submarine deposits. From this, it is possible to express the porosity of the marine sediments by an equation. Berner (1980) expressed a relation between porosity and depth in marine sediments as,

$$\phi = 0.60e^{-0.1x} + 0.30$$

where x is the depth in meter and ϕ is the porosity. If we multiply ϕ with 100, we will get %age porosity. By putting $x = 1$, the corresponding %age porosity would be 84% which is more or less the same as indicated by Keller (1970). A graphical representation of ϕ versus x (from the above equation) suggests that the relation is not linear ϕ changes drastically in a few meter depth and then shows linearity. It means that maximum compaction changes occur in the upper few meters of the sediments.

According to Schlumberger (1972), there also exists a relation between porosity and the formation factor of the sample. Formation factor may be defined as the ratio of the electrical resistance of a brine-filled porous medium to the electrical resistance (in ohms) of the brine occupying the same volume as the bulk porous medium. For-

mation factor is usually denoted by 'f' as follows :

$$f = \frac{R_o}{R_w}$$

Where,

R_o = Resistance of the porous medium filled with brine

R_w = Resistance of the Brine

A number of relations are established for various sediments to relate the porosity with formation actor as given under :

$$f = \frac{\theta^{5/3}}{\phi}$$

$$f = \frac{\phi}{\theta}$$

$$f = \frac{\phi^2}{1} \quad \ldots\ldots\text{for sand stone}$$

$$f = \frac{1}{\phi^2} \quad \ldots\ldots\text{for sand}$$

$$f = \frac{1}{1 \cdot 3\phi} \quad \ldots\ldots\text{for sand}$$

data from Lerman (1979)

$$f = \frac{1}{\phi^n} \quad n - 2.5 - 5.4 \ . .\text{for clays}$$

$$f = \frac{0.81}{\phi^2} \quad \ldots\ldots\text{in sand}$$

data from Schlumberger (1972)

$$f = \frac{0.62}{\phi} \quad \ldots. \text{Humble Formula}$$

where,

ϕ = Porosity of the sediment

ϕ = Tortuosity of the sediments;

It is defined as the ratio of the mean length of the path followed by an ion from one point to the other in the porus medium to the length of the same point joining by the straight line.

From the above relations, one can easily predict the porosity of the formation. The humble formula in this regard, is supposed to have a wide

range applications and gives satisfactory results. The knowledge of porosity is helpful while making diffusion models. The formation factor (f) along with porosity (ϕ) of some deep sea sediments are given in the Table 2.

Porosity has a direct influence on the diagenesis of sediments. The sediments, high in porosity, will obviously hold more pore water hence, more intense and rapid reaction will occur between pore water and the sediments. Therefore, porosity can be taken as a direct measure of the pore water content of the sediments which usually decreases with depth.

The term primary and secondary porosity is quite often used by petroleum engineers to describe the oil well condition and should not be confused here. In a simplest way, the primary porosity is developed in early diagenesis, while secondary porosity is developed in the late diagenesis, e.g., in most of the limestone oil reservoir rocks, the secondary porosity is due to cracks, fissures, joints, or faults developed by tectonic forces or by chemical actions such as dolomitization, dissolution etc.

Permeability

Permeability is defined as the number of interconnected voids present in a sediment or it is the ease by which different rocks, soils and sediments allow water to pass through them. Like porosity, it is also expressed in %age and can be related as,

$$\text{\%age porosity} = \frac{\text{Total number of interconnected voids}}{\text{Total volume of the sample}} \times 100$$

For most civil engineering purposes, the permeability is expressed in Darcy. It is not necessary that a sediment having high porosity should have high permeability, e.g., clay has a maximum porosity but has less permeability due to the lack of interconnected voids. It mainly depends on the type of sediments. The coarse grained well sorted sediments have high values of permeability. It is also

affected by compaction. Like porosity, it has a direct effect on the diagenesis of the sediments in a sense that the sediments having more permeability values allow to pass more water through them. Therefore, more chances are provided to the dissolved species to attack on the particle surfaces. In oceans, permeability has more lateral distribution than the vertical. This phenomenon is more common in near shore sediments.

The empirical relation between porosity (ϕ) and permeability (K) is found by different workers. However, for our purpose, i.e., for most of the marine clayey sediments, the following expression holds good, i.e.,

$$k = 10^{-9} \times \left(\frac{\phi}{1 - \phi}\right)$$

Where k is expressed in Darcy ; permeability is also termed as effective porosity.

Cementation

Cementation is a process by which a cementing material fill in the pore spaces of sediments. This may happen either due to precipitations or chemical reactions. The cementing material is commonly $CaCO_3$. Sometimes dissolved SiO_2 (opaline silica), Fe-oxides, Mn-oxides and very fine clayey particles of colloidal size act as a cementing matter. Cementing phenomenon is more common near shore sediments due to high permeability. Most important is that shore area lies above the CCD (Carbonate Compensation Depth).

In deep sea sediments, especially those lying below the CCD, do have a cementing problem, but here, the cementing material is other than $CaCO_3$, i.e., Fe and Mn oxides. In some cases, the cementing material in deep sea sediments is $CaCO_3$.

Apart from $CaCO_3$, opaline silica ($SiO_2 \cdot nH_2O$) comes from the dissolution of quartz or by the dissolution of shell materials (e.g., diatoms, etc.) Berner (1971) regarded this as a late diagenetic

process due to the absence of cemented silica in recent sediments. From the point of trace metal diagenesis, the cementing process either by $CaCO_3$ or SiO_2 and Mn-Fe-oxides play an important role in precipitating and diffusing the trace elements from one place to other.

Diffusion

This important diagenetic physical process can be defined as the migration of matter from one part of a system to another part of the system either by random molecular motion or turbulent (or eddy) currents. When the migrated matter is in dissolved form (i.e., ions, molecules or atoms) then the phenomenon is called molecular diffusion. When it contains colloidal or particular, form then it is called dispersion. In deep sea sediments, only molecular diffusion is of significant importance. So, more emphasis will be given on this topic.

The molecular diffusion is the migration of molecule, atoms or ions by intermolecular type forces. The driving force for the molecular diffusion is the gradient of the chemical potential of the diffusing species. This simple principle was first quantified by Ficks (1855) and appeared in the form of first and second laws of diffusion. It states that,

"The mass of a substance crossing a unit area per unit time in a given direction is directly proportional to the concentration gradient measured normal to the section," i.e.,

$$F \propto \text{concentration gradient}$$

or

$$F \propto -D \cdot \frac{dc}{dx} \quad \text{(Fick's First Law of Diffusion)}$$

Where D is the proportionality constant and usually known as the molecular diffusion co-efficient expressed in area per unit time. F is the mass of the substance per unit area per unit time. C is

the mass concentration of the diffusing substance per unit volume.

If the diffusing specie is neither produced nor destroyed, i.e., the molecules pass in and out at the same time, then conservation of mass requires (steady state), i.e.,

$$\frac{\delta c}{\delta t} + \frac{\delta F}{\delta X} = 0$$

or

$$\frac{\delta c}{\delta t} = -\frac{\delta F}{\delta X}$$

Putting the value of F from Fick's first law of diffusion we get,

$$\frac{\delta c}{\delta t} = \frac{\delta}{\delta x} \cdot \left(D \cdot \frac{\delta c}{\delta x} \right)$$

or

$$\frac{\delta c}{\delta t} = D \cdot \frac{\delta c^2}{\delta x^2} + kc$$

This is called Fick's second law of diffusion, which relates the rate of change in concentration at a fixed point to the second derivative of concentration with respect to distance at that point. This is the basis of diagenetic diffusional process. Many workers have tried to apply it in the nature especially in the marine sediments for the prediction of diagenetic spikes.

In marine sediments, it is assumed or almost true that water doesn't move in the sedimentary pore spaces. Therefore, the movement of different dissolved species is only due to the result of molecular diffusion process. These dissolved species move from high concentration to low concentration gradient through interstitial water. Many theories were made to explain the migration mechanism of the dissolved species in the interstitial water of marine sediments. According to Schlumberger (1972), the potential developed across the shale is responsible for the movement of positively charged ions through the shale. Similar

idea has been discussed by Berner (1980) in the form of electrical double layer. These ideas are quite true for late diagenesis. However, in our case, i.e., in early diagenesis, these side processes are not important having very little or no effect. So, it is good to make a generalizaed picture of diffusion by considering our first assumption that firstly, dissolved species in the marine sediments during early diagenesis only travel through the interstitial water from high concentration to low concentration. Secondly, the interstitial water in the marine sediments is stationary and dissolved species usually move along vertical upward direction (but not or negligible movement in lateral directions). Thirdly, the marine sediments are isotropic in nature in a given depth. Using these boundaries, one can modify Fick' law of diffusion for marine sediments.

DIAGENETIC BIOLOGICAL PROCESSES

It is evident that the sediment surfaces act as a residential area of small benthic community. The population of these organisms decreases towards the pelagic environments. As they live at the top most layer of sediments, contributes their efforts in changing the nature of recent sediments by physically, chemically or biologically. Their resulting processes are called bioturbation by Berner (1980) and the zone is which they live is called bioturbation zone. In this bioturbation zone, zon, they play their own games, dig their holes and most frequently, they run fom place to place. These movements are responsible for the physical changes of the sediments in the form of mixing especially, their digging process bring bottom material to the top and top material to the bottom Their running activitie may cause small turbidity currents and the resulting effect is the resuspension of sediments. Apart from mixing, their holes or small houses change the overall structure of the top most sediments.

Their shell remains in the sediments are respon-sible for the physical as well as chemical changes in the sediments and interstitial water. These shells are mainly of calcite or opaline silica (called calcareous and arenaceous oozes) which when go into the depth, may dissove and increase the alkalinity of the pore water. This change in alkalinity may cause dissolution or precipitation of some trace metal species. Another important phenomenon that occur in diagenetic biological process indicated by Berner (1980) is that the dissolved species produced by the diagenetic reaction migrate molecular diffusion from high concentration of pore water to the low concentration water of their borrowed holes. These small creatures also mix the interstitial water with the overlying sea water by drinking and flushing processes. The thickness of bioturbation zone varies from coastal to the open sea environeent. However, the average thickness of this biologic active zone is 8cm (Nozaki et al. 1977) because, below 8-10 cm, the conditions become anoxic.

DIAGENETIC CHEMICAL PROCESSES

These are the mot important types of early diagenetic processes which change or tend to change the chemistry of the marine sediments. The intensity of these chemical processes exceeds the physical processes in early diagenesis as mentioned earlier. Among diagenetic chemical processes, the most important processes are adsorption/desorption/ion exchange, bacterial action microbial reactions and precipitation/crystallization/dissolution.

Adsorption/Desorption/ion Exchange

Marine sediments most often consist of very fine grained material, less than one micron. Therefore, provide a large surface area for reactions with the sea water as well as interstitial water. These tiny particles have electrical charges at their surfaces, usually termed as vander walls forces. Especially, clay minerals, due to their silicate net

structure, show such type of behaviour, e.g., in montmorilonite (a clay mineral) structure, the Al can be partly or wholly replaced by Fe^{+++}, Mg^{++}, Zn^{++} and by smaller amount of Li^+, Cr^{+++}, Mn^{++}, Ni^{++} (Mason, 1966). Therefore, these substitutions cause a net negative charge disbalance (or charge deficiency) on their surfaces. This charge deficiency is usually then balanced in the nature by the attachment of cations around their surfaces.

Therefore, the process by which dissolved ions, molecules or atoms are attached to the solid part of the sediments by electrically or vander walls forces is called adsorption. Desorption is the inverse of adsorption in many respect The term ion exchange (or cation exchange) is used when these adsorbed ions are replaced by other ions. These inter related processes occur simultaneously on the surfaces of solid particles, therefore, sometimes called surface phenomena. Berner (1980) indicated another type of surface process called chemisorption in which the adsorbed ions are held by chemical bonds. Electrical double layering in sediments is the process by which a potential determining ion or layer called fixed layer is surrounded or adsorbed by the counter ions present in the solution.

In marine sediments, the mineral Illite (a clay mineral) is the most common mineral, which shows negative charge deficiency on its surface and provides a good opportunity for the adsorbed cations hence gives rise to clay-type-double layer adsorption. The most striking feature of clay-type-double layer in marine environment is the deposition of colloidal particles of Mn and Fe-oxides around the clay minerals.

Dolomitization is another example of this process. Mason and Moore (1988) pointed out that during diagenesis of carbonaceous minerals the Mg rich sea water is responsible for the following dolomitization reaction.

$$2CaCO_3 + Mg^{++} \longleftrightarrow CaMg(CO_3)_2 - Ca^{++}$$

Instead of these ionrganic species in the interstitial water, some organic complexes also play a part in adsorption either by acting a fixed layer or diffusion layer, e.g., humic substances in sediments show higher cation exchange capacity than some clay minerals. It appears that adsorption process has, probably, a greater effect on clay minerals in marine environments which is clearly shown below (Mason, 1966).

"Montmorilonite is the most reactive of the clay minerals and does not generally survive in pre-Mezsozoic sediments. It has a close structural relation to these minerals, especially in the marine environment. The comparatively high concentration of potassium and magnesium in sea water promotes this change. Illite is the commonest clay material in marine sediments and sedimentary rocks. The fixation of potassium in Illite and magnesium in chlorite is probably an important mechanism in regulating sea-water composition. In general, diagenesis promotes the formation of illite and chlorite and the disappearance of kaolinite and montemorilonite, so that shales and argillites consist largely of the former minerals."

During adsorption process, most of the trace elements behave similar to the major ions in interstitial water. The adsorption process is considered to be an equilibrium process, hence can be expressed mathematically as,

$$nA_{aq} + mB_s \longleftrightarrow mB_{aq} + nA_s$$
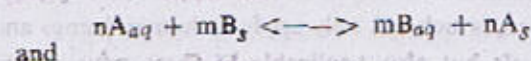
and

$$k = \frac{{}^a B_{aq} \cdot {}^a A_s}{{}^a A_{aq} \cdot {}^a B_s}$$

where,

a = activity
s = solid
aq = aqueous

It is easy to calculate the activity co-efficient for the dissolved ions, but no simple theory is available for the determination of activity co-efficient for adsorbed ions. Different models were presented to explain this problem by taking some serious assumptions.

Bacterial Action or Microbial Reaction

Those changes which are carried out by micro-organisms (called bacteria) in the early diagenesis is known as microbial reactions or simply bacterial action. These bacteria are of a few μm in size hence provide larger surface area in the interstitial water as compared to the organisms present in bioturbation zone. The dissolved species in the interstitial water go and come out of their membranes and are utilized for their body tissues. This process is called metabolism. The metabolism can be divided into two types, i.e., *assimilation* and *dissimlation*. In assimilation process the dissolved species are absorbed by the micro organisms for making their body tissue. Conversely, in dissimilation process, the complex molecules are broken down into the simple one with the release of energy. This release on energy is then used for assimilation processes, therefore, both the processes are interdependent and occur spontaneously. Here, we are only interested in dissimilation process and therefore, discussion will be concerntrated only to the dissimilation metabolic processes.
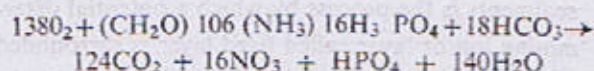
Now we will see how these micro gangsters take part in the destruction of dissolved and undissolved, organic and inorganic species present in the marine sediments for their energy requirements, Greediness is a natural and world wide phenomenon, which not only apply to human beings and animals but also applicable to these micro organisms,i.e., the interstitial water contains a variety of substances. These different species when undergo degradation by these micro organisms release some energy. This energy is then used for the counter process, i.e., assimilation as mentioned earlier. It is obvious that those organic species which release maximum energy on their degradation will be taken first by these tiny gangsters. The actual sequence of these reactions is spectacular.
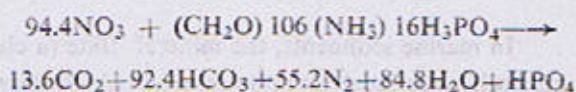
An hypothetical model presented by Berner (1980) is given Table 3. In which the Gibb's free energy is supposed to be the function of their choices. From these reactions, it is evident that first step is the utilization of dissolved O_2 in interstitial water. When it is depleted the reaction turns over to the next favourable specie, i.e., NO_3, called denitrification and so on. The order of degradation of different pspecies by microbial activity is as follows.

$$O_3 > NO_3 > MnO_2 > Fe(OH)_3 > SO_4 > CO_2.$$

As these reactions are hypothetical, therefore, many worker tried to explain their theory by making their own reactions and no one is sure about their results (This is because, we do not know the nature of organic complexes in the sediments) ; e.g., Willson et al. (1984) described his model by assuming the following reactions.

$$138O_2 + (CH_2O)\ 106\ (NH_3)\ 16H_3\ PO_4 + 18HCO_3 \rightarrow$$
$$124CO_2 + 16NO_3 + HPO_4 + 140H_2O$$

and for denitrification,

$$94.4NO_3 + (CH_2O)\ 106\ (NH_3)\ 16H_3PO_4 \longrightarrow$$
$$13.6CO_2 + 92.4HCO_3 + 55.2N_2 + 84.8H_2O + HPO_4$$

A list of complete reactions with their Gibb's free energies have been presented by Froelich et al. (1979) and is given in Table 4. The order in which the oxidants are consumed are given in the following order.

$$O_2 > MnO_2 > NO_3 > Fe_2O_3 > SO_4 > CH_4$$

Similar reaction series were adopted by other workers, such as, Li et al.(1969), Jahnke et al. (1982) and Goloway (1982). A number of diagenetic models in the marine sediments have been demonstrated by taking into account the oxidative destru-

ction of organic matter during early diagenesis as pointed out by Froelich et al. (1979). For example, Nembrini et al. (1982) presented a diagenetic model for sediment/interstitial water system for Mn in which the oxic sediments are divided into three layers depending on the Mn chemistry.

Lyle (1983) introduced his new quantitative interpretation technique using the colour contrast as basis due to change in Fe chemistry, i.e., bown coloured layers in the recent marine sediments indicate the oxidized zone while green colour represents the reduced zone.

David (1983) introduced his ideas by using Mn chemistry (same as Nembrini et al., 1982) but introducing forth zone, i.e., the equilibrium zone, where Mn^{+2} is present as $MnCO_3$ in the early diagenesis of marine sediments.

The mobilization and cycling of trace metals during the early diagenesis in the marine sediments have been discussed by many workers, e.g., Colley et al. (1984), Aller et al. (1985) Shimmield and Price (1986), Anderson and Rippey (1988), Helder (1989), Chester (1990), Shaw et al. (1990) and Richard and Jahnke, (1990). All of them agreed on one point that the mobilization and cycling of metals during the early diagenesis is manifested by the oxidative destruction of organic carbon present in the recent marine sediments.

A detailed work on organic matter diagenesis with special reference to the microbial activity in petroleum geochemistry by using steroids was done by Mackenzie (1982). However, his work was mostly confined to the late diagenetic processes. Early diagenesis of amino acids and organic matter in coastal marine sediments is carried out by Henrich and Farrington (1987).

It's true that in nature, every element has to complete its cycle in one or another way. In geochemistry, this idea is called "Geochemical cycle of the elements." The cycling rate differ from element to element. The microbial or bacterial action

has an important place among most of the geochemical processes and play an important role in converting elements from one phase to another This is also true for trace metals diagenesis

PRECIPITATON/CRYSTALLIZATION/ DISSOLUTION

Precipitation is a process in which dissolved substances separate from solution as a fine suspension of solid particles. These processes are usually carried out by the chemical reactions such as oxidation-reduction and acid-base reactions between some dissolved and undissolved species. However, the acid-base reactions in marine environments are rare and most of the precipitation is due to oxidation-reduction reactions. Crystallization is a process in which the dissolved ions of a super saturated solution arrrange themselves in a regular geometric shape due to the intermolecular forces at given temperature and pressure conditions. Rhombohedral structure of calcite crystals and elongated crystal of aragonite are good examples of crystallization in marine sediments. Dissolution process is completely opposite to these processes, in which different minerals go into the solution under changed conditions. Dissolution of $CaCO_3$ in deep sea sediments due to change in pressure is a good example of this process.

For crystallization/precipitation, the solution should be super saturated or at least saturated. It is possible to determine whether sea water or interstitial water (or any solution) is saturated with respect to certain ions or not. Berner (1980), explained these conditions in the following relation, i.e.

$$\Omega = \frac{IAP}{k}$$

and if,

$\Omega > 1$, solution is supersaturated

$\Omega = 1$, solution is saturated

$\Omega < 1$, solution is under-saturated

where,

IAP = Actual ion activity product, i.e.,

$$IAP = a_A \cdot a_B$$

k = equilibrium ion activity product or (stability product)

The activities of different ions can be calculated as,

$$a_A = \tau C_A$$

where,

C_A — concentration of A

τ = activity co-efficient of A

The activity co-officieants can be found by Davie's equation at different concentrations as,

$$\log \tau = - A. Z^2. \left(\frac{\sqrt{I}}{1 + \sqrt{I}} - 0.2 \, I \right)$$

where,

Z = charge of the ion

$A = 1.82 \times 10^6 \, (\epsilon T)$

where, ϵ = dielectric constant of water at given temperature.

But $A \approx 0.5$ at 25° C

I = Ionic strength of that ion and is related as,

$$I = 1 \tfrac{1}{2} \Sigma \, (C_i . Z^2 i)$$

where C = concentration of ions

Z = valency of the ion

Nucleation is another important phenomenon in crystallization, in which the atoms or ions are attached around a first formed crystal called nucleus. In most of the cases the nucleus is other than the original mineral, e.g., in oolites or pisolite or even in Mn-nodules, a sand grain or a shell remain acts as a nucleus. The resulting minerals are precipitated around these nucleus in a concentric fashion.

Crystallization of minerals is an important tool for the study of sediment's history, e.g., the twinning and irregularities in the crystal shape indicate

the pressure, temperature and compaction pulses in the sediments. Pyrite crystals in sedimentary rocks are frequently used for this purpose under microscopic studies. Dissolution mostly depends on the solubility and saturation conditions of the environment. In marine sediments the pressure and temperature do effect the dissolution processes. The most soluble minerals ever found on the earth is $MgCl_2$ and $NaCl$ whose solubilities are about 5 moles litre at 25° C. The solubilities of different minerals are given Table 5.

DIAGENETCIC RADIOACTIVE PROCESSES

Like other diagenetic processes, radioactive diagenetic processes also got a separate identity. Radioactivity proceeds at a constant rate and therefore, is independent of temperature, pressure and chemical reactions. *Radioactivity* is the spontaneous emission of radiation (i.e., α, β and γ rays from the nuclei. Those elements which emit such radiations are called radioactive elements. Most of the elements in nature have one or more than one isotopes which are similar in atomic number but different in their atomic masses. These isotopes are unstable and continuously emit radiation. A radioactive element, after emission, usually changes into a new element of lower atomic number called daughter element while the former is called parent element. This process is called radioactive decay. In the marine sediments these radioactive elements exist along with their daughter elements. As the decay rate is constant, therefore it is possible to calculate the age of a particular horizon by knowing the concentration of parent and daughter elements. A term half like is used to describe their span. It is defined as the minimum time taken for half of the atoms of a radioactive elements to undergo decay and mathematically is expressed as :
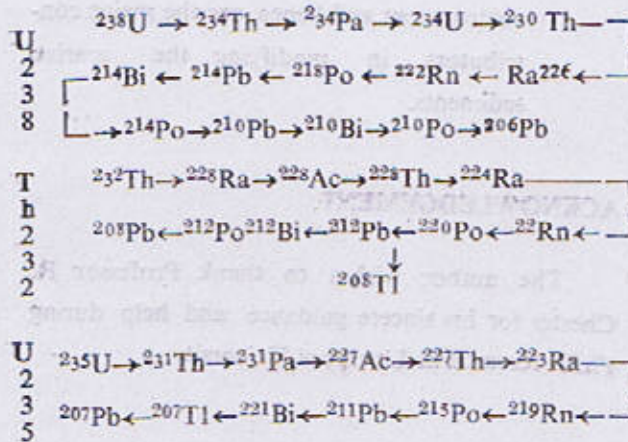
$$t_{\frac{1}{2}} = \frac{0.693}{\lambda}$$

where,

$t\frac{1}{2}$ = half life of an element

γ = decay constant

Three famous radioactive series are in common use for the purpose and are given below :

U
2
3
8
$$^{238}U \rightarrow ^{234}Th \rightarrow ^{234}Pa \rightarrow ^{234}U \rightarrow ^{230}Th$$
$$^{214}Bi \leftarrow ^{214}Pb \leftarrow ^{218}Po \leftarrow ^{222}Rn \leftarrow Ra^{226}$$
$$\rightarrow ^{214}Po \rightarrow ^{210}Pb \rightarrow ^{210}Bi \rightarrow ^{210}Po \rightarrow ^{206}Pb$$

T
h
2
3
2
$$^{232}Th \rightarrow ^{228}Ra \rightarrow ^{228}Ac \rightarrow ^{228}Th \rightarrow ^{224}Ra$$
$$^{208}Pb \leftarrow ^{212}Po \, ^{212}Bi \leftarrow ^{212}Pb \leftarrow ^{220}Po \leftarrow ^{22}Rn \leftarrow$$
$$^{208}Tl$$

U
2
3
5
$$^{235}U \rightarrow ^{231}Th \rightarrow ^{231}Pa \rightarrow ^{227}Ac \rightarrow ^{227}Th \rightarrow ^{223}Ra$$
$$^{207}Pb \leftarrow ^{207}Tl \leftarrow ^{221}Bi \leftarrow ^{211}Pb \leftarrow ^{215}Po \leftarrow ^{219}Rn \leftarrow$$

In the marine sediments, the radioactive elements deposit at a constant rate and undergo constant decay after deposition. Therefore, one can make use of their concentration for the prediction of sedimentation rate or age determination in a particular layer (Broecker, 1974). The key formula used for this purpose is :

$$D = D_0 + \sigma (e\lambda^t - 1)$$

where,

D = concentration of daughter element at time t

D_0 = concentration of daughter element at time 0

σ = concentration of parent element at time t

t = age of the sample

The values of P and D can be determined by the analysis of sedimentary samples, while $\lambda =$ and D_0 are obtained by plotting a graph between D and P.

Now it is easy to find out the values of t by solving two simultaneous equations [i.e., $e\lambda^t - 1 = S$; $D = D_0 + P(e^{\lambda t} - 1)$]. A considerable work has been done on radioactive dating using different radioactive element ratios. Broecker (1974) mentioned three radioactive dating methods especially for the determination of sedimentation rate, i.e., C^{14}/C^{12}, Th^{320}/Pa^{231} and K^{40}/Ar^{40}. A number of combbinations (parent and daughter elements) can be made for this purpose. However, the important point which should be kept in mind is that the daughter elements should be stable enough to support their parents, i.e., It should not be so active that it escapes from the system, e.g., Th is known as unsupported daughter element of U in marine environment due to its high activity.

In terms of trace metal diagenesis, radioactivity in marine sediments provide an idea of decay and production rate of some elements. Therefore, some of the trace elements like K, Pb, etc., in interstitial water as well as in sediments give a combine effect (including radioactive production and the original concentration). For better results, these radioactive spikes (positively or negatively) should be encountered.

CONCLUSIONS

The outcome of this study is as follows :

(i) Weathering is a common phenomenon occurring on the continental crust and is the main cause for the change in rocks present on earth's crust through weathering processes while diagenesis occurs in the marine sediments and brings about the changes in the marine sediments through diagenetic processes.

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(ii)   Diagenesis may be classified into two main groups on the basis of chronology, i.e., early diagenesis and late diagenesis. Early diagenesis occurs immediately after the deposition of sediments and is mostly confined to a few hundred meters in depth, whilst late diagenesis occurs over a longer period of time and is mainly confined to the bottom layers of sediments.

(iii)   In early diagnesis, the chemical processes exceed the physical processes. Conversely, in late diagenesis the physical processes exceed the chemical processes.

(iv)   On the basis of processes, two of the main groups can be divided into three catergories; chemical diagenesis, physical diageensis and biological diagenesis.

(v)   Among diagenetic processes, chemical and biological processes are dominant in marine environment and hence, are the major contributors in modifying the marine sediments.

ACKNOWLEDGEMENT.

TABLE 1. Geochemical classification of sedimentary environment.

I. Oxic ($CO_2 \geqslant 10\text{-}6$)	bematite, goethite, MnO_2-type minerals, no organic matter
II. Anoxic ($CO_2 < 10\text{-}6$) A. Sulfidic ($CH2S \geqslant 10\text{-}6$)	pyrite, marcasite, rhodochrosite, alabandite, organic matter.
B. Nonsulfidic ($CH_2S < 10\text{-}6$) 1. Post-ixic	glauconite & other Fe^{+2}-Fe^{3+} silicates (also siderite, vivianite, rhodochrosite), no sulfide minerals ; minor organic matter
2. Methanic	siderite, vivianite, rhodochro site; earlier formed sulfide minerals, organic matter

TABLE 2. Formation factor (f) for a variety of deep-sea sediments from Deep-Sea Drilling Project (DSDP) ; Data from Berner (1980).

	Depth (m)	ϕ	f
Clayey, Nano-plankton ooze (212)	12	0.79	2.0
do— —do—	170	0.48	4.5
—do— —do—	299	0.55	4.1
Clayey, diatom ooze (213)	<1	0.87	1.6
—do— —do—	15	0.86	1.7
—do— —do—	24	0.87	1.9
—do— —do—	62	0.84	1.7
Foram-nanno ooze (214)	6	0.68	2.9
—do— —do—	63	0.68	2.7
—do— —do—	136	0.66	2.6
—do— —do—	254	0.47	3.7
Radiolarian ooze (215)	6	0.86	1.6
—do— —do—	38	0.88	1.7
Nanno ooze (215)	85	0.58	3.0
—do— —do—	199	0.55	3.2
—do— —do—	115	0.51	3.3
—do— —do—	136	0.50	4.2
Silts with interspersed nanno ooze (218)	72	0.53	3.8
—do— —do—	232	0.45	5.8
—do— —do—	376	0.48	6.8
—do— —do—	461	0.41	6.3
—do— —do—	488	0.41	7.5
—do— —do—	613	0.41	7.9
Clay-rich nanno ooze (217)	7	0.72	2.5

Table 3. Possible degradation processes in the marine sediments as a function of Gibb's free energies.

$CH_2O + O_2 \rightarrow CO_2 + H_2O$	-475
$5CH_2O + 4NO_3 \rightarrow 2N_2 + 4HCO_3^- + CO_2 + 3H_2O$	-448
$CH_2O + 3CO_2 + H_2O + 2MnO_2 \rightarrow 2Mn^{++} + 4HCO_3^-$	-349
$CH_2O + 7CO_2 + 4Fe(OH)_3 \rightarrow 4Fe^{++} + 8HCO_3^- + 3H_4O$	-114
$2CH_2O + SO_4 \rightarrow H_2S + 2HCO_3^-$	-77
$2CH_2O \rightarrow CH_4 + CO_2$	-58

Table 4. Oxidation reactions of sedementary organic matter (after Froelich et al. 1979).

1. $(Cl_2O)\ 106\ (NH_3)\ 16\ (H_3PO_4) + 1380_2 \longrightarrow 106CO_2 + 16\ HNO_3 + H_3PO_4 + 122\ H_2O$

$$\Delta G^\circ = 3190\ kJ/mole\ of\ Glucose$$

2. $(Cl_2O)\ 106\ (NH_3)\ 16\ (H_3PO_4) + 236MnO_2 + 472H^{2+} \longrightarrow 236Mn^{2+} + 106CO_2 + 8N_2 + H_3PO_4 + 366H_2O$

$$\Delta G^\circ = -3090\ kJ/mole\ (BIRNZSSITE)$$
$$-3050\ kJ/mole\ (NSUTITE)$$
$$-2920\ kJ/mole\ (PYROLUSITE)$$

3. $(Cl_2O)\ 106\ (NH_3)\ 16\ (H_3PO_4) + 94 - 4HNO_3 \longrightarrow 106CO_2 + 55.2\ N_2 + H_3PO_4 + 177.2\ H_2O$

$$\Delta G^\circ = -3030\ KJ/mole$$

4. $(Cl_2O)\ 106\ (NH_3)\ 16\ (H_3PO_4) + 212Fe_2O_3\ (or\ 424\ FeOOH) + 848H^+ \longrightarrow 424Fe^{2+} + 106\ CO_2 + 16NH_3 + H_3PO_4 + 530H_2O\ (or\ 742H_2O)$

$$\Delta G^\circ = -1410\ kJ/mole\ (HEMATITE,\ Fe_2O_3)$$
$$-1330\ kJ/mole\ (LIMONITIC\ GOETHITE,\ Fe00H) =$$

5. $(Cl_2O)\ 106\ (NH_3)\ 16\ (H_3PO_4) + 53S042 - \longrightarrow 106CO_2 + 16NH_3 + 53S_2 + H_3PO_4\ 106H_3P$

$$\Delta G^\circ = -380\ kJ/mole$$

6. $(Cl_2O)\ 106\ (NH_3)\ 16\ (H_3PO_4) \longrightarrow 53CO_2 + 53CH_4 + 16NH_3 + H_3PO_4$

$$\Delta\ G^\circ = -350\ k/J\ mole$$

Table 5.   The solubilities of various minerals at 25 C in water (data f—om Lerm an, 1979)

Substance	Solubility moles per litre
Ca$_5$ (PO$_4$) OH	2 $\times$ 10^{-8}
KAlSi$_3$O$_8$	3 $\times$ 10^{-7}
NaAlSi$_3$O$_8$	6 $\times$ 10^{-7}
BaSO$_4$	1 $\times$ 10^{-7}
AgCl	1 $\times$ 10^{-5}
SrCO$_3$	3 $\times$ 10^{-5}
CaCO$_3$	6 $\times$ 10^{-5}
Ag$_2$CrO$_4$	1 $\times$ 10^{-5}
PbSO$_4$	1 $\times$ 10^{-4}
Ba (IO$_3$)$_2$	8 $\times$ 10^{-4}
SrSO$_4$	9 $\times$ 10^{-4}
Opaline SiO$_2$	2 $\times$ 10^{-4}
CaSO$_4$ - $_2$H$_2$O	5 $\times$ 10^{-4}
Na$_2$SO$_4$ - 10H$_2$O	2 $\times$ 10^{-3}
MgSO$_4$ - $_7$H$_2$O	3 $\times$ 10^{+1}
Na$_2$CO$_3$ - 10H$_2$O	3 $\times$ 10^{+1}
KCl	4 $\times$ 10^{+1}
NaCl	5 $\times$ 10^{+1}
MgCl$_2$ - 6H$_2$O	5 $\times$ 10^{+1}

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CHEMICAL AND MINERALOGICAL CHARACTERISTICS OF A SALINE SODIC SOIL UNDER IRRIGATED KALLAR GRASS

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Abstract : The stability of clay minerals under saline sodic soils is not well investigated and may differ from one soil to other depending upon the geochemical characteristics of the soil Field studies were conducted to evaluate changes in soil clay mineralogy, chemistry and soil solution characteristics as a result of long term cropping of salt tolerant kallar grass under brackish ground waters. Data indicates that more unstable clay fraction tends to accumulate at deeper horizons. Under cropping, salinity of the soil solution decreases due to leaching of salts down and decrease in pH accelerates the weathering of clay compared to uncropped soil. The release of K in soil solution indicates the transformation of illite clay to randomly interstratified material probably smectite which increases with growth of grass. The improvement of soil physical properties reported elsewhere (Akhter et al., 1995) and changes in clay surface area and cation exchange capacity may be attributed mainly to the changes in the nature of clay.

INTRODUCTION

In Pakistan, out of 15.62 million hactares of aerable land, 5.8 million hactares are affected with salinity and sodicity (Chaudhary et al., 1978 ; Anonymous, 1985), and more land is lost to cultivation every year due to salinization. A complete solution to the problem of salinity requires leaching of salts with good quality water coupled with comprehensive drainage system, and replacement of exchangeable sodium by adding chemical amendments. These measures being expensive do not seem feasible due to shortage of good supply of

water and ground water under large tracts of saline areas is also brackish. The biological approach considers saline soils and brackish water as useable resource rather than liabilities and recommend growth of salt tolerant plants and among these kallar grass has been the most studied and preferred crop (Malik et al., 1986).

Identification of the properties of the soil solution resulting with irrigation water of moderate to high salinity and evaluation of impact of salinity on soil physico-chemical and water transmission properties is essential (Ayers and Westcott, 1977 ;

Rhoades et al., 1973, 1974 ; Akhter et al., 1988). Several laboratory and theoretical studies (Jury et. al., 1978 a & b) have elaborated the influence of saline irrigation water on soil solution concentration and has predicted the time required to achieve the steady state salinization. Yaron and Shainberg (1973) showed that soils with similar texture and cation exchange capacity (CEC) may differ in their susceptibility to the deleterious effects of exchangeable sodium and electrolyte concentrations.

Mineral weathering and formation may be different in poorly drained saline soils and nonsaline soils. Laboratory studies have indicated that rate of mineral dissolution increases with increasing pH, such as kaolinite (Carroll and Walther, 1990), muscovite (Knauss and Wolery, 1989), quartz (Brady and Walther, 1989) and feldspars (Knauss and Wolery, 1986). Rai and Lindsay (1975) reported that the stability of both primary and secondary minerals increases with increasing pH.

Limited information is available on the characteristics of minerals in saline sodic soils despite the large areas of affected land. Soil investigations have generally focused on reclamation and management techniques rather than on mineralogical transformations and weathering characteristics occuring under these chemical conditions. Mineral characteristics may be affected by composition of the soil solution. Therefore, the objectives of this field study were to characterize the clay mineral composition of a highly saline sodic soil and determine their stability relative to altering soil chemical composition under Kallar grass irrigated with brackish water.

MATERIALS AND METHODS

The experimental description is given elsewhere (Akhter et al., 1995). Soil samples from the horizon A (0-10cm), B (40-60cm) and C (90-100cm) were collected randomly in triplicate from the fields at the end of every growth year of Kallar grass uptill 5 years. Virgin soil was obtained from the field that has been cultivated and kept as control. Subsamples were air dried, crushed and passed through 2mm sieve. Saturation extracts were analysed for pH, Electrical conductivity, cations and anions (U.S. Salinity Laboratory Staff, 1954). Concentrations of CO_3, HCO_3, Cl^- were determined by titration, SO_4^{2-} by turbidimetry (American Public Health Engineering).

The clay fraction of representative samples were separated using gravity sedimentation technique after removing soluble salts. The soils were ultrasonified for three minutes at 400 W and treated with sodium acetate (to remove $CaCO_3$), hydrogen peroxide (to remove organic matter) and sodium dithionite (to remove iron oxides).

For mineralogical analyses with X-ray diffraction (XRD) the clay powder was lightly pressed into an aluminum sample holder to achieve random orientation of mineral particles. A subsample of each clay powder was re-dispersed in distilled water and suspension was sucked under vaccum on each of two 0.2 micron millipore filters to produce maximum orientation of the platy clay mineral particles. One of these so called oriented sample was saturated with magnesium (1M $MgCl_2$) and glycerol to aid identification of clay mineral component by XRD analysis. Diffractograms of the clay slides were obtained with a Philips diffractometer (Model 1710, Philips Elecronics Ltd.) The other, saturated with barium (1M $BaCl_2$) was analyzed by X-ray florescence spectrometry to determine the cation exchange capacity and major chemistry of the clay fraction which were also used for identification purposes.

The specific surface area of soil and clay fractions was determined using adsorption equation of Braunaeur, Emmett and Teller (1938) by using nitrogen adsorption. The samples were degassed in special containers in a stream of dry N_2. Nitrogen was allowed to adsorb on sample for 10 minutes at 77°K and gas desorption was measured using a

catharometer in a sorptometer.

RESULTS

The water used to irrigate kallar grass fields was pumped from a local well and was categorised as C_3S_2 (USDA 1954) and unfit for irrigation (Analysis given in Table 1). Flood irrigations (~8cm) were applied according to the requirement of the grass. Kallar grass being a preniel plant was grown upto 5 years. The grass was harvested from the field in 5-7 cuttings per year and green matter yield remained —50tonshac-1year)1.

The uncropped soils (TC) were highly saline and soil solutions were dominated with Na^+, Cl^-, HCO_3^- and SO_4^{-2} ions upto C horizon (Table 2). The amounts of Na^+, Cl^-, HCO_3^- and SO_4^{2-} ions decreased at all depths significantly with cropping up to 5 years but varied substantially (Table 2). Generally the concentration of K^+ increases in soil solution with growth of grass in all treatments compared to Tc.

EFFECTS ON SOIL SALINTY AND pH

The soil is highly saline because the electrical conductivity (EC) of uncropped soil (TC) remains ~22dSm-1 at depths A and B and ~12 at depth C during the study period. The EC of the cropped soil (T1, T2, T3, T4 and T5) generally decreased significantly at all depths (Fig. 1). It reduced (22.3.2) dS/m at A, (22.2-1.8) dS/m at B and (12.5-4.4.) dS/m at C after one year treatment only (Fig. 1). After T2 the EC increqased slightly than T1 but again declined after T4 and T5 treatments (Fig. 1). The average pH of uncropped soil remained ~10.5 upto C horizonbut decreaased after growth of grass (Fig. 2). The trend of soil pH variarion with treatments was similar to variation in soil EC.

EFFECTS ON SOIL SODIUM ADSORPTION RATIO (SAR)

Sodium chloride was the dominant salt in

natural uncropped soil and SAR values were higher at A and B depths compared to C depth (Fig. 3). The SAR reduced drastically after T1 at all depths compared to Tc and increased after T2 and T3 compared to T1. Soil attained a consistant SAR at A and B depths after T4 and T5 treatments. The SAR values remained highly variable at C horizon and ended up with higher values after T5 compared to Tc (Fig. 3).

SOIL CLAY CHARACTERISTICS

Surface area of soil clay fraction ranges from 74-12Om$_2$g^{-1} and in uncropped soil decreases with soil depths (Table 3). The soil after treatments from T1 to T5 shows a decrease in surface area area at a A horizon and coresponding increase at B and C horizon (Table 3). Characterisation of soil clay reveals micaceous, probably muscovite dominated mineralogies with varying admixture of other minerals (Table 4). The soil contains expanding smectite, a major proportion of randomly interstratified material, while kaoline and chlorite are minor constituents. Quartz, hematite or goethite and feldspar are present in trace amounts (Table 4).

The uncropped soil contains about half the illite and one quarter kaoline (Table 4) and both decrease with growth of grass. The randomely interstratified material, hematite/goethite, feldspar and chlorite increases with the growth of grass (Table 4). The cation exchange capacity (CEC) ranges from 25 - 36 meq / 100g which increases slightly with growth of grass. The chemical composition of soil clay fraction reveals (Table 5) that it contains about half the silica, 20% alumina, oxides of iron, magnesium and potassium as major constituents. Oxides of magnanese, titanium, calcium and phosphorous are present in trace amounts (Table 5). The concentration of alumina increases and K_2O decreases (Table 5) while concentration of other oxides remains similar with growth of grass in soil clay fraction.

DISCUSSION

The salt balance presented in table 2 indicates that growth of grass has caused the shifting of salts down below depth C. The process of leaching seems to be very quick during 1st year (T1). The ionic concentrations in soil solution increases during T2 and T3 than T1 and soil solution attains a so called chemical equilibrium when leaching and addition of salts become equal. The reduction in soil salinity (EC) and sodicity (SAR) at various depths with same treatments has been discussed above. The increase in soil hydraulic permeability soil water retention and improvement in soil st structural stability under same conditions have already been reported elsewhere (Akhter et al., 1994 and 1995).

Table 1. Chemical composition of irrigation water.

$(Ca+Mg)^{2+}$	Na^+	K^+	Cl^-	HCO_3^{2-}	CO_3^{2-}	SO_4^{2-}
		meqdm^{-3}				
3.65	10.5	0.2	0.7	12.86	0.4	0.1

pH	SAR	SARadj	RSC	EC
				dSm^{-1}
7.6	9.6	12.7	9.81	1.4

SAR refers to sodium adsorption ratio, adj to adjusted, RSC to residual sodium carbonate and EC for electrical conductivity

TABLE 2.

Soil solution concentration at depths A (0-10), B (40-50) and C (90-100) cm as function of growth of Kallar grass (KG).   Symbols as in Table 1.

Treatments		Na	K	Ca	Mg	CO	HCO	Cl	SO
				meqdm-3					
TC	A	226	.40	2.0	1.0	14.2	103.4	72.4	39.4
	B	207	.15	2.0	0.5	16.3	101.4	62.1	22.2
	C	128	.20	1.9	0.6	8.6	68.3	40.7	13.5
T1	A	23	.50	1.4	1.1	—	6.2	6.0	13.8
	B	16	.50	1.0	1.5	—	3.6	6.0	9.4
	C	47	.30	0.6	0.4	—	15.0	8.0	21.3
T2	A	136	3.0	3.7	1.3	—	36.1	42.7	65.2
	B	172	0.5	2.6	1.4	—	50.5	54.7	71.3
	C	39.6	0.5	2.0	1.0	—	15.3	13.6	14.2
T3	A	73.0	1.3	1.3	1.2	—	23.1	25.0	28.8
	B	101.3	1.8	1.4	1.1	—	37.8	30.0	37.6
	C	28.5	1.3	1.2	1.3	—	11.0	12.7	86.0
T4	A	18.0	0.7	0.6	0.4	—	6.8	8.2	4.7
	B	19.1	0.7	1.0	0.3	—	8.0	7.5	5.6
	C	33.3	0.9	0.5	0.3	—	13.4	11.6	10.1
T5	A	26.1	0.8	0.9	0.4	—	8.1	10.1	10.0
	B	37.5	0.7	0.7	0.3	—	15.8	13.2	10.2
	C	95.8	0.5	0.4	0.2	—	41.8	29.3	13.8

*TC refers to uncropped control soil and T1, T2, T3, T4 and T5 refers to fields where KG had been grown for 1, 2, 3, 4 and 5 years respectively.

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Table 3. Surface area (m^2g^{-1}) of soil clay fraction determined with nitrogen adsorption methods. Symbols as in Table 1.

Depth	TC	T1	T5
A	82	78	75
B	80	82	80
C	74	112	120

Table 4. Mineralogical analysis of soil clay fraction at depth A. Symbols as in Table 1.

	Illite	Kaoline	R/S	Quartz	H/G	Feldspar	Chlorite	CEC
TC	49—2	15—2	10—6	4—1	4—2	2—1	6—3	23
T3	43—9	9—2	28—7	4—1	5—2	3—1	8—3	
T5	40—11	7—2	30—8	4—1	6—2	4—1	9—3	36

***Randomly interstratified material smectite.
**Hematite Goethite.
*Cation exchange capacity (meg 100g).

Table 5. Chemical Composition (%) of soil clay fraction at depth A. Symbols as in Table 1.

	Fe_2O_3	MnO	TiO_2	CaO	K_2O	P_2O_5	SiO_2	$Al2O_3$	MgO
Tc	7.2	.07	.73	.29	4.21	.1	47.1	20.4	39.4
T3	7.4	.06	.63	.27	4.02	.1	46.1	29.5	3.63
T5	7.8	.06	.065	.25	3.05	.1	46.6	28.9	4.23
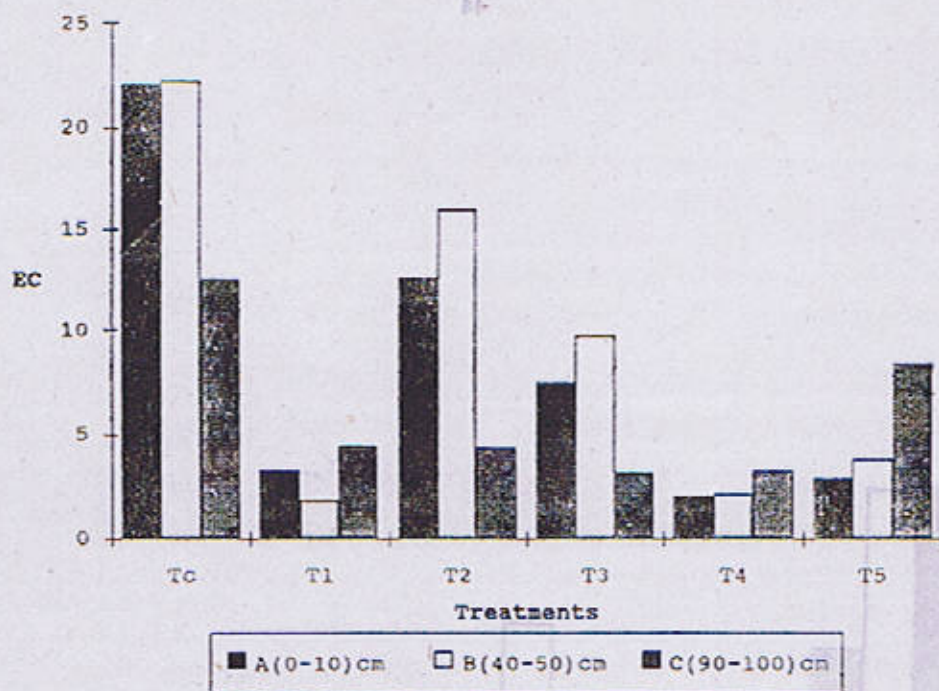
Fig. 1. Soil solution EC (dS/m) as a function of Kallar grass growth at
different depth.
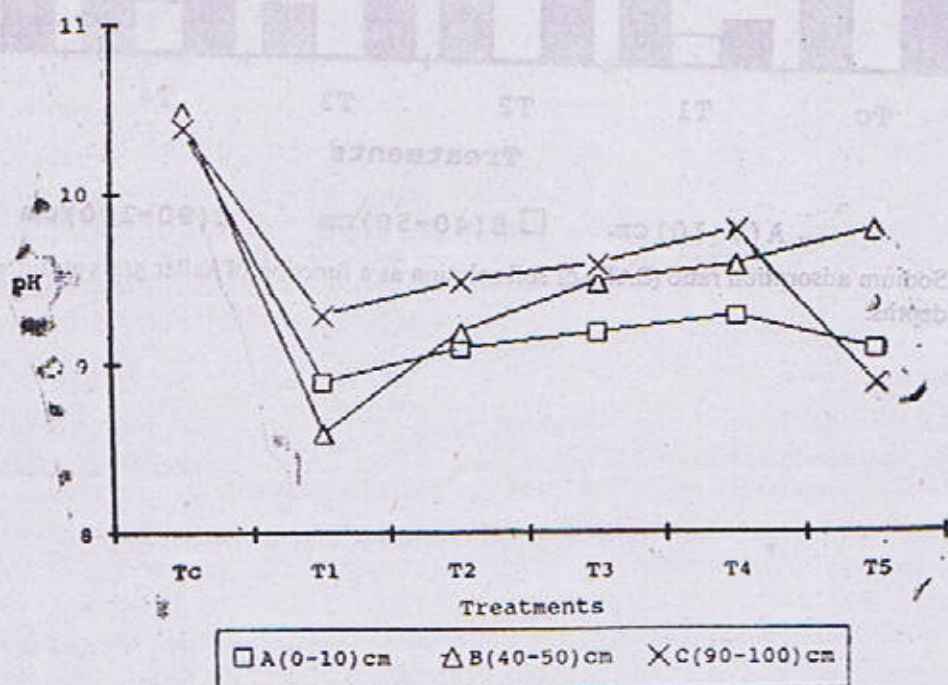
Fig. 2. Soil solution pH as a function of kallar gragss rowth at different depths.
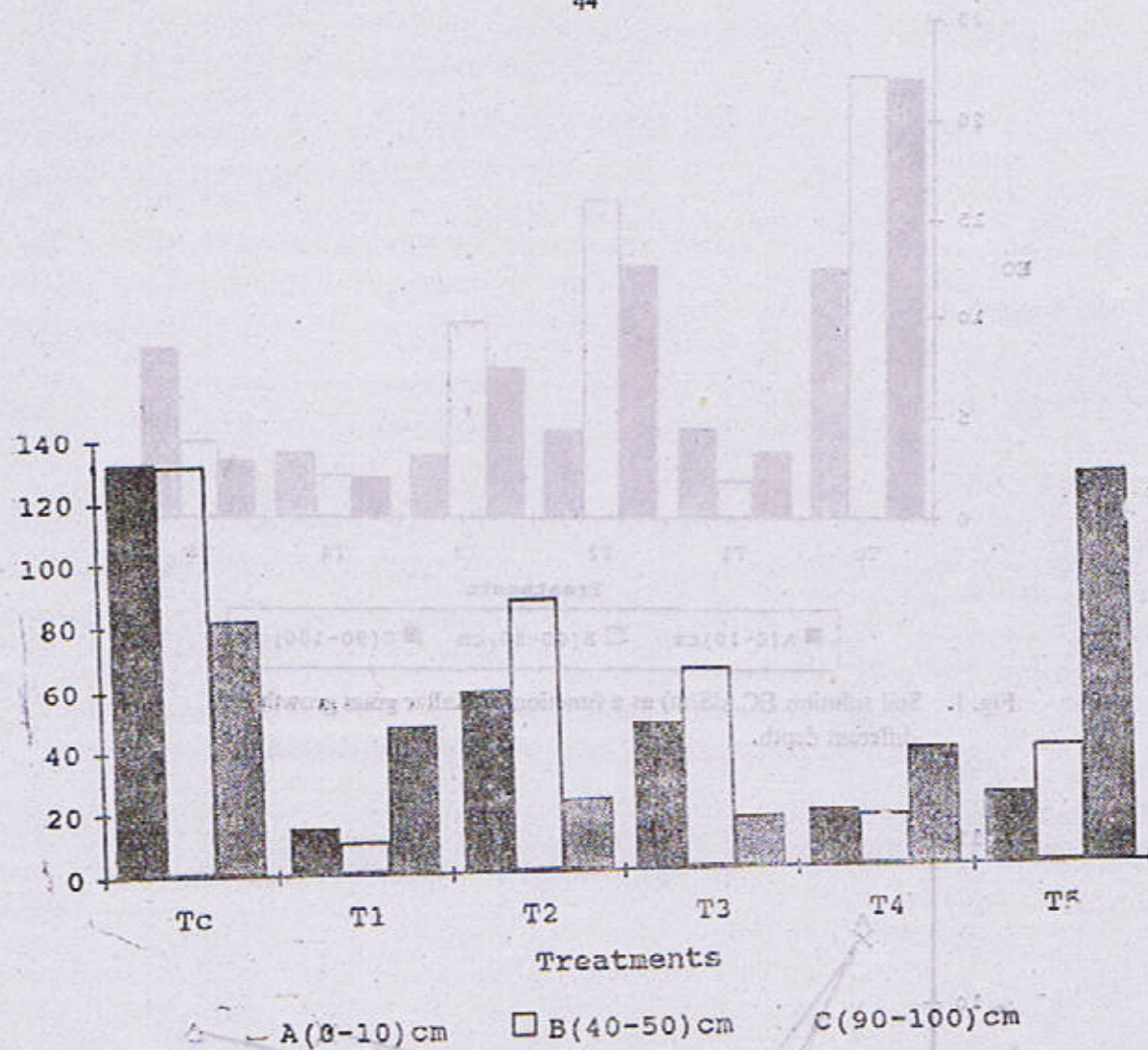
Fig. 3. Sodium adsorption ratio (SAR) of soil solution as a function of kallar grass at different depths.

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PETROGRAPHIC STUDIES OF THE KHEWRAITE, SALT RANGE FORMATION, NORTHERN PAKISTAN

By

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Abstract :— *The igneous intrusion, the Khewraite, exposed in the Khewra Gorge in the Sahiwal Member of the Precambrian Salt Range Formation was sampled for petrographic studies. The results proved that the Khewraite belongs to the Trachyte Series which was subjected to hydrothermal solution.*

INTRODUCTION

The Khewraite (formerly Khewra Trap) out-crops in the Sahiwal Member of the Precambrian Salt Range Formation in the Khewra Gorge. Samples were collected from two exposures in the Khewra Gorge about 400 meters apart for petrographic examinations (Map). Samples were studied both in hand specimen and microscopically. The succession of the Salt Mange Formation as established. by Asrarullah (1967) is as follows :—

3. Sahiwal Marl Member

(*b*) Bright red marl beds with irregular gypsum, dolomite beds and Khewraite (3—100 m).

(*a*) Dull red marl beds with some salt seams and 10 m thick gypsum bed on top (>40m).

2. Bhandar Kas Gypsum Member

Massive gypsum with minor beds of dolomite and clay (> 80 m).

1. Billianwala Salt Member

Ferruginous red marl with seams of salt (> 650 m).

Previous investigations on the detailed study of the Khewraite were made by Mosebach (1956) and Martin (1956, 1962). Mosebach considered the Khewraite as a volcanic rock lying between an alkali-trachyte and lusitanite on the basis of microscopic, X-ray and chemical analysis. He calculated from the chemical analysis of fresh portion of Khewraite the normative minerals as potash feldspar 66.8% and apatite 0.2%. Martin (1956, (1962) investigated the Khewraite from outcrops and cores from Dhariala Well drilled in the eastern part of the Salt Range (Map 1) He called the rock variolitic basalt and described the flow texture in the Khewraite, indicating total absence of the ferromagnesian minerals and the phenocrysts being completely replaced by the fibrous gypseous material. Recently, Jan and Khan (1992) described the nature of the Khewraite as a trachytic rock. The present paper brings to light further details of the Khewraite for its more discrete interpretation.

PETROGRAPHY

The Khewraite in hand specimen, is a hard, rough in touch, compact, non-calcareous, porphyritic, volcanic rock in which the microcrystalline-cryptocrystalline groundmass varies in colour from cherry red, brown to black in the form of patches of different sizes. Prismatic phenocrysts are either radiating spherulitic or in random directions having an average dimension 10 : 2 : 1 (Fig. 1).

Microscopically, the constituents of the Khewraite may be divided into three characteristic groups, namely (1) Phenocrysts (2) Groundmass and (3) Amygdales.

(1) Phenocrysts

Phynocrysts form about 35% in the section and are of two types. First type is partially altered, idiomorphic, mostly euhedral, prismatic and rhombic in form, mainly radiating spherulitic, colourless to slightly greenish, relief fairly high and refractive index greater than canada balsam, extinction angle varies from 0 to 10 in longitudinal or prismatic sections, orientation length slow, interference colours blue-green-orange of second order (birefringence about 0.025). Cleavage is not clear because of alteration but in few rhombic sections, traces of two directions rhombic cleavages are observed. Brown relics resembling groundmass are present in most of this type of phenocrysts which are generally present in their central portions. This phenocryst mineral belongs to amphibole group and seems to be tremolite. The presence of relics mostly in the central areas and resembling groundmass indicate the formation of tremolite from the composition of solidified lava with the introduction of hydrothermal solutions (Harker, 1950). The relics are the remainings of the lava which the idiomorphic tremolite crystals had not been able to utilize and throw or remove during crystal formations (Figs. 2-9).

The second type of phenocryst mineral in thin sections has the same brown colour as the ground-mass and seems to be part of it but it has a definite rectangular outlines and traces of two directions of cleavage at about right angles. Relief is low and and refractive index is greater than canada balsam but less than tremolite phenocrysts. It is mostly euhedral in form. Interference colours are masked by the brownish hematitic and limonitic dust scattered throughout the mineral but in certain comparatively clear portion, it gives first order (birefringence about 0.009), length slow orientation and nearly parallel extinction with reference to boundary or cleavage traces. Mineral belongs to pyroxene group but is completely altered with the introduction of hydrothermal solution and seems to be antigorite pseudomorphs after enstatite.

(2) Groundmass

Groundmass forms about 60% in thin section, brownish in colour, microcrystalline to cryptocrystalline and even glassy (isotropic) in parts. Brownish colour in groundmass is because of the presence of hematitic and limonitic dust Few microscopic magnetite grains are present. Low relief and refractive index generally less than canada balsam. Altered brownish needless and laths of feldspars are embedded in the groundmass and look part of the groundmass but are distinguished by their outlines. Relief and refractive index of feldspars are difficult to determine as they are part of groundmass but in few cases along cracks they seem to have refractive index less than canada balsam and seem to belong to alkali feldspars (orthoclase to albite).

(3) Amygdales

Amygdales are not very common and difficult to recognize in hand specimen. They may form about 5% in thin section. They are cavities/vesicles of the rock which are filled by secondary materials. Here the secondary fillings are ferruginous, calcareous and siliceous constituents. Amygdales are highly irregular in shape and in most cases the central parts are composed of

angular quartz having calcareous, ferruginous and siliceous rims with often presence of grains of magnetite (Figs. 7-10).
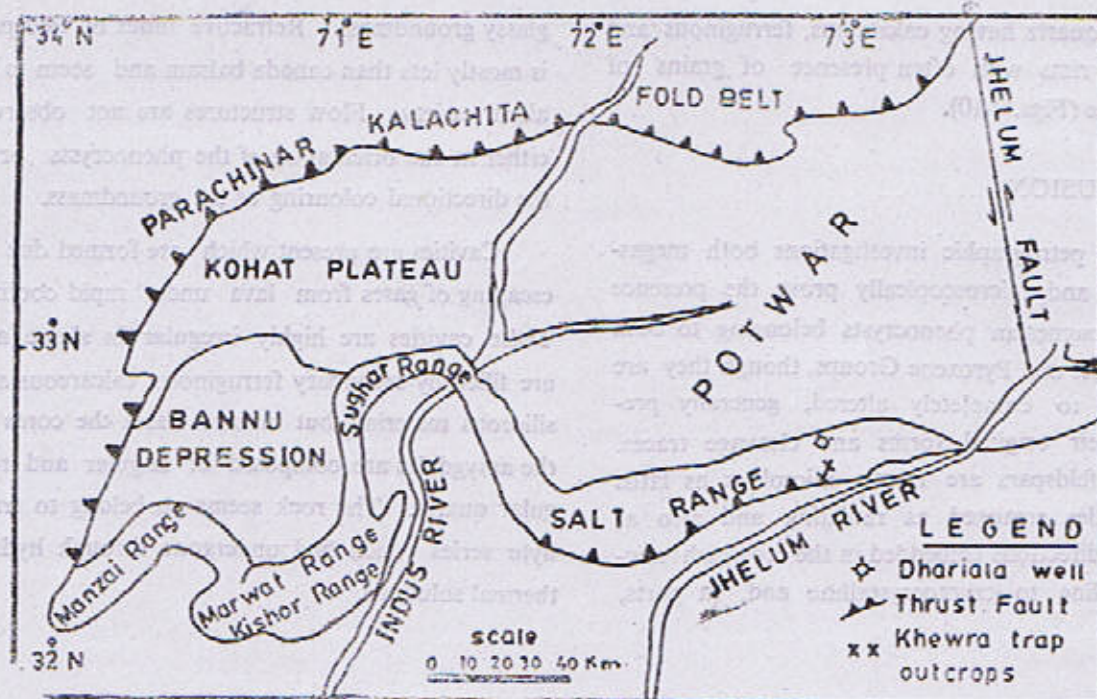
CONCLUSION

Our petrographic investigations both megascopically and microscopically prove the presence of ferromagnesian phenocrysts belonging to both Amphibole and Pyroxene Groups, though they are partially to completely altered, generally preserve their original forms and cleavage traces. Altered feldspars are mostly microlites as laths and needles arranged as radiating and also at random directions embedded in the brownish microcrystalline to cryptocrystalline and, in parts,

glassy groundmass. Refractive Index of feldspars is mostly less than canada balsam and seem to be alkali variety. Flow structures are not observed either in the orientation of the phenocrysts or in the directional colouring of the groundmass.

Cavities are present which are formed due to escaping of gases from lava under rapid cooling. These cavities are highly irregular in shape and are filled by secondary ferruginous, calcareous and siliceous materials but in most cases the cores of the amygdales are composed of angular and irregular quartz. The rock seems to belong to trachyte series which had undergone through hydrothermal solutions.

Map. 1. Potwar - Kohat - Bannu Geological Province of Pakistan showing positions of
Kheara Trap outcrops and Dhariala Well in the Eastern Part of Salt Range.

Fig. 1. Photograph of Khewra trap sample showing phenocrysts of prismatic crystals
radiating and in random directions in microcrystalline to cryptocrystaline ground
mass having patches of cherry red, brown and black colours.

Fig. 2. Radiating idiomorphic prismatic crystals of partially altered tremolite with brownish relics in brownish microcrystalline to cryptocrystalline groundmass in which laths of feldspars are embedded at random direction. Polarized light (x 50)

Fig. 3. Phenocrysts of idiomorphic prismatic and rhombic crystals of partially altered tremolite with brown relics and altered brown enstatite (antigorite) are embedded in microcrystalline to cryptocrystalline groundmass. Polarized light (x 50).

Abbreviations :

T — Partially altered tremolite, P — Enstatite altered to antigorite, F — Feldspars,
M — Magnetite, Gm — groundmass Cb — Empty space formed during slide making,
Cq — Secondary quartz grains in amygdales, Cs, DCf, & Cc — Siliceous, ferruginous & calcareous secondary materials in amygdales.
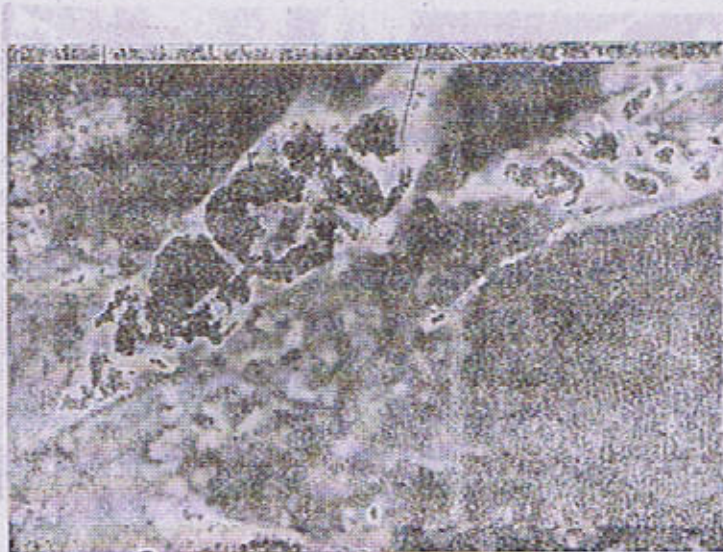
Fig. 4. Phenocrysts of wedge shaped idiomorphic cracked and partially altered tremolite with brown relics and altered brown enstatite (antigorite) in microcrystalline to glassy groundmass. Polarized light (x 50).

Fig. 5. Phenocrysts of cracked idiomorphic prismatic partially altered tremolite with brown relics and rectangular altered brown enstatite with cleavage traces at right angles (antigorite) in microcrystalline to glassy groundmass. Polarized light (x 50).

Figure 6. Phenocrysts of partially altered idiomorphic prismatic tremolite with brown relics in the central portions and brown rectangular altered enstatite preserving cleavage traces at about right angle (antigorite) in microcrystalline to cryptocrystalline groundmas. Polarized light (X 50).

Figure 7. Feldspars microlites in radiating and random directions. Z small idiomorphic prismatic partially altered tremolite. A cavity with highly irregular rims filled with secondary siliceous and ferruginous materials. Polarized light (X 50).

Fig. 8. Phenocrysts of partially altered small prismatic tremolite and brownish altered enstatite preserving zoning (antigorite) in microcrystalline to cryptocrystalline groundmass in which laths of altered feldspars are present. A cavity filled with secondary quartz grains having highly irregular siliceous and ferruginous rims with development of magne magnetite grains. Polarized light (X 50).

Fig. 9. Phenocrysts of idiomorphic cracked rhombic and prismatic tremolite with brownish relics in the central areas and rhombic cleavage traces embedded in brownish microcrystalline to cryptocrystalline groundmass in which laths of microlitic altered feldspars are present. An irregular cavity is filled with secondary siliceous and ferro ferruginous materials and few small magnetite crystals. Polarized light. (X 50).
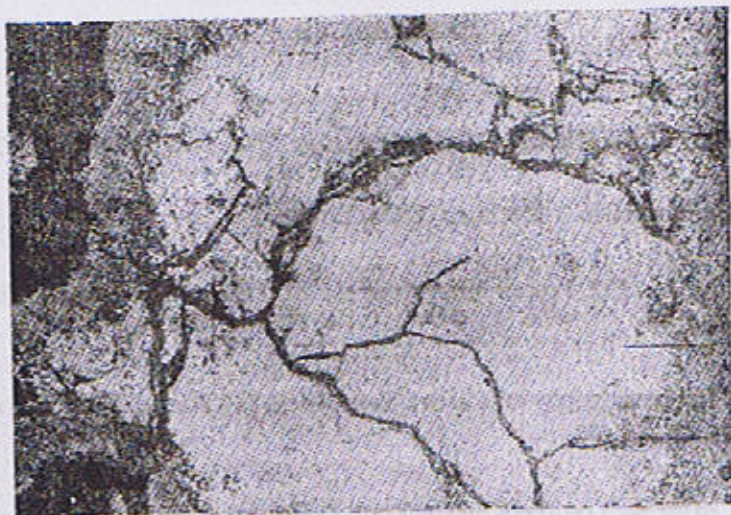
Fig. 10. Cavity is filled with secondary irregular quartz grains which are surrounded by ferruginous and lcareous highly irregular rims. Polarizedalight (X 50).

Fig. 11. Same as figur: 10 but under crossed nicols showing different orienttion of quartz grains surrounded by calcareous material and dark krown fer ginousino materials. Crossed nicols (X 50)

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PETROGRAPHY AND GEOLOGY OF FATHEPUR-SHIN AREA, DISTRICT SWAT, NORTHERN PAKISTAN

By

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Abstract :— *The area studied comprises 48 Kilometers North-West of Saidu Sharif. The area lies within the Southern portion of "Lower Swat". These rocks are probably the extensions of rocks of Dir in the form of a belt running approximately in East-West direction.*

The area mainly comprises Amphibolites, Norite, Diorite, Quartz-O-Feldspar and Pegmatite veins. Quartz-O-feldspathic veins and Pegmatite veins are extensively distributed all over the area. Major minerals are Plagioclase, Hornblende, Epidote and Quartz with Sphene and Magnetite as accessories.

INTRODUCTION

This paper presents a general geological and petrographic account of the Fatehpur-Shin area (District Swat).

The rocks exposed in the area are igneous and metamorphic (amphibolites, norites and diorite) with epidote, quartz quartz-o-feldspathic and pegmatite veins.

The general strike of the area is South-West. The general dip of the area is North-East.

The project area falls in the humid region. The relief of the area is low. The area is full of vegetation. The mapped areas cover the large distance along the River Swat and extends 2 kilometers on both sides across the river. The area is bounded between.

Longitude. . . . . .72° 254" to 72° 300"

Latitude. . . . . . . .35°0 to 35° 53"

The toposheet No. 48 A/B in the scale of 1 inch = 0.789 miles was used. Almost 100 samples were collected from different rock units and 25 thin sections were studied.

Saidu Sharif is accessible by a good metalled road which connects the valley of Swat with rest of Pakistan. Mingora is the biggest shopping centre of Swat, six kilometers from Saidu. Approach to the investigated area is by transport, private vans are available from Mingora to Fatehpur.

PHYSIOGRAPHY OF THE AREA

The physiography of the area is as follows:—

(i) Relief :

The relief of the area studied is moderate to high. The area was mainly the ridge running North-South. The relief of the area increases in North, North-Western part of area due to high peaks. Slopes are gentle to steep.

(ii) Climate :

Cultivation is usually in those areas where "The area lies in the subhumid, subtropical climatic region. The mean annual rainfall record is 4". January is the coldest month.

Temperature in winter : 28.4°F to 51.1°F

Temperature in Summer (June) : 61°F to 91.2°F

(iii) Drainage

The drainage is mainly dendritic i.e. branch like main streams are covered by a thick cover of alluvium.

The main nalas of area are :

(i) Kala Kot Nala, near village Kalakot

(ii) Shin Khawar Nala near village Shin

(iv) Vegetation

The area as a whole is thickly vegitated. At lower altitudes, grasses, shrubs and small bushes and self cultivations like tomato, rice, maize and at the high altitude pine trees are dominated. At some places the exposures are difficult to observe and mapped due to thick vegatation.

(v) Habitation

The population on the higher altitudes is thin and in lower parts the population is thick. The people are hospitable and language spoken is "Pushto".

(vi) Weathering

The area has suffered both physical and chemical weathering.

The rocks are ruptured and fragments are we wedged apart due to physical weathering.

Due to the chemical weathering processes of oxidation hydration and hydrolysis which result in the complete conversion of feldspar into clay minerals which is removed by water. This process is mainly active in the amphibolites of the area.

(vii) Cultivation

spring and river water is available. Gently sloping ridges or terraces along streams are suitable for cultivation. The crops cultivated as wheat, maize, rice and potatoes. Apple and Wallnut trees are also grown.

PREVIOUS WORK

Although much has been written about geology of the Himalayas, little of its contributes directly to the area under discussion.

Wadia (1978) made a preliminary survey of the area and he included the area in "Salkhala Series" and described these rocks as epidotes with basic and ultrabasic intrusions.

Martin et al. (1962) divided the rocks of Swat into six major groups. He gave the name Upper Swat Hornblendic Group to the rocks that are similar to those exposed in the area of investigation.

Jan and Tahirkheli (1969) suggested that the group is composed of Hornblendite, Norite, Diorites and Pegmatite veins.

GENERAL GEOLOGY AND PETROGRAPHY

The majority of rocks outcrop in the area are igneous and metamorphic and the main units are Amphibolites, Diorites and Norite.

Amphibolites of light grey to dark brown colour covers about 20% of the area having pegmatitic and Quartz-O-Feldspathic veins and boudinage structure.

Diorite and Norite occupy roughly 40% and 35% of the mapped area respectively.

In these rocks the concenteration of plagioclase and quartz has been increased due to the hydrothermal alteration of hornblende.

Many small veins of pegmatitic composition

were observed. Due to the disturbance of area by tectonic deformation many small local folds and faults are present in area There is less jointing and fracturing.

PETROGRAPHY

AMPHIBOLITES

It occupies 30—35% of the area. The main outcrop is near Cham and extends towards Shin. It is striking north-east and dipping north-west. It is medium to coarse grained. Foliation and joiniting is well developed in amphibolites. Weathering colour is dark brown and fresh colour is light grey to dark grey. In the mapped area, the upper contact of amphibolite is with diorite. Due to the weathering processes such as oxidation and hydration, the amphiboles have been changed into chlorite, feldspar into sericite and kaolinite.

In field the amphibolites are classified as massive and foliated. The massive amphibolite shows no layering.

The general strike of foliation is north-east to north-west. Both the high and poor grades of foli-ations are present. Foliation is present in a large area but not continuous.

Hornblende occurs in two forms in most of the sections i.e.

(i) Prismatic hornblende

(ii) Anhedral crystals

Prismatic hornblende is fine to coarse grained and anhedral grains are typically medrum grained.

Veins and Dykes

In the mapped area, the quartz-o-felspathic veins, quartz veins, pegmatite veins and streaks of epidote are abundant. These vein are irregu-larly placed.

The pegmatite veins range from few inches to five feet in thickness. Small pegmatite veins of

length 5-20 cm and thickness 2 to 5 cm containing quartz, feldspar and muscovite are abundant.

The Quartz-O-Feldspathic veins are also wide spread in the area and in amphibolites these veins are few inches to one foot wide and are tens of feet long. The thickness of quartz veins ranges from few millimeters to an inch or two.

Small streaks of epidote and quartz are abun-dent in amphibolites. These are few mm to 1 cm in width and from few inches to ten feet long.

Mineralogy

Mineralogically amphibolite consist of am-phibole, hornblende, epidote, plegioclase, quartz, chlorite, sphene, iron ore, clay, muscovite and biotite.

NORITES

Field Relations and Characteristics

These occupy about 30% of the total area and are bounded by diorites in North and by amphibo-lites toward south. These rocks are very hard and resistent to chemical weathering but physical weathering is wide spread in the area. Spheroidal weathering is also present. Big slabs of norite due to physical weathering are found in the main stream. Its weathering colour is reddish brown and fresh colour is whitish, olive-green.

The norite body is usually well jointed and fractured. These joints cut the rock in the form of rectangular and triangular blocks. Foliation is also marked.

The Noritic rocks near the contact are fine-grained and a little away from the contact these are coarse-grained. This type of texture shows the multiple intrusion of noritic magma.

The noritic rocks are cut by numerous veins and dykes of quartz, quartz-o-felspathic, epidote and pegmatites.

Quartz-O-Feldspathic Veins and Dykes

The quartz-O-Feldspathic veins and dykes are very common and are cutting across each other. Some are very thick ranging about 50 feet to 80 feet. In these feldspar has altered to clay and is mostly used as building material.

Mineralogy

Mineralogically the norite consists of plagioclase pyroxene, hornblende, quartz, chlorite and sphene etc.

Contact Zone Between Norites and Diorites

The contact is mostly gradational ranging about 150 feet to 200 feet in thickness but near "Parangdara". The contact is near about sharp not more than 40 feet thick. Here quartz grains are megascopically visible and this rock is termed as tonalite. Here big xenoliths of garnet crystals are clearly seen.

The gradational contact near is marked by the development of big partches of hornblende and pegmatite veins are quite clearly seen.

Big and beautiful apophysis of norites are extending into diorites show that the former is younger than the later.

Mineralogy

The essential minerals of this contact zone are pyroxene hornblende, quartz, plagioclase and garnet while, sphene biotite, magnetite are the accessory minerals.

DIORITE

Diorite in the field occupies about 35% of the total area surveyed. It expands in the South-east. It pinches against an amphibolitic body in the north.

The diorite body does not appear uniform in texture and mineralogy in the field. Around the amphibolitic body diorite is rich in hornblende and quartz and it is rich in quartz and feldspar.

The hand speciman appears medium to coarse grained with colour index from 20-50%. However, the microscopic studies show that the rock is fine to coarse-grained. In the field the diorite is classified on the basis of quartz and colour index.

In the field the quartz can be readily distinguished from amphibolite due to layered and foliated structure of amphibolite.

Diorite is massive and jointed. The colour of the weathered diorite is dirty white and dark brown to grey. Pegmatite veins, quartz feldspar and epidote veins are also present.

Contact

Diorite is in contact with amphibolite and norite is sharp and concordant. With amphibolite the contact is gradational.

Mineralogy

Diorite mineralogically consists of plagioclase hornblende, quartz, chlorite and epidote as essential minerals and magnetite, sphene and orthoclase as accessory minerals.

The mineralogy of diorite is variable according to the field relation. In some quartz is very excessive than other minerals. Quartz-o-feldspathic veins and pegmatit veins are common showing that there is a change in mineralogy due to seccessive crystallization.

HORNBLENDITES

This rock unit is mainly associated with amphibolites and is present as scattered patches and dyke like masses in it. It is highly magnetic in composition. The biggest exposure of thin units is in the north of the area and is situated at the peak near Fatehpur.

In hand specimen they are coarse grained with the hornblende crystals ranging from 1" to 4". The colour index of this rock is 95 to 100%. It is black due to entire concenteration of magnetite hornblende. Felsic minerals are rare.

The weathering colour is coal black. The patches of hornblendites are well jointed and irregular fractures are present on small scale. The joints are usually small as well as large rectangular blocks. Their contact with the surrounding rock is sharp.

Mineralogy

The accessory minerals of hornblendites are hornblende and magnetite making about 98% of the bulk body. The accessories are quartz, sphene, plagioclase.

PEGMATITES

Pegmatite bodies are fairly common in the surveyed area. It occurrs as minor bodies in the form of dikes, veins and patches with commonly irregular boundaries.

In the field pegmatites can be recognised very easily being coarse grained and low colour index lower than 15%. Commonly a graphitic texture is ovserved. In the surveyed area pegmatites are usually weathered having surface full of granular scree. The pegmatites in the area are acidic. These have sharp contact with host rock.

On the basis of mineralogy, texture, zoning and their nature the pegmatites are classed as

(i) Simple pegmatites

(ii) Complex pegmatites

The simple pegmatites were observed by the author.

Mineralogy

Simple pegmatites include basic, intermediate as well as acidic pegmatites which have simple mineralogy. Under microscope, quartz orthoclase, plagioclase, muscovite, biotite and ore minerals are noted.

ECONOMIC MINERALS

The area investigated is poor in economic minerals. Quartz, Feldspar and Muscovite can be used for economic purposes.

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GEOLOGY OF THE LOWER SWAT BUNER SCHISTOSE GROUP OF MANIAR, SWAT DISTRICT, NORTHERN PAKISTAN

By

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Abstract — Geological mapping of the Maniar area, Swat District has been carried out on 1 : 12500 scale south of the River Swat. Petrographic and mineralogical details of various units of the Lower Swat Buner Schistose Group are given alongwith their chemical composition. The structural features and the nature of metamorphism of the area are briefly discussed.

INTRODUCTION

The Maniar area (Survey of Pakistan Topo-Sheet 43B/6) was mapped on a 1 : 12500 scale of the Lower Swat Buner Schistose Group to describe the various lithological units and the metamorphic grades. The presence of Talc Carbonate Rock was included in view of petrotectonic importance of the area.

The terrain is rugged. The landscape is composed of both steep as well as gentle slopes The highest altitude is 5908 (Kashala), whereas the lowest altitude is 2908 near Maniar within number of peaks within ranging heights in between the rock exposures are generally good, dipping southwest.

In view of the structural framework of Northern Pakistan, the project area lies within the MMT (Main Mantle Thrust) and the MCT (Main Central Thrust).

DESCRIPTION OF THE LITHOLOGIC UNITS

1. **Graphitic Schist :**   The Graphitic Schist

is exposed in a sharp contact with the Garnet Mica Schist.

It is dark grey, greyish black to inky blue in colour. It is strongly schistose rock with lineation, jointing and quartz veining.

The constituent minerals are Graphite (32-50%) in banded flakes and dust-like masses with inclusions of Quartz (10-20%) and Biotite (15-20%). Muscovite (3-7%) is present as fine elongated flakes with parallel allignment. Orthoclase (5-12%) and Chlorite (2-5%) are also found, whereas carbonates are minor constituents (0-2%). Fine to coarse anhedral grains of magnetite, hematite and siderite (5-20%) are present.

2. **Phyllites :** The Phyllites are argillaceous and intermediate metamorphic rocks between Slates and Schists. These have some boudinage structures as a result of hydrothermal actions. These rocks are metamorphosed sandstones and placer deposits. In the area they are dark grey in colour and a almost pelitic. Thin psammitic layers are also reported.

The main constituent minerals are Quartz

(32-35%) as fine to coarse anhedral and strained grains with wavy extinction and sutured margin, Chlorite (16-25%) as light green to green pleochroic large flakes — the flakes are elongated curved and occasionally strained. Biotite (7-10%) is present as large dispersed flakes with common inclusions of quartz. Graphite (15-20%) is found as flakes and dust-like forms while Muscovite (5-7%) is observed as fine elongated flakes with parallel allignments. Orthoclase (5-8%) as medium grains with low relief and pale yellow alterations is found alongwith Iron (5-10%) as fine to coarse grained magnetite and hematite.

3. Quartzite : The Quartzite is a metasedimentary rock as a result of the metamorphism of sandstone with siliceous contents. Its fresh colour is light brown and weathering colour is dark brown. Quartz and Marble veins are seen in it.

The main constituent minerals are Quartz (46-65%) as fine to coarse grain with wavy extinction; Graphite (8-10%) as flaky and dust-like for forms; Muscovite (7-20%) as fine elongated flakes flakes with parallel allignments. Orthoclase (3-5%), Biotite inclusions (8-15%) and Iron (2-10%) as hematite and magnetite are also reported.

4. Calcareous Quartzite : It is a metasedimentary rock with excess of calcium contents. It is light brown to dark brown in colour. This unit is thinly bedded and possesses thin, grey marble patches.

Its main constituent minerals are Quartz (35 (35-41%) as fine to coarse anhedral and strained grains with wavy extinctions; calcite (25-35%) as fine to coarse, anhedral, bent and strained grains; Graphite (3-7%) as flaky and dust-like form with parallely alligned Muscovite (3-8%) flakes. Orthoclase (2-7%) and Biotite (8-17%) as large dispersed flakes with common inclusions of quartz are also seen. Iron ores (1-6%) are as anhedral coarse grains of hematite and magnetite.

5. Biotite Schist : It is exposed in the Eastern part of the area. Its Northern contact is with calcareous quartzite and Quartzite whereas the Southern contact is with Talc carbonate Rocks.

It is light brown to dark brown in colour and is strongly schistose with thick patches of marble at various places.

The rock contains Biotite (33-55%) as large dispersed flakes with common inclusions of quartz; Quartz (15-26%) as fine to coarse anhedral grains with wavy extinction and sutured margins; calcite (5-30%) as fine to coarse, anhedral, bent and strained grains with inclusions of quartz; Graphite (3-7%) as flaky and dust-like forms and Muscovite (5-25%) as fine elongated flakes with parallel allignments; Orthoclase (2-7%) as medium grains with low relief and pale yellow alterations along with Epidote (1-25%) as high relief grains, giving sharp varigated colours; sphalerite traces, showing grey to yellow colour in reflected light, its relief is very high. Iron ore (1-8%) as hematite with deep red colour in reflected light.

6. Talc Carbonate Rock : At Tendo Dok (little exposure) appearance. It possesses smoothness and is free from grit. In the area its exposure is not strong. On the basis of softness scale, it is placed in Grade II and is assumed due to hydrothermal action and regional metamorphism of magnesium rich rocks like serpentinite, chlorite, Dolomite and Amphibolite.

The main constituent minerals are Talc (20-25%) as main mineral with association of Chlorite (25-30%) as light green to green pleochroic large flakes, the flakes are elongated curved and occasionally strained, and carbonates (10-14%) aggregates with inclusions of Quartz (18-21%) as fine grains with wavy extinction; Muscovite (10-15%) as fine flakes, parallely alligned; (2-5%) Feldspar is also seen.

7. Sprinkled Marble : At Mainar Sprinkled Marble is seen with offwhite and light black colour. Its main constituents are carbonates

(70-75%) with association of medium grained, low relief, pale yellow Orthoclase (4-6%) and altertnaing, anhedral Quartz (7-10%), (7-12%) Epidote with high relief and varigated sharp colours large dispersed flakes of Biotite (8-10%) are also seen with the Muscovite traces.

8. Marble : Marble is a huge exposure in the project area which extends towards down stream (S—W), contacted with G. M>S. At different places, it has very dull lusture and possessed white to greyish black fresh colour whereas its weathering colour is yellowish brown, greyish brown and grey to dark grey. At some places alternate white and dark layers are also seen. At some places, it shows spheroidal weathering. Lamination and jointing is also clear at various places. It also possesses fracture and solutioning effects at some places.

The constituent minerals are calcite (60-90%) as fine to coarse, anhedral, bent and strained grains with inclusions of Quartz, Iron ore, Graphite, Muscovite Biotite; Quartz (5-20%) occurs as fine to coarse, anhedral grains with wavy extinction; Biotite (5-20%) occurs as small flakes with weak pleochroism; Ore minerals (1-80%) are present as fine to coarse grains of magnetite and hematite; Graphite (2-7%) as dust like mass and Muscovite (traces 20%) are seen as small elongated flakes.

9. Garnet Mica Schist : is the 2nd considerable portion of the project area which is sharply contacted with Marble and indicates the Tectonic Activity in the region. With Graphitic Schist, its contact is gradational. It is grey, brownish black and shiny black in colour. It is a strongly schistose rock with large, porphyroblasts of garnet. Joining, lineation and veins of quartz and calcite showing boundinage structures are frequent. The grain size of Garnet decreases northwards.

The constituent minerals are Garnet (5-30%) as medium to coarse, subhedral to hexagonal fractures and rotated porphyroblasts surrounded by elongated flakes of Muscovite (5-10%) and inclusions of Quartz (12-22%), Graphite (4-30%) Biotite (10-35%), chlorite (2-4%), Iron ore (3-10%) and Staurolite (6-12%).

DISCUSSION

The presence of pelitic, psammitic and calcareous rocks marks the marine sedimentation during Paleozoic or earlier which remained in progress till Eocene.

Above discussion suggests the area is in Higher Himalayas which contains the minerals of low to high grade regional metamorphism such as chlorite, biotite, garnet and staurolite. The exact age of this project area can be suggested as Precambrian to Paleozoic.

DYNAMICS OF MASS EROSION IN THE KARAKORUM HIMALAYAS, NORTHERN PAKISTAN

By

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Abstract : *Reviewing various aspects of mass erosion in the Karakorum- Himalayas of northern Pakistan, comparison is presented in the erosional patterns of Hunza and Gilgit Rivers Drainage Systems. Certain peculiarities are critically discussed with reference to sediment contributions to the Tarbela surface water reservoir.*

INTRODUCTION

The northern mountainous regions of Pakistan are composed of NW Himalayas, Central Karakorum and northeastern Hindu Kush. While the Himalayas belong to the Indo-Pakistan Plate, the Karakorum constitutes southern part of the Asian Plate. Sandwiched in between these two plates is the Kohistan Island Arc, with its northern and southern margins sutured to respective plates by the Main Karakorum Thrust (MKT) Zone and the Main Mantle Thrust (MMT) Zone. The latter represents the late Cretaceous subduction zone of the Indo-Pakistan Plate, that was closed during mid Tertiary (Searle, 1989) and got locked during Miocene (Zeitler et al. 1985, Fig. 1). Notably, this region had been acting as a regional depocentre of detrital sediments transported into the shrinking Tethyan Sea mainly from northern and southern continental masses. After emergence of the Himalayas, however, the direction of sedimentation got reversed so that the region became source of sediments transported southwards by the Indus River Drainage System. (Fig. 2) Among

such products are the sediments of Rawalpindi and Siawalik groups in the South of the main Himalayas that were deposited between 20 and 1 million years ago (Meissmer et al. 1974).

While the processes of weathering and erosion initiate as soon as topographic level starts rising, these get highly intensified in the case of tectonically active mountains, such as those of the northern Pakistan, when considered on regional scale, this problem deserves serious notice particularly with reference to the surface water reservoirs. Rapid sedimentation can severely shorten service life of affecting both irrigation agriculture and energy generation. For planning remedial measures, it is essential that erosional and sedimentation potential of a relevant drainage is assessed and evaluated as to the dynamics of regional characterisations. The present study aims gional characterisations. The present study aims at assessing the comparative erosion potentials of Hunza and Gilgit Rivers as the reference drainage system.

MASS EROSION PROCESSES

The peculiarities of mass erosion processes in the Karakorum-Himalayas are rooted in their, rapid rise (2 mm to over 10 mm per year; (zeitler, 1985) and exceptionally steep slopes (valley floors 1500 m and mountain peaks 7000 m and above).

Consequently, weathering is intense and mass erosion formidable seen as thick valley-fills exceeding 700 m or so (Goudie et al. 1984). The major processes and their effects are reviewed below as a background to the problem under study :—

1. The collisional-type Karakorum and Himalayas represent active crustal plate regimes, involving both drifting and rising components to produce crustal shortening. While the drift is adjusted through regional system of active faults, the uplift is countered by mass denudation. Fission track data on NW Himalayas over the last 10 years (Zeitler, 1985), shows that it had suffered uplift up to 10 km or so, similar activity has been accepted in the case of Karakorum Range as well. Even presently, the Nanga Parbat is rising at a rate of 5 mm/year which is rather phenomenal. Ahnert (1970) has proposed that to have a balance between erosion and uplift rate of even 1 cm/year, a topographic relief of more than 50 km is required Notably, the Himalayas are atleast six times lower than it should have been. This has been attributed to its phased uplift and the high rate of erosion. For instance, the total volume of sediment shed into the Indian Ocean over the last 40 million years through the agency of Himalayan drainage system is estimated to be about $8-5 \times 10^6$ km^3, giving an annual erosion rate of 0.2 mm/year (Schroder, 1989). Notably, the present rate of denudation of about 1 mm/year shows at least five times increase over the historical rate. Even higher rates of denudation have been calculated for the upper Hunza basin of the Karakourum Rnage. However, surface lowering rate of nearly 11.8 mm/year represents among the highest rate of denudation in the world (Ferguson, 1984).

2. In addition to water transport of eroded material, glaciers also play a very effective role in mass movement in the Karakorum-Himalays region. Notably, karakorum Range hosts the largest cluster of valley glaciers in the world. On the other hand, the Karakorum glaciers are also among the longest, the Siachin Glacier alone being more than 75 km long (Shams and Khan, 1987). These valley glaciers are in fact the remants of last Ice Sheet that covered northern Pakistan till about 10,000 years ago (Mason, 1930; Derbyshire et al. 1984; Desio, 1974). The past glaciation periods had created hundreds of metres thick moraines and tillite deposite widespread in northern Pakistan. The studies on the 59 km long Batura Glacier (Hunza Karakorum)shows the great volumes of debris and embedded-rock material that is continuously transported down-slope (Batura Glaceir Investigation Group, 1980). The snow avalanches are also a powerful vehicle of debris transport to valley beds. For instance, a single Kapan snow avalanch in the Kaghan Valley, transported about 103 m^3 of rock debris (de Scally, 1986; Bell et al., 1990). Hewitt (1982, 1988) has described a catastrophic deposition of about 20 x 106 m^6 m^3 debris on the Baultar Glacier in the Karakorum during July, 1986. Flash floods, glacier-lake outbrust floods and mudflows are also responsible for voluminous transport of weathered material. For instance, the notorious Shishkit event of 1974, originating from Balt Bar Valley of upper Hunza, involved pouring down of nearly 5

million m³ of mud-rock slurrry at a speed of 6300 m/second (Wenying et al., 1984).

3. Landslides, debris-slides, flowslides and related phenomena are notoriously widespread in the Karakorum-Himalayas region. (Fig. 3) Goudie et al. (1984), and Owen (1991) have given comprehensive descriptions, supported with location examples of scree slopes, debris-fans and huge alluvial terraces. Butler et al. (1988) described the persistent debris-flow activity along the active Liacher Fault on the western shoulder of the Nanga Parbat, occasionally depositing huge volumes of debris down to the River Indus ; and historical event of temporary caming of there river and later catastrophic flooding is recorded (Abbot, 1948).

4. Wind is yet another powerful agent of erosion, although it is not given its due importance. Considering the huge loss of soil from great loess plains of China and the smaller plain of Potwar, Punjab, the role of wind erosion is vident. For example, Goudie et al. (1984) experienced many severe dust storms in the upper Hunza Valley during the single month of July, 1980. The erosion created by vally-channelling of wind is spectacular. Notably, the dust falling in the drainage system cannot be ignored, although not easy to estimate quantitatively. Besides silt to clay sized material, wind can move even large stones and generally destabilizes rock projections.

5. Man has also become a powerful agent of erosion in order to meet the demands of fastly expaning population. His activity is now considerably strengthened with the power of modern science and technology. Beside earth-moving operations, concerned with mining, engineering works and human settlements man is also responsible for high rate of deforestation and overgrazing of mountain pastures. Consequently, landscapes are exposed to erosion excessively, resulting into greater yield of sediment-load to the drainage systems. Estimates on the Kunhar River, Kaghan Valley, N.W.F.P., show that annually about 1.38 million tonnes of soils is removed through erosion, deforestation and overgrazing of Apline pastures in the upper reaches of the valley is well known. The same applies to other parts of the mountainous terrains of northern Pakistan.

COMPARATIVE SEDIMENTATOION POTENTIAL

The Upper Indus Drainage Basin (152, 680 km²) includes catachment area of River Shyok in the East and of rivers Hunza and Gilgit in the North (Fig. 4). The total annual water discharge of River Indus rated at Darband gauging station is 62,60 MST (Million Short Tons) 100% of susupanded sediments. In the present study, a comparative examination was made of the Hunza River drainage system and the Gilgit River drainage system, because their catchment areas are concerned with comparable terrains latitudinally. The water discharge and sediment data for 22 years period) (1986-1990) of the Hunza River taken at Dainyor gauging station, and of the Gilgit River taken at Gilgit gauging station, are shown in (Fig. 5 and 6). Some pertinent data are given in Table I and II along with average grain size percentages of the suspended sediments.

DISCUSSION

Some interesting inferences can be drawn out of the comparative data of the two rivers :—

1. In the case of the Hunza River, there is a fair degree of conformability between volume of water discharge and the amount of suspended sediment. However, the relation in the case of the Gilgit River is highly erratic (Fig. 7).

2. While the minima of water discharge and

sediment load in cases of both the rivers appear during different years, the maximu are however, during the same year.

3. Despite complimentary nature of data referred to in (2) above, the years of minimum and maximum are different, 1973 in the case of Hunza River and 1988 in the case of Gilgit River.

4. There are slightly less prominent maxima peaks in the case of Hunza River for the year 1978, while similar promineances are shown by the Gilgit River for the year 1981.

5. While the sediments transported by the Hunza River are dominately silt and clay sized (83%), those are sand and silt sized (79%) in the case of Gilgit River.

The differences in the hydrologic and sedimentation potentials of the two drainage systems are impressive, as both cover comparable terrain, while the difference in their catchment areas is only 831 km². Thus, the two rivers are making highly variable water and sediment contributions to the Indus River. The explanation is rooted in the lithologies, tectonic and physiographic factors influencing the two drainage areas. While the Hunza River drains northern part of the trerritory along with its E-W oriented tributaries, the Gilgit River drains western part with its N-S oriented tributaries; thus, on the two rivers shown distinctively different drainage patterns (Fig. 8).

1. Lithologic Factor

The lithologic framework of the area concerned involves southern part of the Asian Plate, represented by the Karakorum Range, and northern part of the Indo-Pakistan Plate, represented by the Nanga Parbat-Harmamosh system. The two plates are intervened by the Kohistan (fossil) Island Arc complex that is limited by the MKT zone in the North and there MMT zone in the South (Desio et al. 1972, Desio, 1979; Tahirkheli, 1982; Geae-

tani et al. 1988). The regional trend is NW-SE, with a swing to SW towards Chitral where Hindu Kush elements interfigner with the Karakorum western terminus.

The drainage area of the Hunza River is concerned with unmetamorphosed dominatly argillaceous-carbonatic sediments North of the Axial Batholith and slates, schists and basic valcanics in the South. Except for the acidic plutonic rocks of the Karakourm Batholith, other lithologies weather easily and contribute heavily to the mass erosion. However, these northern sedimentary formations thin out westwardly within the Gilgit River catchment area, and also swing out of its drainage regime. On the other hand, plutonic acidic and basic complexes dominate within the Gilgit River catchment area as northern parts of the Kohistan complex and components of the MKT zone. Most of these rocks are compact and hard, and comparatively resistant to weathering. Consequently, the catchment area of the Hunza River contributes more detritues as compared with the Gilgit River area.

2. Tectonic Factor

Although entrie region of the Indo-Pakistan and the Asian Plates is tectonically active, yet uplift components are concerened more with the NE-SW Nanga Parbat-Haramosh oroganic axis that influences the Karakorum Range as well. The estimated rate of uplift varies from 2 to 12 mm/year (Zeitler, 1985) which is rather phenomenal. Such a tectonic activity is strong enough to shatter rock systems, destabilize hill-slopes and generate mass erosion. Due to lithologic differences as shown above, the Hunza River catchment area will suffer strongly and will yield higher volumes of erodable material as compared with the Gilgit River areas.

3. Physiographic Factor

The catchment area of the Hunza River hosts large number of long valley glaciers, Hispar

(61.km), Batura (59 km), Batura-Hopar (25 km), Pasu (24 km), Gulkin (18 km), Minapin (13 km), Pisan (4 km) and Gulmit (7 km) and a large number of smaller in length. These glaciers are of Alpine Type so that their maxima of snowfall and ablation occures in the summer half-year (Goudie et al., 1984). Notably, although these are among the steepest in the world yet their termini are at the losest levels, in the Range of 2070 m or so, while their average flow rate varies from 100 to 1000 m/year. These glaciers create deep erosional incision, adopt rapid modification, carry large lateral and end-morain, and suffer hazardous rock avalanches, collectively discharging large volumes of eroded material into the Hunza River dranage system. The situation of the Gilgit River catchment area is much different, where glaciers are less frequent, while some extend northwards, to join northerly drainage system.

Besides, monsoon frequently crosses Haramosh Range to intermingle with the north-easterly, and causes widespread precipitation in the Hunza River catchment area as compared with the Gilgit River area. The resultant differences in the run-off and the sediment-load between the two rivers is shown in Table 1, 2. Notably, of the seventeen rivers of China, Pakistan and India, the Hunza River is surpassed in erodability by only two Chinese rivers; the latter, however,

draining the easily erodable loessic material (Goudie et al., 1948).

CONCLUSIONS

The above study shows that each and every drainage sub-system in northern Paistan may have its distinct dynamics of water discharge and sediment load. Therefore, for planning strategy to control sedimentation of dams, all sub-systems should be individually investigated, and dependence should be avoided on the main drainage regime of the Indus River. In this manner, transport of sediments into the Tarbela water reservor will be better checked, when planning will be based on an erosion-potential contoured map of northern Pakistan. The addition of 194.44 MST of sediments (Fig. 9) annually has already decreased the reservoir capacity by 17.38% over the last 20 years. There is an urgent need to initiate research on the lines suggested herewith, as the conclusions apply also to Mangla Dam and other proposed surface water reservoirs that are to be built in the future.

ACKNOWLEMENTS

TABLE I
Monthly Mean Water Discharge in CFS

Year	Hunza R. at Dainyor Bridge	Astor R. at Doyian Bridge	Shigar R. at Shigar	Gilgit R. at Gilgit	Shoyok R. at Yogo	Indus R. at Partap
1980	21170	7982.5		15310	44580	200450
1981	22535	7962		19585	52810	225700
1982	19845	5101.5		12775	58855	200720
1983	24265	7051		16035	50170	220945
1984	27860	10087.5		17155	69660	218860
1985	22960	5007.5		15520	44550	168650
1986	21055	10193	8495	21265	38830	194770
1987	15175	7675.5	13798.5	13645	36735	164200
1988	27585	9610	13410	21405	55235	223750
1989	13475	8765	8369.5	15615	28120	209100
1990	20945	9475	17287.5	13975	56055	222850

TABLE 2.
Showing comparative data of Hunza and Gilgit Rivers.

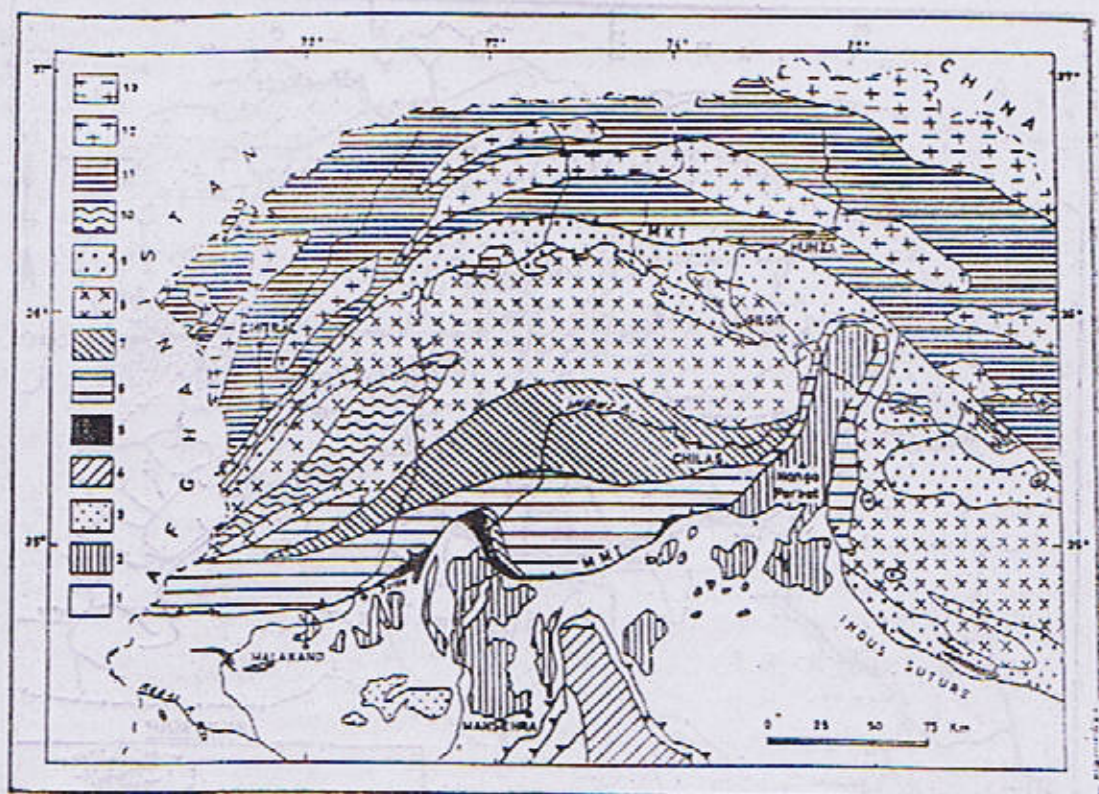| River	Minimum (years)		Maximum (years)		%age Content		
Drainage Area	Inflow Sediment Load MST		Inflow Sediment load MST		Sand	Silt	Clay
Hunza	6.38	25.65	12.50	111.0			
					17	58	25
13,448 km²	(1987)	(1990)	(1973)	(1973)			
Gilgit	4.65	4.52	9.20	25.90			
					34	54	21
12,617 km²	(1977)	(1971)	(1988)	(1988)			

(MST. Million Short Tonnes)

Fig. 1. Lithotectonic Map of Northern Pakistan (1) Precambrian to Mesozoic sedimentary rocks of the Indo-Pakistan Plate ; (2) Camorian granitic rocks ; (3) Early Tertiary alkaline to subalkaline igneous rocks ; (4) Middle Tartiary calantic sediments ; (5) Ultramafic ophiolites ; (6) Amphibolite belt ; (7) Chilas-Jijal mafic complex; (8) Kohistan-Ladakh (Transhimalayan) granitic rocks; (9) Cretaceous sedimentsand volcanics of Yasin; (10) Creto-Eocene sediments and volcanics of Kalam-Dir area; (11) Sediments and Metasediments of the Karakoum Plate; (12) Khunjerab-Wakhan Tirachmir granites; and (13) Karakorum granitic belt. MMT: Main Mantle Thrust; MKT : Main Karakorum Thrust.
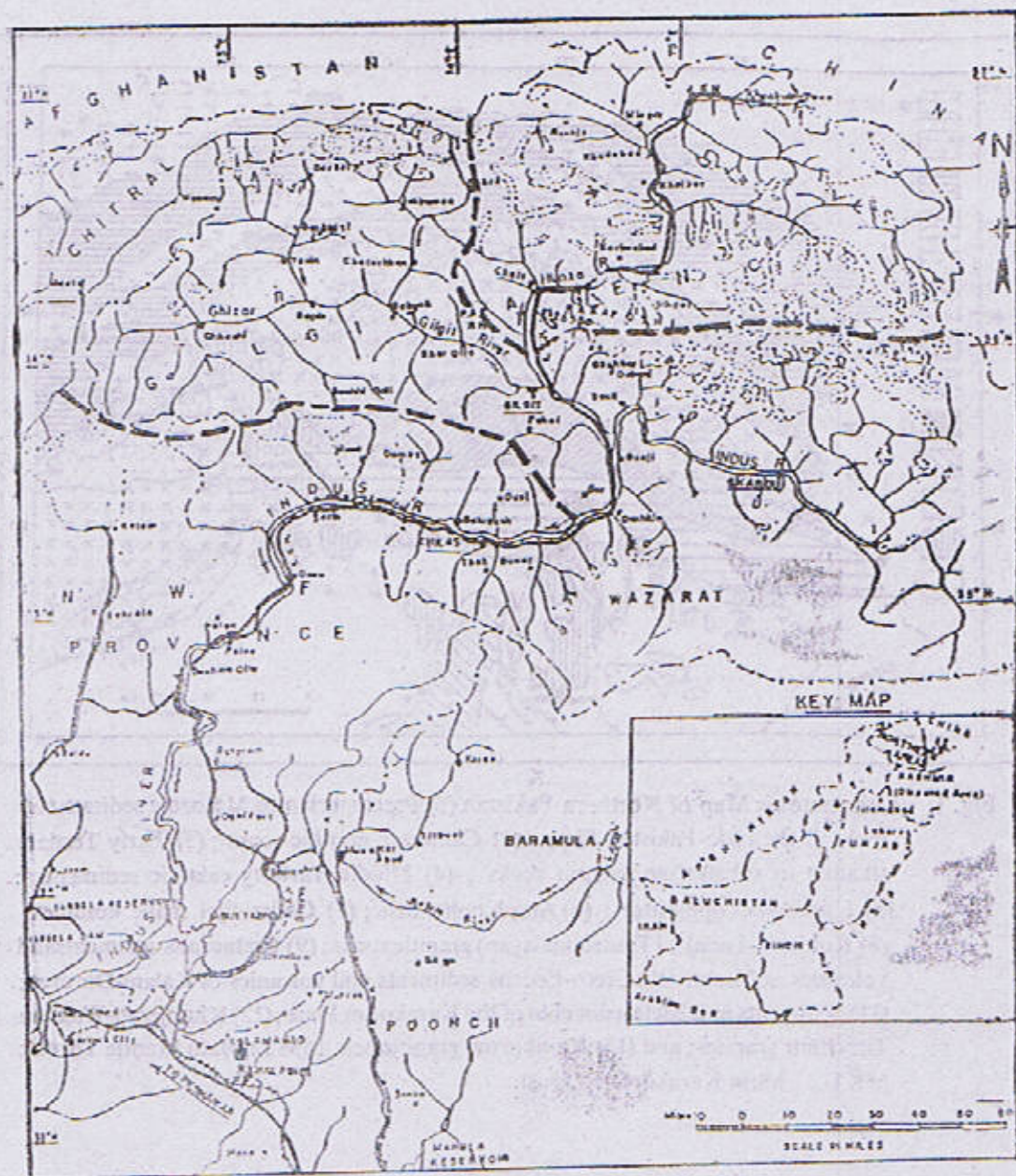
! Fig. 2. Drainage Basins of Northern Pakistan

Fig. 3.   A debriflow along the Karakorum Highway, including
water erosion in the background.

Dainyor Hunza suspension bridge severely eroded soil/losse
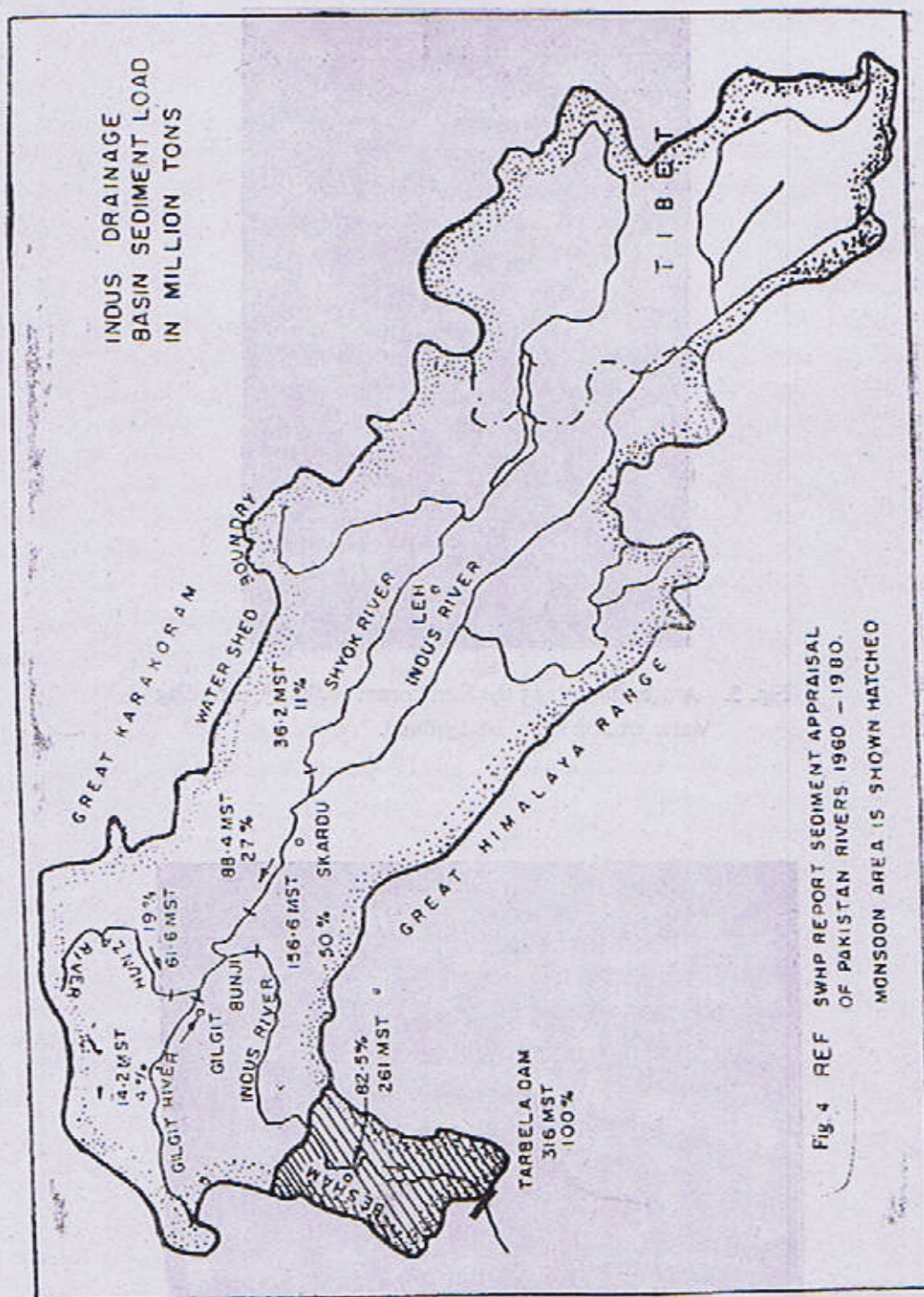belt in the background.

INDUS DRAINAGE
BASIN SEDIMENT LOAD
IN MILLION TONS

GREAT KARAKORAM

WATER SHED BOUNDRY

T I B E T

36·2 MST
11%

SHYOK RIVER

LEH
o

INDUS RIVER

88·4 MST
27%

SKARDU
o

156·6 MST
50%

GREAT HIMALAYA RANGE

HUNZA
RIVER
19%
61·6 MST

GILGIT RIVER

14·2 MST
4%

GILGIT
BUNJI

INDUS RIVER

82·5%
261 MST

BESHAM

TARBELA DAM
316 MST
100%

Fig. 4   REF   SWHP REPORT SEDIMENT APPRAISAL
OF PAKISTAN RIVERS 1960 — 1980.

MONSOON AREA IS SHOWN HATCHED
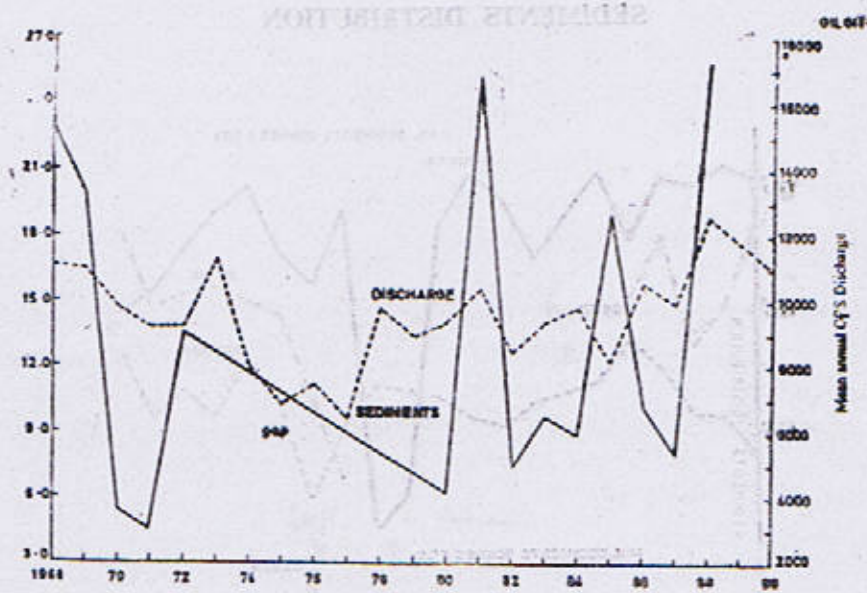
Fig. 5. Graphs Showing water discharge data and Sediment load data of River Gilgiat Northern Pakistan (After WAPDA).

[HUNZA RIVER AT DINYAR BRIDGE
1983—1990
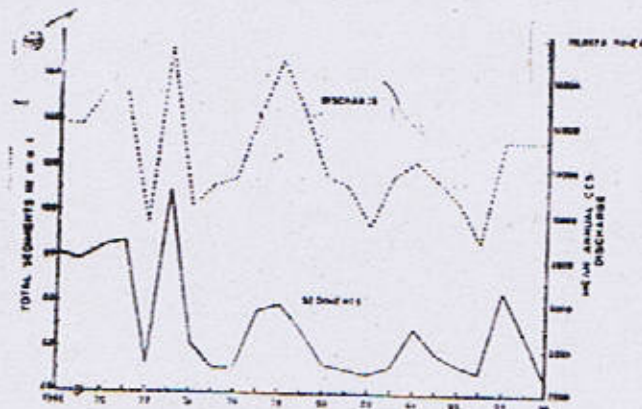
Fig. 6. Graph showing water discharge data and sedimen load data River Hunza, Norther Pakistan (after WAPDA).
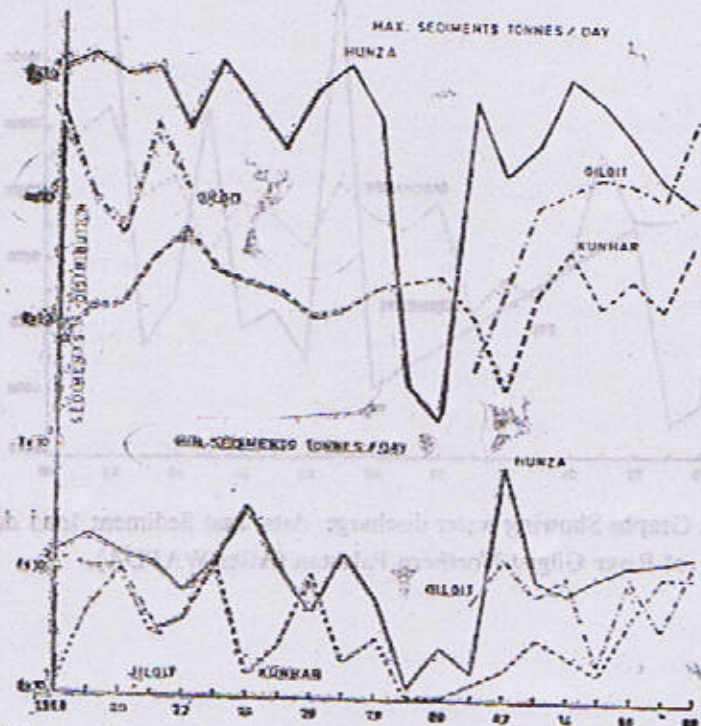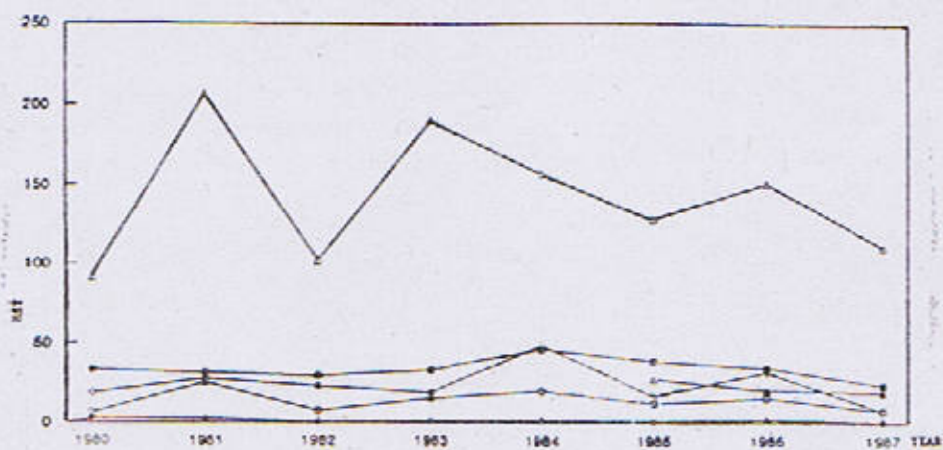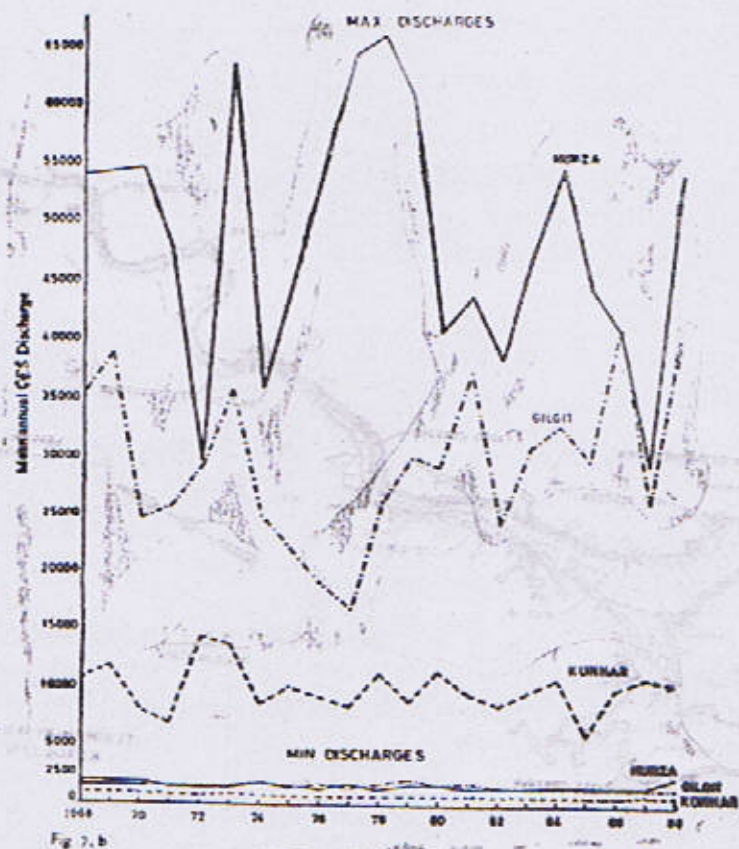
SEDIMENTS DISTRIBUTION

Fig. 7. Graphs Showing Sediments Distribution and water
discharge of Hunza, Gilgit and Kunhar rivers

Fig 7. b

YEAR	HUNZA DAINYOR	ASTORE DOYIAN	KOGAR AT KOGAR	GILGAT AT GILGAT	SHOTOR AT YUGO	INDUS AT PART BRIDGE
1980	51.5	2.40		9.85	18.4	90.9
1981	51.4	2.45		25.2	27.8	206
1982	29.2	6.47		5.37	13.8	102
1983	33.1	1.16		15.3	18.7	190
1984	46.4	1.67		20.1	48.9	157
1985	30.7	0.864	27.4	12	16.5	128
1986	34.2	3.98	30.2	15.3	31.5	151
1987	23.3	0.316	34	7.44	7.16	150

TERBELA RESERVOIR
RANGE LINES
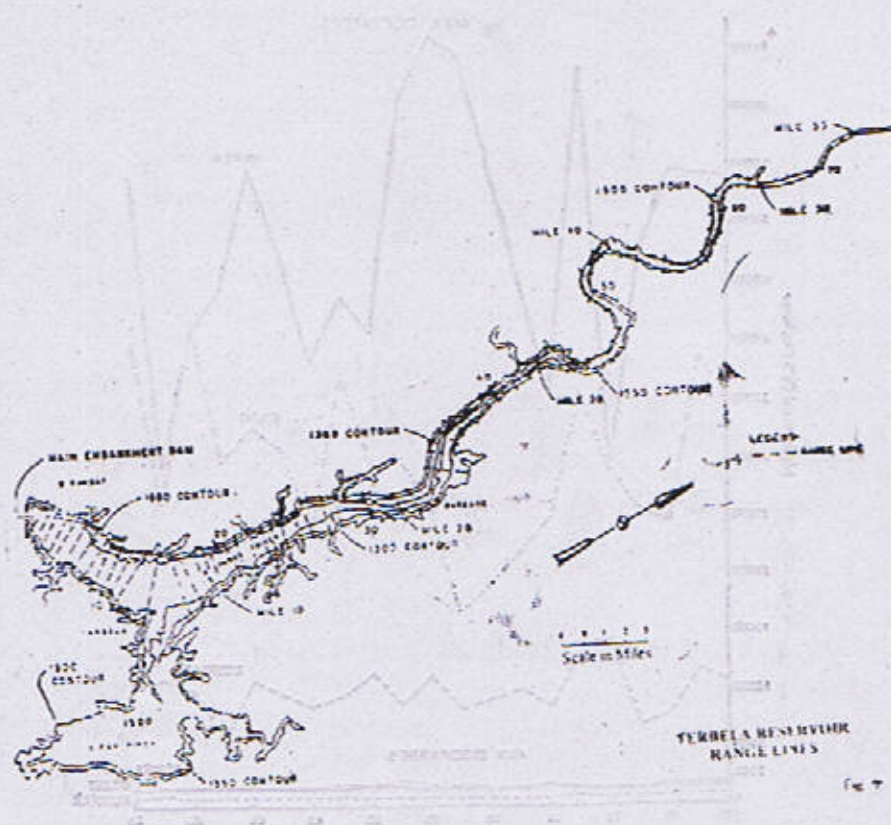
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THE POTWAR PLATEAU, PAKISTAN : A CASE OF SEVERE DEGRADATION

By

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Abstract :   *The Potwar Plateau makes a 11,0200 km 2 upland, 306 m to 610 m a.s.l that had developed originally as a sedimentary basin in front of the rising Himalaya It is composed of about 7 km thick pile of sandstones, mudstones and shales, succeeded by thick cover of basal conglomerates and loessic soil.   The deposition of the latter coincided with the disappearance of Palaeolithic Soan Culture, with resurgence of human sett ments only a few thousand years ago; the present population being approx. 7,071,361.   The plateau presents typical badland topography and is suffering serve degradation.   Out of a total of 1.82 mha arable land, only 0.6 0.6 mha is under agricultural production while about 5,000 ha land surface becomes inaccessible for cultivation every year due to soil erosion.   Besides rainfall run-off producing gully erosion neotectonics play vital role in causing mass wastage.*

INTRODUCTION

The Potwar Plateau is a well-defined physiographic unit of Pakistan (Fig. 1) between the Indus Basin plain and the foothills of the Himalayas. It covers about 11,200 km² area bounded by Kalachitta and Margalla Hills (Lat. 33° 35' N) in the North and Salt Range (Lat. 31° 45' N) in the South, Indus River (Long. 71° 35' E) in the West and Jhelum River (73° 45' E) in the East. Its topographic level varies from 306 m to 610 m a.s. l., except the Khair-i-Murat and the Bakrala ridges that rise above the general level. Regionnally, the plateau slopes from NE to SW, in the direction of flow of the River Soan, which is the main river of the area and joins the River Indus North of Kalabagh. In the eastern Potwar, Kanshi, Kahan and Bunha rivers drain into the Jhelum River. Only the Soan and Kanshi rivers are perennial while rest of the drainage consists of seasonal stream

The Potwar Plateau has been the cradle of the so called Soan Culture of Palaeolithic age (about 4,00,000 yr. old), that had succeeded the much older period of Homonoid including species like *Ranapithecus, Sivapithecus* and *Gigentopithecus* (Shah et al., 1985). The region is also world famous for its treasures of vertabrate fauna (Pilgrim, 1913; Pilbeam et al., 1977). Presently, Potwar has a population of approx. 7,071,361 (6,871,224 : 1981 Census; 3% annual increase). The Federal Capital, Islamabad, and its twin city Rawalpindi, make the two most populous settlements in the area. The Potwar is also well known for its hydrocarbon wealth; its first oil well was drilled in 1866 which was among the oldest in the world. Industrial minerals consist of lime-

stones, clays and building stones, while rock salt, gypsum, dolomite, glass sand, limestone, coal and fireclay are found in the adjoining Salt Range (Shams, 1980).

During the period of Soan Culture, Potwar had a humid climate and was covered with thick forest; presently, however, the climate is generally subtropical, the forests are limited and bushes and scrubs make the main natural vegetation. Wheat, gram, lentils, mustard, millets and pulses are the major agricultural produce while groundnut and fruit cultivation is steadily increasing. Birds and animals of games bound although their population is dewindling and some species are becoming almost extinct. Monkey, bear, panther, deer, fox, rabbit, peacock, pheasant, wild boar, porcupine, hyaena and chakor are the more common species.

GEOLOGY AND TECTONICS

The Potwar Plateau is a post-Eocene sedimentary basin that had developed in front of the rising Himalaya. The dominant lithologies are referred to as the Siwalik Group (Gill, 1952) making up to 7 km thick middle Miocene to Pleistocene synorogenic fluvial sediments composed essentially of interbedded stream-channel sandstones and flood plain mudstones and shales ; these compare well with the present-day sedimentation in the Indus Plain South of the Potwar Plateau. Lacustrine, fluvial and aeolian deposits make the more recent cover sediments (Fig. 1b).

The northern limits of the Siwalik basin are marked by a major tectonic break, the so called Main Boundary Thrust (MBT) that separates the Siwalik Group sediments from the older Murree Formation. The southern limits of the basin are again defined by another major break, the Main Frontal Thrust (MFT) that makes the overriding zone to the Indus Basin alluvial. Due to the combined effects of compressional regimes of the Jhelum re-entract in the East and the Kalabagh re-entrant in the West, and southward over thrusting of the Himalaya, plunging anticlinal and synclinal structures had developed with well-defined tectonic ridges and troughs (Fig. 1c). The most prominent regional structure is defined by the NE-SW Soan syncline to which are aligned most of the other structures. Steep and vertical fault planes are very common and are related to fold systems that become more and more closer away from the Soan Syncline (Martin, 1962). There is ample evidence to show that tectonic movements are continuing, including slow uprise of the plateau as a consequence of mobile behaviour of the Indo-Pakistan crustal plate (Zeitler, 1985).

HYDROLOGY AND DRAINAGE

Due to changes in altitude, climate of the Potwar Plateau varies from humid temperate in the NE to sub-humid subtropical towards SW. The precipitation also decreases in the same direction, from snowfall at high altitudes in the NE to poor rainfall in the SW. Temperature rises as high as 44°C during summer while it may drop below 0°C during winter at high altitudes in the NE (Ahmad, 1951). Climatic data based on averages for 30 years (1959 to 1988) are given of Islamabad and Jhelum towns as graphical representations, and mean annual rainfall isohyetes pattern over the plateau (Fig. 2) More than 50% of the precipitation occurs during monsoon season (July to September) and the rest during spring and winter. On average, about 20% of the rain water constitutes runoff while the rest seeps into the ground. Due to lower level of the drainage system, much of the groundwater seeps into rivers and streams, also out of the soil from the walls of the deep erosion gullies. In the river-plain areas, water may become available in shallow wells (9/m to 15/m), but those get exhausted during dry periods. The sands and sandstones make best acquifers for storing groundwater, which is suitable for domestic, agricultural and industrial purposes, with TDS — 220 to 1550 ppm and pH — 7.3 to 8.8 (Ismail, 1983).

LANDSCAPE AND SOIL EROSION

Landscape of the Potwar Plateau is controlled mainly by the specific lithologies and their regional structures, but the final sculpturing is carried out by the activity of soil erosion processes (Elahi et al., 1961). The blanket gravel and loessic soil over the Siwalik Group rocks are present as rounded ramnents in the marginal areas left by the eroding drainage. In the central part of the Soan Syncline, however, thick soil deposits are present composed of reworked loess Generally, erosion is also very intense here but the gullies so formed provide flat-bed soil for agriculture. The soft bedrocks here too are exploited due to their rather flat surfaces. Away from the Soan Syncline axis, typical dip and strike streams are present that give rise to badland topography, particularly where drainage is dendritic and closely spaced (Fig. 3). The interfluves tablelands are composed of old mature Udic Haplustalfs soils, their upper slopes (0-8%) having the Typic Ustochrepts soils while the lower slopes (2-25%) are constituted of Typic Ustocthent soils. Surface gradients play effective role in the rate of soil loss. In follow surface cover, increase in surface gradient of 1% to 10%, increases run-off from 17% to 56% soil loss from 17 t/ha to 41 t/ha. Beg et al. (1985) distinguished 17 soil families and delineated 47 pedo-geometically landuse areas by combing agroclimatic and agro-edaphic environments. Towards erosion gullies, soils are leached of their calcareous matter that mostly makes crust on gully rims as well as seeps along the gully walls. This crust tends to resist water erosion but the situation is changed due to farming practices or by the torrential monsoon run-off, and the soil gets exposed to ersoion.

Generally, two to three levels of erosion surfaces (Terra et al., 1939) are easily recognised although up to five have been identified. Between these surfaces, potholing and scouring actions are fairly common that assist in accelerated erosion of the successive surfaces. The rate of erosion is so high that in the second or third erosion surface, sometime layers of bushes and shrubs are exposed that were transported and deposited there during rain storms only a few years old. The high rate of run-off is mainly responsible for soil erosion. During three months of the monsoon season (July to September), an average of eleven storms are received, with time duration of 35 to 217 min. In a single storm, the rainfall varies from 9 to 94 mm, and storm intensity from 3mm/hr to 78 mm/hr. The run-off measurements show a range from 16% to 74%, with an average of 50% for the monsoon season. The soil loss also increases in conformity with increase in the rate of run-off. Measurements have shown that even with small increase in the run-off rate from 47% to 50%, the soil loss increases from 17 to 41t/ha (Shafiq et al., 1988). Notably, out of a total of 1.82 mha arable land, only 0.61 mha is under agricultural production. On the other hand, about 5,000 ha of land surface becomes inaccessible for cultivation every year due to soil erosion (Anwar, 1986; Shafiq et al., 1986).

A peculiar gravity falling of earth pillers along banks of the gullies is yet another major process that is responsible for considerable soil wastage. Huge volumes of soil fall stepwise or slopewise and fill beds of the gullies. This soil gets removed during rainy season and the sediment-loaded water not only causes permanent loss of soil but also rapidly fills up small water reservoirs constructed for agricultural and domestic use. In this manner, a higher agricultural terrace is lost while the lower one become heapy and unsuitable for ploughing (Shams et al., 1990).

Many landfarming techniques are being employed for achieving maximum utilization of soil of the erosion slopes (Shahid et al. 1989). For instance, where slope is more than 50%, eyebrow, reverse slope and conservation catchment terraces are prepared for agriculture, plantation and Pasture development. Soil conservation practices have been employed also by certain organisations with variable success. The Soil Conservation

Directorate, Punjab, employs engineering works in order to level the fields including gullies and terraces, with concrete structures to control the run-off. The Pakistan Forest Research Institute, Peshawar, attempts re-establishment of lost vegetation; particularly trees are planted along steep gully walls while grass and shrubs are used for controlling the run-off. The Agricultral Research Council, Islamabad, adopts redesigning of the watershed and employs both engineering and ecological measures. This method applied only to small areas and is costly too while the cutting of trees and grazing of animals acts against the logical technique. So far, only the engineering practices have proved successful but again these cannot be applied regionally due to high cost of machinery and the engineering problems involved (Shafiq et al., 1986; Chaudhary, 1985; Anwar, 1986).

During dry season, wind revmoves lot of fine dust in storms and refers to a reversal of the process of loess deposition in the past. However, no data exist on this aspect, although it is an important erosion agent when considered on the plateau scale

THE TECTONIC FACTOR

At least in one aspect, the Potwar Plateau can be distinguished from many such regions that are suffering from severe soil erosion; it concerns the influence of slow but persistent neotectonic activity (Yeats et al., 1984). The presence of pwerful regional thrust zones of MBT and MFT, and activities related to Jhelum and Kalabagh re-entrant faults in the East and West respectively, make the Potwar Plateau prone to tectonic stresses (Fig. 1c). This has been happening continuously since the development of Potwar basin in front of the rising Himalaya. Geological record shows that the Siwalik sedimentation had passed through many phases of progradation and aggradation, including repeated eastwards and westward tilting of the basin, and ultimately suffering regional folding into SW pluuging Soan syncline. Absolute ages of the

initiation of deformation of the latest anticlines adjoining the Potwar Plateau (Mangla, 2.7 m.m. B.P. ; Chambal, 2.4 m.y. B.P. ; Rohtas, 1.7 m.y. B.P. and Pabbi, , 1.2 m.y. B. P. ; with ages of surface expression as 1.5, 0.7, 0.4 and 0.4 m.y. B.P. respectively) show younging towards South (Johnson et at; , , 1979). The Khair-i-Murat and Bakrala ridges emerging out of the plateau are not yet dated. This shows that the Potwar Plateau was already present before these structures developed, the activity being still continuing. Notably, the sedimentary beds carrying primitive man's stone implements also stand tilted as a result of tectonic activity (Marks, 1962). Investigations in the Soan River vallye have shown the presence of up to five erosion terraces that refer to the periods of tectonic quiscence following rapid rise of the head-water montane areas (Terra et al., 1939). The extensive system of plunging anticilnes and synclines (Fig. 6) has given rise to broad coss-folding in the bedrocks, with enhaced development of strike-dip system of soil erosion leaving limited esxtent of soil strips as the tablelands.

A significant effect of neotectonics is the development of earth-pillars and resultant mass wastage. This phenomenon can be observed in the marginal zones of the tablelands. Composed dominently of loessic material, the soil acts as an sotropic material towards uplift tectoic stresses. Consequently, it develops poor to well-defined hexagonal fractures at the surface that extend depthwise to make earth-pillars. The ultimately suffer fall into the adjoining gully and thus soil suffer fall into the adjoining gully and thus soil is lost in abundance (Fig. 5). Considering the area affected by this phenomenon, nearly 50% of the eroded soil is lost by this process. Notably, this activity is stronger during dry season when run-off water is not active otherwise. Thus, the tectonic factor plays a major role in the degradation of the Potwar plateau, and should be considdered in all soil conservation strategies.
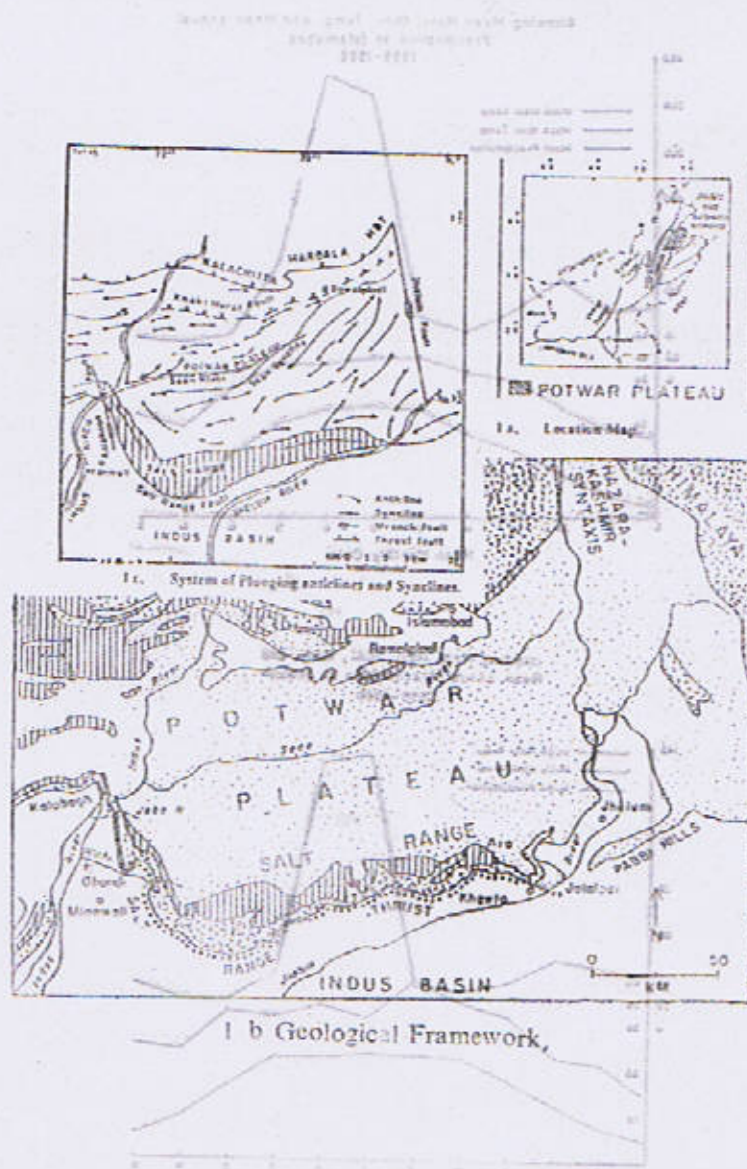
1 A. Location Map.

1 x. System of Plunging anticlines and Synclines.

1 b Geological Framework.

Showing Mean Maxi, Mini, Temp. and Mean annual
Precipitation at Islamabad
1959 - 1988

Mean Maxi Temp
Mean Mini Temp
Mean Precipitation

Mean Monthly Data

Showing Mean Maxi, Mini, Temp. and
Mean annual Precipitation at Jhelum
1959 - 1988

Mean Maxi Temp
Mean Mini Temp
Mean Precipitation

Mean Monthly Data

Fig. 2, a.   Graphical Variation of Climatic data of Islamabad and Jhelum Towns
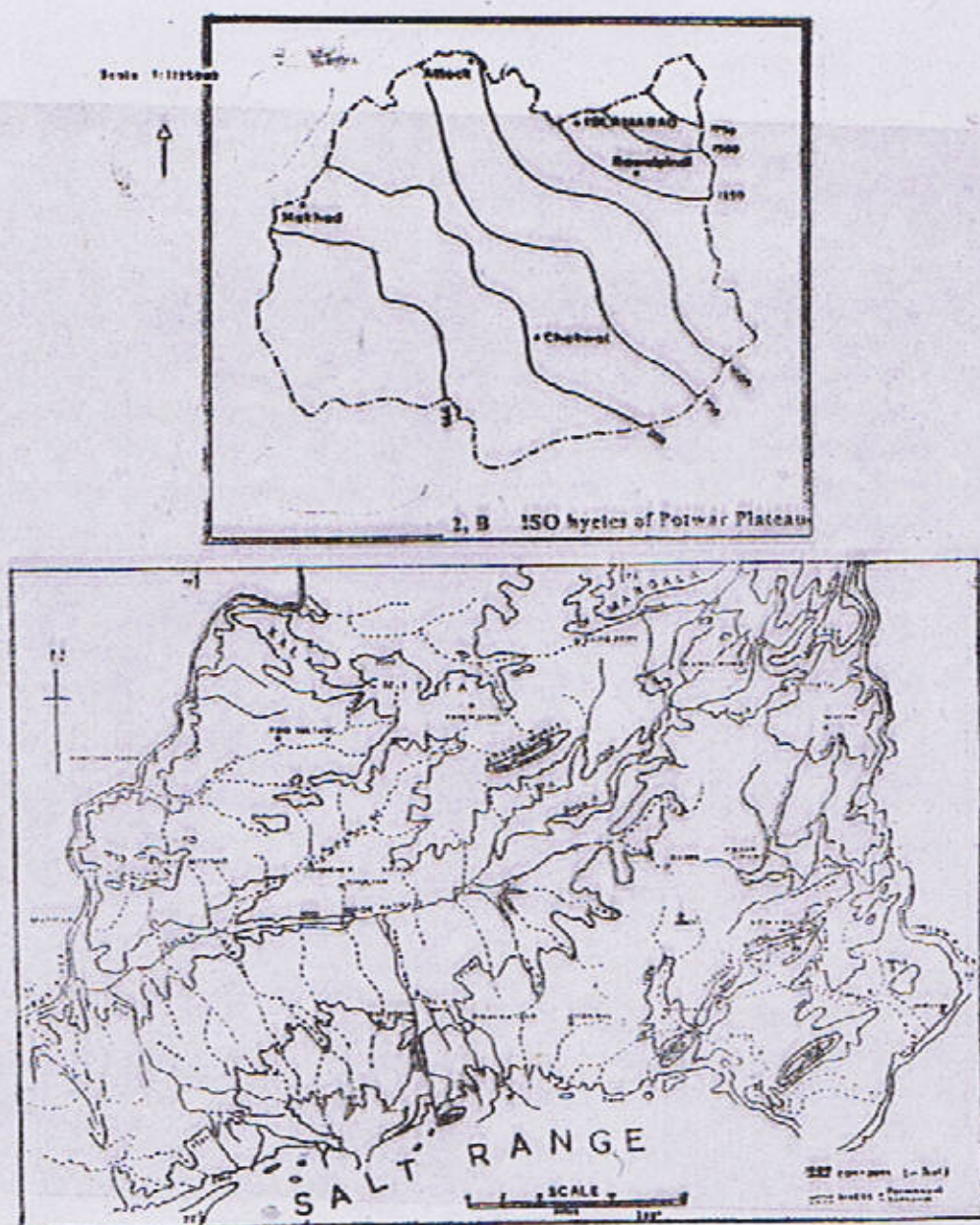
2, B   ISO hyetes of Potwar Plateau

Fig. 3.   Zrainage Map of Potwar Plateau

Fig. 4. Cross-Section of reworked loess an older loess belt, the former
showing calcification

Fig. 5. Cross-Section of a massive deposit of loess]near chhni Alam Sher.

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INDUSTRIAL UTILISATION OF LIMESTONE FOR COMBATING ENVIRONMENTAL POLLUTION

By

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Abstract : *Limestone, a sedimentary rock containing 95 percent or more of calcite, finds utilisation in a number of industries. Limestone deposits of Pakistan range in age from Carboniferous to Eocene and its reserves are widely distributed throughout Pakistan. Limestone finds applications as acid neutraliser for wastes of mining and chemical processing, soil conditioner, coal mine dusts and in filter beds of sewage plants. Lime, the first derivative, manufactured product of limestone also finds a number of application in environmental control such as neutralisation, coagulation and absorption. Lime is also used for stabilisation of soils in unstable slopes.*

INTRODUCTION

Pakistan has large and widely distributed limestone deposits exposed from North to South (Fig. 1) Limestone deposits of Pakistan have been described in detail by Gauhar, (1966) and Ahmed (1969, 1975). Representative chemical analysis of limestone deposits from various localities are given (Table 1). In Pakistan, limestone has a range of uses in many sectors of industry based on its physical, mineralogical and chemical properties. The primary use of limestone and other carbonate rocks is in construction as aggregate or in the production of cement. High purity limestone is extensively used in the iron and steel industry, in the chemicals industry, in the manufacture of glass and in many more specialised uses.

This country is facing an acute problem of environmental pollution mainly because of rapid growth of industries around the cities and mining activities. So far, no effective remedies have been taken to overcome this problem. This paper is an attempt to propose the use of limestone and lime to overcome the environmental pollution caused by the wastes of mining and industrial processing.

ENVIRONMENTAL USE OF LIMESTONE

(i) Acid Neutralisation

Limestone is considered to be the lowest cost acid neutraliser. However, it cannot neutralise a strong acid much over pH 6.0 and its reactivity is very slow as compared to lime and sodium-based alkalis. This also needs a much bigger neutralisation plant and yields a large volume and weight of sludge. Limestone-lime treatment is recommended to overcome these disavantages or when over neutralisation above pH 6.0 is required. Limestone with high calcium contents with 75% passing through 200 mesh, is the most suitable form to be used for neutralisation. Coarse limestone or dolomitic limestone have not been found

as successful. Coarse limestone passing through 8-80 mesh, never reacts completely. The acid and much of it is wasted in the form of sludge. Dolomitic limestone is too slow to react unless brought to extreme fineness.

Burt (1986), made separate studies regarding treatment of pyrite sample with deionised water, with crushed limestone in presence of saturated limestone solution and with crushed limestone in presence of deionised water. The study revealed that the maximum effectiveness of acid neutralisation was achieved by thorough mixing of limestone with pyritic gangue material. Initially the pyrite oxidation would increase, howevesr, with the rapid dissolution of limestone, the process of neutralisation increases and this effect iron precipitation and coat pyrite surfaces. In case of insufficient amount of limestone, the pyrite oxidation continuously increases, thus minimising the neutralisation effect of limestone. So in order to have best results of limestone treatment of pyritic gangue, an amount sufficient to maintain the alkalinity should be applied to retard pyrite oxidation.

(ii) Mine Safety

Limestone as rock dust is used in coal mines for mine safety purposes. The mine explosions due to highly combustible coal dust can be avoided with mixing rock dust with coal dust upto 66%. Limestone in pulverised form is applied by machines to ceilings, walls and floors in working area of coal mines.

(iii) Sewage Treatment

In sewage plants limestone of 3.8 to 6.35 cm size are used to provide surfaces for growth of such bacteria that feed on other bacteria in the effluents. Limestone used should be free of pyrite, marcasite and clays.

LIME AND ENVIRONMENTAL CONTROL

Lime obtained as a derivative product of lime-stone finds a number of application in the control of environment. Lime is found to be effective in precipitating trace amounts of heavy metals, many of which are toxic. These form highly insoluble calcium based compounds. Fig. 2 shows heavy metal precipitation with lime for Ag, As, Ba, Cd, Co, Cr Cu, Hg, Mn, Ni, Pb and Zn. With the exception of Cr, lime removes in excess of 85% of these metals The removal of Ag, Cd, Cu, Mn and Zn is between 95% to 99%. The removal of Cr increases when hexavalent Cr is redced to trivalent form. The pH levels also effect the removal efficiencies (Table 2). Lime is also found to be effective in removal of traces of radium 226, uranium and thorium 230, (Boynton, 1980).

Lime finds a number of applications for environmental purposes. These include potable and industrial process water treatment ; the retreatment of waste process waters for recyclical use ; treatment of effluents from sewage plants, industries and mines, absorption of toxious acid oxide gases and treatment of solid wastes for safe disposal in the ground. Lime applications with fertiliser have been found to rehabilitate stagnant ponds and logy turbid lakes with aquatic life very poor or dormant due to heavy algal growth, decayed vegetation and acid water (Boynton, 1980).

Bell (1990) studied in detail the effects and actions in a soil-lime mixture. The addition of lime to soils, enhances many of their engineering properties. Soil stabilisation with lime has been used in unstable slopes, where addition of lime results in the replacement of Na with Ca in the interlayer structure of clays of smectite group, which results in decrease of clay expansion.

Three layer clay minerals with silica faces on both sides (montmorillonite) is more reactive than two layer clay minerals (chlorite). This contributes towards the improvement of soil workability.

The lime content required to modify a clay soil varies from1-3% and that required for cementation varies from2-8%. The emissions, produced during firing in bricks making kilns, in addition to carbon dioxide, chlorine and fluorine. The addition of lime reacts with sulphur dioxide and fluorine to produce anhydrite and fluorite. This reaction prevents escape of these gases into the environment.

CONCLUSIONS

Limestone with varying degree of concentration and size can be used for acid neutralisation of acid mine drainage, chemical industries effluents and for mines safetypurposes. Pakistan has huge inexhaustible limestone deposits and are being usd in a number of mineral based industries. Lime, a derivative product of limestone finds a number of applications in the control of environments; particularly in precipitating trace amounts of heavy metals, industrial process water treatment, treatment of sewage plant etc. Lime addition to soils helps to improve the stability of unstable slopes. There is wide scope for setting up of limestone and lime industries in Pakistan to produce products for control of environmental pollution due to mining, chemical industries and sewage disposal etc.

TABLE 1

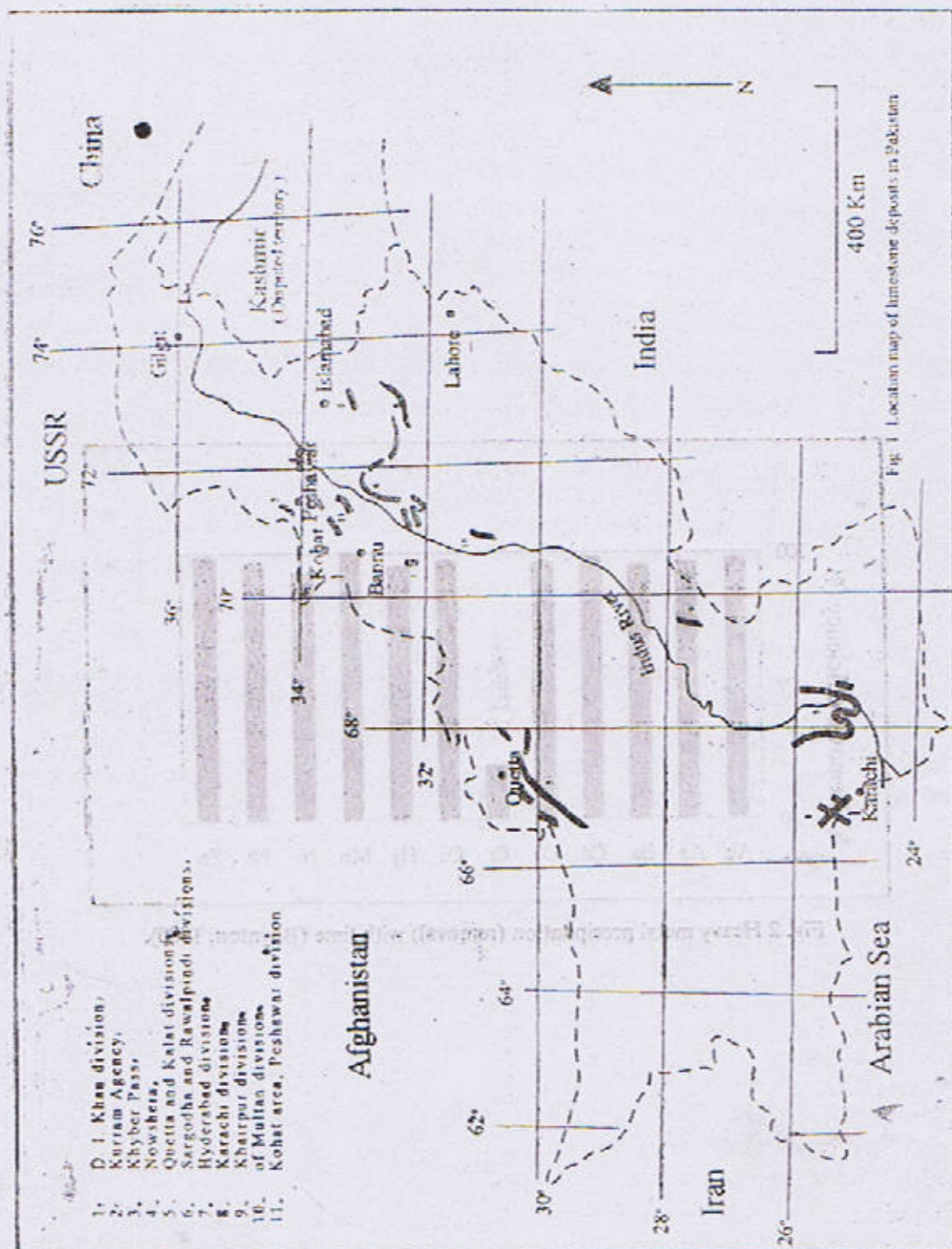### Representative chemical analysis of different limestones from Pakistan

	1	2	3	4	5	6
CaO	43.0-52.0	53.16	53.70	51.31-54.26	49.52-54.52	41.98-50.54
MgO	Traces-2.87	0.92	0.30	1.15-3.10	0.15-4.40	0.12-0.76
Al_2O_3	1.0-3.0	0.94	1.00	0.09-0.31		
Fe_2O_3	0.40-1.70	0.39	0.50	0.15-0.39	0.24-1.52	0.35-2.65
LOI	36.0-42.0	42.92	43.30	43.67-44.04	40.47-43.13	38.24-44.74

1. Sorinala Limestone (Gauhar, 1966).   2. Kohat Limestone (Gauhar, 1966)   3. Rohri Limestone
(Gauhar, 1966)   4. Dungan Limestone (Saleemi, 1991)   5. Sakessar Limestone (Gauhar, 1966)
6. Ganjo Takar Limestone (Gauhar, 1966)

TABLE 2.

Removal efficiencies of lime at different pH values. (Boynton, 1980)

	pH 6.7	pH 12.7
Cd	1.3	0.02
Fe	6.0	0.1
Ni	0.13	0.03
Cu	5.3	0.05
Zn	31.25	0.11
Mn	26.50	0.04

Fig. 1 Location map of limestone deposits in Pakistan

1. D. I. Khan division.
2. Kurram Agency.
3. Khyber Pass.
4. Nowshera.
5. Quetta and Kalat divisions.
6. Sargodha and Rawalpindi divisions.
7. Hyderabad divisions
8. Karachi division
9. Khairpur division
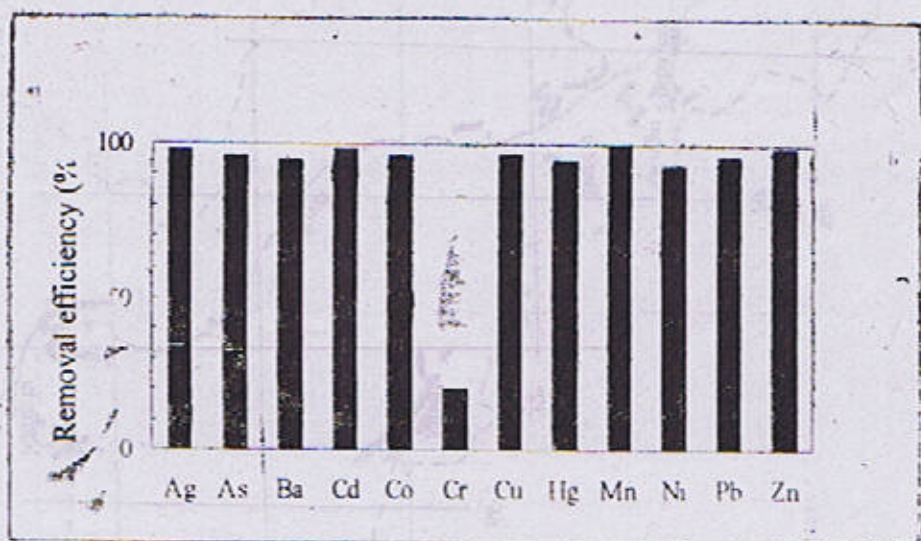10. of Multan divisions
11. Kohat area, Peshawar division

Fig. 2 Heavy metal precipitation (removal) with lime (Boynton, 1980).

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THE ENVIRONMENTAL IMPACTS OF COAL MINING FROM SALT RANGE PAKISTAN AND THEIR REMEDIAL MEASURES

By

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Abstract : *Detailed mineralogical and chemical studies of the coal deposits from the Salt Range indicate that the downstream environmental pollution is due to Pyrite, Gypsum, Clays, Halite, Carbonates and acid mine drainage. Thep resence of these minerals in and around the coal deposits of the area under study and presence of certain trace elements, are affecting the downstream soil and water. During rainy seasons, the addition of toxic elements and fine sediments from the mining wastes increases the rate of downward pollution.*

Some remedial measures are suggested to minimize the environmental impact of coal mining in the studied area.

INTRODUCTION

The Salt Range Coal deposits are in Paleocene Patala Formation with minor occurrences in Permian (Tobra Formation) The Patala Formation is 5 to 90 mthick and is composed of dark grey, fossiliferous shale and coal. These deposits are there sult of deposition in back barrier and near marine environments.

In the eastern and central Salt Range, coal seams occur in single bed less than one meter thick, commonly split by dark-greys hales or thin bandsof quartzose sandstone. Coal seams upto 2.13 m have been reported in the extreme eastern Salt Range.

The coal bearing strata in the Makarwal coal field is within the Hangu formation of Paleocene age. These are overlain by Younger tertiary rocks. The thickness of coal beds varies from—1 m to 2 m.

Detailed mineralogical studies of coal samples show the presence of clays, quartz, and pyrite,

chloride (Nawaz, 1986).

ENVIRONMENTAL IMPACTS

The exploitation of coal and its associated processing activities, causes environmental degradations and their gravity depends upon the nature and quantity of coal mining activity. Pervaiz (1992), described in detail the mining hazards and classified them into four major categories ; Biological (bacteria, fungi) ; Chemical (toxic chemicals, dusts and gases) ; Physical (heat, noise, radiation and vibration) ; Stress (created by chemical, ergonomic, physical or psychological factors).

During surface mining operations, rock dust is constantly released into the air. The intake of fine particles by mine workers causes lung diseases due to high level of quartz or free silica in the waste rocks. Similarly coal dust also causes lung diseases.

Health hazards due to underground mining includes dust related diseases such as silicosis and

toxic effects of harmful gases such as carbon monoxide, nitrogen oxides, hydrogen sulphide and hydrogen cyanide and sulfur dioxide.

The presence of pyritic material and clays in the coal seams of the studied area causes a great deal of environmental pollution at the mining site and also downstream. These effects are enhanced during the rainy season as the input of mine water along with fine sediments to the downstreams increases. As a result of mining activities, down stream pollution results due to :
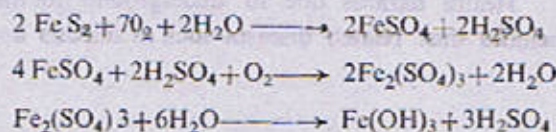
1. Acid Mine drainage

2. Waste Disposal

GENERATION AND QUALITY OF MINE DRAINAGE

One of the most persistent environmental pollution problems in coal mining is the acid mine drainage. The source of A.M.D. is the availability of sulphur in coal seams in the form of sulphides, sulphates. The pyritic sulphur contents varies from seam to seam and from one geographic region to another. Acid mine water results from the contact of pyrite with the incoming water from the aquifers or surface water travelling downwards.

There are six factors responsible for generation and the quality of mine drainage :

1. Availability of sulphide minerals.

2. Availability of dissolved oxygen and ferric/iron.

3. Bacterian.

4. Surface area of exposed sulphides bearing.

5. The presence of acid neutralizing minerals.

6. Temperature and salinity of ground water.

Doyle, 1976 ; gave the following equations for the formation of acid mine water from pyrite :—

$$2\,FeS_2 + 7O_2 + 2H_2O \longrightarrow 2FeSO_4 + 2H_2SO_4$$

$$4\,FeSO_4 + 2H_2SO_4 + O_2 \longrightarrow 2Fe_2(SO_4)_3 + 2H_2O$$

$$Fe_2(SO_4)3 + 6H_2O \longrightarrow Fe(OH)_3 + 3H_2SO_4$$

OR

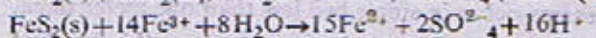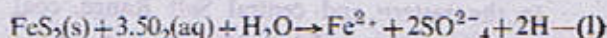$$Fe_2(SO_4)3 + 2H_2O \longrightarrow 2Fe(OH)SO_4 + H_2SO_4$$

Ferric Hydroxide or basic ferric sulphate forms depending upon the physical and chemical conditions.

The downstream mine drainage dissolve constituents from most materials with which it comes in contact. This result, in the increase of dissoloved concentration of certain elements However, as a result of exposure to oxygen, change in water chemistry and increase of pH certain elements separates out : e.g. iron frequently forms iron rich precipitates under these conditions (Nordstrom, 1982).

$$Fe^{3+} + 3H_2O \longrightarrow Fe(OH)_3(s) + 3H^+$$

$$Fe^{2+} + 2.5H_2O + 0.25O_2(aq) \longrightarrow Fe(OH)_3(s) + 2H^+$$
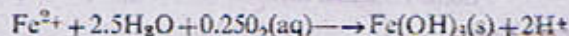
The hazardous elements and precipitates introduced into streams and rivers can adversely affect the quality, ecology, and chemistry of the receiving waters (Moore and Luoma, 1990; Ficklin and Smith, 1993).

Although the solubility of sulphide minerals in water is generally low, yet the sulphides are unstable in presence of dissolved oxygen and/or ferric iron. Dissolved oxygen and ferric iron can oxidize the sulfide minerals (Smith, 1994)

$$FeS_2(s) + 3.5O_2(aq) + H_2O \rightarrow Fe^{2+} + 2SO^{2-}{}_4 + 2H \quad —(1)$$

$$FeS_2(s) + 14Fe^{3+} + 8H_2O \rightarrow 15Fe^{2+} + 2SO^{2-}{}_4 + 16H^+ \quad —(2)$$

where $Fe_2(s)$ is pyrite, $O_2(aq)$ is dissoved oxygen, H_2O is water, Fe^{2+} is dissoved ferrous iron, $SO^{2-}{}_4$ is dissoved sulphate, H— is dissoved proton (responsible for acidity), and Fe^{3+} is dissolved ferric iron (Garrels and Thompson, 1960). Pyrite oxidation is accomplished according to reaction(2) in the pH range of 2 to 7 (Moses et al., 1987 ; 1991) and eight times more acidity is produced as compared to when dissolved oxygen serves as the oxidant. In reaction(2), the role of dissoled oxygen appears to

be limited to form ferric iron by oxidizing Fe^{2+},

$$Fe^{2+} + 0.25O_2(aq) + H^+ \rightarrow Fe^{3+} + 0.5H_2O \quad\text{---(3)}$$

The bacterias, Thiobacillus and Leptospirillum, are able to derive energy from the conversion of ferrous to ferric iron (Harrison, 1984) and their presence accelerates enormously the conversion of ferrous to ferric iron (Singer and Stumm, 1970). The other factors responsible for producing acid mine drainage include the exposed surface area of sulphide minerals, the quality and temperature of ground water and the presence of carbonates, neutralizing the acid mine drainage.

Smith, (1994) ; summarizes the chemical and biological factors involved in the production of acid mine drainage as ;

$$Pyrite + Fe^{3+} + Water \rightarrow Fe^{2+} + Sulphate + Acid$$
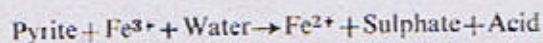
Dissolved oxygen and ferric iron oxidizes other sulphide minerals and the respective elements are dissolved in the acid maine drainage.

Warwick et al. (1995) reported total sulphur variation from 3.13% to 7.21% ; Sulphate Sulphur 0.06% to 0.69% ; Pyritic Sulphur from 0.48% to 3.72% ; and Organic Sulphur from 2.37% to 3.93% in 20 coal samples from Surghar Range. Their presence contribute towards for formation of acid mine water.

This mine water loaded with a number of undesirable and hazardous constituents cannot be used in any form unless purified. Coal mines water may have bacteria which are formed due to decay of timber or other organic matter. This water containing bacteria is also harmful for health.

The environmental effects of mine water pollution lies not only at the mining sites, but also migrate downstream all the way from the origin until the final pollution disappearance, either by dilution or through treatment.

The variation of Se contents from 7.4 to 19.1 ppm, (Warwick et al., 1995) is in the hazardous range. Selenium shows affinity with iron sulphides and during combustion of coal shows segregations in fly ash (Querol et al., 1995). Similar behaviour is shown by As, the concentration of which varies from 2.44 to 8.00 ppm (Warwick et al., 1995). Use of coal with such high concentration of Se can create environmental pollution from its accumulation in the environment from fly ash.

Remedial Measures

Wetland Treatment Cell

As a result of geochemical processes in mountanous regions involving oxidation of metal sulphides present in the mineralized rock the incoming water attains low pH and high metal concentrations. The downstream flow of this water affects the water quality and aquatic resources of streams and rivers in the mineralised belts. This demands effective measures to treat acid mine drainage and acid leachate from minging waste. Emerick et al, 1994 discussed various methods for treatment of acid mine drainage and described in detail the treatment of acid mine drainage by metal and dydrogen ion (H^+ or proton) adsorption, and by transformation of metals into insoluble compounds. Reduction of sulphate present in the mine drainage by certain bacteria is the major metal removal process in the wetland. The hydrogen sulfide, produced, precipitates out the solution. The organic matter, on decomposition by anaerobic bacteria, releases ammonia, bicarbonate ions and methane. These causes a raise in the pH, which is sufficient for the reduction of sulphate.

Treatment of acid mine drainage with limestone in treatment tanks or channeling the drainage through carbonate rocks can also effectively neutralise the acidity of the mine drainage and adsorption of metallic ions.

Sedimentation Ponds

The surface mines run offs have usually high

silt content. The silt contents be allowed to settle in sedimentation ponds before their discharge. In case of mine effluent containing chemical reagents liable to affect downstream water bodies, water treatment facilities suitable to the nature of the effluent should be created before allowing it to mix with the downstream water.

Reclamation of Affected Areas

The extent of downstream areas affected by acid mine water and hazardous sediments, be identified by electrical resistivity methods (Umar

Farooq et al 1994). The nature and extent of hazardous metals be determined by detailed geo-chemical study of the affected area. The soil be chemically treated to undo the affects of pollution.

Fletcher (1992) reported a feasibility study on reclamation of soil contaminated with Copper, Chromium, nickel and cadmium in Tucson Arisona U.S.A. The process would involve crushing, grinding followed by sulphuric acid leaching, filtration and washing. The treated soil would be returned to site for landscaping, seeding and planting.

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