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CONTENTS

AN APPRECIATION

By

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It was with great pleasure and no little surprise that I received the notice of the issue of the Institute Number of the Geological Bulletin of the Punjab University, which is to mark the occasion of the elevation of the Department. Pleasure, because it is always for me a happy occasion when I receive information and documentation about its activities and development. Surprise because to talk of the passage of so many years I could, at first, hardly credit so clear are my memories of the early years of the establishment of the Department, of the challenges, the achievements and the bounding enthusiasm of staff and students alike. That the notice was addressed over the signature of the current Director of the Institute, Professor F.A. Shams, was doubly warming because he was the first of the staff members who came to, and has stayed with it almost from the beginning. I remember well how much we depended on him and his deep concern for the Department and the science of geology. It is also noteworthy that so many of the early students who became staff members have also stayed. This is a remarkable circumstances in the modern world in which the fashion for mobility has become extreme and brought a loss of the sense of, and need for, continuity, which is an essential factor in building excellence. In a real sense the Department became a home, something to which all could dedicate themselves and settle into for the purpose of acquiring and developing their knowlege of geology and its associated subjects.

There is much ado, these days, about the need for university institutions to be involved in the development of the resources of their country. This is natural, and nothing new for a vigorous department alert to its larger responsibilities. There is, however, a tendency for this need to be exaggerated and somewhat misplaced, given the usual institutionalisation of a science and its use in a country in all but the very early stages of institutional and economic development. It seems sometimes to be forgotten that scientific knowledge cannot be applied until it is adequate to the problem indicated. The paradox is clear in these simple words, but it is not always so at the policy-making level where, however, it is essential to strike a balance between the support for basic scientific research, which has not immediate foreseeable use, and the demand for that which is evidently usable for the relief of mankind's socio-economic condition. In countries, like Pakistan, which have government establishments and private industry directly concerned with the exploration for, and exploitation of, natural resources, the universities have the prime responsibility for basic research and the training of practitioners in the subject concerned. This does mean exclusiveness ; that, for example, university staff should not engage in economically justified scientific activities and research but that their prime purpose must not be subordinated. The weighting of the relevances, scientific social, economic and environmental must be varied in assessing the priorities for research, according to the purpose of the institute concerned. For a university department it must be responsive to the ability and propensity of the staff available : talent, a much needed requirement for developing a country, can only be expressed through their choice. It is the responsibility of senior university scientists to ensure that their role in the affairs of the nation are properly understood by the policy-makers if the balance of effort and its right point of application are to be properly maintained. The division of labour, which is solely meant to improve efficiency and thereby productivity throughout society is just as applicable to the scientific activities as to other activities of man.

As Founder-Editor of the Geological Bulletin of the Punjab University, I am proud of its continuance, growing coverage of geosciences and admixture of articles on both the purely scientific and the economic aspects of them. I know that there have been times when its production has faced difficulties in the intervening years, but these have been overcome because of a firm belief in its importance. I recall how, at the outset, there were criticisms of its initiation. These sprung the then fashionable thinking that the authors of the research could only obtain national recognition through publication in western journals, and that the Department was guilty of adding to the list of journals which were proliferating too rapidly and that it was likely to fail after a few issues. The historical facts have clearly rebutted these. I believe the decision to go ahead has been completely vindicated. The Bulletin provided a much needed vehicle for the ready release of the research potential of the Department and thereby stimulated it, and launched the Department on the path of seeking excellence. It was important also in improving the teaching function of the Department, because moribundity in teaching follows from the endless repetition of the work of others. Research stimulates the criticality with which this latter is approached and adds zest to teaching. It develops the problem-solving attitude of mind, so necessary not only for the advance of science but also to its application to socioeconomic problems and objectives.

May the future sees, the capacity, vigour and excellence of the Institute and its voice, the Bulletin, reach even higher levels and make it, as we all aspired, second to none.

15 January, 1979

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Manor Form Road,
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PETROLOGY OF MINOR OLIVINE GABBROS AND ULTRAMAFIC ROCKS FROM UPPER SWAT, N.W. PAKISTAN

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Abstract : *Small bodies of ultramafic and olivine gabbroic rocks have been reported from a number of places in the amphibolites and pyroxene granulites of Swat. Most of these rocks are inconsistent in texture, mineralogy, chemistry and the extent of metamorphism. They have probably been emplaced at different times and do not seem to be directly related mutually or to their host rocks. As an illustration, the petrography and chemistry of two olovine gabbros, two pyroxenites, one bahiaite, and a two-pyroxene-two-amphibole-olivine-plagioclase.-spinel rock is presented, together with comments on the relationship between various rock types of the area.*

INTRODUCTION

The northern part of Swat district (34° 43 N' 72° 24' E) is occupied largely by basic and intermediate rocks of the Kohistan complex. The principal rock-types occur in three NE-stretching belts : amphibolites forming the southern, noritic rocks occupying the middle, and quartz diorites making the northern belt (Jan and Kempe, 1973). East to West the complex spans a distance of more than 200 km between Nanga Parbat and eastern Afghanistan whilst North to South it stretches 75 km along the Swat river between Kalam and to the South of Kabal.

To the North the complex is bounded by a narrow mixed zone of quartzites, metasediments, and acidic porphyries just to the South of Kalam. Further North of this zone occur metasediments of the Kalam group (dominated by cherts and radiolarites), followed by the Utror volcanic rocks (lava flows, tuffs, breccias), and undifferentiated quartz diorites and granites (Jan and Mian, 1971). In the South the amphibolites are thrust-faulted over the Palaeozoic Lower Swat-Buner Schistose Group of Martin *et al.* (1962). The occurrence along/near this fault of glaucophane schists (Shams, 1972), high-pressure granulites (Jan and Howie, In preparation) ; and of ultramafic rocks in Bajaur, Dir, Swat, Indus Kohistan, Thak Valley, is suggestive of a major tectonism ; it is probably an extension of the Indus Suture-line which, according to Gansser (1974), marks the subduction zone of the Indian plate below the Tibetan mass.

Detailed investigations by Jan (1977 a, 1977 b, and unpublished data) suggest that (a) the ultramafic rocks and high-pressure granulites of the Jijal complex might have formed originally in the Tethyan upper mantle-lowermost crust, (b) the amphibolites probably, represent, an oceanic crust, (c) the pyroxene granulites (formerly called norites), metamorphosed under relatively uniform T, P (800° C, 7 to 8 K bar) conditions and have chemical similarities with rocks of island arcs/continental margins, (d) the above mentioned rocks and the quartz diorites have been derived from different magmas (e) the quartz diorites, at least some of the granites, and the volcanic rocks are products of partial melting connected with collision and subsequent Himalayan orogeny, (f) the noritic and intermediate to silicic plutonic and volcanic rocks and the radiolarian cherts may have formed in a continental margin or in an island arc (see also Tahirkheli et al, 1978), and (g) the greenschists of the shangla-Mingora-Kabal area, locally containing glaucophane-bearing rocks (Shams, 1972), piedmontite schists, etc, may be a (Mesozoic) tectonic slice representing a marginal part of the Tethyan crust bordering the Indian plate.

A surprising feature of such a large mass of basic and intermediate plutonic rocks is the apparent lack of olivine-bearing mafic and ultramafic differentiated members. The two large ultramafic bodies in the area (Alpurai serpentinites associated with the greenschists of Shangla, and the pyroxenites peridotites in a faulted block at Jijal are alpine-type and do not seem to be comagmatic with the amphibolites or pyroxene granulites. Although the area has not been fully investigated, yet it appears that olivine-bearing rocks are present only locally in the form of small and irregular outcrops, making less than one percent of the complex. They range from dunite to harzburgite, lherzolite wehrlite, clinopyroxenite, hornblende websterite, bahiaite and olivine gabbros, but in most localities only one or two of these rock-types occur. These rocks are inconsistent in grade of metamorphism also and it appears that they are neither directly related to the amphibolites/granulites in which they are emplaced, nor among themselves. As an illustration, detailed petrography and chemistry of six of these rocks is presented below. The outcrop areas of the analysed samples range from a few tens (SK 586, US 26) to a few thousand sq. km. (SI 355). The rocks were analysed by XRF, making pressed tablets of rock powder and cellulose binder (1 : 1). FeO was determined by Wilson's scheme and H_2O by a modified Penfield's method.

PETROGRAPHY

1. Rock samples US 26 and SI 356 are medium-grained gabbros, emplaced about 50 km. apart in the epidote amphibolites. The former is 20 x 4m in area whilst the latter, not yet fully investigated, is much larger. They are composed of plagioclase (An_{80} and An_{65}, respectively), two pyroxenes, olivine, amphibole, spinel, opaque mineral, with minor garnet and epidote in the former. The orthopyroxene in US 26 is marginally replaced by clinopyroxene in some in the interior also, whilst the main clinopyroxene in both the rocks is ophitic, cloudy, and partially replaced by an amphibole.

Corona texture, apparently resulting from a reaction between olivine and plagioclase, is displayed by both the rocks The olivine is surrounded by an envelope of radiating short prisms of orthopyroxene, which is followed by a middle shell composed of a radial intergrowth of amphibole+vermicular spinel. In US 26, however, the middle amphibole shell is separated from that of the orthopyroxene by an incomplete thin envelope of granular clinopyroxene, whilst the outermost part of the symplectic shell may have epidote needles the complete picture in this rock being : (olivine)- orthopyroxene-clinopyroxene-amphibole – amphibole + spinel ± epidote – (plagioclase)

The inner part of the symplectic shell in both the rocks is cloudy while the outer main part is clear. A thin amphibole envelope separates also the clinopyroxene from plagioclase in the two rocks. The minor garnet in 26, however, does not seem to be a product of corona development. A more detailed account of the coronas is intended for a later publication.

2. Rock Sample SK 326 is composed of olivine, ortho-and clinopyroxenes, amphibole, spinel, opaque oxide, calcite and biotite. The olivine is strained and is partially enclosed in the pyroxene, olivine itself contains spinel and, in places, brown hornblende. Opaque oxide and calcite are alteration products but biotite (deep reddish brown) occurs only in the form of rare 'inclusions' in olivine and pyroxene. Much of the amphibole is brown hornblende ; however, cross-sections of a colourless variety are also seen. The plagioclase, at places in large grains, is calcic bytownite with well developed albite and pericline twinning. It is surrounded and etched by an intergrowth of myrmekitic green spinel and clinopyroxene ± brown hornblende (Fig. 1). Such intergrowths also occur independent of

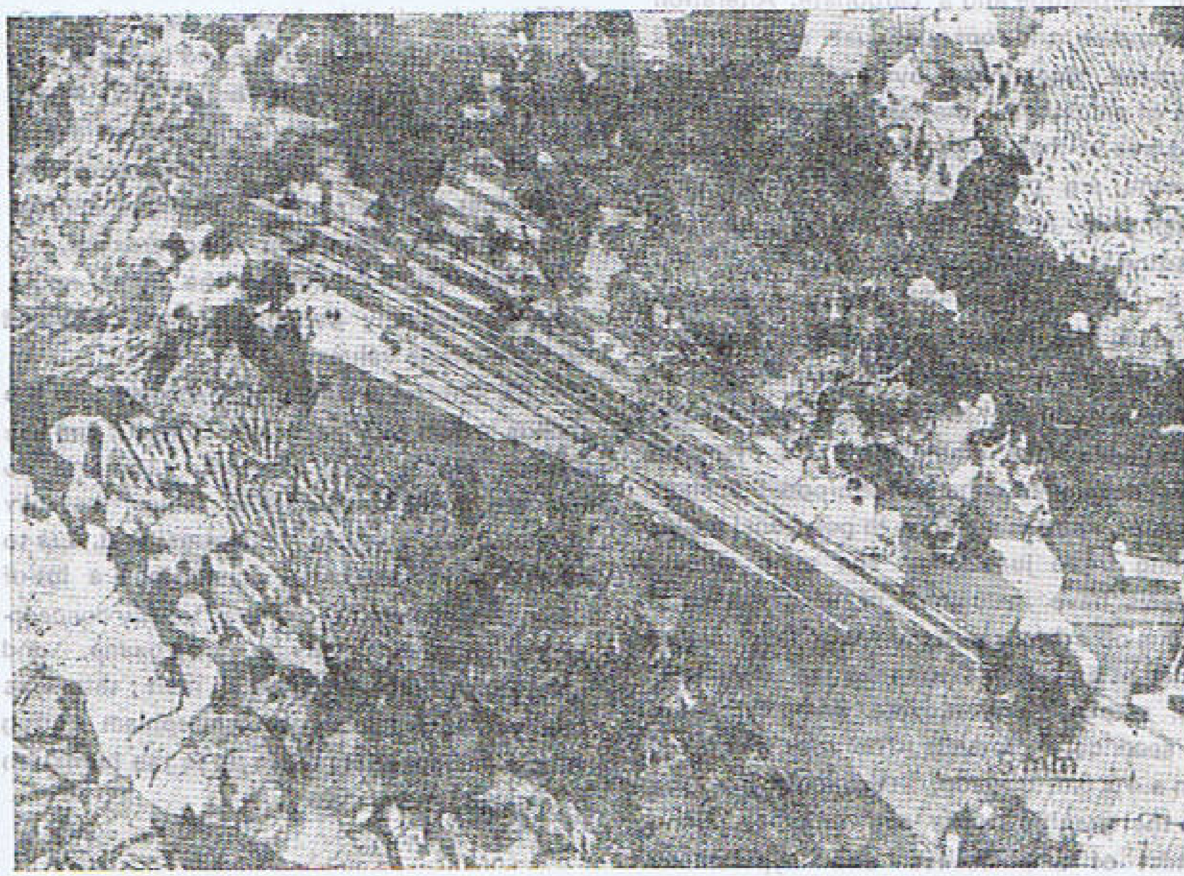

Fig. 1. Ultramafic granulite (326) showing myrmekitically brown green spinel and clinopyroxene (± orthopyroxene and brown hornblende) around plagioclase. Spinel inclusions also occur in the plagioclase. Olivine is in the lower left part.

the plagioclase ; in these the latter may have been completely destroyed. Much of this 100 x 40m lenticular outcrop in the pyroxene granulites, however, lacks olivine, amphibole and the symplectic intergrowth, but contains rutile as a common accessory. The overall chemical composition of this dark gabbroic intrusion, judging from its mineral composition (orthopyroxene +plagioclase + clinopyroxene+iron oxide), seems to be less basic than the analysed sample.

3. Rock Sample SI 246 Is a medium-grained, allotriomorphic pyroxenite intruding the pyroxene granulites. It consists of clinopyroxene, amphibole, bronzite, olivine, opaque oxide, serpentine and a carbonate. Alteration is extensive and opaque dust and needles are spread throughout pyroxene and in the cores of amphibole, the margins of the latter being free of them. The amphibole and orthopyroxene are poikilitic : the former also replacing the latter intensively and thereby imparting it a spongy appearence.

4. Rock Sample Sk 586 is a bahiaite composed of a pale green amphibole, bronzitic pyroxene, green spinel, olivine and traces of opaque mineral (s). It is medium-grained and granoblastic ; the amphibole and pyroxene having developed either as sub-poikilitic short prisms or, more commonly, in polygonal grains forming triple junctions. The main silicate minerals have inclusions of each other and there is no evidence to suggest that olivine formed at an earlier stage than the amphibole. Talc, serpentine, iron oxide and a carbonate are secondary products. The rock was taken from a 4 x 6m outcrop, seemingly intrusive into the granitic rocks and emplaced along contact of amphibolites and hypersthene diorites (granulite).

5. Rock Sample US 24, based on 5664 points counted in one thin section, consist of 62. 3% augite, 18.7 % bronzite, 14 % hornblende, and 5 % of secondary talc, amphibole and opaque mineral, all occurring along fractures. Much of the hornblende is strongly poikiloblastic, however, it also occurs in small grains some of which are enclosed in the pyroxenes. Its deep brown colour and relatively high birefringence ($\alpha = 1.647$ $\beta = 1.677$) are possibly due to its high chromium content (> 6000 ppm).

CHEMISTRY

Chemical analyses and CIPW norms of the rocks under study are presented in Table 1. The analysis of 356 is comparable with the average of olivine gabbros given by Nockolds (1954). It is slightly higher in MgO, CaO, appreciably higher in SiO_2. and lower in TiO_2 and iron oxides. US26 has higher SiO_2 Al_2O_3, CaO, and lower TiO_2, Na_2O and iron oxides as compared with an average troctolite. The differences are probably due to higher content of calcic plagioclase and clinopyroxene, and more magnesian olivine in the Swat rocks. Both are markedly depleted in K_2O compared to the average values.

SK 326 has an unusual chemistry ; for the rock is low in SiO_2 and high in MgO, and has a much higher iron content. There is no average in Nockolds (1954) tables that may resemble this analysis. It seems that, due to certain physicochemical conditions, a lot of magnetite crystallised or was locally concentrated alongwith olivine, pyroxene, and plagioclase from an original melt ; this was followed by regional metamorphism during which magetite was taken up in the formation of amphibole and spinel.

TABLE 1. XRF analyses, CIPW norms and trace elements contents of ppm of some minor and metamorphosed ultramafic rocks from olivine gabbros northern Swat, NW Pakistan.

	US 26	SI 356A	Sk326B	SK 586	US 24	SI 246
SiO_2	48 00	50.14	45.05	48.46	50.80	50.89
TiO_2	00.21	0.38	0.24	0 58	0.69	0.32
Al_2O_3	14.15	16.46	4.00	6.57	5.30	3.70
Fe_2O_3	1.41	1.16	4.24	3.69	2.27	1.41
FeO	5.50	5.13	15.37	6.60	6.54	6.17
MnO	0.13	0.14	0.34	0.22	0.20	0.08
MgO	16.85	11.54	25.45	24.86	18.15	21.00
CaO	12.58	13 30	4.17	6.18	14.50	16.56
Na_2O	0 84	1.75	0.27	0.30	0.46	0.27
K_2O	0.06	0.08	0.05	0.10	0.19	0.03
H_2O+	1.29	0.81	0.31	2.28	0.93	0.67
P_2O_5	0.11	0.03	0.03	0.12	0.09	0.11
Total	101.13	100.92	99.52	99.96	100.12	101.21
CIPW Norms						
or	0.35	0.47	0.30	0.59	1.12	0.18
ab	7.10	14.80	2.28	2.54	3.89	2.28
an	34.66	36.82	9.55	16.28	11.84	8.80
di (wo	11.28	12.09	4 56	5.67	24.84	30.32
di (en	8.40	8.60	3.04	4.44	18.55	22.94
di (fs	1.77	2.42	1.20	0.61	3.84	4.29
hy (en	13.28	10.86	28.25	43.71	21.27	11.75
hy (fs	2.79	3.06	11.13	6.02	4.41	2.20
ol (fo	14.20	6.50	22.48	9.63	3.76	12.32
ol (fa	3.29	2.02	9.76	1.46	0.86	2.64
mt	2.04	1.68	6.15	5.35	3.29	2.04
il	0.40	0.72	0.46	1.10	1.31	0.61
ap	0.26	0.07	0.07	0.28	0.21	0.26

Trace Elements (p.p.m.)

Ba	—	∠30	—	∠30	—	—
Co	50	28	314	75	55	54
Cr	1117	440	1276	1725	3440	1148
Cu	74	69	∠30	44	33	252
Ga	∠10	∠10	∠10	∠10	∠10	∠10
Ni	522	130	546	793	280	397
Rb	10	∠10	∠10	16	∠10	∠10
Sr	103	116	90	∠15	63	20
Y	14	17	∠10	∠10	20	∠10
Zn	∠30	∠30	93	83	59	∠30
Zr	∠10	∠10	∠10	12	∠10	∠10

Analyst : M.Q. Jan.

US 26. Olivine gabbro intrusion in amphibolites, 4 km N. of Khwaza Khela.
SI 356A. Olivine gabbro intrusion in amphibolites 4 km N. of Kiru, Indus Valley.
SK 326B. Two—pyroxene—two—amphibole—olivine—plagioclase--spinel rock intruding norites, 2 km N. of Madyan, to the east of Swat river.
SK 586. Hornblende granulite, 3 km SW. of Asrit along the stream.
US 24. Hornblende granulite, 4 km NE. of Parao Bridge, Upper Swat.
SI 246. Altered pyroxenite, 1.5 km SW. of the confluence of the Indus and Kandia rivers.

The values for the minor constituents in the four ultramafic rocks have been compared with the values for average ultramafic rocks reported by Turekian and Wedepohl (1961) and Goles (1967). The values for Ti, Mn, K, and P are higher and those for Cr (except in 24), Ni, and Zr are lower in the Swat rocks. Sk 326 is higher in Zn and, especially in Co and 246 is lower in these elements and Zr, Co content is also lower in 586 and 24 ; the values of Rb and Zn in the former and Sr and Y in the latter are higher. The generally higher Al, K, Sr, and Y of these rocks (except in 246) is consistent with an original plagioclase content ; texture and mineralogy also suggest a metamorphic origin for the three rocks. The molar Mg/(Mg + Fe + Mn) of the rocks (about 0.80) is substantialy lower than those (0.90) of the pyroxenites of the jijal area (Jan and Howie, in preparation) and other alpine-type ultramafic rocks. It seems that the ultramafic rocks of this study (with the possible exception of 246) are not similar to those found in the alpine-type complexes.

Chemical analyses of the pyroxene pair and tschermakitic hornblende from US24 reveal the following compositions :

Bronzite : $(Ca_{.038}\ Na_{.001}\ Mg_{1.438}\ Fe^{2+}_{.438}\ Mn_{.011}Al^{vi}_{.029}Fe^{3+}_{.038}\ Ti_{.006})_{1.999}, (Al^{iv}_{.074}\ Si_{1.926})_2O_6$

Augite : $(Ca_{.877}Na_{.036}\ Mg_{.812}\ Fe^{2+}_{.145}\ Mn_{.006}\ Al^{vi}_{.064}\ Fe^{3+}_{.041}\ Ti_{.015})\ 1.996, (Al^{iv}_{.089}\ Si_{1.911})_2\ O_6$

Hornblende : $(Ca_{1.809}\ Na_{.522}\ K_{.082})\ 2.413\ (Mg_{3.237}\ Fe^{2+}_{.890}\ Mn_{.016}\ Al^{iv}_{.458}, Fe^{3+}_{233}\ Cr_{.103}\ Ti_{.256})\ 5.193\ (Al^{iv}_{1.615}\ Si_{6.358})\ 8\ O_{22.297}, (OH_{1.576}\ F_{.128})\ 1.703.$

The rather high Cr content of the amphibole is due to the high Cr content of its host rock lacking spinel ; the presence of F in the analysis suggests its introduction during metamorphism since the average F content of the ultramafic rocks is only 100 ppm (Turekian and Wedepohl, 1961). The hornblende also has the relatively high Al_2O_3 content typical of high-grade metamorphic rocks. The distribution of the major and minor elements is in agreement with the findings of other workers summarised in Deer *et al.* (1963). The Mg – Fe distribution coefficient (0.48) for the pyroxene pair is somewhat lower but close to those computed for metamorphic pyroxene pairs (Kretz, 1963). The K_D Fe – Mg for hornblende-orthopyroxene and hornblende-clinopyroxene pair (0.90 and 1.54, respectively) fall within the range shown by Swedish charnockites (Saxena and Hollander, 1969) and West Bengal granulites (Sen and Manna, 1976). The tie – lines joining the orthopyroxene – hornblende – clinopyroxene on the pyroxene quadrilateral are similar to those of the Quairading granulites (Davidson, 1971) and the two – pyroxene tie – line intersects the Wo – En join at Wo 81.

DISCUSSION

Among various theories on the origin of coronas (late magmatic, deuteric, metasomatict, contact/regional metamorphic) the regional metamorphic possibility does not seem to be responsible for the formation of coronas in the two rocks because (a) in contrast to the generally well-developed parallel fabric in the surrounding amphibolites, the coronas-bearing gabbros lack such a fabric, (b) the coronas contain orthopyroxene, a mineral sofar not recorded in the Swat amphibolites. Temperature-pressure estimates for the amphibolites (570° – 670° C, 4 – 6 kb ar) are somewhat lower than those during which orthopyroxene would develop, and (c) Griffin and Heier (1973) have pointed out that "regional metamorphism also usually involves penetrative deformation, which would certainly be expected to destroy the delicate corona structure". Such a situation seems to be exemplified by the marginal part of the outcrop of sample 356 where the rock is metamorphosed to epidote-plagioclase amphibolite (chemically identical to 356 on H_2O – free basis) without a trace of corona structure.

It seems likely that the corona formation took place during late magmatic stages, either at a greater depth before the gabbros were intruded as a solid material in the amphibolites, or the intrusion of magma and formation of coronas occurred during the last phases of (or after) the regional amphibolite facies metamorphism. A late magmatic origin for the corona is consistent with the more recent work of Griffin and Heier (1973) and Gardner and Robins (1974).

Layered or alpine-type peridotites (setting aside the metamorphosed and concentrically zoned complexes) do not normally contain a hydrous mineral phase of major proportion in stable coexistence with olivine. The association of olivine and amphibole (at places including each other) in 586 and 322, and the texture of these rocks suggest metamorphism in the hornblende granulite sub-facies. Textures similar to those developed in 326 have been described from a spinel-bearing metagabbro in the pyroxene granulits of Western Australia (Wilson and Middleton, 1968). Since the host rocks (pyroxene granulites) in which 326 and 586 are intruded are devoid of olivine, even when olivine-normative, the two ultramafic bodies may have been emplaced during the later phases of the granulite facies metamorphism. But the possibility that 586 is a remobilised mass cannot be ruled out.

Mineralogical evidence favouring a metamorphic origin for US24 has been given above (Section 3). Five different geothermometers based on the coexisting minerals yield temperatures of 860°C (amphibole-clinopyroxene), 890° C (amphibole-orthopyroxene) and 845° C, 934°C, 9:0°C (all by different methods of two-pyroxene geothermometry). These temperatures are lower for the formation of the rock directly from a magma but are significantly higher than those (570°-670° C) estimated for the surrounding amphibolites. It is thus probable that US24 was metamorphosed at depth under the granulite facies conditions and was emplaced in the amphibolites tectonically or as a remobilised mass. SI246 may be an alpine type intrusion although it has also undergone an earlier phase of amphibolisation and a later phase of steatisation. It is not clear whether this rock was intruded in the noritic rocks during or after the granulite facies metmorphism.

CONCLUSIONS

Detailed study of small bodies of olivine--bearing gabbros and ultramafic rocks in the amphibolites and pyroxene granulites of Swat reveal following points of petrogenetic interest :

(a) they are not confined to particular horizons of the host rocks but are dispersed throughout,

(b) instead of forming cumulus layers, they are found in the form of small lenses, dykes and sills,

(c) they are not consistent in chemistry and are significantly different from their host rocks as well as the pyroxenite layers found in the noritic pyroxene granulites,

(d) they are variable in texture and mineralogy ; also some of them show low-grade alteration (clouding, serpentinisation and so on) whilst others have undergone moderate to high-grade metamorphism evidenced by the occurrence of metamorphic hornblende, rutile, epidote, biotite ; intergrowth of amphibole and pyroxene or, rarely, two pyroxenes ; and vermicular growth of a green spinel within amphibole or pyroxene,

(e) the varying degree of alteration/metamorphism suggests that the minor mafic and ultramafic bodies formed at different depths and intruded in their host rocks at different times. They show independent histories of evolution and do not seem to be directly related mutually or to their host amphibolites and noritic pyroxene granulites.

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THE SMALL MAMMAL FAUNA OF THE NEOGENE SIWALIK GROUP POTWAR PLATEAU, PAKISTAN

BY

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Abstract : *Thirty-five genera of small mammals have been recorded from the Siwalik Group (Miocene-Pleistocene) of the Potwar Plateau, northern Pakistan, by Yale-Geological Survey of Pakistan and Dartmouth-Peshawar expeditions. Preliminary range zones constructed for selected rodent taxa indicate non-synchronous appearances and last occurrences of taxa throughout the section. The small mammal fauna suggest that much of the Siwalik molasse was deposited in an area of warm moist climate. In the Pliocene or Early Pleistocene, the trend toward modern warm dry conditions may have started. There is no evidence from the small mammal fauna to indicate a cold Pleistocene in the Potwar Plateau area.*

INTRODUCTION

The fundamental contribution of paleontology to geology is the resolution of geologic time which is necessary for the understanding and unravelling of events in Earth history. Major advances in the techniques and philosophy of geochronology have occurred in the past few years (see, for instance, the papers in volumes edited by Kauffman and Hazel (1977), and Cohee, Glaessner and Hedberg, (1978) as well as discussions in Emry (1973), Savage (1975), and Delson, (1975). Particularly important are the developments in magnetic polarity stratigraphy and radiometric dating which, when used in conjuction with biostratigraphy, often provide finer resolution of geologic time than was previously possible.

The purpose of this paper is to report the extensive collections of small mammal fossils recently recovered from the Neogene Siwalik Group of northern Pakistan, to define preliminary range zones for some of these small mammal taxa and to speculate briefly on paleoecological implications of the Siwalik small mammal fauna. Systematic studies of individual taxa are now in progress, and field work is continuing. However, even though the data presented here are preliminary, they can be incorporated with biostratigraphic studies of large mammal taxa, with magnetic-stratigraphic studies, and with radiometric dating of suitable rocks to provide a precise synthesis of Siwalik chronology.

The Siwalik Group is a thick sequence of continental molassic sediments ranging in age from Miocene to Pleistocene and exposed in a belt at the foot of the Himalayas. Fossil vertebrates have been collected from the Siwaliks for over a hundred years. The remains recorded from the Siwaliks represent a large variety of taxa including the hominoid Primates *Ramapithecus*, *Sivapithecus* and *Gigantopithecus*. Until recently small mammals were rare in collections.

The most complete section of the Siwalik Group is found in the Potwar Plateau (see Elahi and Martin, 1961) of northern Pakistan where most of the stratotypes of the formations are located (Fatmi, 1973). The rocks and fossils of the Potwar formed the basis of the classic Siwalik "zones" formulated by

Pilgrim (mainly 1910, 1913). Since 1974, joint expeditions from Yale University (U.S.A) and the Geological Survey of Pakistan, and Dartmouth College (U.S.A) and Peshawar University have been involved in paleontological and chronological studies of the Potwar Plateau. The Yale-Geological Survey of Pakistan (YGSP) expeditions have mainly been concerned with the significance of Siwalik hominoid fossils and associated fauna to human evolution. The Dartmouth-Peshawar (DP) expeditions have mainly been concerned with the magnetic polarity-stratigraphy of the Siwalik Group. Small mammals have been recovered by both the YGSP and DP projects and these are reported herein.

The term "small mammal" refers to those taxa of diminutive size which are often overlooked in fossil collecting by surface prospecting or quarrying, but which may be recovered, often in abundance, by applying sieving techniques. Insectivores, small primates, bats, rabbits, and rodents are the major small mammal groups. These groups, particularly the rodents, are important in the biostratigraphic and biochronologic frameworks of Europe and North America. They are highly significant to South Asian geochronology as well. Discussions of the correlation of the Siwalik sequence with European biochronology can be found in Pilbeam, *et al.* (1977), and Jacobs (1978).

PREVIOUS WORK

The first report of a small mammal fossil from the Siwalik Group is of a rodent identified as *Mus* by Cautley in 1835 (Cautley, 1835, Cautley and Falconer, 1835). Falconer (1868), in the *Fauna Antiqua Sivalensis*, briefly mentions rodents, but no other small mammals. Lydekker (1878) named *Hystrix sivalensis* and *Rhizomys sivalensis*, and in 1884, published the first paper which had a strong emphasis on Siwalik rodents. Other early references to Siwalik rodents include Lydekker (1880, 1883, 1885, a,b, 1886), but these references do not add significantly to the knowledge of Siwalik rodents.

Later work on Siwalik rodents includes a brief review of earlier works by Matthew (1929) Hinton (1933) and Wood (1937) described several new taxa, mainly rhizomyids, but also a thryonomyid and a ctenodactylid. G E Lewis (1939) described a murid from near Haritalyangar, India. Colbert (1933 and 1935) added significantly to the knowledge of Siwalik rodents by describing those in the American Museum of Natural History collected by Barnum Brown.

More recently, Prasad (1968) reported more rodents from near Haritalyangar and named two species. Black (1972) reviewed the Siwalik fossil rodents with emphasis on those specimens studied originally by Hinton (1933). Hussain, *et al.* (1977), have reported a significant small mammal fauna with abundant rodents from near Daud khel in the western Potwar. Jacobs (1977, 1978, 1979 a) has discussed rodents collected by YGSP and DP expeditions. Other collections of rodents have been made from the Siwaliks by several investigators, but these have not been the subject of any significant reports.

Small mammals, other than rodents, are even more poorly known. Lydekker (1884) reported *Lepus* from the Siwaliks. This specimen was later named *Caprolagus sivalensis* by Major (1899). Sahni and Khare (1976) named the soricid insectovore *Siwalikosorex prasadi*. Hussain, *et al*, (1977) reported both soricids and erinaceids from the Daud Khel fauna. Jacobs (1979b) has reported treeshrews (Tupaiidae) from Siwalik deposits. *Indraloris* is the only prosimian primate described from the Siwaliks.

LOCALITY	ERINACEIDAE	SORICIDAE A	SORICIDAE B	TUPAIIDAE A	TUPAIIDAE B	LORISIDAE A	LORISIDAE B	LORISIDAE C	CHIROPTERA	LAGOMORPHA	SCIURIDAE A	SCIURIDAE B	SCIURIDAE C	SCIURIDAE D	CRICETIDAE: DEMOCRICETODON	CRICETIDAE: MEGACRICETODON	CRICETIDAE A	CRICETIDAE B	CRICETIDAE C	CRICETIDAE D	RHIZOMYIDAE: KANISAMYS	RHIZOMYIDAE: PROTACHYORYCTES	RHIZOMYIDAE: RHIZOMYOIDES	RHIZOMYIDAE: RHIZOMYS	MURIDAE: ANTEMUS	MURIDAE: PROGONOMYS	MURIDAE: MUS	MURIDAE: PARAPODEMUS	MURIDAE: KARNIMATA	MURIDAE: PARAPELOMYS	MURIDAE: GOLUNDA	MURIDAE: CF RATTUS	GLIRIDAE	HYSTRICIDAE	CTENODACTYLIDAE
DP 54																																		X	
DP 24		X	X							X																X				X	X				
DP 70																								X											
DP 8										X																									
YGSP 369																						X													
YGSP 363								X																											
DP 13		X	X							X													X				X		X	X					
YGSP 457										X											X								X						
YGSP 17																							X											X	
YGSP 24																					X					X			X						
YGSP 34																					X					X			X						
YGSP 260																					X		X												
YGSP 182											X										X		X			X			X						
YGSP 182A		X			X		X				X		X								X		X			X		X	X						
YGSP 224																					X														
YGSP 310																					X														
YGSP 172																							X												
YGSP 270																							X			X									
YGSP-330																					X		X			X									
YGSP 450		X		X															X																X
YGSP 311		X							X		X	X							X	X	X					X									X
YGSP 259	X			X		X					X	X		X			X	X			X					X							X		X
YGSP 430											X				X						X				X										X
YGSP 41									X						X	X							X		X										X

Fig. 1. Siwalik small mammal taxa and localities.

The YGSP-DP MAMMAL COLLECTIONS

The Yale-Geological Survey of Pakistan (YGSP) and Dartmouth—Peshawar University (DP) collections made since 1974 include at least thirty-five genera of small mammals, representing thirteen families. Although not all taxa are well represented, the collections consist of hundreds of specimens, most of which were collected by YGSP expeditions. Rhizomyid and murid rodents are particularly abundant and make up the bulk of the collections. The specimens were recovered by sieving fossiliferous sediments and surface prospecting. Sieving has yielded abundant specimens, mainly isolated teeth; surface finds generally yield more complete specimens, including skulls and associated postcranial elements. All specimens will be housed in the Pakistan National Museum of Natural History, Islamabad following completion of studies.

Figure 1 lists all small mammal taxa recovered through 1978 and the localities at which they were found. The taxa are identified only to the generic level. Genera represented by letters have not been fully identified; some probably represent new taxa. The localities are listed in approximate stratigraphic order, although this listing is not meant to represent strictly the superposition of localities (see following section).

The insectivore families Erinaceidae (hedge hogs and Soricidae (shrews) are poorly represented in the Potwar by isolated teeth, and in the case of shrews, by a few jaw fragments. The articular condyles, necessary for precise identification, are not preserved in any of the soricids jaw fragments. Apparently, at least two taxa of soricids are present. Microchiropteran bats are represented by rare fragmentary specimens.

Treeshrews (Tupaidae) are represented by 3 specimens including the anterior portion of a cranium, one complete lower molar, and questionably a lower molar fragment. Tupaiids are often considered either primitive primates on the one hand, or advanced insectivores on the other. These specimens are significant in that they are the only fossils known from any continent that can be referred to the Tupaiidae with reasonable certainty (Jacobs, 1979b).

Three specimens probably representing as many genera, of lorisid primate have been recovered. These include a complete lower molar, a broken lower molar, and cranial fragments, dentaries, and associated postranial elements of one individual. The dentition of the last mentioned specimen is essentially complete, including the incisors and canines, which formed the grooming comb of the mandible.

Lagomorphs are rare and represented mainly by isolated teeth. They occur rather high in the Siwalik sequence, about at the Bhandar level (Colbert, 1935) and above. As the record improves, I suspect that lagomorphs will become more important in Siwalik biostratigraphy and biochronology, particularly in the Upper Siwaliks.

Seven families of rodents are represented: Sciuridae (squirrels), Cricetidae (hamsters and their relatives), Rhizomyidae (bamboo rats), Muridae (rats and mice), Gliridae (dormice), Hystricidae (porcupines) and Ctenodactylidae (gundis). Cricetids, rhizomyids, murids and ctenodactylids are discussed in the following section. Squirrels are fairly diverse, but not particularly abundant. One lower molar with wrinkled enamel from locality

YGSP 259 may represent a flying squirrel. Dormice are rare, probably due at least in part to the small size of their molars. Two species of porcupine (*Hystrix*), represented by one tooth each, have been recovered.

PRELIMINARY RANGE ZONES FOR SELECTED SIWALIK RODENT TAXA OF THE POTWAR PLATEAU

Cricetids, rhyizomyids, murids, and ctenodactylids are abundant in the Siwaliks and present at many localities. The vertical distribution of these taxa leads to refinement of Siwalik geochronology, particularly when coupled with lithostratigraphy, magnetostratigraphy, radiometric dating and the biostratigraphy, of large mammals. The range zones presented here are preliminary and will almost certainly be modified in the light of future collections and interpretations. They are applicable only to the Potwar Plateau where the data for documentation are derived, but they should contribute to the precise (and reasonable) correlation of the Potwar Plateau with other areas.

Fossils utilized in this study were recovered from four broad regions of the Potwar Plateau. These regions are Chinji, Hasnot, Khaur and Pabbi Hills (see map in Jacobs, 1978). In any particular region, the relative ages of localities and the sequence of fossils can be documented by demonstrating superposition. Thus, the biostratigraphy of each region can be established with a high degree of confidence. The regions are correlated with each other on the basis of first or last occurrence of certain rodent taxa in a given region, and the stage of evolution of rodent genera at each locality. The composite range zones are derived from the resulting biochronologic arrangement of localities, and therefore, are only as accurate and precise as the correlations. Although I have based the correlation of regions on rodent taxa in this paper, these correlations are consistant with the homotaxis of beds and correlations based on large mammals (equids, suids and other artiodactyls, etc. see discussion in Pilbeam *et al.*, 1977 and Jacobs, 1978), and supported by published paleomagnetic studies (Keller. *et al.*, 1977, Barndt, *et al.*, 1978). Ecological effects on the distribution of fossil taxa in the separate regions of the Potwar are difficult to evaluate (but necessary to evaluate if the fossils are to be used in paleoecological reconstruction). However, given the restricted geographic extent of the Potwar Plateau, composite range zones for these four regions probably realistically reflect faunal succession for the Potwar as a whole rather than minor ecological fluctuations within a given region.

The superposition of selected localities in each of the four regions of the Potwar and their correlation is shown on the left in Figure 2. The vertical separation of localities in Figure 2; is not to scale. Only localities with large samples or significant first or least occurrences in a given region are shown in Figure 2. However, all localities have been considered in the construction of Fig. 2 and can be accommodated in this biostratigraphic-biochronologic framework. Composite range zones for selected rodent taxa are shown to the right in Figure 2. The following discussion considers the superposition and correlation of localities region by region.

The Chinji region includes the stratotypes of the Chinji and overlying Nagri Formations (Fatmi, 1973). Locality YGSP 41 is in the Chinji Formation, and, for convenience in presentation in Figure 2, includes locality

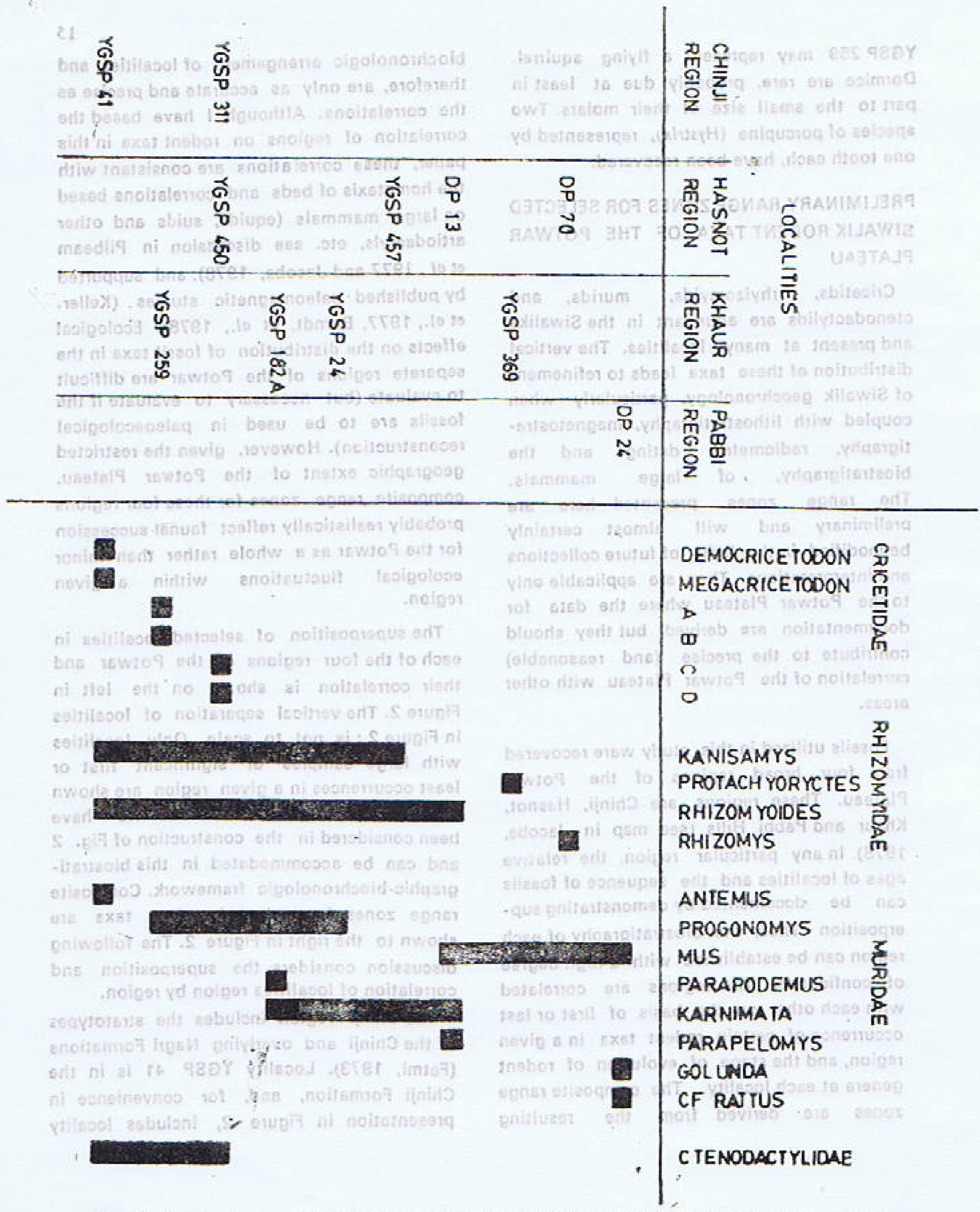

Fig. 2. Regional superposition and correlation of selected Siwalik small mammal localities (left), and preliminary range zones for some rodent genera (right). Vertical separation of localities not to scale.

YGSP 430. The localities are approximately 100 meters apart with YGSP 430 situated 10 meters above YGSP 41. Their vertical separation is slight relative to that of other localities and is not of the same order of magnitude. YGSP 41 (plus YGSP 430) has a diverse rodent fauna with the cricetids (*Democricetidon* and *Megacricetodon*, the rhizomyids *Kanisamys* and *Rhizomyoides*, the murid *Antemus*, and a ctenodactylid, probably *Saylmys*. I consider *Antemus* primitive and near the base of murid evolution (Jacobs, 1977, 1978, 1979a). The age of YGSP 41 is probably Astaracian equivalent (Jacobs, 1978).

Locality YGSP 311 is in the type Nagri Formation which directly overlies the type Chinji Formation. The rodent fauna includes two cricetid genera distinct from *Democricetodon* or *Megacricetodon*, the rhizomylid *Kanisamys*, the murid *Progonomys*, and a ctenodactylid, probably *Saylmys*. The *Progonomys* at YGSP 311 is easily distinguished from *Antemus* from YGSP 41 and shows several advanced characters relative to *Antemus*.

Locality YGSP 450 in the Hasnot region is probably the same locality from which G E. Lewis (1934) recovered *Sugrivapithecus*, a synonym of *Ramapithecus punjabicus*. The cricetid and ctenodactylid found at YGSP 450 are similar to those found at locality YGSP 311 and, therefore, these two localities are considered similar in age. Ctenodactylid rodents have not yet been recovered from levels higher than YGSP 311 and 450. Cricetids were recovered above the YGSP 311-450 level for the first time during 1979 and are not incuded in this paper.

Localities YGSP 457 and DP 13 are also found in the Hasnot region. These localities are separated by two hundred feet of section, but apparently both can be cansidered as coming from levels contributing to the Bhandar fauna (see Colbert, 1935). No cricetids are known from either locality. The youngest record of Kanisamys in the YGSP or DP collections is from YGSP 457, and the last record of *Rhizomyoides* is from DP 13. YGSP 457 has produced the murid genus *Karnimata*. Murids from DP 13 include the last record of *Karnimata* and the first records of *Parapelomys*, and *Mus*. The age of DP 13 is probably Turolian equivalent (Jacobs, 1978), and therefore includes the earliest-known record of the modern genus *Mus*. *Parapelomys* has characters similar to the modern genera *Pelomys* and *Golunda*. The earliest record of the modern rhizomyid genus *Rhizomys* is from locality DP 70 near the village of Jallalpur in the Hasnot region.

The extensive deposits of the Khaur region (which includes the area around the village of Dhok Pathan) have yielded abundant fossils. The lowest small mammal locality in this region is YGSP 259 which has produced cricetids, the rhizomyid *Kanisamys*, the murid *Progonomys*, and a ctenodactylid, probably *Saylmys*, YGSP 259, is considered younger than YGSP 41 in the Chinji region because of the presence of *Progonomys*. It is considered older than YGSP 311 (Chinji region) and YGSP 450 (Hasnot region) because of differences in the cricetids.

Locality YGSP 182A has produced the rhizomyids *Kanisamys* and *Rhizomyoides*, an advanced species of the murid *Progonomys*, an early record of the murid *Karnimata*, and the only Siwalik record of the common European murid genus *Parapodemus*. The age of YGSP locality 182A is probably late Vallesian or early Turolian equivalent (Jacobs, 1978).

The stratotype of the Dhok Pathan Formaation (Fatmi, 1973) is in the Khaur region and includes locality YGSP 24 The small mammal fauna is similar to that from the underlying locality YGSP 182A. Locality YGSP 369 in the Khaur region has produced the rhizomyid genus *Protachyoryctes*, previously known only from the Tatrot fauna in the Hasnot region (Black, 1972).

Only one mammal locality, DP 24, is known from the Pabbi Hills region. This locality has produced the murid genus *Golunda* which occurs in the Pabbi Hills today, and an apparently modern species of *Mus*, a genus which also lives today in the Pabbi Hills An additional murid genus exhibits advanced characters and I have assigned it to cf. *Rattus* (Jacobs, 1978). Keller, et *al.* (1977) consider this locality to be early Pleistocene, Villafranchian equivalent, and slightly younger than about 1 8 million years based on magnetostratigraphic evidence.

DISCUSSION

As illustrated in Figure 2 and elaborated above, significant changes in the Siwalik rodent fauna occur throughout the section which facilitate biostratigraphic and biochronologic studies. This paper deals with taxa at the generic level; however, there are specific changes within genera throughout the Siwalik sequence that will ultimately facilitate additional refinement of Siwalik biochronology. Particularly significant in this regard are the rhizomyid genera *Kanisamys* and *Rhizomyoides* and the murid genera *Progonomys Mus*, and *Karnimata*.

Siwalik rhizomyids are currently under review by Lawrence J. Flynn (University of Arizona, Tucson, U. S. A.). Cricetids are being studied jointly by E. H. Lindsay (University of Arizona) and myself. I am studying the systematics of the remaining groups of small mammals.

Along with systematic and biostratigraphic studies, Siwalik small mammals are being approached from a paleoecological point of view as well. Information concerning past environments gathered from small mammals is relevant to the study of evolution in other groups, specifically in this case, human evolution. Some paleoecological aspects of Siwalik small mammals are currently under study by Andrew Hill (The International Louis Leakey Memorial Institute for African Prehistory, Nairobi Kenya) and myself.

The YGSP and DP collections made in recent years have greatly improved the record of Siwalik small mammals. However, the record needs further improvement. In every field season from 1974 through 1979, new taxa have been recovered. In addition of the taxa reviewed by Black (1972), *Sivacanthion* and *Paraulacodus* are not yet represented in YGSP or DP collections. *Myocricetodon* is also not represented although it is reported from Daud Khel by Hussain, et al. (1977).

It appears that older Siwalik small mammal assemblages (including those from type Nagri and Chinji Formations) are characterized by cricetids, ctenodactylids, and primitive murids. Above the YGSP 311 level (type Nagri), cricetids are apparently quite rare and ctenodactylids are not recorded at all. Changes in murid taxa become the most useful biochronologic indicators. The murid fauna as a whole exhibits progressive modernization from *Antemus* at YGSP 41 (type Chinji), through primitive *Progonomys* at YGSP 311 (type Nagri) and YGSP 259, advanced *Progonomys* (YGSP 182A and 24) and Karnimata (YGSP 182A, 24, 457, and DP 13), to essentially modern forms at DP 13 and above. The rhizomyid genera *Kanisamys* and *Rhizomyoides* are rather long-lived and therefore not particularly useful in Siwalik biochronology at the generic level. In the younger Siwaliks, the rhizomyids *Protachyoryctes* and *Rhizomys* are distinctive. There are no rhizomyids in the modern fauna of the Potwar Plateau (Roberts, 1977).

The appearance and disappearance of rodents throughout the Siwalik sequence seem to occur for the most part as non-related events, at least at the generic level. There are no horizons characterised by an unusually high occurrence of new genera or extinction of others. This pattern of replacement, without major synchronous events, suggests that there were no paleoecologic events sufficiently traumatic to have an immediate effect on a wide spectrum of Siwalik rodents.

The Siwalik record suggests that murid rodents were common elements of the biota of this area from late Miocene time onward. In the early Pleistocene, *Mus* and *Golunda* are found in the Pabbi Hills, and both of these genera live there today. The last record of rhizomyids in the Potwar Plateau is probably in the Pliocene. These observations suggest that the modern fauna of the Potwar was becoming established by Pliocene or early Pleistocene time

Murid rodents are taxonomically a diverse group at the present time (Misonne, 1969). Most modern taxa prefer warm moist environments, although there are exceptions. A few murids now live in warm dry areas, notably *Golunda*, the Indian bush rat, which lives today on the Potwar Plateau. Murid taxa are rare in cold climates. The diversity of fossil murids in the Siwaliks, and the presence of tupaids, rhizomyids, and glirids, suggest that much of the Siwalik molasse was deposited in an area with a warm moist climate.

The modern fauna of the Potwar Plateau is a warm dry fauna with abundant gerbils, as well as the murids *Mus* and *Golunda* (and some other rodents), but no rhizomyids (Roberts, 1977). If the modern rodent fauna became established in the Pliocene or early Pleistocene, as suggested above, then it is plausible that the climate was becoming dryer at that time. The major implication here is that the Pleistocene in the area of the Potwar Pleatau was relatively warm without the trauma of cold climates indicated by abundant faunal evidence in the Holarctic realm.

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URANIUM-THORIUM MINERALIZATION IN SOME GRANITIC BODIES OF THE PARACHINAR AREA, N.W.F.P., PAKISTAN

BY

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Abstract : *A uranium-thorium mineralization distributed in some granite gneiss and pegmatite bodies occurs in the Parachinar area, N.W.F.P. Laboratory investigations involving petrography, autoradiography, mineragraphy and chemical analyses were conducted on sixteen selected rock samples from the area. The resits indicated that allanite and radioactive epidote, present as accessory constituents of the granitic bodies, were the sources for both uranium and thorium. Another notable mineral was uraniferous limonite which was present as secondary uranium enrichment, depending upon mobility of uranium and iron during weathering process. The study suggests that the mineralization is present in the form of discretely disseminated grains of allanite and radioactive epidote as well as an uraniferous limonite in minor amounts.*

INTRODUCTION AND GEOLOGY

Recent radiometric surveys conducted by geologists of the Atomic Energy Minerals Centre, Lahore, helped to locate some radioactive anomalies in the Parachinar area, N.W F.P., Pakistan, which showed rather wider distribution on subsequent field work (Baig 1976). The present work was undertaken to provide laboratory data on the host rocks as well as on their radioactive constituents. Accordingly, the work involved field observations alongwith collection of samples and subsequent extensive laboratory investigations.

The Parachinar area lies in the northwest-Pakistan. The area was geologically studied as part of mapping of the Parachinar Quadrangle by Meissner et *al.* (1975). This consists mainly of quartzites, limestones, sandstones and shales ranging in age from Jurassic to Pliocene. The sedimentary rocks are inrtuded by granitic bodies in which pegmatites occur frequently. The stratigraphic succession of rock formations in Parachinar area is given in Table 1. A generalized geological map of the area showing distribution of rock samples is shown in Fig. 1. Radioactive anomalies are present mainly in the granitic rocks which show high radioactivity in local spots on the surface.

Sixteen representative samples from radioactive granitic bodies were examined for their petrographic characteristics. The studies helped to classify the rocks into three types :

1. Granite
2. Granitic Gneiss
3. Pegmatite

PETROGRAPHY

1. Granite

Texture and Structure **:** The granite generally shows hypidiomorphic granular texture. The rock indicates poor orientation of biotite flakes. The granite represents such forms as sheared granite and foliated granite. In sheared granite, plagioclase feldspar grains are bent and fractured. The foliated granite exhibits parallel alignment of mica flakes and quartz bands.

Petrographic Description : The granite essentially consists of quartz, microcline, microcline-perthite, plagioclase, biotite and muscovite ; chlorite, epidote, sphene, tourmaline, rutile and opaques are present as accessory minerals. Rarely garnet is also present.

Generally, *quartz* is the most abundant constituent of the rock. The grains are fractured and show invariably strong strain shadows. Fine grained quartz is polycrystalline and occurs interstitially. It is also present as inclusions in feldspar.

In the granite rocks, *alkali feldspars* are present as microcline-perthite and perthite. Microcline is sometimes fractured and highly stressed which is indicated by the bending of twin lamellae. It shows development of myrmekite growth at the grain boundry. Microcline-perthites are characterized by string and vein type forms. (Moorhouse, 1959). Perthite-microcline is rarely present as porphyroblasts, Plagioclase feldspar is of albite/oligoclase composition, present as porphyroblasts with bent twin lamallae.

Biotite is distributed throughout the rock, showing fairly parallel orientation. Frequently, its flakes are curved and show kinking. These are also intergrown with chlorite. Muscovite is present as fine flakes associated with biotite.

Chlorite is present in minor amount. It occurs as aggregates and as irregular growths locally. *Epidote* occurs as fine-grained aggregates generally in association with biotite. It is also present as an alteration product associated with feldspar. *Tourmaline, rutile* and *sphene* are rare constituents. *Garnet* is also rarely present. The opaque minerals are identified as *pyrite* grains irregularly disseminated in the rock.

2. Granitic Gneiss

Texture and Structure: Texturally, the granite gneiss is porphyroblastic granular containing porphyroblasts of feldspar and sometimes of quartz as well. The feldspar is generally altered, showing sericitization and enclosing biotite flakes. Occasionally quartz exhibits short thin bands forming a sort of lamellar structure.

Petrographic Description : The granitic gneiss consists essentially of microcline-perthite, plagioclase feldspar. quartz, muscovite and biotite. Chlorite, epidote, tourmaline, rutile and opaques are present as accessory minerals.

Feldspar is present predominantly as microcline and microcline-perthite. The perthite grains show vein type form and are porphyroblastic. Plagioclase-feldspar is albite/oligoclase in composition and is generally enclosed by perthites. In some samples, the grains show sericitization. *Quartz* as porphyroblasts occurs commonly as fractured grains and is highly strained. The apparently coarse-grained quartz is generally aggregate of fine-grained and polycrystalline quartz.

Muscovite flakes with *biotite* create foliation in the rock. At places chlorite is also associated which occurs as fine flaky aggregates in the interstitial areas. Biotite occurs as porphyroblasts, generally bent and showing kinking. it is also present as fine grained aggregates.

Epidote is mainly present at one location, where it forms a major constituent of the

Table 1

Stratigraphic Succession in the Parachinar Quadrangle (Modified after Meissner Et Al., 1975)

System	Series	Group	Description
Tertiary	Pliocene	Siwalik	Dhok Pathan Formation : Conglomerates and sandstones with beds of siltstone and silty clay
			Nagri Formation ; Sandstone and clay (conglomeratic)
			Chinji Formation : Clay and sandstone
		Rawalpindi	Kmlial Formation : Sandstone, siltstone and clay
			Murree Formation : Clay, sandstone and conglomeratic grit layers
			Unconformity
	Eocene	Chharat	Kohat Formation : Limestone and shale
			Mami Khel Clay : Clay with dolomitic limestone and sandstone
			Jatta Gypsum : Gypsum bands
			Bahadur Khel Salt : Rock Salt containing clay layers
			Panoba Shale : Shale with limestone and sandstone
			Patala Formation ; Shale with argillaceous limestone and sandstone
	Paleocene		Lokhart Limestone : Massive limestone
			Hangu Formation : Sandstone
			Unconformity
Cretaceous			Darsamand Limestone : Shale and marl
			Lumshiwal Sandstone : Sandstone
			Chichali Formation : Sandstone and shale
			Cretaceous Quartzite : Conglomeratic quartzite
			Unconformity
Jurassic			Samana Suk Limestone : Limestone
			Datta Formation : Interbeded limestone, sandstone and shale
			Unconformity
			Igneous Rocks : Igneous rocks intrude Jurassic and Cretaceous rocks.

rock. It occurs generally as aggregates of columner grains showing fracturing. fine-grained epidote is present however along intergranular areas. *Tourmaline* is present as schorlite variety in minor amount in the granitic gneiss. *Rutile* is also present in the rock. Minor amount of *apatite* is also present. *Limonite* occurs in iron stained areas. *Pyrite* is also present as opaque mineral.

3. Pegmatite

Texture and Structure : The rocks are generally hypidiomorphic granular in which quartz is highly strained. Pegmatite bodies occur having concordant contact with granite and granitic gneiss in the area.

Petrographic Description : The pegmatites consist of quartz, microcline and chlorite. Tourmaline, epidote and muscovite are present as minor minerals.

Quartz is abundantly present, the grains being highly strained. Chlorite is intergrown with *sericite* generally enclosing *epidote* grains. *Tourmaline*, as schorlite variety, occurs as aggregates generally developed at the grain boundary of quartz. *Epidote* and *muscovite* are also present in the rock in minor amounts. The pegmatite contains *allanite* and the *radioactive epidote* as radioactive mineral grains. Radioactive epidote was distinguished from the common epidote (non-radioactive) by autoradiography.

AUTORADIOGRAPHY AND X-RAY DIFFRACTION

A radiometric measurement of the samples was first made using a minimonitor with geiger tube and a spectrometer to determine general levels of radioactivity. Autoradiography was used to locate radioactive mineral sources in thin sections and polished sections employing nuclear emulsion plates. Alpha particle tracks shown on the autoradiographs appeared as point sources as well as disseminated sources. The tracks so obtained were matched with thin and polished sections to locate radioactive sources. The mineral phases thus located were examined for their optical properties for possible identifications. Table 2 lists distribution of radioactive minerals in the rock samples.

A sample rich in radioactive grains was crushed and ground to less than 60 mesh in order to liberate radioactive minerals, the mineral grains were concentrated using heavy liquids and Isodynamic magnetic separator. The grains were then mounted on an Ilford Nuclear Emulsion Plate (thickness 50 um) to obtain Alpha tracks around radioactive grains. About 20 to 25 grains of allanite, previously identified by transmitted light microscopy, were hand-picked under a binocular microscope for the X-ray diffraction work. The mineral did not show any X-ray pattern indicating that the mineral is metamict. This also provided a confirmation to the optical character of the allanite.

MINERAGRAPHY

Mineragraphic studies were conducted on polished sections of rock samples. The samples indicated presence of minor amounts of pyrite, ilmenite and goethite which are briefly described as follows :

Pyrite : Pyrite is irregularly disseminated in the rock as subhedral to anhedral grains, generally ranging in size from 0 01 to 0.1 mm. The grains are yellowish white in colour with reflectivity of nearly 50% at 500 nm in the air. It is weekly anisotropic. The grains are generally fractured and show alteration to limonite, sometime leading to complete pseudomorphism. Consequently pyrite is also present as very fine grains in the rock.

Ilmenite : Ilmenite is present as fine sub hedral grains showing light to dark brown colour and distinct bireflectance, giving reflectivity range from 17 to 20%. The mineral is characterized by strong anisotropy and brown internal reflection. The ilmenite grains are irregularly disseminated in minor amount in the granitic gneiss.

Table 2

Radioactive Minerals Detected in Rock Samples

Sample No.	Radioactive Minerals in Order of Abundance
PC—39	Uraniferous Limonite, Allanite, Radioactive Epidote
PC—42	Allanite, Radioactive Epidote
PC—49	Allanite, Radioactive Epidote
PC—60	Not detected
PC—61	Uraniferous Limonite, Radioactive Epidote
PC—66	Allanite, Radioactive Epidote
PC—69	Allanite, Radioactive Epidote, Uraniferous Limonite
PR—1	Allanite, Uraniferous Limonite
PR—2	Allanite
PR—3	Allanite, Radioactive Epidote
PR—4	Not detected
PR—5	Allanite
PR—6	: Allanite
PR—11	Not detected
PR—12	Not detected
PR—13	Radioactive Epidote, Uraniferous Limonite

Limonite : Limonite is white in colour distinctly bireflectant and with reflectivity about 20% in air. It is strongly anisotropic and shows reddish brown internal reflection. Limonite is present as an alteration product of pyrite and occurs as fracture-filling veins and as pseudomorphs after pyrite. Minor amount of goethite is present in association with limonite. The radioactivity is found to be distributed in areas localised with limonite generally in association with colloform goethite.

Goethite : Goethite is present as fine grained colloform phase less than 0.01 mm in aggregates. Goethite is characterized by grayish white colour with bluish tint, weekly bireflectant and showing strong anisotropy. It shows reflectivity between 15 and 20% in air and reddish brown internal reflection. Goethite is present as colloform aggregates in association with limonite, as filing of the pyrite pseudomorphs and of fractures.

CHEMICAL ANALYSIS

The suite of samples were chemically analysed for uranium and thorium. The analyses provided uranium and thorium levels in the samples as given in Table 3. The analyses gave average values for

$U_3O_8 = 0.088\%$ and $ThO_2 = 0.284\%$.

The highest level of uranium is indicated in sample PR—1 which can be accounted for the presence of uranium in limonite in addition to that in allanite as shown in Table 3. On the other hand, minimum value of uranium is indicated in sample PR—5 which is otherwise devoid of uraniferous limonite. The maximum value of thorium in sample PR—13 is due to the presence of higher amount of radioactive epidote in that sample.

RADIOACTIVE MINERALS

The radioactive minerals identified in the rock samples are allanite, radioactive epidote as primary minerals and uraniferous limonite associated with goethite as secondary uranium phase. The optical properties of allanite and radioactive epidote are summarised in Table 4.

Table 3

Analyses of Radioactive Samples for Uranium and Thorium

Sample No.	Radiometric ThO_2%	Radiometric U_3O_8%	Chemical U_3O_8%
PC—39	0.901	0.185	0.230
PC—42	0.050	0.146	0.126
PC—49	0.203	0.107	0.104
PC—60	0.083	0.206	0.196
PC—61	0.051	0.046	0.041
PC—66	0.157	0.071	0.070
PC—69	Traces only		
PR—1	0.087	0.234	...
PR—2	0.023	0.020	...
PR—3	0.026	0.012	...
PR—4	0.010	0.005	...
PR—5	0.022	0.007	...
PR—6	0.029	0.167	...
PR—11	0.208	0.038	...
PR—12	0.022	0.012	...
PR—13	2.389	0.080	...

* Analyses provided by Dr. F. I. Nagi, Head, Chemistry Division, A.E.M.C., Lahore.

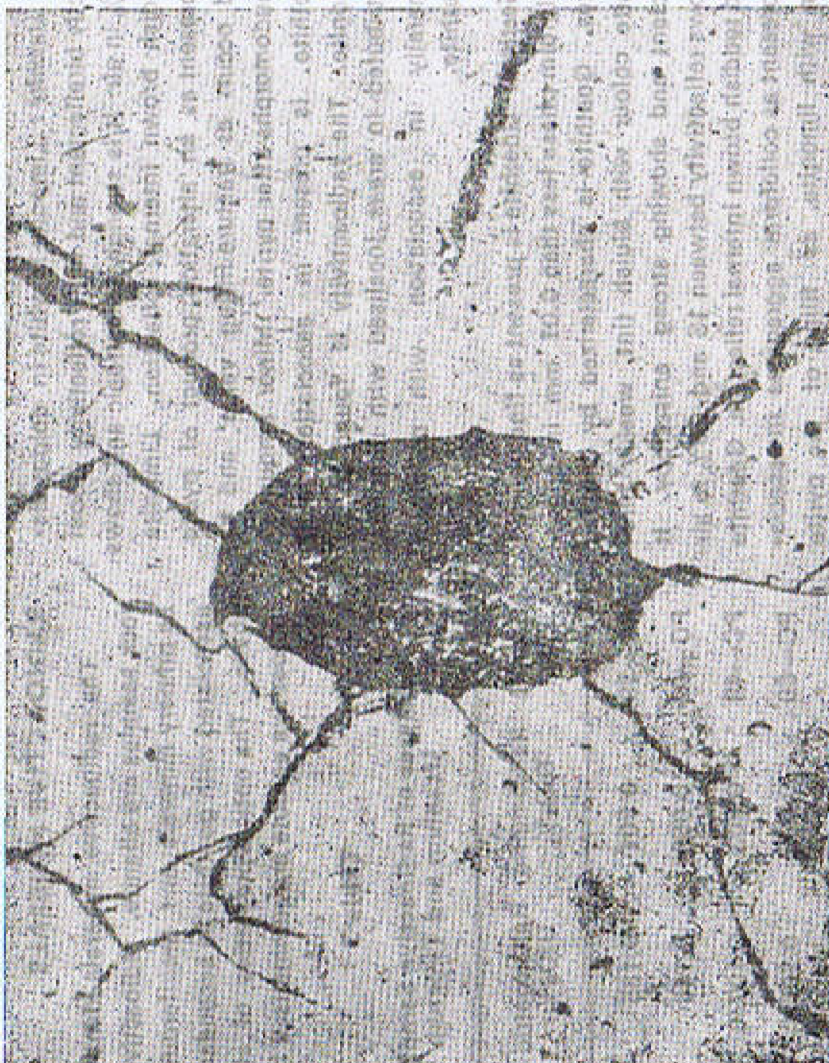

Fig. 2 Allanite grain showing radial fractures around it. Polarized light (X240).

Fig. 3 : Radioactive epidote grain showing quartz inclusions. Polarized light (X60).

Fig. 4 Common epidote grain (middle) associated with allanite (dark grey). Polarized light (X60).

Fig. 5 Uraniferous limonite (dark areas) showing fracture filling in the rock. Polarized light (X60).

Allanite

Allanite shows its development from pidote as indicated by its overgrowth on epidote. Generally radial fractures are developed around it (Fig. 2), resulting from stresses that originated on metamictization (Hutton, 1960). The allanite grains are more abundant in the rocks than radioactive epidote.

Radioactive Epidote

The radioactive epidote (Fig. 3) is characterized by yellowish green colour and distinct pleochroism. It can be distinguished from normal epidote (Fig. 4) present in the granitic bodies by their weak pleochroism, pale colours and strong birefringence. Fractures are more common in the radioactive epidote than in the normal epidote. Radioactive epidote is present as discrete grains disseminated in the rock with the exception of sample PR—13 which contains radioactive epidote in abundance.

Uraniferous Limonite

Mineragraphic studies have indicated the presence of uranium as dispersed phase in association with goethite. It suggests that limonite is formed as a result of alteration of pyrite disseminated in the rock. Uraniferous limonite is irregularly distributed in such features as minor fractures (Fig. 5) and pyrite pseudomorphs.

NATURE OF MINERALIZATION

In igneous rocks, radioactivity is generally due to uranium and thorium elements in which uranium is distributed in the higher amounts near the acidic end. On the other hand, the concentration of uranium in basic and ultrabasic rocks is extremely low. On an average, uranium content in granites ranges from 2,2 to 15 ppm (Rogers and Adams, 1974). The Th/U ratio varies between 2.5 to 5 for most igneous rocks (Adams and Pliler, 1956). Furthermore, in igneous rocks, the radioactivity due to uranium and thorium is present in eccessory minerals, essential minerals or in insterstitial phases.

Table 4 Optical Properties of Allanite and Radioactive Epidote

Properties	Allanite	Radioactive Epidote
Form	Prismatic to irregularly shaped grains	Subhedral grains
Colour	Pale brown to reddish brown	Yellowish green
Grain size	0.8 to 0.2 mm	Average 0.9 mm
Cleavage	Two	Two
Relief	High	High
Pleochroism	Non-pleochroic	Distinctly pleochroic
Birefringence	Weak and spotty (due to meta-mictization)	Anomalous and weak 2nd order
Isotropism	Weakly anisotropic	Anisotropic
Extinction	Parallel	Parallel
Interference Figure	Not determinable	Biaxial (-ve)

This work has established that anomalous radioactivity is distributed in some granite, granitic gneiss and pegmatite bodies in Parachinar area. The concentration of uranium and thorium in the rocks is of mixed nature. The studies have indicated that both uranium and thorium are contained in the allanite and radioactive epidote which are present as accessory constituents of the granitic bodies. These mineral grains are discretely disseminated in the rocks.

Allanite is characterized by partially anisotropic nature which can be explained by the partial destruction of its crystal structure by metamictization.

Radioactive epidote is present in the granite and granitic gneiss in addition to the normal epidote. The two types of the epidote probably belong to two different phases, the older phase being the radioactive epidote as its structure is disturbed due to metamictization. The normal epidote probably belongs to the younger phase. Secondary uranium is also distributed in association with limonite and goethite.

In the granitic bodies in Parachinar area, allanite and radioactive epidote are mainly responsible for the source of uranium and thorium in the rock. This can probably be explained by the concentration of both U^{4+} and Th^{4+} ions in these accessory minerals in late magmatic fractions. This view can be supported by the fact that relatively large ionic radii of U^{4+} and Th^{4+} make it difficult to enter into the crystal structure of essential constituents of the rock (Heinrich, 1958).

The uraniferous limonite is localised along minor fractures and in pyrite pseudomorphs. The association of uranium with limonite can probably be explained by the simultaneous mobilization of uranyl ion with iron in solution as the latter has a greater affinity for uranium. Thus uranium was fixed with the iron oxide on precipitation.

Chemical analyses of the samples as given in Table 2 and 3 indicate that the allanite and radioactive epidote are related to very low levels of uranium and thorium with thorium predominating. Furthermore, higher uranium content up to 0.234% U_3O_8 in the sample can probably be accounted by the presence of uraniferous limonite in addition to allanite in the rock.

From Table 3 average values can be calculated for Th=0.241% and U=0.074% which provides a ratio of Th/U=3.2. This value falls within the range of Th/U ratios for igneous rocks as determined by Adams and Pliler (1956).

It is interesting to note that the average level of thorium and uranium in the rock samples from Parachinar are higher than average U and Th contents in the primary minerals allanite and radioactive epidote (Heinrich, 1958, Deer et al., 1974). At this stage, it is not possible to account for this variation. Probably the higher average values for uranium in these rocks can be explained by the fixation of uranium in uraniferous limonite. Furthermore, trace amount of both U and Th is contributed by their presence in the essential rock forming minerals (Rogers and Adams, 1974).

CONCLUSIONS

Radioactive anomalies occur in the Parachinar area in some granite, granitic gneiss and pegmatite bodies of post-Cretaceous age. Primary radioactive minerals in these rocks are identified as allanite and radioactive epidote which are irregularly disseminated in the rock. This forms a low level mixed uranium-thorium mineralization in the area. Secondary uranium mineralization also occurs in these rocks as uraniferous limonite concentrated in minor fractures and fillings in pseudomorphs. This form of uranium enrichment is of local nature depending on the mobility of iron oxide by weathering. Further work is suggested to understand the relationship of the secondary mineralization with possib'e primary sources of uranium in the area.

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INVESTIGATION OF PROSPECTING AREAS AND HORIZONS OF OIL AND GAS IN PAKISTAN

BY

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Abstract. *Belt, of Potwar-Sulaiman-Kirthar foredeeps along with adjoining uplifts and highs in Punjab Sind plains and Mekran Coastal areas are considered important for the exploration and prospecting of oil and Gas reservoirs in Protoquarlzrte to orthoquartzite sandstones and fractured limestones belonging to Paleozoic, Mesozoic and Paleogene ages. These contain all the geological factors which are characteristic for oil and gas bearing regions namely thick sodimentary sequences ; presence of regional and local traps for hydrocarbons ; almost all the oil and gas seepages including mud-volcanoes, and so far all the discovered oil and gas fields. Prespecting areas are discussed in the light of the wells drilled and tectonc movements.*

INTRODUCTION

Pakistan has sufficient gas reserves to last about ninety years at the present rate of production i.e 5 billion cubic metres per year. However, annual oil production is 0.3 - 0 5 million tons which is about 8% of the country's demand. So investigation and drilling may be concentrated in areas of possible oil reserves and there seems to be no reason as to why sufficiently large oil reserves are not discovered to meet country's requirement with the stepped-up exploratory operations.

The general outlook for Petroleum prospecting in Pakistan has been ably summarized by Dr. D. N. Wadia, who outline the region concerned as the broad zone of Mesozoic and Paleogene sediments which stretches from Lower Sind to north-eastern Punjab, passing through Baluchistan and the North-West Frontier Province. Surface indications of both oil and gas are known at many places in it, some locations have been tested, others have been examined, many but superficially, others in great detail. Great tracts of the region still await methodical investigation by petroleum geologists : indeed, the most widely spread expanse of Mesozoic and Paleogene rocks ranging from Mekran to Karachi and thence northwards to Kohat, in which the sinuous. folded, surface exposures have a width of from 150 to 400 Kms., remain for the most part unexplored from this point of view.

AREAS OF OIL AND GAS PROSPECTING

Structurally, Pakistan is divided into five zones as shown in Fig. 1, which are further divided into sub-zones. These zones are as follows :

Zone - I : Indian Platform ;

(*a*) Basement areas exposed at Sargodha and Nagar Parkar.

(*b*) West slope of Indian Platform namely Punjab and Sind plains having number of uplifts and highs such as Mari-Kandhkot uplifts, Jacobabad high, lakhra uplifts etc.

Zone II : Belt of Foredeeps :—

(a) Potwar and Bannu-Kohat foredeeps

(b) Sulaiman-Khirthar foredeeps consisting of Sub-Sulaiman foredeeps, Marri-Bughti Transverse uplift, Sibi trough, Sub-Khirthar foredeeps, Badhra-Sunbank Transverse uplift and Karachi trough.

Zone III : Folded Arc or Belt :

(a) Attock-Hazara folded zone.

(b) Sulaiman-Khirthar Maganticlinorium.

Zone IV : Belt of Rear Troughs :

(a) Sulaiman-Khirthar Meganticlinorium rear flysch trough.

(b) Mekran coast rear molasse trough.

Zone V, Median Mass :

(a) Karakorum median mass.

(b) Baluchistan median mass.

Out of the above five structural zones of Pakistan, belt of Potwar-Sulaiman-Khirthar foredeeps (Zone II) alongwith adjoining uplifts and highs in Punjab-Sind plains and Mekran coast rear trough (Zone IV b) are considered important for the exploration and prospecting of oil and gas reservoirs as shown in Fig. 1. These zones contain all the geological factors which are characteristic for oil and gas bearing regions, namely (1) thick sedimentary sequences (2) presence of regional and local traps for hydrocarbons and (3) almost all the oil and gas seepages including mud-volcanoes.

HROIZONS OF OIL & GAS PROSPECTING

Protoquartizite to orthoquartizite sandstones and fractured limestones belonging to Paleozoic, Mesozoic and Paleogene (Paleocene and Eocene) are considered important reservoir rocks. Oil and gas are trapped in the suitable structures such as paleoreefs, deltas, etc. but mostly in anticlines in these rocks of above mentioned prospecting areas.

Potwar, Kohat and Sub-Sulaiman foredeeps as well as the adjoining Punjab plain had undergone through salt intrusions which played significant role in the formation of oil and gas reserviors in the region. Salts behave like plastics under pressure, induce the formation of specific shapes and are good screens as well as cap rocks for oil and gas. Salt of Salt Range, its Trans Indus continuation and adjoining areas, is of Pre-Cambrian to Cambrian age which is proved by deep drilled wells such as Kallar Kahar 1, Dhariala 1, Adhi 5 and Karampur 1, whereas Kohat Salt exposed in central Kohat is supposed to be of Middle Eocene age but it's age is still to be confirmed by drilling deep wells to penetrate the formations below Kohat Salt. In the Kohat Salt bearing region according to Dr. E. R. Gee, "the rock salt at several places contains traces of oil and it is not improbable that it forms a cap-rock overlying in places petroliferous limestones and shales of Lower Eocene age." This view is shared by Professor N. A. Kalinin, Chief of Russian expert team on a short visit to Pakistan during 1976-77 and suggested drilling in Nandrakki and Shakardara structures to penetrate the formations below Kohat Salt. So a detail study of salt movements in these areas will help to locate and understand the influence of salt tectonics on the formation of oil and gas pools.

Clays and shales also possess plastic properties like salt under pressure and temperature. For example Ghazij shales of Early Eocene age in Sulaiman foredeep show thickening and flow along the folded anticline portions of Pirkoh, Rodho, Dodhak and Domanda wells.

DISCUSSION :

Wells were not drilled deep enough in Mekran coast area (Zone IV b) to penetrate Mesozoic or even Paleogene formations to investigate the presence of oil and gas reservoirs in these formations. However, oil and gas reservoirs were discovered in Potwar-Sulaiman-Khirthar foredeeps (Zone II) in Paleozoic, Mesozoic and Paleogene formations. Wells drilled in different parts of prospecting areas along with a brief description are given below. These wells are shown in Fig 2.

I. Northern and Eastern Potwar Wells

1.	Chharat	(AOC)
2.	Chakbeli Khan	(PPL/POL)
3	Bains	(POL)
4.	Adhi 1-4	(PPL/POL)
4b.	Adhi 5 & 6	(PPL/AMOCO)
5.	Mahesian	(PPL)

Mesozoic and Paleogene formations are either missing or thinned out in Eastern Potwar and so Cambrian sandstone (Paleozoic) may be tested for oil and gas reservoirs. Adhi 5 well was drilled up to the depth of 2810 metres and penetrated 3 metres of Pre-Cambrian Saline series (Salt Range formation). Oil was discovered in Permian Conglomeratic sandstone (Tobra formation) and Cambrian Khewra sandstone in 1978. Thus base of Permian namely Tobra formation and Cambrian sandstone are proved to be prospective horizons in Eastern Potwar region. So a detail geological explorations are recommended to study the structures and thicknesses of prospective horizons in order to drill exploratory wells on suitable structures.

Northern Potwar adjoining Attock-Hazara folded zone is too compressed, faulted and broken to hold commercial oil/gas reser years.

II. Central & Western Potwar Wells

1.	Dadhumbar	(OGDC)
2.	Tut	(OGDC)
3.	Nuryal	(OGDC)
4.	Meyal	(BOC/AOC)
5.	Khaur	(POL)
6.	Dhulian	(POL)
7.	Kot Sarang	(OGDC)
8.	Karsal	(POL/PPL)
9.	Balkassar	(POL/PPL)
10.	Joya Mair	(POL)
11.	Chak Naurang	(POL)

Oil reservoirs were discovered in Jurassic sandstone and Paleocene-Eocene limestones in Toot, Meyal, Khaur and Dhulian wells as well as in Eocence limestones in Karsaj, Balkassar and Joya Mair wells. However, Joya Mair 3 is the first well to find oil in Cambrian sandstone in 1947.

Triassic shales may be the source rocks for oil reservoir in Jurassic sandstone which is capped unconformably by Paleocene Dhak Pass shales. Paleocene Khairabad limestone seems to be good source and reservoir rock which is capped by Paleocene Patala shale. Eocene Sakessar and Bhadrar (Chorgali) limestones are also good source and reservoir rocks capped by red clay and shale. Thus Central-Western Potwar and Kohat region seems to be attractive for further prospecting for oil and gas. Important known structures in the region for further drilling are Dhormund, Parawali, Jabbi Dhok, Nandrakki, Shakardara and Latambar .

III. Bannu—Southern Potwar Wells

1.	Pezu	(PPL)
2.	Marwat	(PPL)
3.	Kundian	(PPL)
4.	Kallar Kahar	POL)
5.	Karang	(OGDC)
6.	Khabakki	(AOC)
7.	Jhatla	(POL)
8.	Dhariala	(POL)

The possiblility of oil and gas reservoirs in the southern Potwar does not seem to be bright because of the proximity of Salt Range where Pre-Cambrian to Cambrian rocks including Saline series are exposed. However, Paleozoic sandstone (mainly Cambrian spnds-tone) may prove to be oil/gas reservoir where it is capped by proper shaly cover.

IV. Punjab Slope We ls Adjoining Sub-Sulaiman Foredeep

1.	Karampur	(PSOC)
2.	Tola	(AMOCO)
3.	Sarai Sidhu	(AMOCO)
4.	Budhuana	(AMOCO)
5.	Kamyab	(AMOCO)

No oil and gas reservoir is encountered in this area though gas shows are recorded in Mesozoic sediments of Sarai sidhu well and in Pre-Cambrian Saline Series of Karampur well. The area is covered by alluvium and so requires detail gravity and seismic survey in order to explore the existence of possible trap structures and stratigraphic thicknesses.

V. Sub-Sulaiman Foredeep Wells

1.	Giandari	(PSOC)
2.	Kot Rum or Choti	(OGDC)
3.	Sakhi Sarwar	(AMOCO)
4.	Rodho	(OGDC)
5.	Dodhak	(OGDC)
6.	Domanda	(PPL/POL)

Gas reservoirs were discovered in cretaceous Pab sandstone and Paleocene Dunghan/Ranikot formation, capped by Eocene Ghazij shales in Rodho and Dodhak wells. Condensate was also discovered in Dodhak 1 well in Late Cretaceous Pab sandstone in 1976. It was for the first time that condensate was discovered outside Potwar region in Sulaiman foredeep. So the area of Sub-Sulaiman foredeep seem to be interesting from the point of future discovery of oil and gas reservoirs in Mesozoic and Paleogene formations. Important known structures where wells are recommended for drilling are Afiband, Zindapir, Domanda and Drazinda (Fig. 2).

VI. Sibi Trough, Marr-i-Bugti transverse uplift and adjoining high uplifts in Sind plain and Northern part of Sub-Kirthar foredeep Wells

1.	Khairpur	(PPL)
2.	Mari	(SVOC)
3.	Kandhkot	(PPL)
4.	Jacobabad	(PPL)
5.	Uch	(PPL)
6.	Sui	(PPL)
7.	Zin	(PPL)
8.	Pirkoh	(OGDC)
9.	Bannh	(PPL)

Gas reservoirs were discovered in Lower Eocene—Paleocene Sui Main limestone capped by Eocene shales in Khairpur, Mari, Kandhkot, Sui, Uch and Zin wells. Gas was also discovered in Late Cretaceous Pab sandstone in Pirkoh 1 well in 1977. Area requires further geological and geophysical investigations specially in Sibi trough because of the presence of numerous oil-seepages. However, known structures in the region for exploration oil and gas are East Zin, Bambor (Mumtaz) and Loti in Marri-Bugti region ; Nari and Kot in Sibi trough and Bolan Pass area of northern Sub-Kirthar foredeep.

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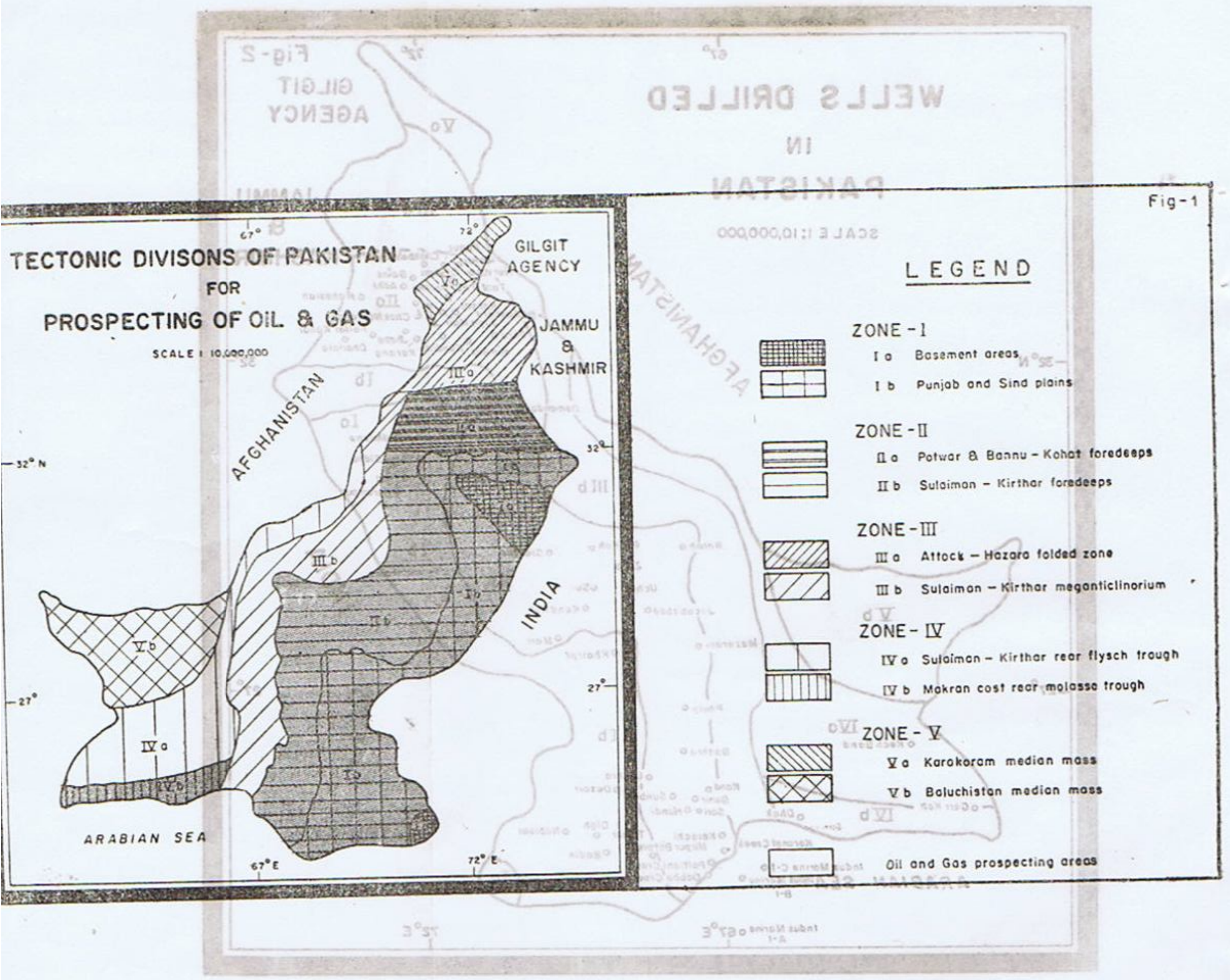

Fig-1
TECTONIC DIVISONS OF PAKISTAN
FOR
PROSPECTING OF OIL & GAS
SCALE 1:10,000,000
GILGIT AGENCY
JAMMU & KASHMIR
AFGHANISTAN
INDIA
ARABIAN SEA
LEGEND
ZONE - I
I a Basement areas
I b Punjab and Sind plains
ZONE - II
II a Potwar & Bannu - Kohat foredeeps
II b Sulaiman - Kirthar foredeeps
ZONE - III
III a Attock - Hazara folded zone
III b Sulaiman - Kirthar meganticlinorium
ZONE - IV
IV a Sulaiman - Kirthar rear flysch trough
IV b Makran cost rear molasse trough
ZONE - V
V a Karakoram median mass
V b Baluchistan median mass
Oil and Gas prospecting areas
WELLS DRILLED
IN
PAKISTAN
Fig-2

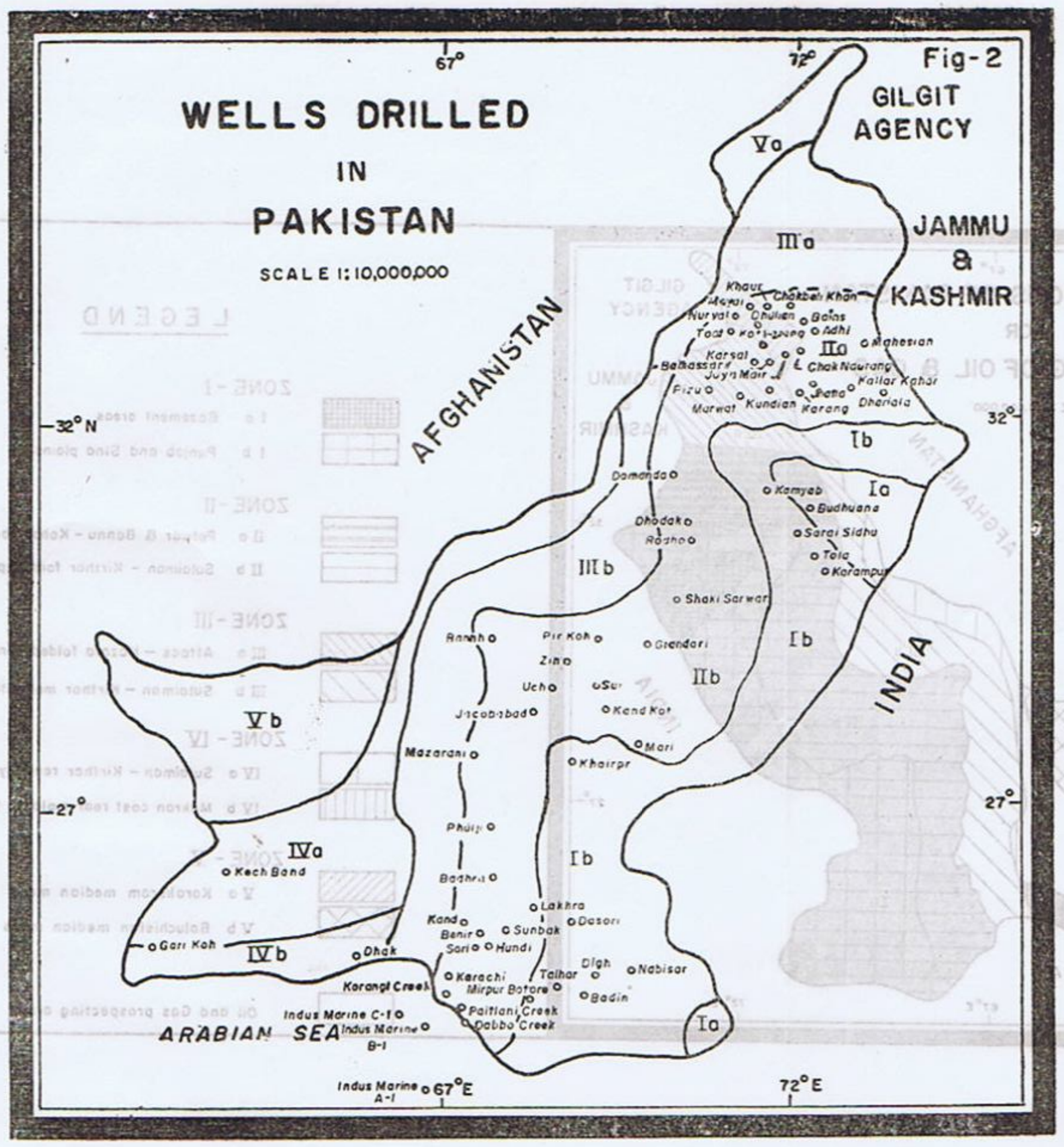
Fig-2
WELLS DRILLED
IN
PAKISTAN
SCALE 1:10,000,000
67°
72°
32° N
32°
27°
27°
67° E
72° E
GILGIT
AGENCY
JAMMU
&
KASHMIR
AFGHANISTAN
INDIA
ARABIAN SEA
Va
IIIa
IIa
Ib
Ia
IIIb
IIb
Ib
Vb
IVa
IVb
Ia
Khaur
Chakbel Khan
Meyal
Nurvali
Dhulian
Balas
Adhi
Toot
Karsal
Maheslan
Chak Naurang
Balkassar
Joya Mair
Kallar Kahar
Pizu
Jhelia
Marwat
Kundian
Karang
Dhariala
Damanda
Kamyab
Budhuana
Dhodak
Sarai Sidhu
Rosho
Tola
Karampur
Shaki Sarwar
Ranah
Pir Koh
Giandari
Zin
Uch
Sui
Kand Kot
Jacobabad
Mari
Mazarani
Khairpr
Phulji
Bathra
Lakhra
Kand
Dasori
Benir
Sunbak
Sari
Hundi
Kech Band
Gari Koh
Dhak
Korangi Creek
Karachi
Talhar
Digh
Nabisar
Mirpur Batore
Badin
Indus Marine C-1
Indus Marine B-1
Paitiani Creek
Dabbo Creek
Indus Marine A-1

VII. Karachi Trough to Southren Part of Sub-Kirthar foredeep Wells

1.	Karachi	(PPL)
2.	Sari	(OGDC)
3.	Hundi	(OGDC)
4.	Khothar	(OGDC)
5.	Benir	(OGDC)
6.	Kand	(OGDC)
7.	Badhra	(HIPC)
8.	Phulji	(HIPC)
9.	Mazarani	(PPL/HIPC)

Gas reservoirs were discovered in Paleocene Ranikot limestone/sandstone and Lower Eocene Laki limestones, capped by Eocene shales in Sari, Hundi, Khothar and Mazarani wells. Gas reservoirs are comparatively smaller because of lateral change in facies to Karara shales towards west of the area in Karachi and Kand wells. Important areas of oil and gas exploration in Mesozoic and Paleogene formations, after further geological and geophysical investigations, seem to be (1) South of Mazarani gas field in the southern portion of Sub-Kirthar foredeep and (2) Benir and Mann structures of northern part of Karachi trough.

VIII. Karachi Shore Line to Lakhra High wells.

1.	Dabbo Creek	(Sun oil)
2.	Patiani Creek	(Sun oil)
3.	Korangi Creek	(Sun oil)
4.	Karachi	(PPL/Tide)
5.	Sunbak	(HIPC)
6.	Lakhra	(HIPC)
7.	Dasori	(PPL/Sun oil)

Comments on Karachi trough are already made above.

However, the prospect of oil and gas deposits in post-Paleocene sediments in Indus off-shore basin seem to be quite encouraging in view of the discovery of oil and gas in Bombay off shore basin in Early Eocene sandstone and oligocene as well as Miocene limestone (biomicrite).

IX. Karachi trough to Nagar Parkar Slope Wells Fig. 2.

1.	Pataini Creek	(Sun oil)
2.	Mirpur Batore	(SVOC)
3.	Talhar	(SVOC)
4.	Badin	(SVOC)
5.	Digh	(SVOC)
6	Nabisar	(SVOC)

X. Mekran coast to Indus Marine Wells Fig. 2.

1.	Garr Koh	(Marathon)
2.	Kech Band	(Tide)
3.	Dhak	(DIPC)
4.	Indus Marine C-I	(Wint)
5.	Indus Marine B-I	(Wint)
6.	Indus Marine A-1	(Wint)

None of the above wells penetrated through Paleogene and Mesozoic formations. However, on the basis of field evidence of South Baluchistan Mesozoic formations are to be explored for the prospect of oil and gas reservoirs.

IX. Area between Karachi Trough and Nagar Parkar basement i.e. Thar Slop wells.

1.	Mirpur Batoro	(SVOC)
2.	Talhar	(SVOC)
3.	Badin	(SVOC)
4.	Digh	(SNOC)
5.	Nabisar	(SVOC)

Thar Slop lies between Karachi Trough and Nagar Parkar basement. It is covered by alluvium and so wells were drilled on the basis of geophysical investigations. Post Early Cretaceous sediments are generally missing or thinning out eastward from Karachi in Thar Slope as such Mesozoic and possibly Paleozoic sediments become drilable depths. Sandstone horizons of Mesozoic/Paleozoic formations may prove to be oil/gas reservoirs and further drilling on suitable structural traps should be pursued after detail geophysical investigations.

ACKNOWLEDGEMENT

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PHYSICO-CHEMICAL METHOD FOR THE DETERMINATION OF CHEMICAL COMPOSITION OF CHROMITE

BY

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Abstract: *A detailed study of the physical properties such as specific gravity, cell edge dimension, microhardness and refractive index is described and compared with chemical composition of chromite. t has been found that from known values of microhardness and refracti.e index, it is possible to guess the weight percentages of Cr_2O_3, Al_2O_3 while with the help of specific gravity and cell edge dimension it is possible to find out weight percentages of Cr_2O_3, Al_2O_3, Fe_2O_3, FeO and MgO within ± 5% error.*

INTRODUCTION

Some attempts have been made to correlate the chemistry of chromites with some of its physical properties. Fisher (1929) while comparing specific gravity with weight percentages of Cr_2O_3, Al_2O_3, Fe_2O_3, FeO, reported that spinellids, taken as a group do not show any relationship between the mentioned weight percentages and specific gravity. Chakraborty (1965) has given specific gravity values of five chromites from India. None of the constituent oxides show any positive or negative relationship towards specific gravity. Chromite analyses provided by Thayer (Personal communication) also showed that there is no simple relation between specific gravity and weight percentages of the constituent oxides.

Clark (1932), compared weight percentage of Al_2O_3 with cell edge dimension and observed an increase in its value with decrease in weight percentage of Al_2O_3. Chakraborty (1965) observed similar results Steven (1944) showed an increase in cell edge dimension with increase in weight percentage of Cr_2O_3 Golding (1971), related cell edge dimension with weight percentages of Cr_2O_3, Al_2O_3 FeO, MgO and observed an increase in cell edge dimension, with increase of Cr_2O_3, FeO and a decrease in its value with an increase of Al_2O_3 and MgO.

Demirsoy (1968), presented a comparative study of microhardness with Cr and Fe contents in chromite. The wide spread of points showed that microhardness does not very linearly with variation of Cr and Fe contents.

Fisher (1929a) reported that spinellids taken as a group do not show any relationship when Cr_2O_3, Al_2O_3, Fe_2O_3 and FeO are plotted against refractive index.

EXPERIMENTAL

Chromite samples separated by magnetic separator and purified by heavy liquids were analysed by the analytical scheme of Ahmed (1969). Specific gravity of clean chromite concentrates were determined by pycnometer method. The values given are mean of three determinations. Values for cell edge dimension were determined using a powder camera with 190 mm diameter and Mo K ∝ radiations. Microhardness of polished samples were determined in terms of Vickers Hardness Number (V.H.N.) using a G. K. N. microhardness tester at a load of 200 grams. The values given are mean of ten determinations made on each sample. Refractive indices were determined by immersion method.

For the present study specific gravity, cell edge dimension, and microhardness of 18 chromite specimens are given in table 1, which cover the maximum range of variation observed in chromites from Pakistan. The table also include refractive indices of 8 samples.

SPECIFIC GRAVITY

A plot of weight percentages of Cr_2O_3, Al_2O_3, Fe_2O_3, FeO, MgO and specific gravity in Fig. 1, show that there is no simple relationship between weight percentages of the constituent oxides and specific gravity. A rough conclusion that can be drawn is that with an incrdase in Cr_2O_3, Fe_2O_3, FeO and Cr/Fe ratio, specific gravity increase and it shows a decrease with an increase in Al_2O_3 and MgO.

In order to study the effects of all the major oxides on specific grvaity, a new diagram Fig. 2, is presented from the data given in Ahmad (1972). This is based on the assumption that the total sum of trivalent cations is 16 and that of bivalent cations is 8. It was observed that there is a gradual change in specific gravity from one end with high Al to the other with low Al contents. Points having similar values of specific gravity were joined, and it was observed that these lines are parallel to each other as shown in Fig. 2. In order to ascertain whether the spacing of the lines is uniform or not, Fig. 3, was drawn between specific gravity and Al cations at constant value of Fe^{3+} cations (3 00) This figure showed a linear relation between Al cations and specific gravity at constant value of Fe^{3+} cations. Keeping in view of these observations, a detailed Fig. 4 was drawn covering the specific gravity variation range in chromites from Pakistan. Plot of chromite analyses of Chakraborty (1965) and Thayer (Personnel communications) in this figure showed behaviour similar to the one observed during the present study.

An equation was derived between specific gravity and cations of Al, Fe^{2+} as :

$$X = 2.44 (4.02 + a - 10\ b).$$

X = Cations of Al,

a = Cations of Fe.

b = Specific gravity.

With the help of above equation, number of cations of Al in a chromite sample can be calculated from known values of Fe^{3+} cations and specific gravity. If Fe^{3+} cations are also known the cations of Cr can be calculated by subtracting the total Al, Fe^{3+} cations from 16 (the total number of trivalent cations per unit cell in chromite). Similarly cations of Mg are obtained by subtracting cations of Fe^{2+} from 8, (The total number of bivalent cations per unit cell in chromite).

In order to convert these cations into weight percentages of respective oxides, Figs, 5 to 9 were drawn on the basis of least square method with 95 % confidence interval, from the data given in Ahmed, (1972).

From the above mentioned discussion it is clear that from known values of Fe^{2+}, Fe^{3+} and specific gravity of a chromite, weight percentages of Cr_2O_3, Al_2O_3, and MgO can be calculated. These values when checked on an unknown sample, came out to be very near to the analytical values with an error of only ± 5% as shown in table 2.

CELL EDGE DIMENSION

A comparative study of cell edge dimension with weight percentages of Cr_2O_3, Al_2O_3, Fe_2O_3, FeO, MgO and Cr/Fe ratio is presented in Fig. 10. This figure shows that with an increase in weight percentage of Cr_2O_3, celledge dimension increases whereas the case is reverse for Al_2O_3. The effect of weight percentages of Fe 0, Mg 0, Fe_2O_3 and Cr/Fe ratio is not so significant as the spread of points is quite large.

However a rough conclusion may be drawn that with an increase in FeO, Fe_2O_3 cell edge dimension increases, and with an increase of MgO, it decreases.

Keeping in view the relation between, cell edge dimension and weight percentages of Cr_2O_3, Al_2O_3 Fig. 11 and 12 were drawn on basis of least square method with 95% confidence interval. These figures help to find out weight percentages of Cr_2O_3, Al_2O_3 from known value of cell edge dimension. The weight percentage of Al_2O_3, Cr_2O_3 so determined, on substitution in the equation for specific gravity, will help to determine Fe^{2+}, and Fe^{3+} cation. So a combination of these two physical properties help to find out weight percentages of all the five major oxides as shown in table-3. Difference in the observed and calculated values for Fe_2O_3 may be as much as ±5% of the contained oxide. However, Fe_2O_3 contents of podiform chromites all over the world rarely exceeds 8.00 percent. Therefore the absolute value of error in the estimation of Fe_2O_3 by the method outlined above is not likely to be more than a few percent.

MICROHARDNESS

A comparison of microhardness with weight percentages of Cr_2O_3, Al_2O_3, Fe_2O_3, FeO, MgO and Cr/Fe ratio, given in Fig. 13, shows a wide spread of points. However a rough conclusion that can be drawn is that with an increase in weight percentages of Cr_2O_3, Fe 0, microhardness decreases, while it shows an increase with increase of Al_2O_3. A plot of microhardness value in Figs. 14 and 15 show that the influence of variation in chemical composition of chromite on microhardness is not uniform and is comparatively less at higher values of microhardness.

REFRACTIVE INDEX

Refractive indices of only eight samples are presented in table and compared with weight percentages of Cr_2O_3, Al_2O_3, Fe_2O_3, FeO, MgO and Cr/Fe ratio in fig. 16. The figure shows that with an increase in weight percentage of Al_2O_3, refractive index decreases and is reverse for Cr_2O_3 contents. The curves for weight percentages of FeO, MgO and Fe_2O_3 do not show a definite relationship. Increase in Cr/Fe ratio is attended by an increase in refractive index.

Plot of refractive index values in Fig. 17 and 18 show that the influence, of variation in chemical composition of chromite on refractive index is not uniform and is comparatively less at lower values of refractive index.

The above mentioned study shows that from known values of specific gravity and Fe 0, Fe_2O_3, contents, the weight percentages of Cr_2O_3, Al_2O_3 and MgO can be determined within ±5% error. Weight percentages of all the five major oxides i.e Cr_2O_3, Al_2O_3, Fe_2O_3, Fe 0 and MgO can be determined within ±5% error from known values of specific gravity and cell edge dimension.

TABLE I

Weight percentages of major oxides and physical properties of chromites covering the range of variation Ahmed, (1972).

Cr_2O_3	Al_2O_3	Fe_2O_3	Fe 0	Mg 0	Cr/Fe	Specific Gravity	Vickers hardness numbers	Refractive index	Cell edge dimension
1. 39.06	28.24	4.48	11.99	15 52	2.21	4 245	1321	1.955	8.231
2. 42.05	26.29	3.07	15.19	12 83	2.06	4.340	1314	1.963	8.241
3. 49.95	20.31	1.14	15.04	12.96	2.07	4 418	1283	—	8.258
4. 50.66	18 86	2.34	12.26	15.26	3.11	4.383	1299	—	8 268
5. 52.55	16.66	3.22	11.17	15.09	3.15	4.406	1305	2.025	8 277
6. 52.55	16.40	3.20	12.64	14 57	2.98	4.428	1299	—	8.274
7. 53.19	14.63	3 63	14.01	13.71	2.71	4.476	1239	—	8.283
8. 53.35	15.18	2.54	15.48	12.46	2.64	4 500	1225	—	8.279
9 53.82	12.34	4 64	16.98	11.56	2.24	4.567	1204	—	8.292
10. 54 45	15.11	1.60	15.68	12 62	2 80	4.501	1218	—	8.277
11. 55.09	12.61	1.96	18.97	10.55	2.34	4.595	1197	—	8.292
12. 55.21	12.65	4 06	14.97	12 61	2.64	4.537	1218	2.105	8.292
13. 55.72	13.15	2 88	15 57	12 06	2.70	4.532	1211	—	8.286
14. 57.11	12.67	2 56	12.01	15.15	3.52	4 461	1249	2.068	8.249
15. 57.11	13 83	2.61	10.87	14 94	3 80	4.428	1275	2.05	8 288
16 58 25	10.54	5.11	9.77	15.62	3.57	4.457	1249	—	8 299
17, 58.89	9.60	5.51	9.41	15 98	3.61	4 455	1249	2.088	8.302
18 59 61	11 52	2.36	11.97	14.14	3 72	4.483	1245	2.088	8 295

TABLE 2

Comparison between observed and calculated weight percentages Cr_2O_3 Al_2O_3, Mg 0.

	Cr_2O_3		Al_2O_3		Mg 0	
	Observed	Calculated	Observed	Calculated	Observed	Calculated
A.	55.72	58.20	12.59	12.00	13.56	13 80
B,	47.26	47.70	19.19	18 85	14.56	13 95

TABLE 3

Comparison between weight percentages of Cr_2O_3, Al_2O_3 FeO_3 Fe_2O_3 and MgO obtained by analysis and by the use of cell edge dimension and specific gravity.

	Weight percentages					
	Cr_2O_3		Al_2O_3		Fe_2O_3	
	Calculated	Observed	Calculated	Observed	Calculated	Observed
1.	40.05	39.06	27.60	28.24	3.15	4.48
2.	43 00	42 05	25.10	26.29	3.05	3.07
3.	47.50	49.95	20.80	20.31	3.30	1.14
4.	50.50	50.66	18.20	18.86	3 02	2.34
5.	53.00	52.55	15.94	16.66	3.25	3.22
6.	52.50	52.55	16.68	16.40	2.75	3.20
7.	54.30	53.19	14.40	14.63	3.00	3.63
8.	53.20	53 35	15.50	15.18	3.30	2.54
9.	56.00	53.82	12 21	12.34	3.35	4.64
10.	52.80	54.45	15.76	15.11	3.10	1.60
11.	56.80	55.09	12.25	12.61	3.36	1.96
12.	56.80	55.21	12.25	12.65	3.36	4.06
13.	55 00	55.72	13.76	13.15	3.25	2.88
14.	57.20	57.11	12.04	12.67	3.35	2.56
15.	56 50	57.11	13.20	13.83	2.30	2.61
16.	58.81	58.25	10 50	10.54	3.58	5.11
17.	59.40	58.89	9.80	9.60	3.45	5.41
18.	57.50	59.61	11.50	11.52	3.51	2.36

TABLE (3)—continued

	Weight percentage			
	Fe 0		Mg 0	
	Calculated	Observed	Calculated	Observed
1.	11.60	11.99	15.0	15.52
2.	14.80	15.19	13.25	12.83
3.	15.80	15.04	12.75	12.96
4.	12 40	12.26	14 75	15.26
5.	11.68	11.77	14.70	15.09
6.	13.10	12 64	14.20	14.57
7.	14.30	14.01	13.55	13.71
8.	16.20	15.48	12.80	12.46
9.	17.30	16.98	11.95	11.56
10.	16.22	15.68	12.78	12.62
11.	18 80	18.97	10.95	10.55
12.	14 80	14.97	13.20	12 61
13.	16.22	15 57	12.20	12 06
14.	11.58	12.01	14 67	15.15
15.	10.40	10.87	15 50	14 94
16.	9.80	9.77	15.80	15.62
17.	9.30	9.41	16.15	15.98
18.	12.00	11.97	14.75	14.14

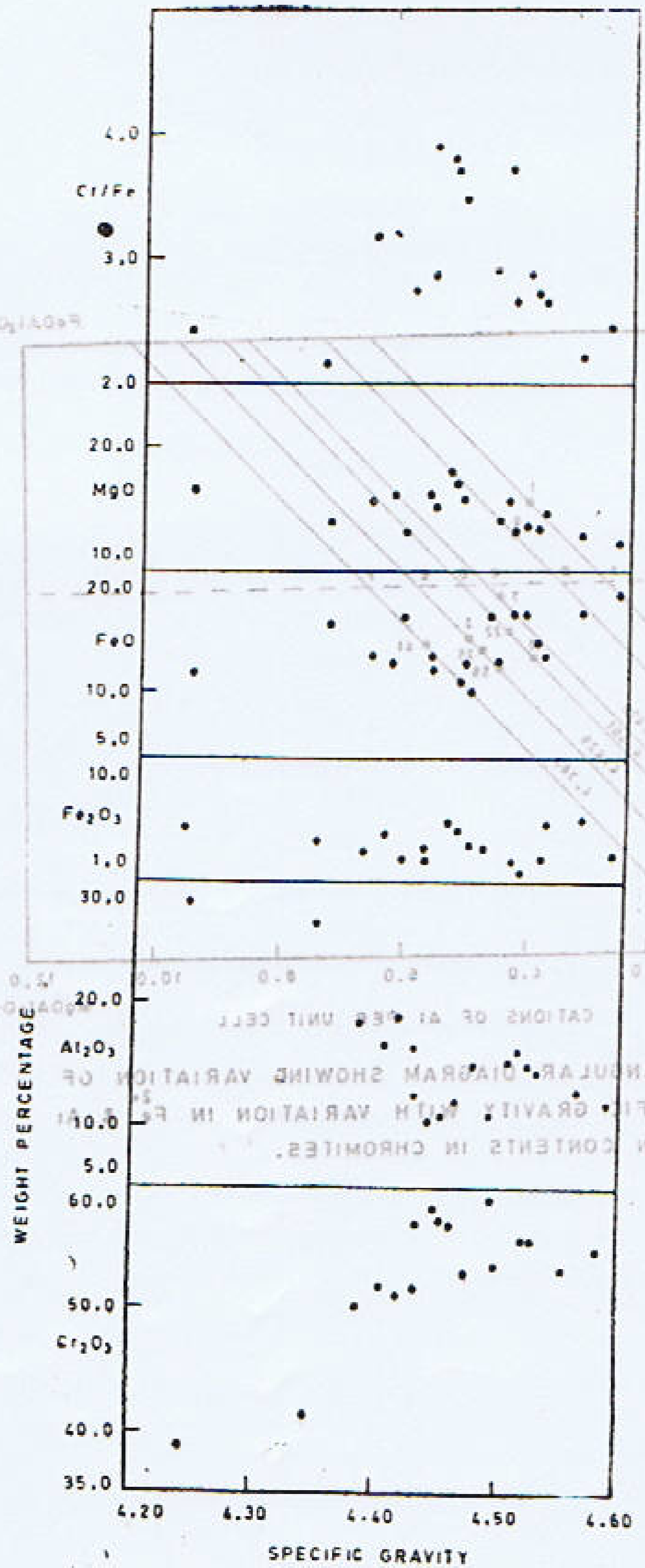


Fig. 1 GRAPH BETWEEN SPECIFIC GRAVITY & WEIGHT PERCENTAGES OF VARIOUS OXIDES IN CHROMITES

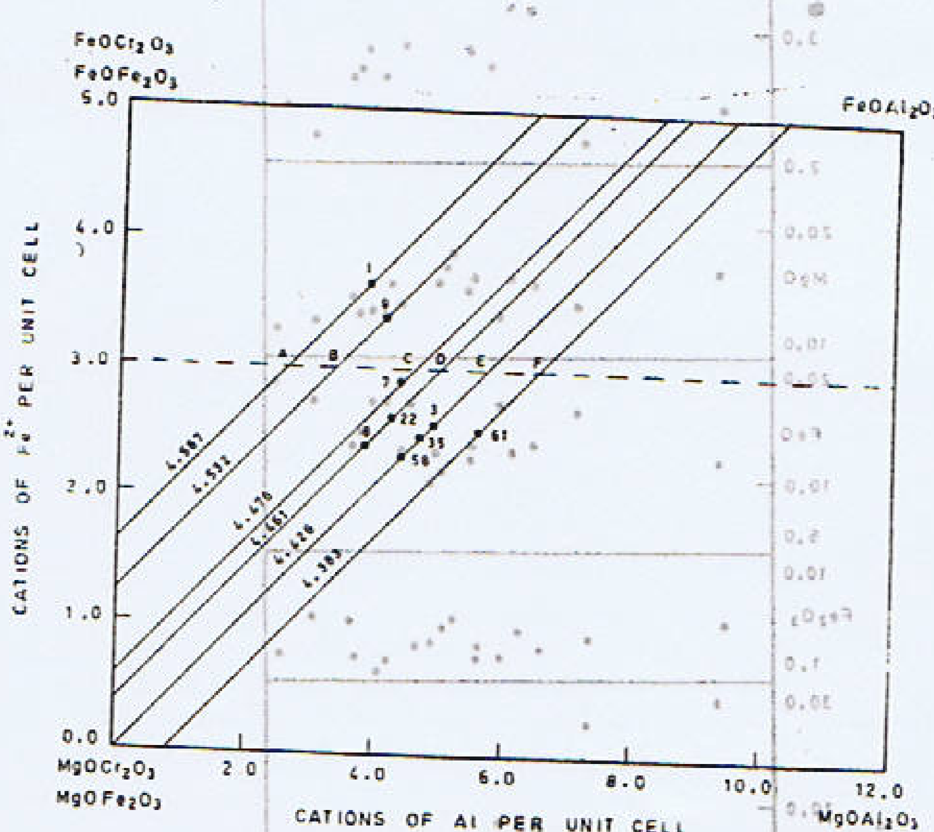


Fig. 2 RECTANGULAR DIAGRAM SHOWING VARIATION OF SPECIFIC GRAVITY WITH VARIATION IN Fe^{2+} & Al CATION CONTENTS IN CHROMITES.

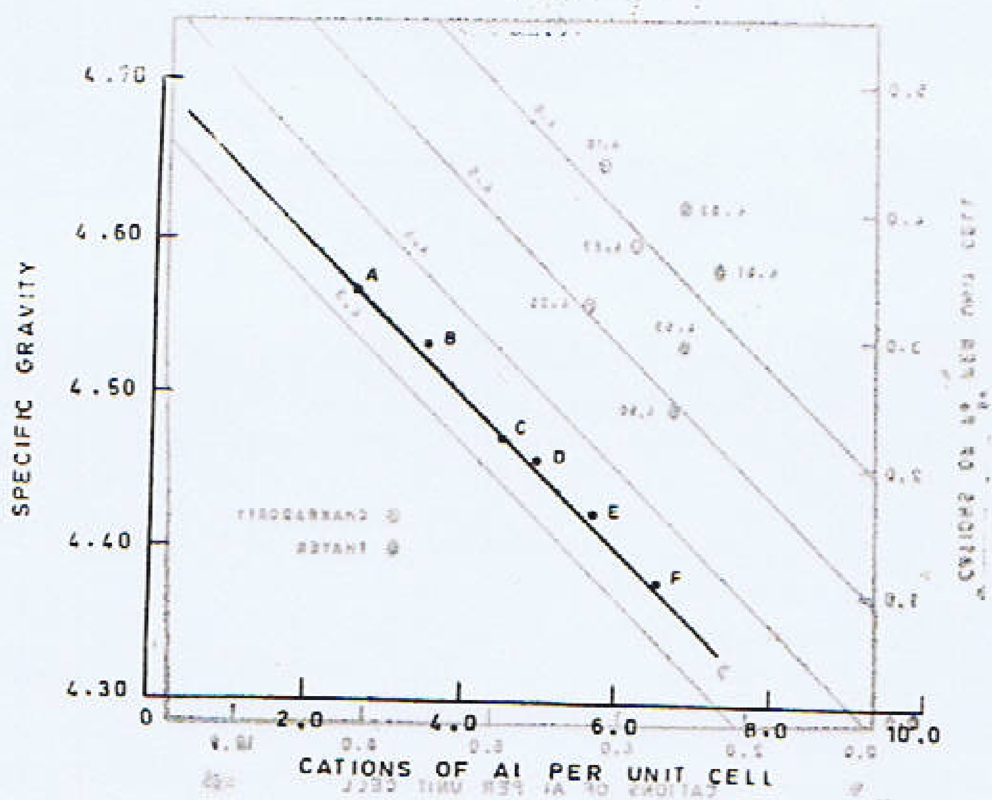


Fig. 3 GRAPH BETWEEN Al CATIONS & SPECIFIC GRAVITY AT CONSTANT VALUE OF Fe^{2+} CATIONS (3.00) IN CHROMITES.

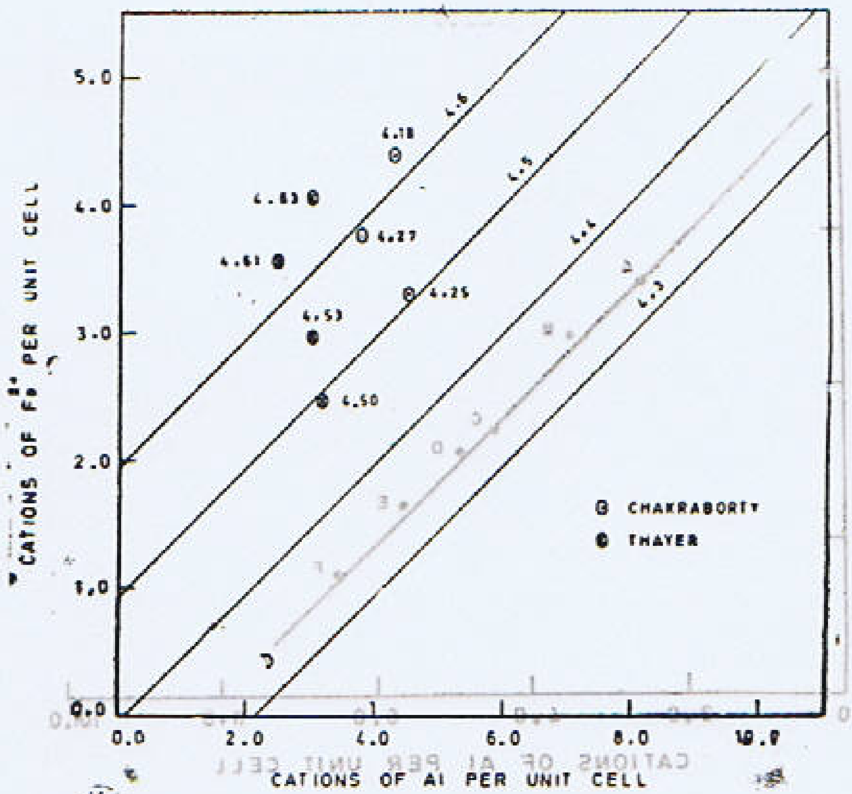


Fig. 4 PLOT OF ANALYSES REPORTED BY CHAKRABORTY AND THAYER BETWEEN Al & Fe^{2+} CATIONS.

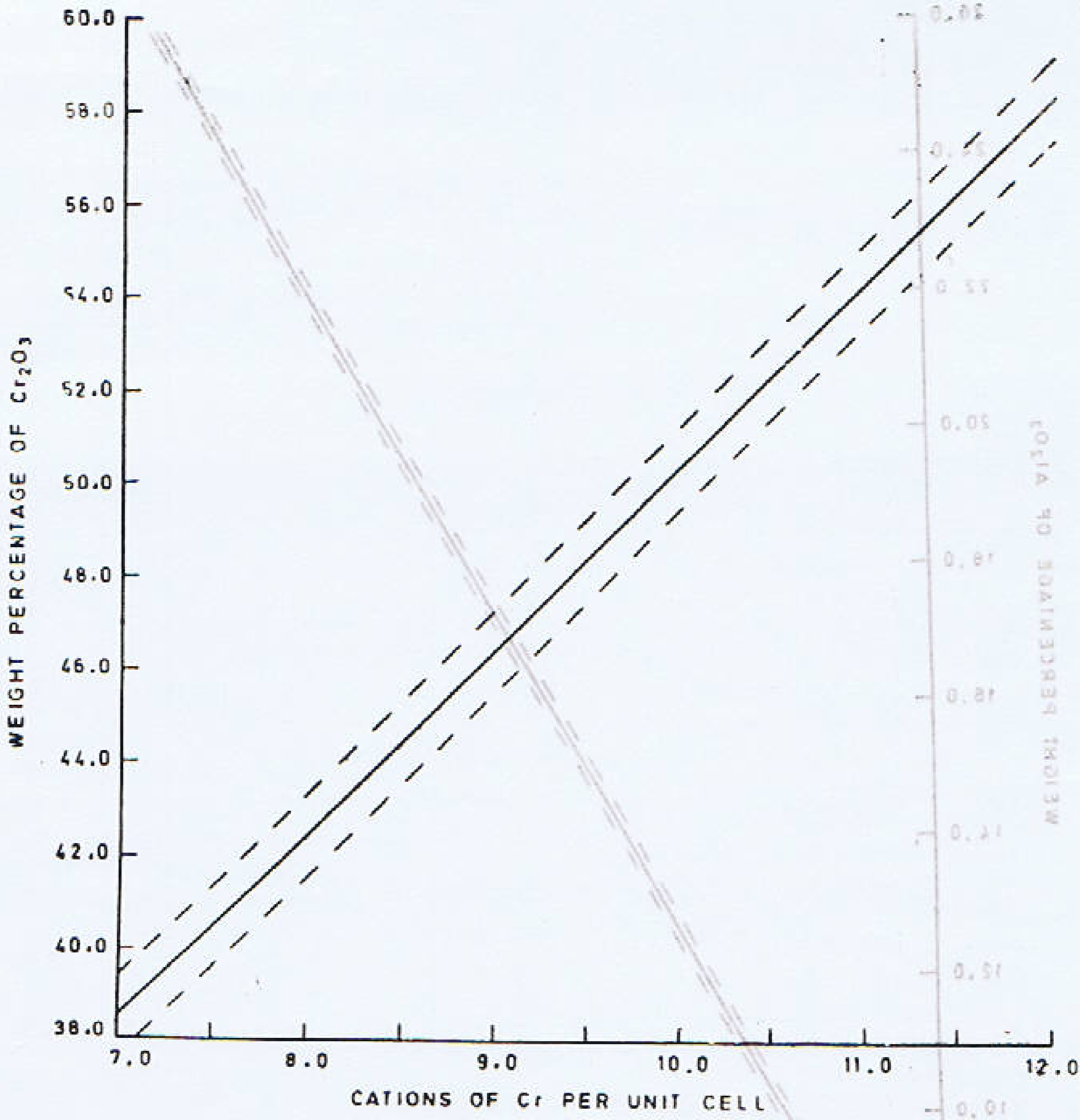


Fig. 5 GRAPH BETWEEN CATIONS OF Cr & WEIGHT PERCENTAGE OF Cr_2O_3 ON BASIS OF LEAST SQUARE METHOD WITH 95 CONFIDENCE INTERVAL

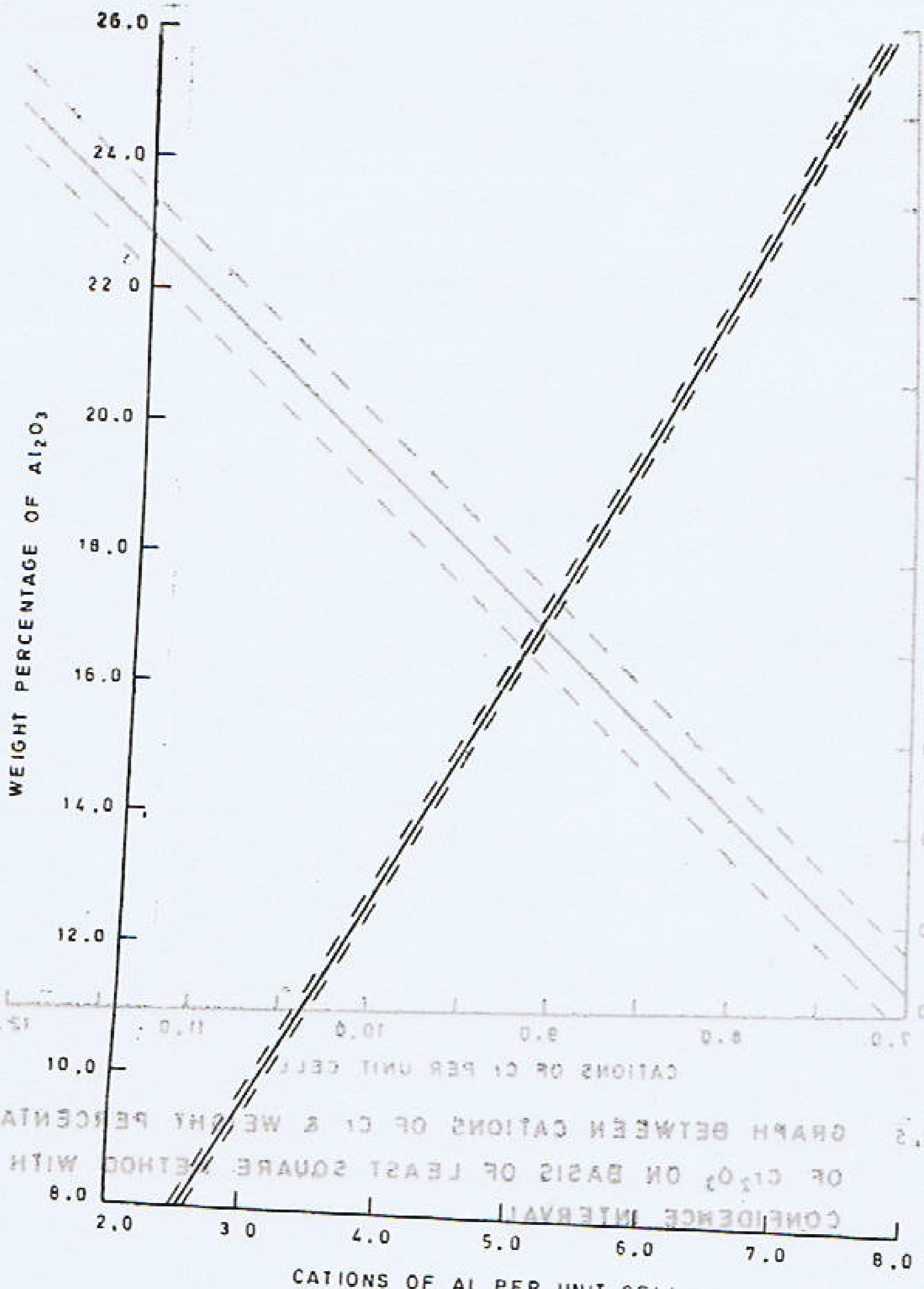


Fig. 6 GRAPH BETWEEN CATIONS & WEIGHT PERCENTAGE OF Al_2O_3 ON THE BASIS OF LEAST SQUARE METHOD WITH 95 % CONFIDENCE INTERVAL

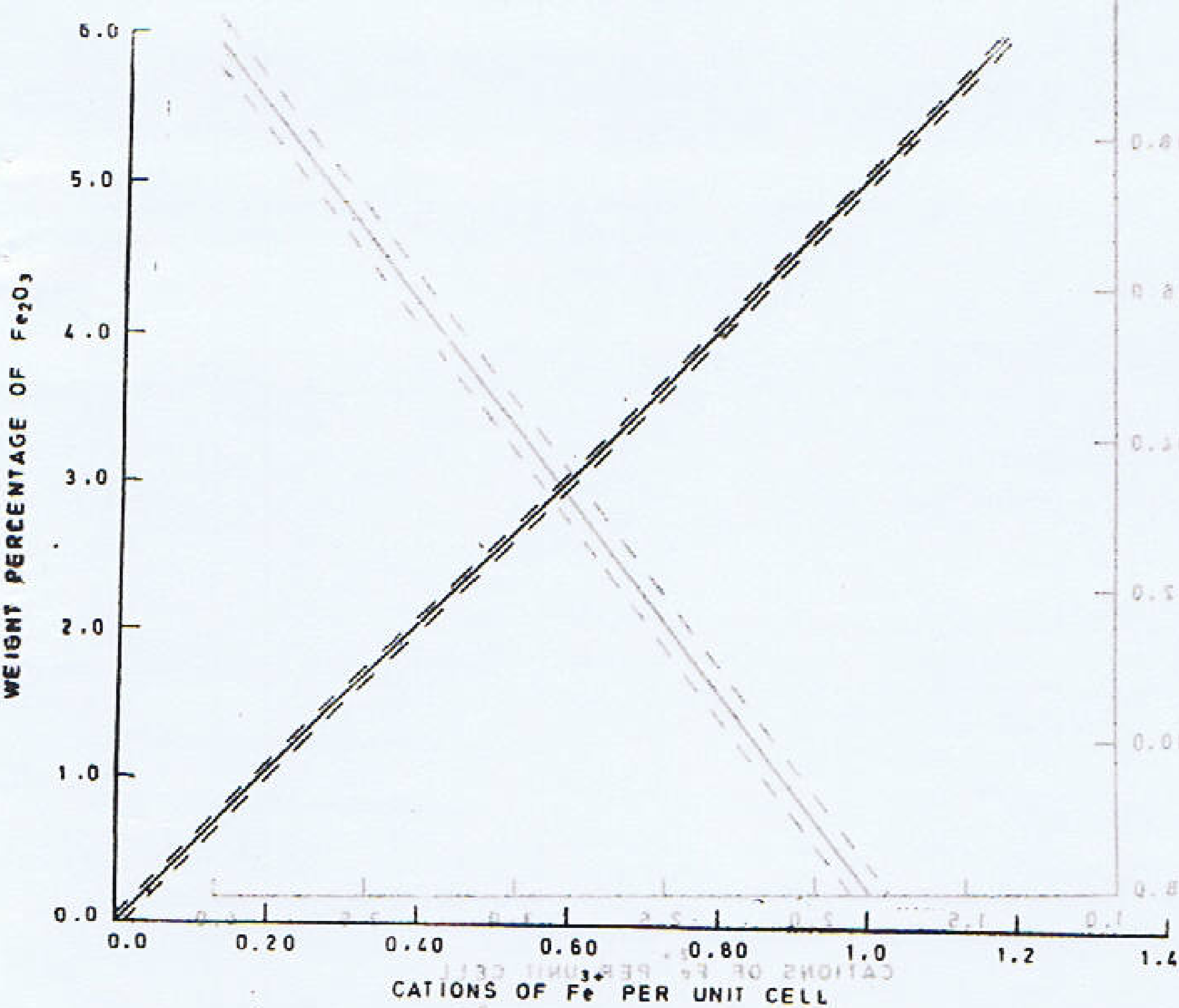


Fig. 7 GRAPH BETWEEN CATIONS OF Fe^{3+} & WEIGHT PERCENTAGE OF Fe_2O_3 ON THE BASIS OF LEAST SQUARE METHOD WITH 95 % CONFIDENCE INTERVAL

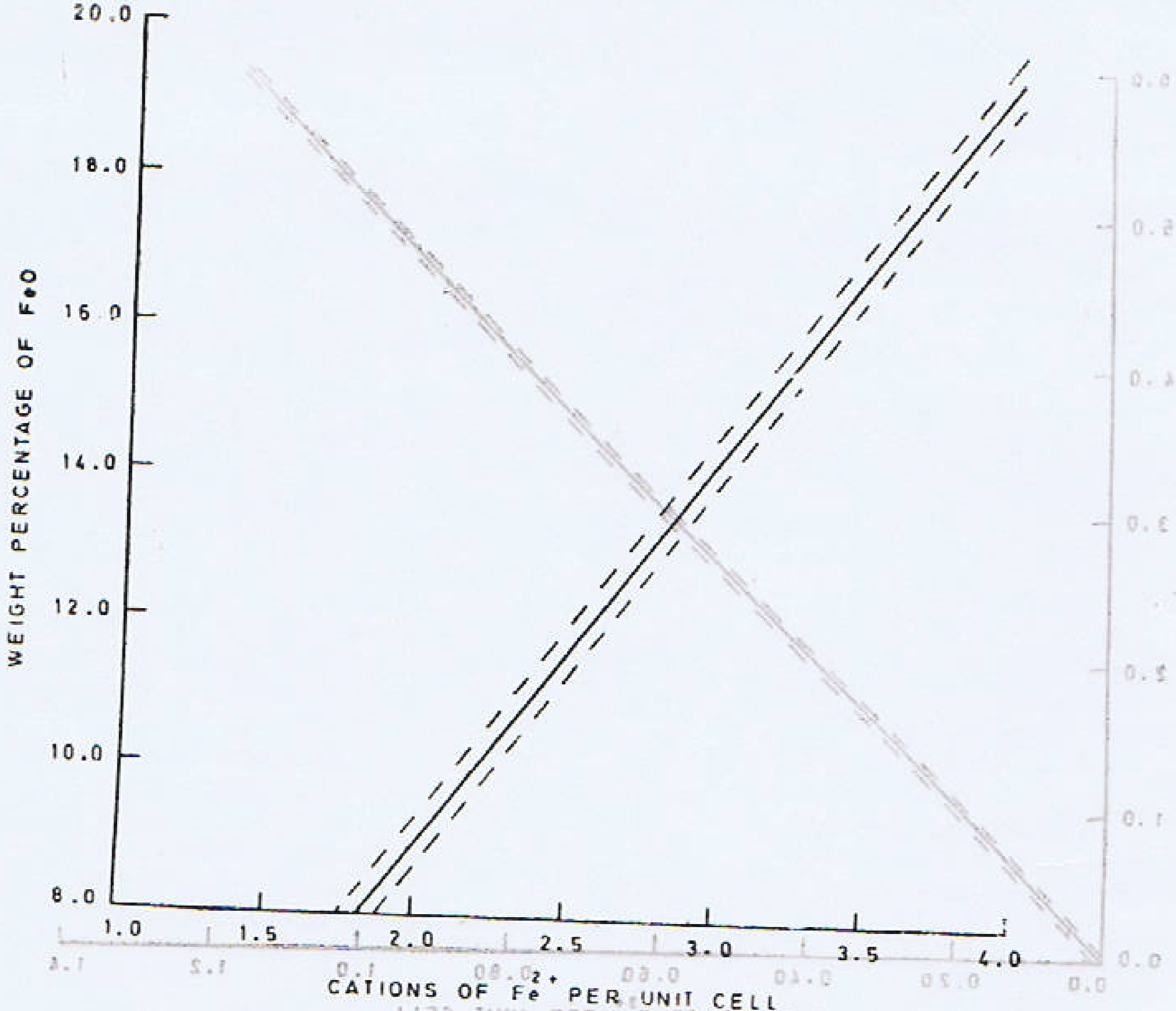


Fig. 8 GRAPH BETWEEN CATIONS OF Fe^{2+} & WEIGHT PERCENTAGE OF FeO ON THE BASIS OF LEAST SQUARE METHOD WITH 95 % CONFIDENCE INTERVAL

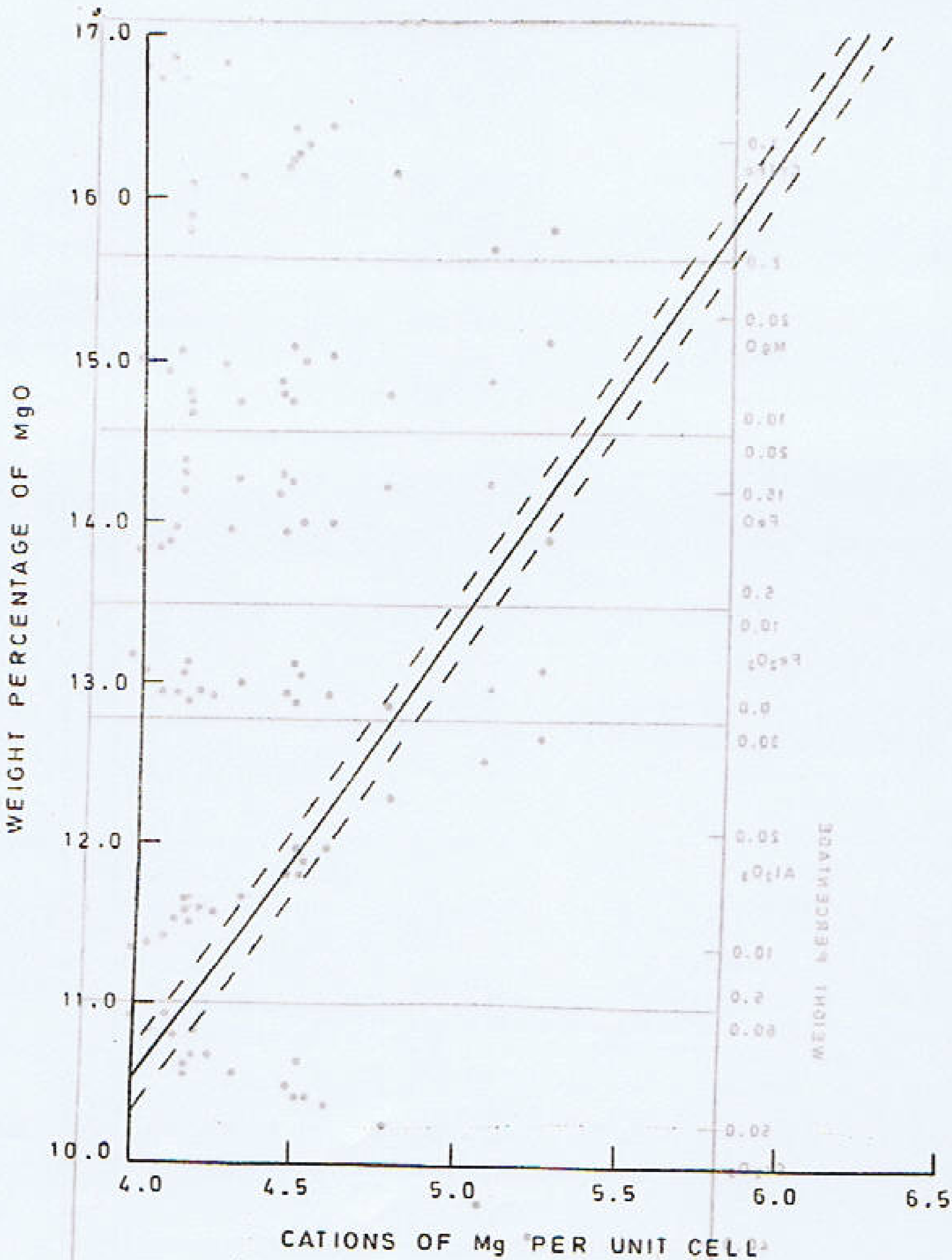


Fig 10 GRAPH BETWEEN CATIONS OF Mg & WEIGHT PERCENTAGE OF MgO ON THE BASIS OF LEAST SQUARE METHOD WITH 95 % CONFIDENCE INTERVAL.

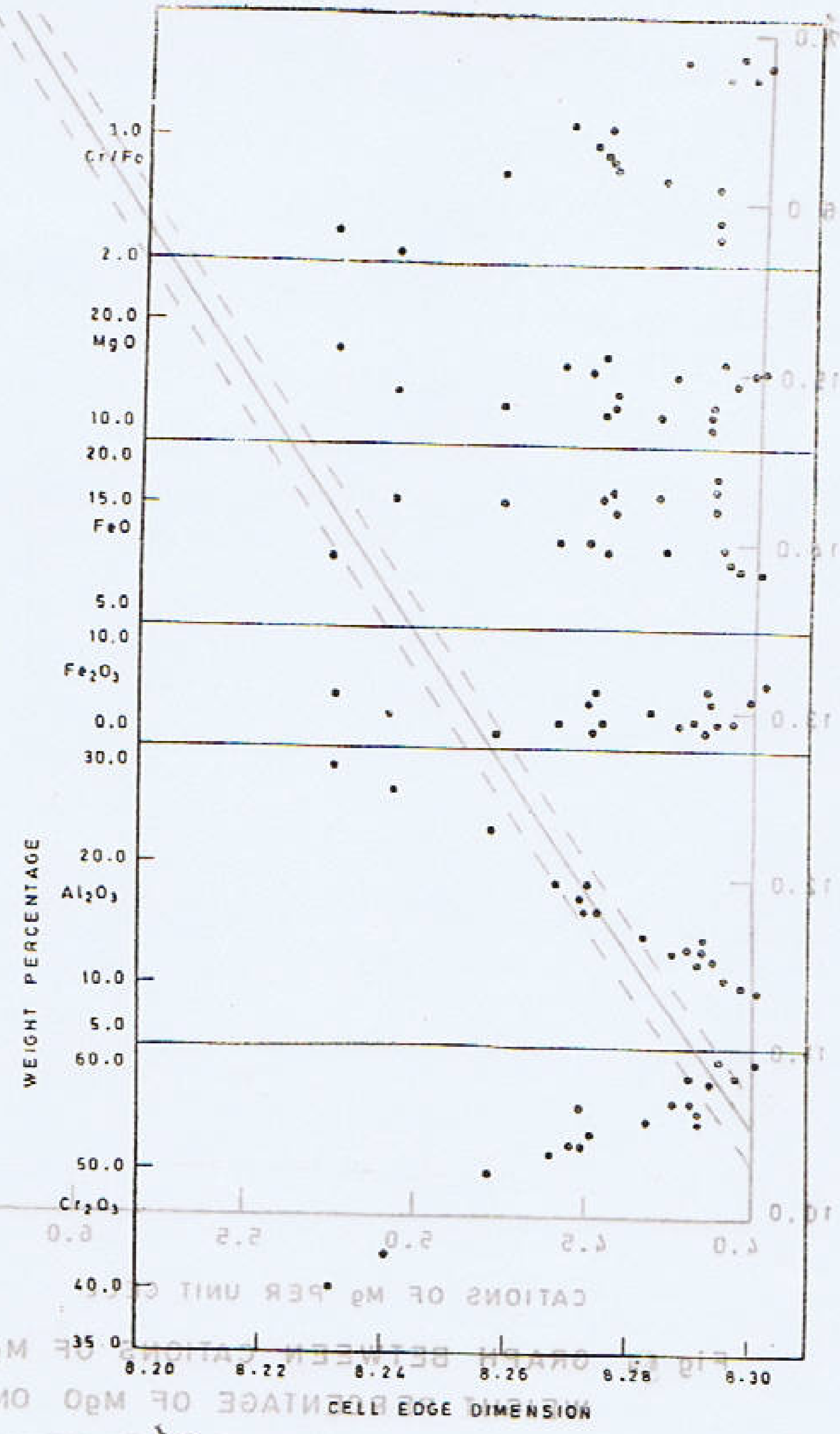


Fig. [illegible] GRAPH BETWEEN CELL EDGE DIMENSION & WEIGHT PERCENTAGE OF VARIOUS OXIDES IN CHROMITES

S8/61

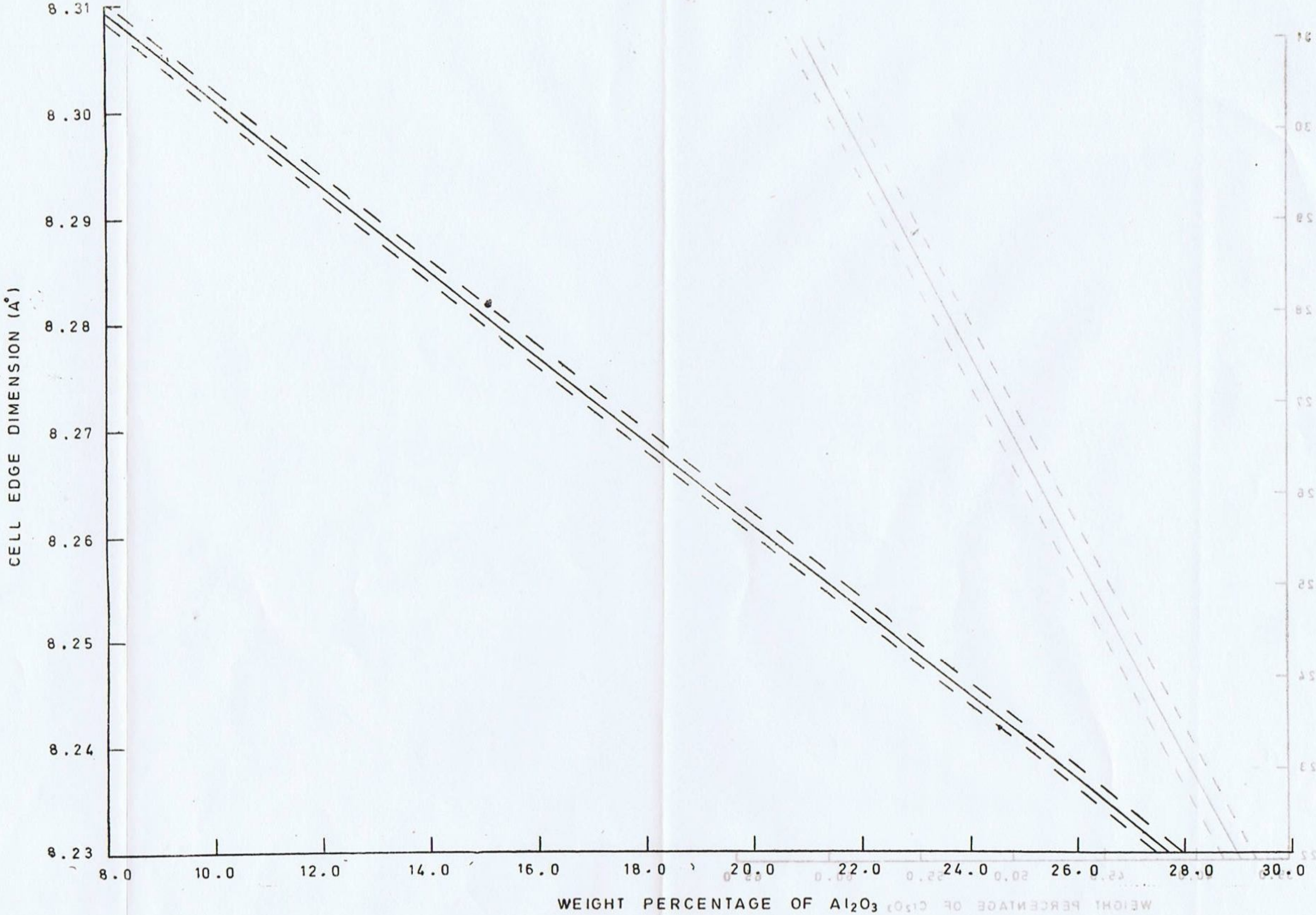


Fig. 12 GRAPH BETWEEN WEIGHT PERCENTAGE OF Al_2O_3 & CELL EDGE DIMENSION (A°) ON BASIS OF LEAST SQUARE METHOD WITH 95% CONFIDENCE INTERVAL.

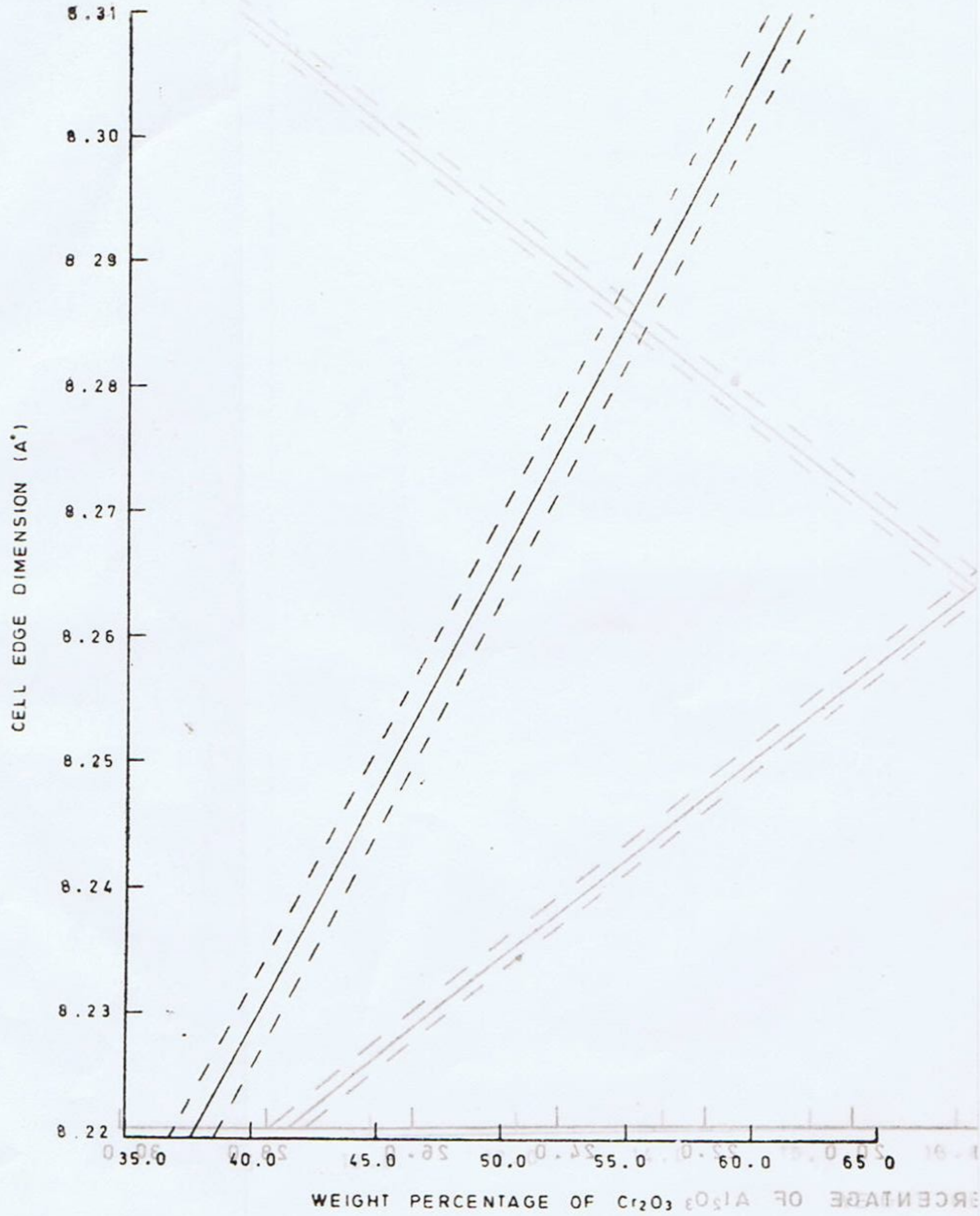


Fig. 11 GRAPH BETWEEN WEIGHT PERCENTAGE OF Cr_2O_3 & CELL EDGE DIMENSION ON BASIS OF LEAST SQUARE METHOD WITH 95 % CONFIDENCE INTERVAL

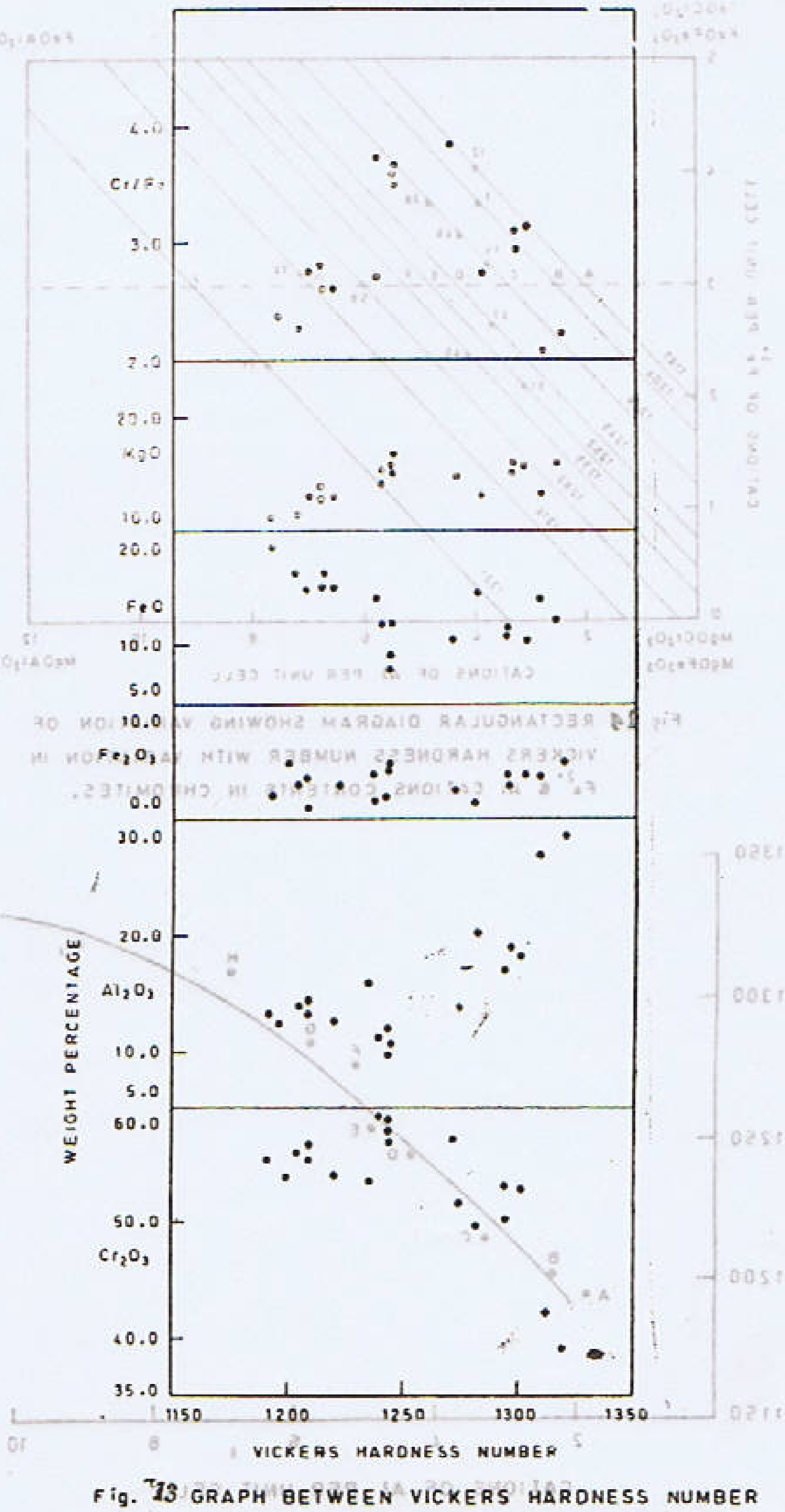
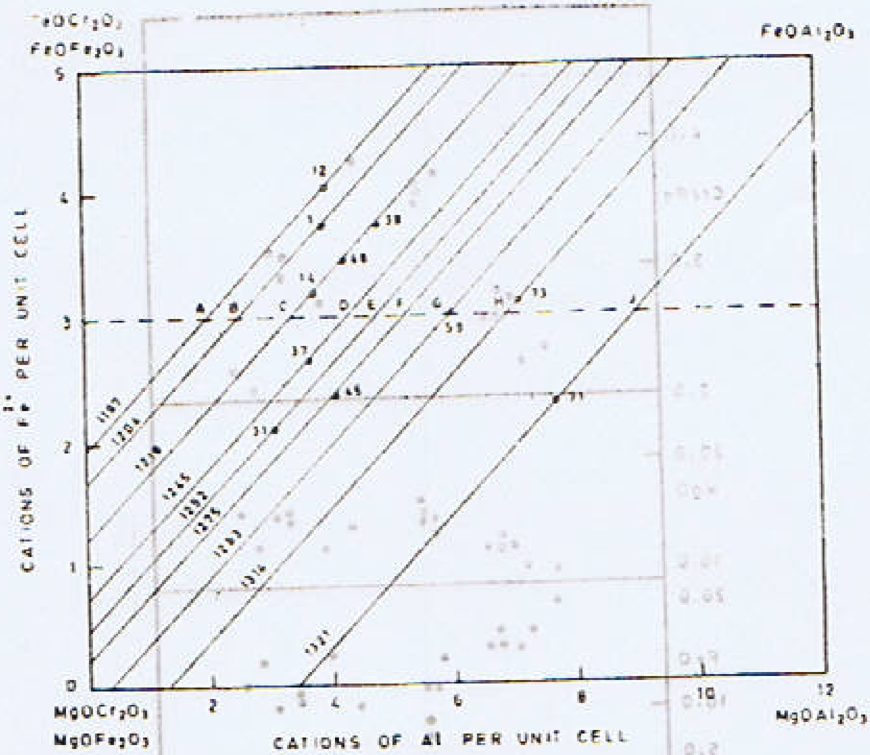


Fig. 13 GRAPH BETWEEN VICKERS HARDNESS NUMBER & WEIGHT PERCENTAGES OF VARIOUS OXIDES IN CHROMITES



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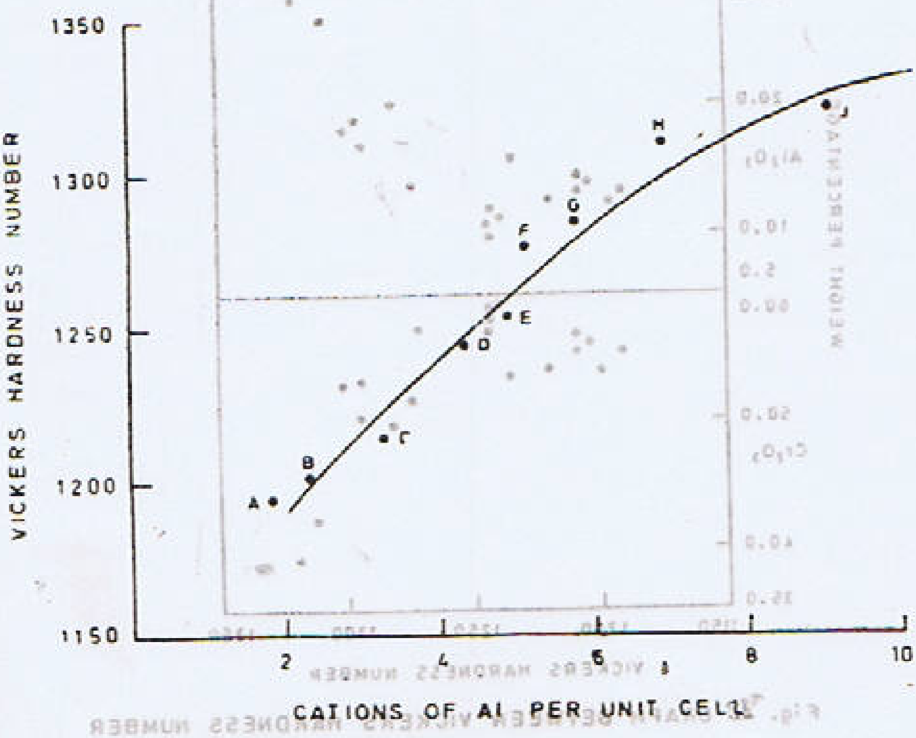

Fig 15 GRAPH BETWEEN Al CATIONS & VICKERS HARDNESS NUMBER AT CONSTANT VALUE OF Fe^{2+} CATIONS (3.00) IN CHROMITES.

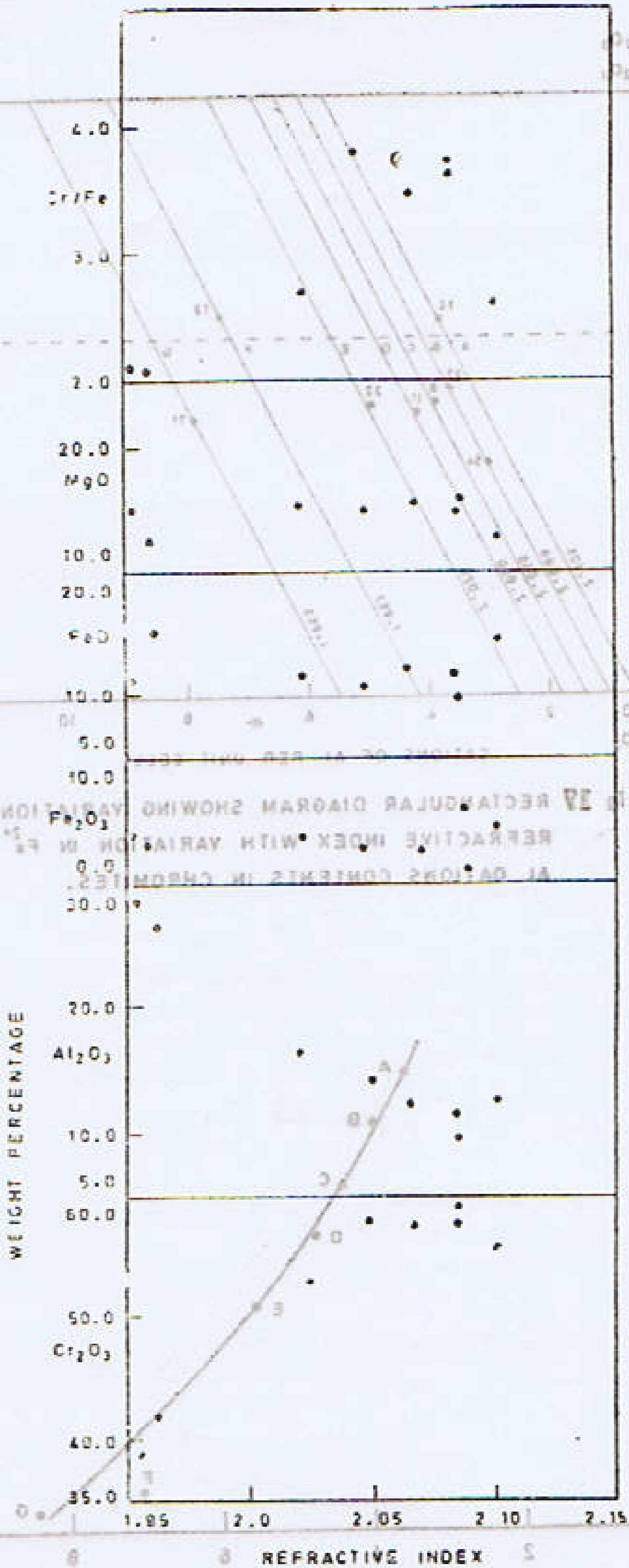

Fig 16 GRAPH BETWEEN REFRACTIVE INDEX AND WEIGHT PERCENTAGE OF VARIOUS OXIDES IN CHROMITES

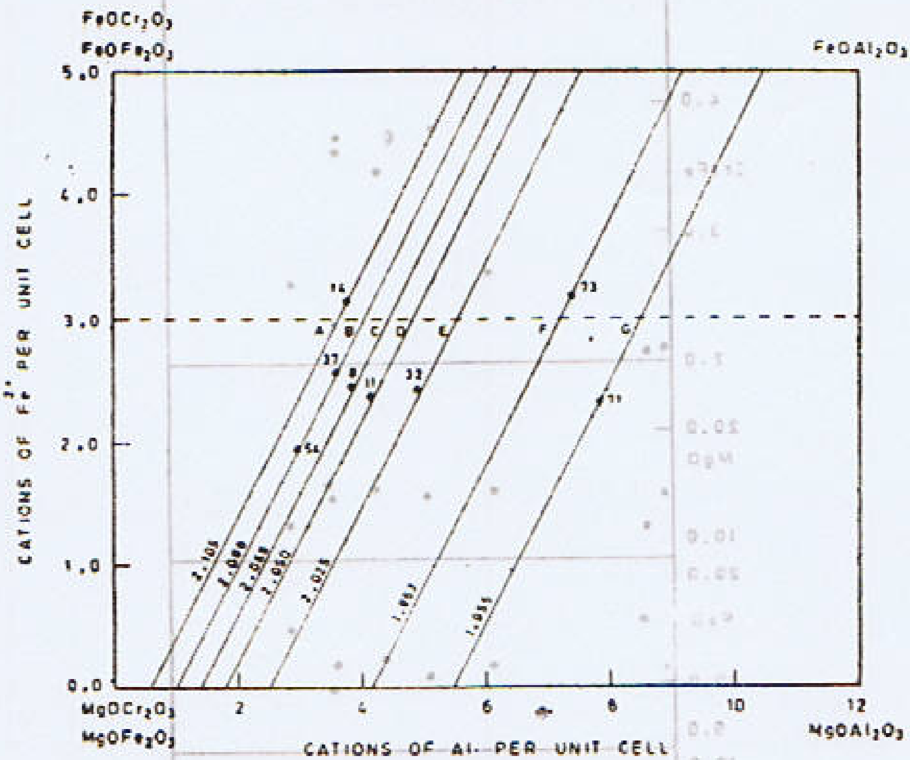

Fig 17 RECTANGULAR DIAGRAM SHOWING VARIATION OF REFRACTIVE INDEX WITH VARIATION IN Fe^{2+} & Al CATIONS CONTENTS IN CHROMITES.

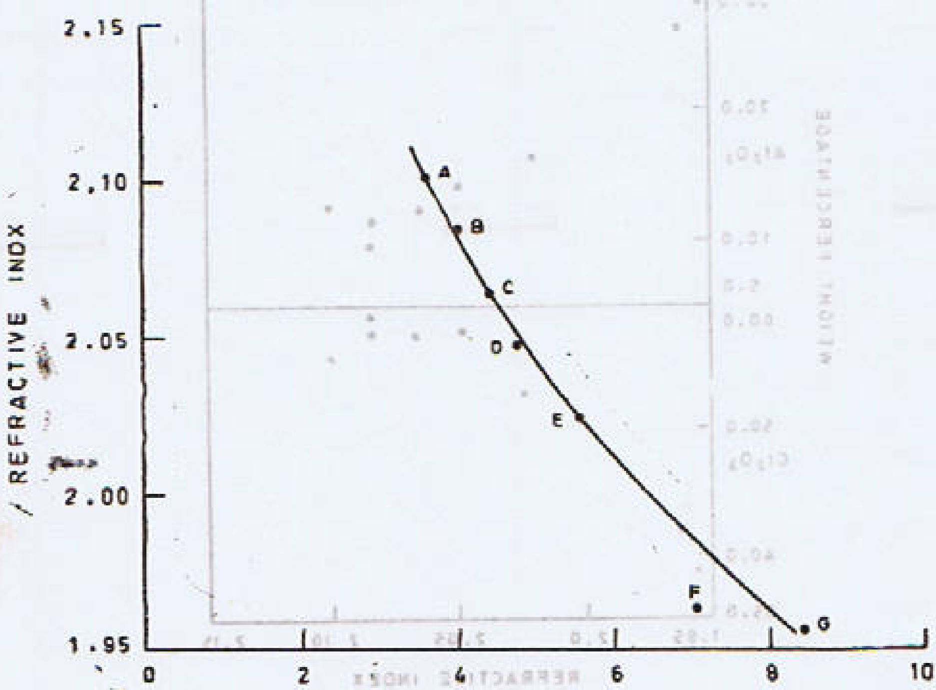

Fig 18 GRAPH BETWEEN Al CATIONS AND REFRACTIVE INDEX AT CONSTANT VALUE OF Fe^{2+} CATIONS 3.00 IN CHROMITES.

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GEOLOGICAL RECONNAISSANCE IN THE ISHKUMAN AND KARAMBAR VALLEYS (NORTHERN PAKISTAN)

BY

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Abstract: *The formations crossed on a route travelled in the Ishkuman and Karambar valleys, along the profile of the Karakorum Geophysical project, are described. The section includes a plutonic core of granodioritic composition surrounded by metamorphic rocks; in this body two batholiths can be identified, the northern one of which seems to constitute the axial batholith of the Karakorum. To the S of this structure there is development of metasedimentary and igneous rocks divided into two complexes ; the greenstone complex with slates, phyllites, marbles, intrusives and middle-basic volcanics, and the clastic metasedimentary succession of turbiditic origin. To the N a thick sedimentary sequence was observed, consisting of sandstones, limestones, dolomites, argillites, marls and conglomerates comprising terms from the Permian to the Cretaceous, never reported before.*

INTRODUCTION

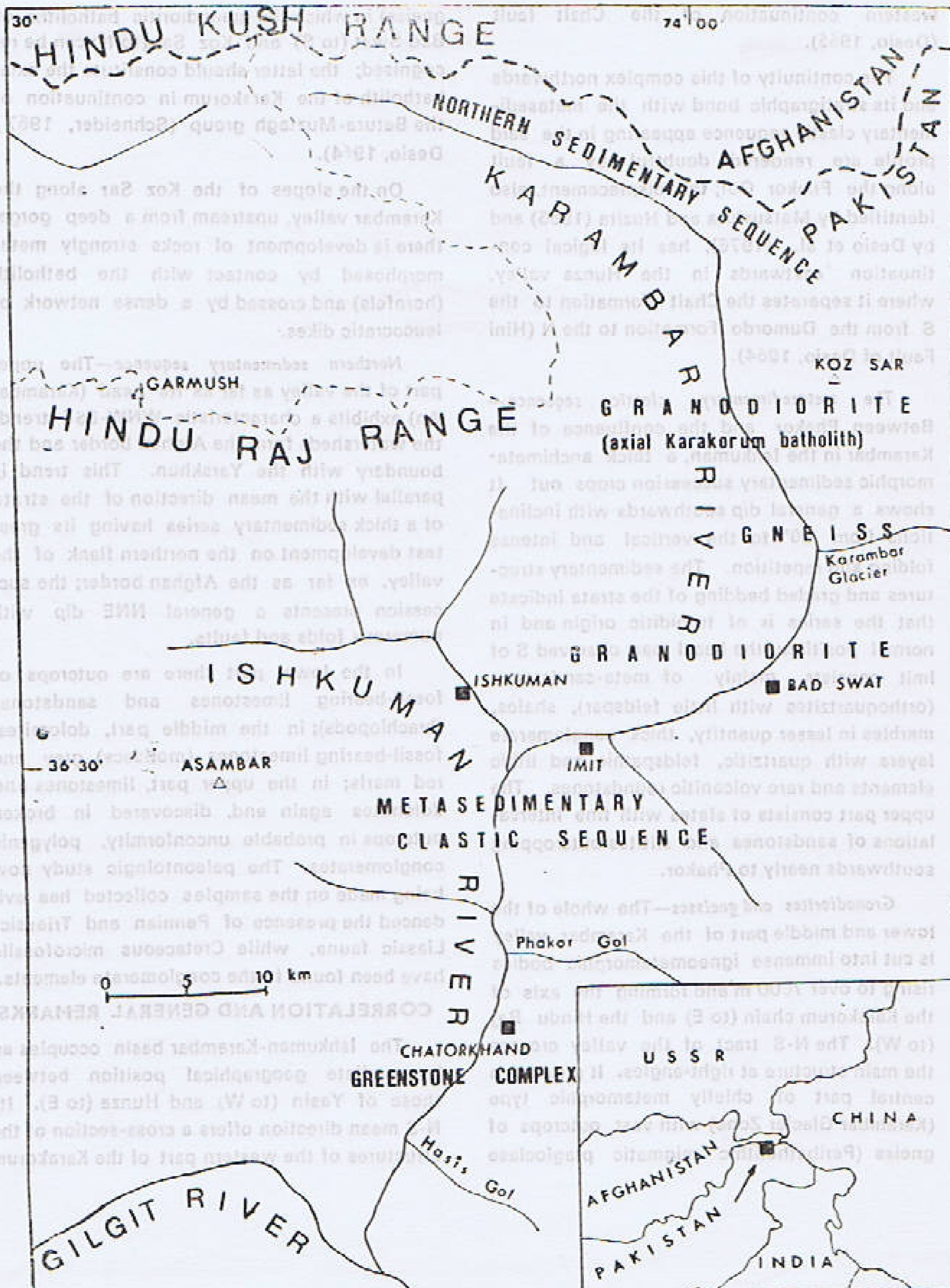
The Ishkuman-Karambar valleys constitute the geographical western limit of the Karakorum and separate this chain from the massifs of the Hindu Kush and the Hindu Raj. The upper part of the Karambar valley is difficult to explore both for military reasons due to its closeness to the Afghan border and for logistic reasons, since there are no roads and the vortiginous river must be forded on several occasions.

The Ishkuman valley and the lower part of the Karambar valley were already visited and briefly described by Ivanac, Traves and King (1956), and by the Kyoto University-Punjab University Joint Expedition (Matsushita and Huzita 1965) up to the height of the confluence of the Karambar Glacier, while cartographic representations were carried by Gamerith and Kolmer (1973) and Buchroitner and Gamerith (1978).

LITHO-STRATIGRAPHY

From the confluence of the Ishkuman valley in the Gilgit River to the head of the Karambar valley there are outcrops of igneous, sedimentary and metamorphic rocks which can be grouped into four complexes, greenstone metasedimentary clastic sequence, granodiorites and gneisses, northern (Tethys) sedimentary sequence. They have an E-W development and are separated by large displacement along this direction.

The greenstone complex—The term was coined by Ivanac et al. (1956), who described the complex along the sections of the lower Yasin, Ishkuman and Hunza valleys. In the Ishkuman valley the outcrops are mainly slates and phyllites with marble intercalations; at various levels there are basic intrusive rocks and volcanites of andesitic-basaltic type, with corresponding pyroclastites. The green rocks are more widespread S of Hasis Gol, where they form a possibly tectonic cover for the sedimentary rocks. The complex dips southwards with repetitions due to faults (see Schneider's profile 1960), the most important of which, along the Hasis Gol, is probably the


HINDU KUSH RANGE
30'
74°00'
AFGHANISTAN
PAKISTAN
NORTHERN SEDIMENTARY SEQUENCE
KARAMBAR RIVER
KOZ SAR
GARMUSH
HINDU RAJ RANGE
GRANODIORITE
(axial Karakorum batholith)
GNEISS
Karambar Glacier
GRANODIORITE
BAD SWAT
ISHKUMAN
IMIT
ISHKUMAN RIVER
36°30'
ASAMBAR
METASEDIMENTARY
CLASTIC SEQUENCE
Phakor Gol
0 5 10 km
CHATORKHAND
GREENSTONE COMPLEX
Hasis Gol
GILGIT RIVER
USSR
CHINA
AFGHANISTAN
PAKISTAN
INDIA

western continuation of the Chalt fault (Desio, 1965).

The continuity of this complex northwards and its stratigraphic bond with the metasedimentary clastic sequence appearing in the said profile are rendered doubtful by a fault along the Phakor Gol; this displacement, also identified by Matsushita and Huzita (1965) and by Desio et al. (1976), has its logical continuation eastwards in the Hunza valley, where it separates the Chalt Formation to the S from the Dumordo Formation to the N (Hini Fault of Desio, 1964).

The metasedimentary clastic sequence—Between Phakor and the confluence of the Karambar in the Ishkuman, a thick anchimetamorphic sedimentary succession crops out. It shows a general dip southwards with inclinations from 50° to the vertical and intense folding and repetition. The sedimentary structures and graded bedding of the strata indicate that the series is of turbiditic origin and in normal position: the basal part observed S of Imit consists mainly of meta-sandstones (orthoquartzites with little feldspar), shales, marbles in lesser quantity, thick conglomerate layers with quartzitic, feldspathic and lithic elements and rare volcanitic roundstones. The upper part consists of slates with fine intercalations of sandstones and siltites outcropping southwards nearly to Phakor.

Granodiorites and gneisses—The whole of the lower and middle part of the Karambar valley is cut into immense igneometamorphic bodies rising to over 7000 m and forming the axis of the Karakorum chain (to E) and the Hindu Raj (to W). The N-S tract of the valley crosses the main structure at right-angles. It presents a central part of chiefly metamorphic type (Karambar Glacier Zone) with vast outcrops of gneiss (Peribatholithic migmatic plagioclase gneiss) in which the granodioritic batholiths of Bad Swat (to S) and Koz Sar (to N) can be recognised; the latter should constitute the axial batholith of the Karakorum in continuation of the Batura-Muztagh group (Schneider, 1957; Desio, 1964).

On the slopes of the Koz Sar along the Karambar valley, upstream from a deep gorge, there is development of rocks strongly metamorphosed by contact with the batholith (hornfels) and crossed by a dense network of leucocratic dikes.

Northern sedimentary sequence—The upper part of the valley as far as its head (Karambar An) exhibits a characteristic WNW-ESE trend; the watersheds form the Afghan border and the boundary with the Yarskhun. This trend is parallel with the mean direction of the strata of a thick sedimentary series having its greatest development on the northern flank of the valley, as far as the Afghan border; the succession presents a general NNE dip with numerous folds and faults.

In the lower part there are outcrops of fossil-bearing limestones and sandstones (brachiopods); in the middle part, dolomites, fossil-bearing limestones (molluscs), grey and red marls; in the upper part, limestones and dolomites again and, discovered in broken outcrops in probable unconformity, polygenic conglomerates. The paleontologic study now being made on the samples collected has evidenced the presence of Permian and Triassic-Liassic fauna, while Cretaceous microfossils have been found in the conglomerate elements.

CORRELATION AND GENERAL REMARKS

The Ishkuman-Karambar basin occupies an intermediate geographical position between those of Yasin (to W) and Hunza (to E). Its N-S mean direction offers a cross-section of the structures of the western part of the Karakorum parallel to that of the two mentioned valleys, and hence lends itself to good correlations with the series cropping out in the said basins and already studied previously.

The greenstone complex, according to the assumption of Ivanac et al. (1956), form a band with a considerable surface area to the W (see map by Desio et al., 1977), in which it is distinguished into the following formations: Dundi Gal volcanic agglomerates, volcanic rocks mostly porphyritic andesite and basic igneous rocks while to the E, in the Hunza valley, a complex with similar lithological characteristics crops out at Chalt (Schneider's Chalt-Schieferserie, 1957). The complex, previously referred to the Paleozoic, was attributed to the lower Cretaceous by Matsushita and Huzita (1965) on the basis of the discovery of corals in the Ghizar valley.

The clastic metasedimentary sequence offers some analogies with the Darkot Group (Ivanac et al., 1956), and more particularly with the southern element of this group which crops out S of the Gamugal batholith (Casnedi, 1976), it may in fact constitute the lateral continuation thereof with a higher degree of metamorphism. This progressive increase in the degree of metamorphism from W to E may explain the presence, in a similar structural position, of the parametamorphic formation indicated as Dumordo Formation in Desio's map (1964) which might therefore constitute the side equivalent of such series. The attribution of this complex to the Darkot Group (Upper Paleozoic) does not exclude the possibility of more recent, Mesozoic terms in it.

Recent absolute datings (Casnedi et al. 1978) have referred the batholith of the Hindu, Raj—Darkot Pass Granodiorite Auctorum to the oligocene-Miocene boundary and, through the Karambar valley, it should correlate with Koz Sar and hence Batura-Muztagh and constitute the axial batholith of the Karakorum. The distinction between this batholith and that of the Gamugal (of similar composition, but more ancient) is very evident in the Yasin valley, since the Darkot Group is inserted between the two structures; it cannot be excluded that a similar distribution can also be made in the Karambar valley between the Koz Sar granodiorites and those of Bad Swat. To confirm this hypothesis radiometric determinations on the granodioritic samples I collected between Bad Swat and the Koz Sar base are desirable.

The lithological characteristics and the fossils contained in the northern sedimentary Zone gives reason to suppose that it may be correlated with a group of formations cropping out in the Hunza valley to the N of the axial batholith (Schneider, 1957 ; Desio and Martina, 1972). Paleontologic studies are being carried out with a view to establishing preci:e chronostratigraphic correspondences.

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GEOTHERMAL GRADIENTS IN PAKISTAN

BY

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Abstract: *Hydrocarbons are generated by thermal diagenesis of organic matter. The study of sub-surface temperatures and thermal gradients within the earth, therefore, offers clues for hydrocarbon. exploration. Temperature ranges within which particular types of hydrocarbons, for example, oil or gas, would form are now well known. Geothermal gradients as determined from bottom hole temperatures recorded during logging operations in 27 wells drilled in Pakistan show that general geothermal gradients in Pakistan are between 1 and 2°F per 100 feet. The gradients are comparatively higher in the south perhaps because of the Cretaceous/Paleocene igneous activity. ,Oil Window'. I. e., the depth sector having prospects for liquid hydrocarbons, lies at variable depths in different regions, but within the depth range of 6,000 to 18,000 feet.*

INTRODUCTION

The present study was undertaken in the Hydrocarbon Development Institute of Pakistan (HDIP) as a part of the Basin Studies programme, which is aimed at looking *into* the basins from fresh angles, in order to evaluate and re-evaluate hydrocarbon prospects. Data of 27 wells (Fig. 1) were used in the study which were taken from oil company reports pertaining to the surrendered concessions lodged with the Directorate of Petroleum Concessions in the Ministry of Petroleum and Natural Resources, and seconded to the HDIP for Basin Studies programme. These data were presented by permission of the Ministry, at the 6th P. I. P. Symposium held at Lahore in December, 1977.

GEOTHERMAL GRADIENTS AND THEIR EFFECTS

It is now well known that hydrocarbon generation in the geological column is mainly a function of progressive heating of the kerogen. Experimental and basinal studies have shown that within certain broad temperature ranges particular types of hydrocarbons are generated from the mother substance called kerogen. These temperature ranges are (Gill, 1978) :

150°—180°F	biogenic gas only
180°—270°F	oil (& gas) : "Oil Window"
270°—325°F	gas and condensate
325°—500°F	dry gas
more than 500°F	barren (if no surviving poroperm).

This general theory has very satisfactorily answered many questions relating to anomalous reservoir contents where other variables were constant. The study of geothermal gradients should, therefore, now be applied as a standard tool of prospect evaluation.

However, geothermal gradients as determined from bore-hole temperature evaluation alone may be meaningless unless tied-up with other relevant studies of the conventional source—reservoir—

cap—trap evaluation. Most important of these in petroleum exploration is the application of parameters of source rock thermal diagenesis which has assumed new dimensions in recent years. In Pakistan, a study has been undertaken by the author, at HDIP, to investigate into the organic content and thermal diagenesis of source rocks in Potwar and Sulaiman regions which has given important leads.

The question whether the ambient subsurface temperatures are the maximum is a serious one. This has to be resolved by the study of changes in chemical and optical properties of rock constitutents which is a vast subject by itself and demands very detailed investigation. However, if the facts that rocks are not good conductors of heat and that the thermal gradients require *long* time in geological history to establish themselves, are taken into account then it is perhaps safe to assume that in younger rocks (Tertiary, Mesozoic) the ambient thermal gradients are within acceptable limits of being the maximum. Another point to note while generalising temperature data is that thermal gradients often vary significantly within short distances, horizontally as well as vertically (Fig. 2).

Furthermore, the ambient bottom hole temperatures (BHT) measured during logging are normally lower than the temperature of the formation due to cooling effects of the mud during circulation. Mathematical and graphical methods have been designed to compute the true formation temperatures from the observed ones by applying certain corrections which involve knowledge of circulation time and the timing of recording of the temperature. Details of the method are described by Dowdle & Cobb (1974) and also used by Kenyon & Beddoes (1977). A comparison of recorded BHTs and the true formation temperature computed after applying corrections, for 53 wells in Indonesia (Kenyon et al., 1976) has, however, shown that the two parameters are in reasonably close agreement with each other. Thus, the BHTs actually recorded during logging operations can safely be used for computing the geothermal gradients. In view of this, and since the data required for computation of the corrections was not available to the present study, the recorded BHTs have been assumed as corresponding to the true formation temperatures.

The object of this paper is not to attempt a comprehensive evaluation of the entire territory of Pakistan for thermal gradients but to make some initial determinations for assistance in designing a petroleum exploration strategy, and to present the subsurface temperature information for general geological modelling.

EVALUATION OF DATA

The electric logs of 27 exploratory wells which were available were used in this study (Fig. 1). The BHTs recorded in the logs were plotted on equidistant scale against the depth. Average geothermal gradients were computed for individual wells in degrees Fahrenheit per thousand feet (Figs. 3 to 7). In cases where significant variation in geothermal gradients existed as a function of depth, the gradients were separately established for the different depth sectors. The data were used to postulate probable depths in which particular types of hydrocarbons may be expected.

THE OIL WINDOW

Since the current pressures on the country's economy demand higher priorities for locating liquid hydrocarbons, the data have been generalised to show probable depths in different regions which correspond to the "OIL WINDOW" i. e., depth sector in which temperatures are favourable for oil to be present (Fig. 8). It may be seen that in the Potwar region the Oil Window lies between 9,000 to 18,000 feet whereas in the south, in Kirthar and Karachi regions, since the geothermal gradients are high the Oil Window goes only as deep as 12,000 feet. In Thatta region, the wells are hotter like the ones in the Kirthar and Karachi regions while the wells in Badin region are cooler like those in Potwar. Karampur well has a very low thermal gradient having not reached the Oil Window even at 14,500 feet (inferred from gradient). Domanda well would remain within Oil Window down to 16,000 feet (inferred) whereas Giandari is sufficiently hot to cross the Oil Window even at 8,500 feet. Kech Band in the Baluchistan basin had yet to reach Oil Window at 11,000 feet and, with a gradient of 13°F/1000 feet, may be expected to be within the Oil Window at depths as mnch as 18,000 feet, if drilled.

CONCLUSION

Importance of geothermal gradients within drillable depths, locally and regionally, is significant. It should be taken into account, besides other factors, while planning exploration strategy.

Geothermal gradients often vary significantly within short distances, horizontally as well as vertically. Within the region studied, "hot spots" (e. g. wells Dabbo Creek-1. Lakhra-1 Giandari-1, etc) and "cold spots" (e. g. Karampur-1, Kech Band-1, Kundian-1) are irregularly located. However, it is observed that the dominant gradient in the northern areas, i. e. Potwar region, is between 1° and 1.5°F per 100 feet, while in the south, i. e. Kirthar region, the gradient is between 1° and 2°F per 100 feet. A plausible explanation for the "hotter south" could be the igneous activity that took place in the region during Cretaceous/Paleocene times.

The study of geothermal gradients show that prospects for liquid hydrocarbons are likely to be present in Pakistan at depths as shown below :

Region	*Depth to "Oil Window" In feet*
Potwar	9,000—18,000
Kirthar	9,000—12,000
Karachi region	8,000—12,000
Thatta region	6,000—11,000
Badin region	8,000—17,000

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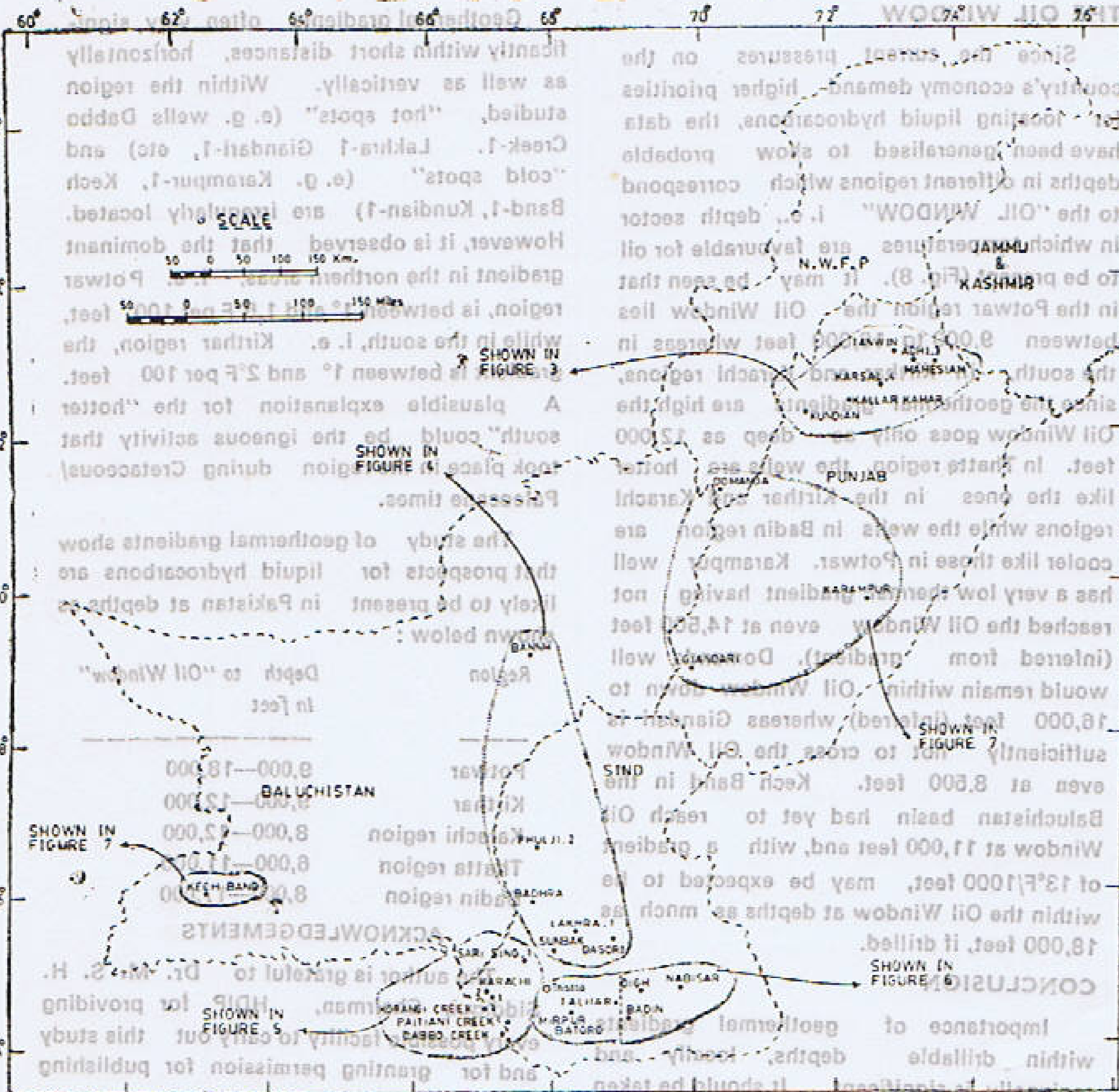

Fig 1 LOCATION OF WELLS DISCUSSED IN THE PAPER

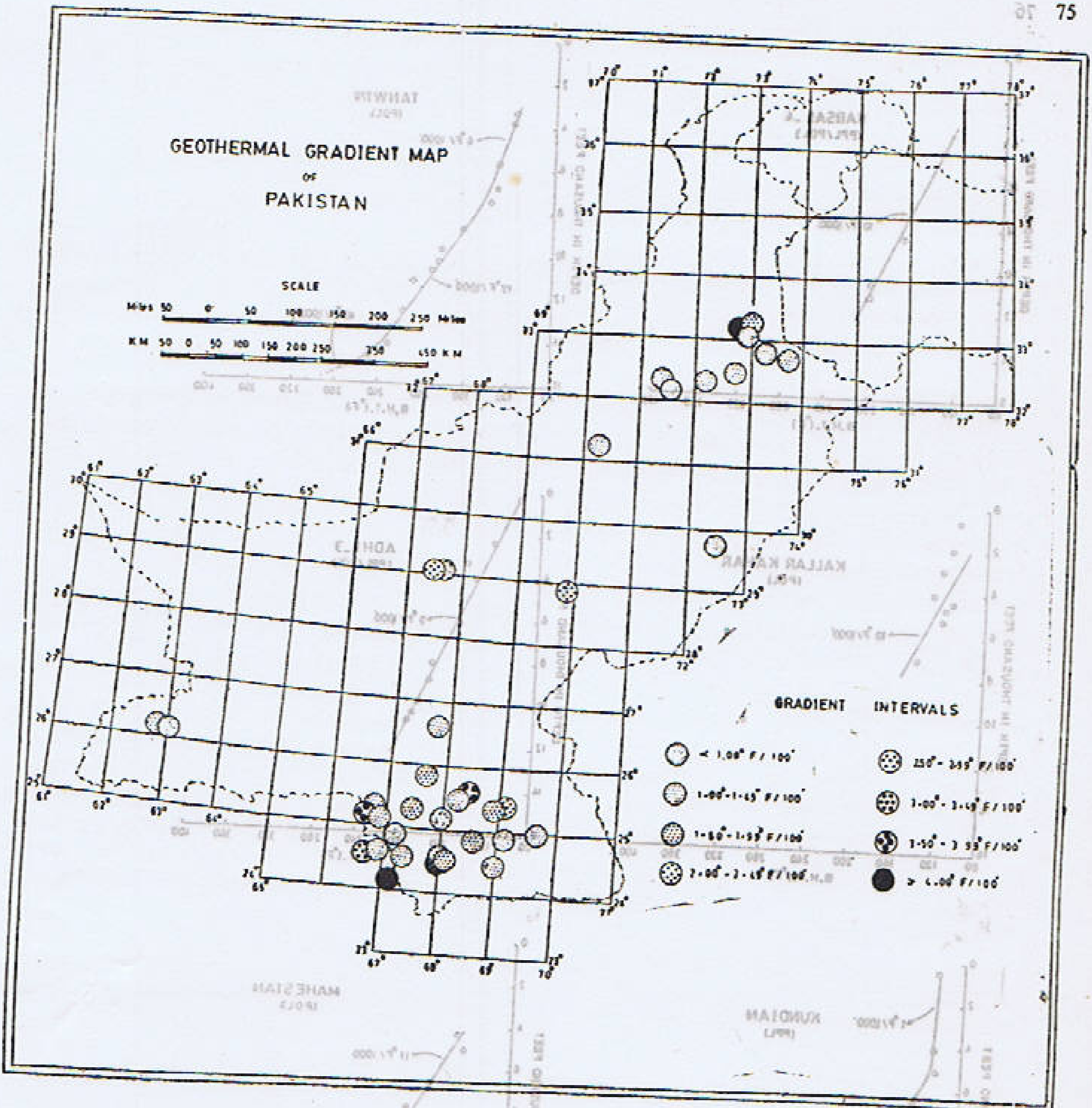

Fig. 2 GEOTHERMAL GRADIENT MAP OF PAKISTAN

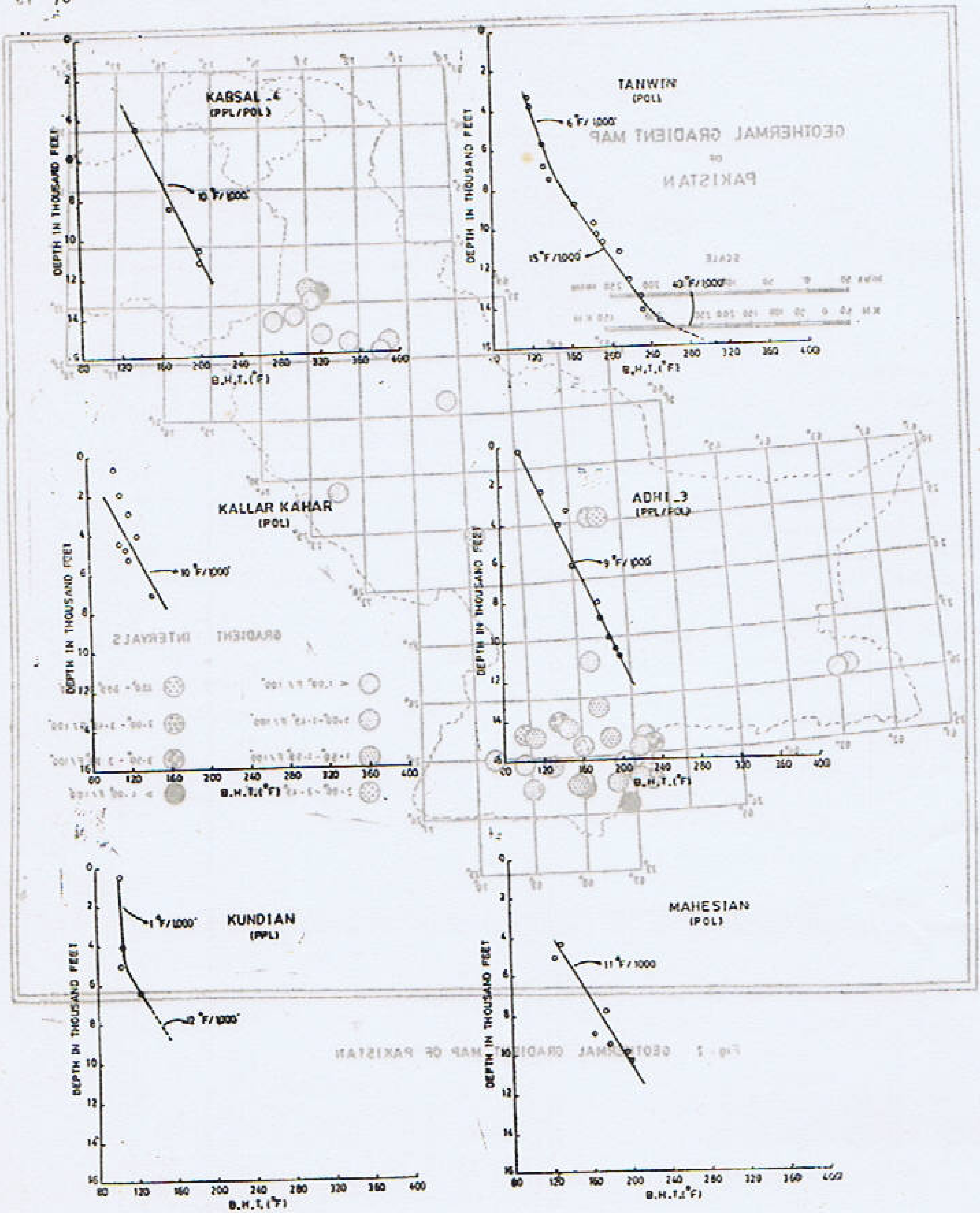

Fig.3 PLOTS OF B.H.T. vs DEPTH IN 6 WELLS IN POTWAR REGION

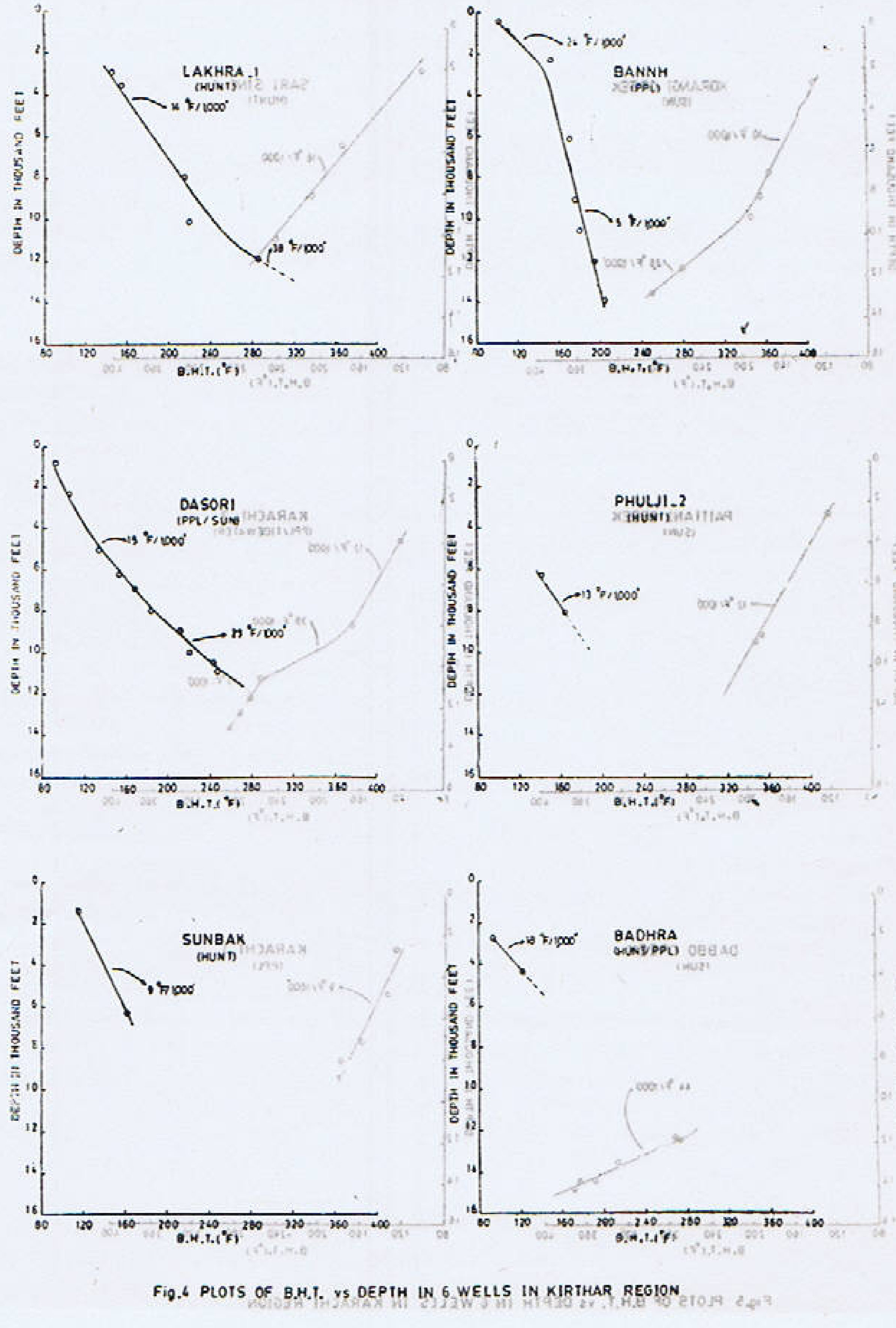

Fig.4 PLOTS OF B.H.T. vs DEPTH IN 6 WELLS IN KIRTHAR REGION

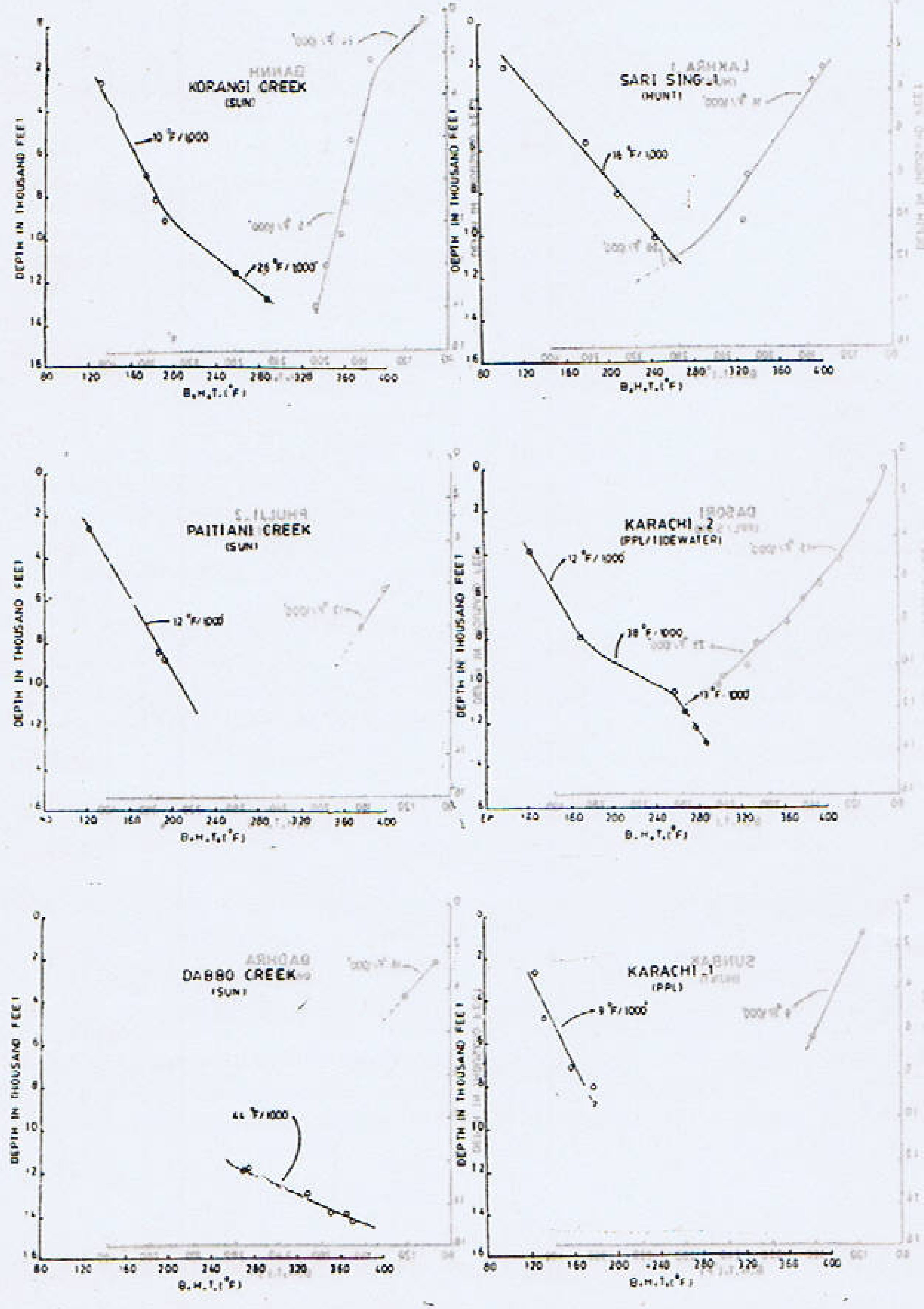

Fig.5 PLOTS OF B.H.T. vs DEPTH IN 6 WELLS IN KARACHI REGION

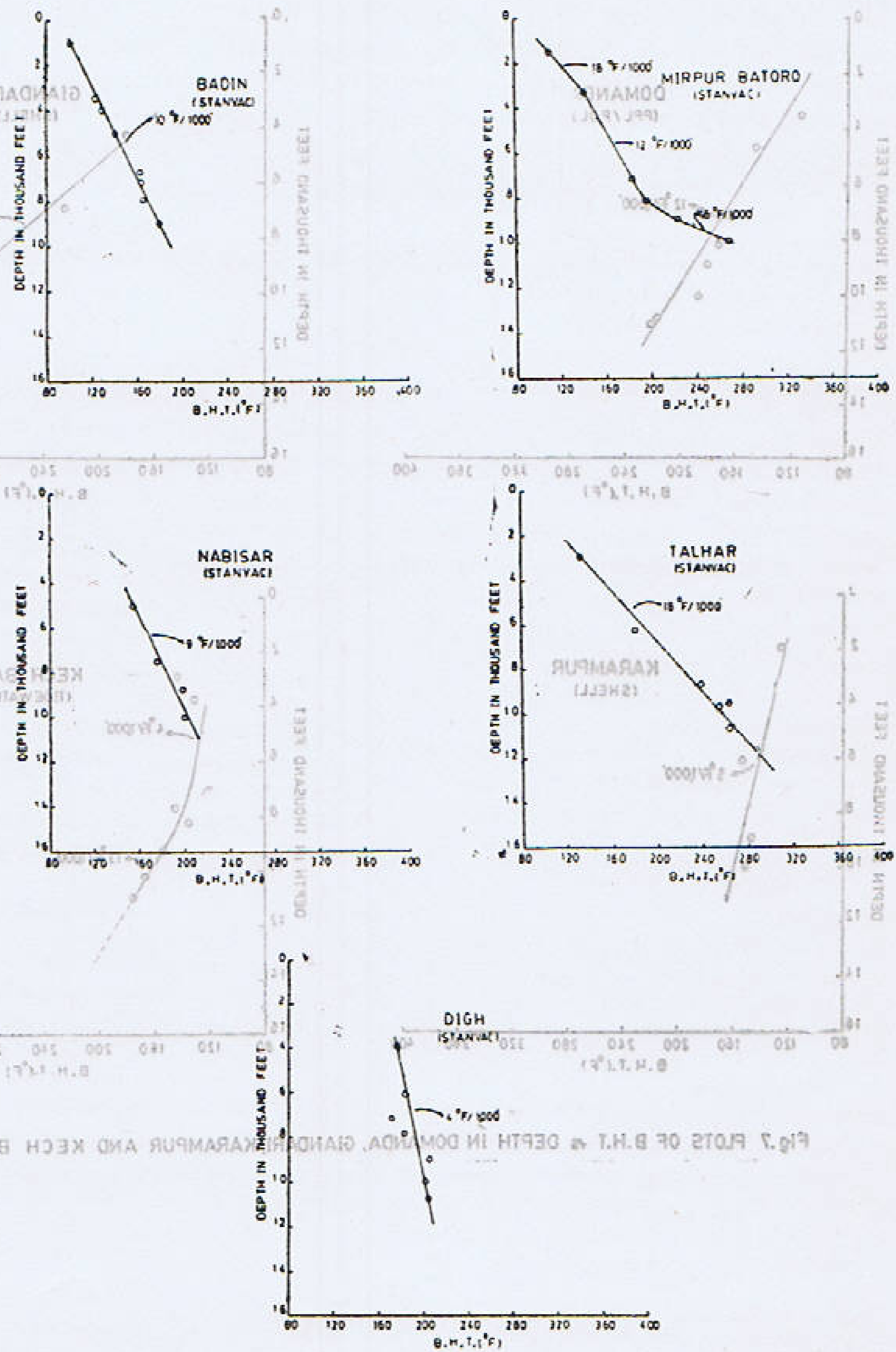

Fig 6 PLOTS OF B.H.T. vs DEPTH IN 5 WELLS IN THATTA - BADIN REGIONS

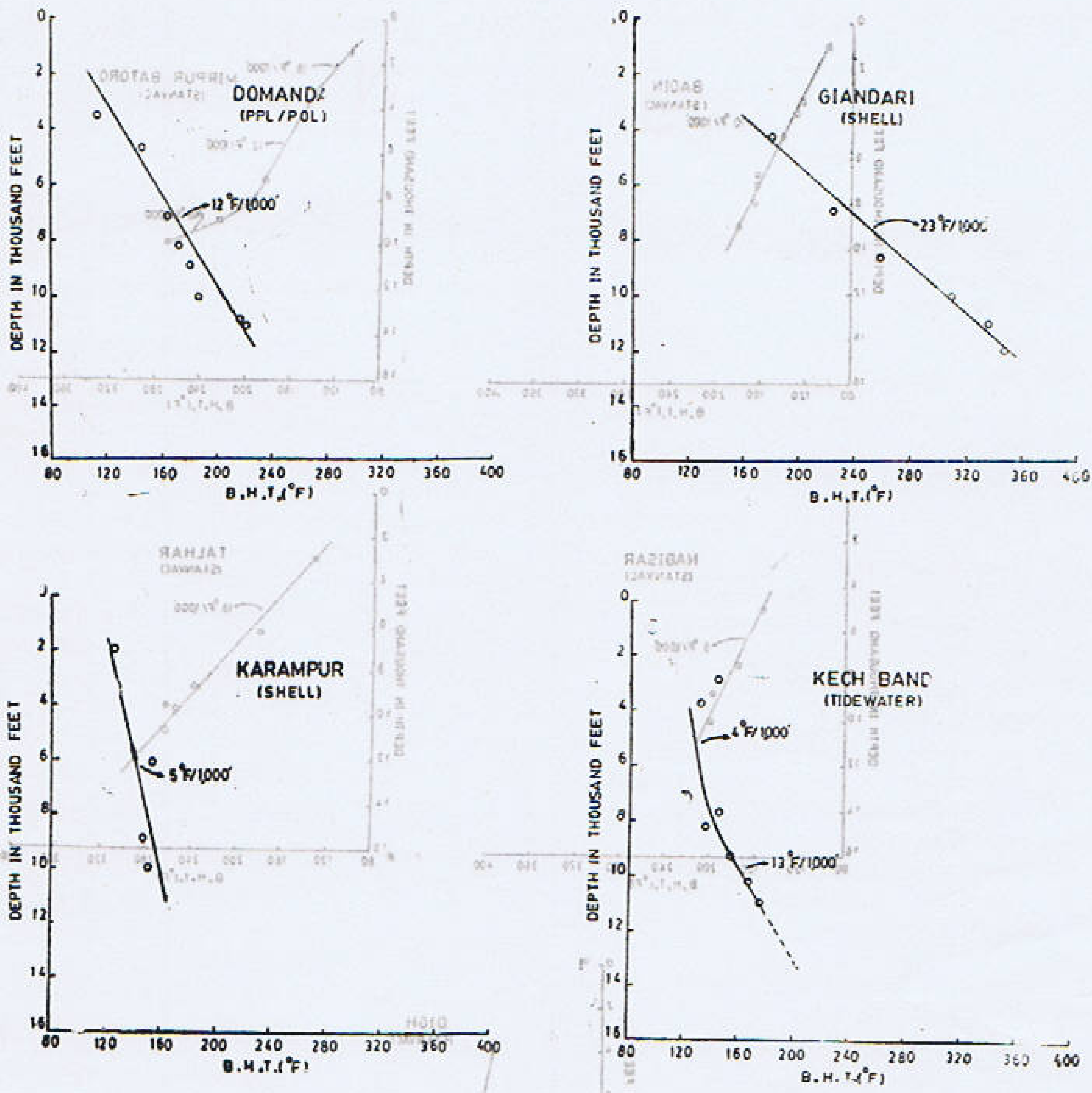

Fig.7 PLOTS OF B.H.T vs DEPTH IN DOMANDA, GIANDARI, KARAMPUR AND KECH BAND WELLS

S.NO	WELL & COMPANY	Thermal Gradient °F/1000	From (Depth Ft)	To (Depth Ft)	Minimum Temperature Recorded °F	Min. Depth (Ft)	Maximum Temperature Recorded °F	Max. Depth (Ft)	150°–180°F GAS (from)	150°–180°F GAS (to)	180°–270°F OIL & GAS (from)	180°–270°F OIL & GAS (to)	270°–325°F GAS & CONDENSATE (from)	270°–325°F GAS & CONDENSATE (to)	325°–500°F DRY GAS (from)	325°–500°F DRY GAS (to)	Approximate Depth (in Feet) of "Oil Window" in Generalized Areas
1	TANWIN (POL)	6	3,000	6,000	120	3,314	248	14,742	8000	10000	10,000	15000	15000	?	?		POTWAR REGION
		15	7,000	13,000													
		40	14,000	15,000													
2	ADHI-3 (PPL/PEL)	9	100	11,000	99	100	197	10,710	5500	8,500	8,500	18,000(?)	?		?		9,000 TO 18000
3	MAHESIAN (POL)	11	4,000	11,000	125	5006	200	10,409	6500	9000	9000	16,500(?)	?		?		
4	KARSAL-4 (PPL/POL)	10	4,000	11,000	138	4,520	200	11,218	6000	9000	9000	18,000(?)	?		?		
5	KALLAR KAHAR (POL)	10	2,000	7,000	107	538	142	7,123	7000(?)	?	?		?		?		
6	KUNDIAN (PPL/POL)	1	500	4,000	104	500	123	6,504	8500(?)	11,000(?)	11,000(?)	?	?		?		8500 TO 16000 (?)
		12	5,000	7000													
7	DOMANDA (PPL/POL)	12	3,000	12000	112	3,506	220	11,182	6000	8,500	8,500	16000(?)	?		?		MORE THAN 14500(?)
8	KARAMPUR (SHELL)	5	2,000	10,000	124	1,983	152	9,949	8000	14,500(?)	?		?		?		4500 TO 8,500
9	GIANDARI (SHELL)	23	4,000	12000	180	4,317	350	12010	3000(?)	4,500	4,500	8,500	8500	11000	11000	?	KIRTHAR REGION 9,000 TO 12000
10	BANNH (PPL)	24	500	2000	100	458	205	12,999	3500	9,500	9,500	?	?		?		
		5	4,000	14,000													
11	PHULJI-2 (HUNT)	13	6,000	8,000	142	6,336	164	8,092	7000	9,500	9,500	?	?		?		
12	BADHRA (HUNT/PPL)	18	2,500	4,500	90	2,686	120	4,334	6000(?)	8000(?)	8000(?)	13000(?)	?		?		
13	LAKHRA-1 (HUNT)	14	3,000	8,000	144	3012	290	11,886	3500	5500	5,500	11000	11000	13000(?)	?		
		38	10,000	12,000													
14	DASGRI (PPL/SUN)	15	500	8,000	91	861	250	10,996	6000	8,000	8000	11,500	11,500	?	?		
		23	8,000	11,000													
15	SUNBAK (HUNT)	9	1,500	6500	117	1,430	162	6,323	5000	8500	8,500	17,000(?)	?		?		KARACHI REGION 8,000 TO 12,000
16	SARI SING-1 (HUNT)	16	2,000	10,000	105	2,002	245	10,126	4000	6000	6000	11,500	11500	14500(?)	?		
17	KARACHI-2 (PPL/TIDEWATER)	12	4,000	8,000	175	3,998	290	12,942	6000	8,500	8500	11500	11500	15000(?)	?		
		38	8,000	10,500													
		13	10,500	13,000													
18	KARACHI-1 (PPL)	9	2,000	8000	177	2,704	276	8,408	6000	9000(?)	?		?		?		
19	KORANGI CREEK (SUN)	10	2,500	9,000	131	2,756	290	13,582	5000	8,000	8000	12000	12000	?	?		
		26	9,000	13,000													
20	PAITIANI CREEK (SUN)	12	2,000	9,000	122	2,625	194	8,720	5000	7,500	7500	15000(?)	?		?		
21	DABBO CREEK (SUN)	44	12,000	14,000	270	11,855	372	14,212	?		?	12000	12000	13500	13,500	?	THATTA REGION 6,000 TO 11,000
22	MIRPUR BATORO (STANVAC)	18	1,000	3,000	110	1,560	266	10,003	4000	7,000	7000	10000	10000	11500(?)	?		
		11	3,000	8000													
		46	8,000	11000													
23	TALHAR (STANVAC)	18	3,000	11,000	132	2,956	265	10,740	4,000	5,500	5,500	10,500	10,500	13500(?)	?		BADIN REGION 8000 TO 17000
24	DIGH (STANVAC)	4	4,000	11000	159	7,240	202	10,806	?	6,000	6,000	?	?		?		
25	BADIN (STANVAC)	10	1,000	9000	101	1,004	180	9,004	6000	9,000	9000	12,000(?)	?		?		
26	NABISAR (STANVAC)	9	5,000	10,000	155	5,048	200	10,022	4,500	8000	8,000	17,000(?)	?		?		11,500 TO 18,000 (?)
27	KECH BAND (TIDEWATER)	4	4,000	8,000	132	3704	175	10,984	9000	11500	11500	18,000(?)	?		?		
		13	9,000	11,000													

(?) INFERRED

? DATA NOT AVAILABLE

Fig.8 ANALYSIS OF BOTTOM HOLE TEMPERATURES IN 27 SELECTED EXPLORATORY WELLS OF PAKISTAN

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PETROLOGY OF KOGA NEPHELINE SYENITES AND PEGMATITES OF SWAT DISTT :

BY

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Abstract ; *Detailed petrography, chemistry and petrogenesis of the Koga nepheline syenite intrusion is being described. A total of 70 petrographic modal analyses and 56 chemical analyses of various types of nepheline syenite and its associates were carried out. The data was processed on IBM 1130 computer using fortran IV language, thus averages, standard devations and correlation co-efficients were worked out. The nepheline syenites show characteristics of miaskitic type. A generalised evolutionary sequence of the nepheline syenitic rocks is as follows .*

Pulaskite-nepheline syenite-foyaite-sodalite syenite-fenite-carbonatite.

The Intruson is a part of the alkaline province lying between Loe Shulman and Chamla. The province is composed of northern nepheline syenites, syenites and carbonatites and southern soda granites and soda porphyries. The extent of eastward extension of this province is not known. The province is associated with substantial dislocations.

INTRODUCTION

The Koga area, of nepheline syenite, is a part of Swat and Mardan districts of N.W.F.P. The deposits of nepheline syenite occur in the south southeast and southwest of Koga. Koga lies at latitude 34°23'N and longitude 70°32'E (43B/11). Koga is a small village of Swat district situated in the Chamla valley of Bunair area, and lies at a distance of about 56 km. northeast of Mardan via Rustam and about 90 km from Mingora via *Karakar* Kandao and Daggar.

Previous work: The Koga nepheline syenite was reported for the first time by Siddiqui (1965). The area was mapped by Siddiqui, Shakoor and students of Department of Geology, University of the Punjab in 1966-1967. The occurrence of a few carbonatite bodies was noted by Siddiqui (1967). Koga syenite is an oval shaped body with irregular outlines-originated by the crystallization differentiation from a peralkaline parent magma (Siddiqui, Chaudhry and Shakoor, 1968). The nepheline syenite area was investigated by Engineers Combine Limited (E.C.L., 1975), on behalf of Directorate of Industries and Mineral Development to evaluate its utilization in various fields like glass, ceramics and allied industries. On the basis of encouraging results a detailed investigation survey was carried out by E.C.L. in 1976. This paper is an outcome of the same.

GEOLOGY OF THE AREA

The geologic region of Swat in which the Koga area lies, consists of low to high grade metamorphics which are cut by various igneous intrusions. Metamorphic rocks grade from chlorite to sillimanite schists while the igneous rocks range from ultrabasic to acidic (Martin et al. 1962).

Two rock units of the area are worth mentioning. They are "Swat-Chamla" metasedimentary group and "Ambela granitic complex." The former group consists of low grade metamorphics and forms the lower most part of this geologic region.

The Ambela granitic complex has been emplaced into the core of an anticline in Swat-Chamla metasedimentary group. Nepheline syenite occurs in this complex.

Geology of Nepheline Syenite : Nepheline syenite of Koga lies in the central part of the alkaline complex. It roughly extends from Koga, to Naranji Kandao, Miane Kandao and Sura. These rocks occur as massive bodies near Naranji Kandao, Bagoch Sar, Shpala and Kharkai and as dykes of various texture intruded in the host Babaji syenite. The dykes appear to be younger than rest of the rocks, Generally weathered colour is grey, rusty grey and dark grey and fresh colour is whitish grey and light grey with black specks of mafics. Rocks are much jointed. Boulder and spheroidal weathering is the prominent feature of these rocks.

There prevails marked heterogeneity both as regards compositions and lithology. Nepheline poor to nepheline rich syenites are present in this area. Rocks are also cut by numerous nepheline bearing or nepheline free microcline pegmatites.

Texturally nepheline syenite is medium to coarse grained but aplitic dykes at some places are also found. Chilling and coarsening of the rock is a common phenomenon observed in the whole area. These rocks also show flow structure. Dykes of the nepheline syenite are fine to coarse grained. Fine to medium grained dykes are exposed to the west, southwest and south of village Koga, at Bibi Dheri, and south of Agarai and Sura.

Central and eastern parts of the nepheline syenite consist of small to huge dykes intruded in the Babaji syenite. These dykes, measurable upto hundreds of feet, have been chille at their contacts with the host rocks.

Minerals recognisable in hand specimen are nepheline, microcline, albite, sodalite, pyribole, biotites, sphene, zircon, apatite, fluorite, magnetite and pyrite. The older rocks contain pyribole as dominant minor mineral whereas younger dykes contain biotite instead of pyribole. Calcite is the essential mineral of nepheline syenite exposed around Naranji Kandao. Sodalite can be observed in almost whole nepheline syenite complex excluding pulaskite, Fluorite in younger dykes is also common.

Low nepheline bearing rocks are exposed at Kharkhal and around Bagoch Sar whereas rocks around Landi Patao Sar, South of Agarai and Miane Kandao are very rich in nepheline.

Nepheline syenite has been hydrothermal y altered at many places. These altered rocks make discontinuous belt starting from north of Landi Patao Sar to south of Naranji Kandao.

Apophyses of the nepheline syenite with chilled margins cut the Chinglai granodiorite gneiss as well as the Babaji syenite. Xenoliths and screens occur within nepheline syenite at contact with the Chinglai granodiorite gneiss.

Corbonatites : The Koga carbonatite rocks are confined to the western part of the syenite and occur (around Naranji Kandao) in the form of lenses, pockets and veins that vary from a few inches to about 45 metres in width with lengths of upto 120 metres. These bodies are mostly observed in calcite bearing nepheline syenite.

They are composed essentially of carbonates and pyriboles while feldspar, apatite, sphene, magnetite and sodalite occur as minor to accessory minerals. The mineral distribution is known with segregations of mafics at many places.

Fenites : Carbonatites of Koga nepheline syenite have fenitized the country rock. At a few places to the north west as well as southwest of Naranji Kandao dark grey lenticularf bodies measurable in few metres are present. Light grey to dark grey microcline is the major constituent of the rock. Its megacrysts range from 2 cm to 15 cm in length. Other minerals recognisable in hand specimen are calcite, pyroxene, amphibole, magnetite and biotite. These may be the melanocratic fenites as described by Heinrich (1966).

Lamprophyres : These bodies range in length from 2 to about 75 metres and from 1.25 to 18 metres in width. Lamprophyric dykes occur within nepheline syenite (as well as in Babaji syenite). These dykes are particularly conspicuous south of Agarai, south of Naranji Kandao in nepheline syenite and southwest of Koga village in Babaji syenite. The lamprophyres are composed essentially of pyriboles. Apatite, sphene and magnetite are minor to accessory minerals. Quartz may occur as a rare accessory. Yellowish brown sphene occurs as crystals of about 0.5 cm in size. Some of the lamprophyre dykes are traversed by small veins and dykes of feldspathic and epidositic composition. The feldspathic dykes are a few cm to 2 metres in width and from about 1.25 to 12 metres in length. The epidositic veins are composed mainly of epidote and feldspar. The minor to accessory minerals are amphibole and magnetite. These bodies are a few cm wide and upto 6 metres long.

Acidic Bodies and Albitites : Acidic bodies and albitites are present in the nepheline syenite as well as in Babaji syenite. In nepheline syenite acidic bodies are of two types. First type of bodies are much sheared and weathered and second type occur as massive and compact rocks. First type seems to be older. In Babaji syenite acidic dykes with larger dimensions are in abundance.

An albitite-aplite pegmatite (minor) composite body about 75 metres long and 45 metres wide is observed to the southwest of syenite. The aplite is composed of albite, microcline, biotite and quartz. Within the body coarsening of its crystals at some places has taken place whereas albitite appears to consist of major plagioclase and minor biotite and quartz.

Pegmatites : Pegmatites of various compositions and dimensions are present in the nepheline syenite. A major body of type 'A' given below occurs in Babaji syenite. This type is however, genetically directly connected with nepheline syenite. Only a few pegmatites are zoned and the rest are unzoned. These pegmatites show a complex mineralogy. The pegmatites fill the joints and weak zones of the rock. Microcline is the essential constituent of all the pegmatites. On the basis of mineralogy they can be divided into the following types :

A. Sodalite-nepheline-cancrinite-microcline-(zircon)-(biotite) pegmatite = zoned.

B. Nepheline-microcline pegmatites = zoned mostly / unzoned

C. Microcline-albite-nepheline-pyribole pegmatites = zoned mostly / unzoned

D. Microcline-pegmatites = unzoned

E. Microcline-nepheline-cancrinite-fluorite-(zircon) pegmatites = zoned (only one).

F. Nepheline cancrinite-albite-pyribole-calcite-(zircon)-pegmatite = zoned.

A. *Sodalite—nepheline-cancrinite-microcline-(zircon)-(biotite) pegmatite.* This is the largest pegmatite of the area which contains sodalite in addition to nepheline, cancrinite, microcline, albite, ilmenite, biotite and pyroxene. Pyrite and zircon are also present at a few places within this body. This pegmatite is about 13.5 metres long and 7.5 metres wide (coordinates 529379). On western side of the pegmatite a few small unzoned pegmatite veins consisting mainly of microcline and nepheline branch off from the main body. The main pegmatite consists of three zones.

(i) *Outer Zone*: This zone is mainly composed of microcline with some albite and black minerals. Thickness of microcline is different on either sides of the body and varies from 1.2 to 3.6 metres. Microcline crystals upto 23 cm long are present. Microcline is white to greyish white in colour. In the eastern side of the pegmatite 0.60 metres thick biotite veins project from the intermediate zone to microcline zone. Biotite is black in colour and pinches out after about 2 metres.

(ii) *Intermediate Zone*: This Zone consists of nepheline with small amount of cancrinite and microcline. Nepheline crystals are upto 30cm across. It is grey to black in colour. Cancrinite is present associated with nepheline and is white to pinkish white. At a few places crystals of ilmenite upto 15 cm long also occur in this Zone. Zircon crystals showing bipyramidal habit are also present. These are yellow in colour with a size of upto 1 cm.

(iii) *Core*: In the core of the pegmatite sodalite and nepheline are the dominant minerals. Sodalite is formed by the replacement of the nepheline. Sodalite concentration is more in the lower half of the pegmatite. It forms upto 21 cm thick veins in the nepheline mass. Colour of the sodalite is light blue to deep blue. Albite, biotite and microcline are usually present alongwith sodalite.

B. *Nepheline-Microcline Pegmatites*: These pegmatites are present at Bibi Dherai outcrop and in the locality south of village Agarai. At Bibi Dherai outcrop, it occurs as irregular veins upto 30 cm thick and 1.8 metres in length (coordinates 543382, sheet 43 B/11). Nepheline is green coloured and the microcline is light grey. Microcline crystals are upto 2.5 cm long.

In thin pegmatites (coordinates 557372, sheet 43 B/11) microcline and nepheline crystals have developed parallel to the walls of the pegmatite and form the alternate layers.

At coordinates 560364 (Sheet 43 B/11) a few pegmatites upto 0.60 metres thick are present. These pegmatites consist of nepheline and microcline with small amount of pyroxene and other black minerals. In the core the minerals are comparatively fine grained.

C. *Microcline-albite-nepheline-pyribole pegmatites*: One of the zoned pegmatites is present at coordinates 515386 (Sheet, 43 B/7). It is about 4.5 metres thick and 7.5 metres long. Albite is present in the outer-intermediate zone and rest of the zones consist of microcline and black minerals and a little amount of nepheline. Brownish coloured zircon crystals were also found in this pegmatite. Another zoned pegmatite is present at coordinates 513371, (Sheet 43 B/7). It is composed of microcline, albite, nepheline, biotite pyroxene and other black minerals. This pegmatite can be divided into 4 zones.

(i) *Wall zone*: This zone consists of albite and microcline with some black specks.

(ii) *Outer Intermediate Zone*: It consists of albite, microcline and muscovite.

(iii) *Intermediate Zone*: It is rich in albite, microcline and muscovite.

(iv) *The core*: It consists of albite, microcline and nepheline.

D. *Microcline Pegmatites*: Numerous pegmatites are present in the area consisting predominantly of microcline. At a few places black minerals are also found in these pegmatites. Size of these pegmatites varies from few cms to 3 metres and length is upto 30 metres. One pegmatite is present on the way from Shpala to Lalu. It is composed of microcline only. This is 1.2 metres thick and 30 metres in length.

E. *Microcline-nepheline-cancrinte-fluorite-(Zircon) Pegmatite*: Fluorite bearing nepheline syenitic pegmatite is present at coordinates 557373 (sheet 43 B/11). This is 1.2 meters thick and 6 metres in length. Numerous small pegmatites are also present around this place which fill the joints. In hand specimen composition is microcline, nepheline, cancrinite, fluorite, biotite and other black minerals. Buff coloured zircon crystals are also found in this pegmatite.

F. *Nepheline-cancrinite-albite-pyribole-calcite-(Zircon) pegmatites*: Calcite-bearing pegmatites occur around Naranji Kandao. They are from small veins to 1.8 metres thick and upto 4.5. metres long. The pegmatites are zoned. Different zones and their minerals of the pegmatite present at coordinates 505336 (sheet 43 B/7) follow :—

(i) *Wall Zone*: This zone consists mainly of amphibole with calcite and albite. It is green coloured with high specific gravity.

(ii) *Intermediate Zone*: Albite, nepheline and black minerals are present in this zone. A few grains of chalcopyrite can also be seen.

(iii) *Core*: In the centre of the pegmatite nepheline and cancrinite are present with small amounts of albite.

PETROGRAPHY.

General: The following is a petrographic account of the Koga nepheline syenite and some of the associated rocks. The petrographic study included the mineral identification as well as textural and structural studies. A total of seventy thin sections were studied. They included twenty three nepheline syenites (sensu stricto), five nepheline syenite dykes, eight sodalite nepheline syenites, eight litchfieldites, three foyaites, ten intermediate (feldspathoidal) pegmatites two carbonatites, one acidic dyke from the Babaji syenite, three acidic dykes from nepheline syenite and one albitite. Computer analysis giving averages, standard deviations and correlation coefficients are given. The significance level used throughout is 0.05 or 5%. It may be noted that some constituents show truncated distribution. They have also been included in the statistical analysis. The data was processed on IBM 1130 computer using Fortran IV language.

A few lines regarding the current classification and the classification followed hereafter merit attention. There is as yet no general agreement on the classification of the alkaline rocks. However, the classification given by Sorensen (1974) is regarded more or less acceptable. But the classification followed here departs in some respects from that of Sorensen (op. cit). This has been done in view of the practical considerations which require laying greater emphasis on the nepheline contents, mode of occurrence and relative amounts of soda feldspar and the potash feldspar. The classification followed here is mainly after Siddrqui, Chaudhry and

Shakoor (1968) given for the alkaline rocks of Koga. Where the amount of nephline is more than the amount of total feldspar, the rocks have been termed as foyaites. Those, in which nepheline is less than total feldspar, have been further classified into nepheline syenites and litchfieldites depending upon the relative amounts of alkali feldspar. The litchfieldites contain more albite than microperthite whereas the nepheline syenites contain more microcline perthite than albite The nepheline syenite dykes and the pegmatites have been separated from the nepheline syenites on the basis of mode of occurrence and texture. The sodalite-nepheline syenite (dykes) have been separated on the basis of significant presence of sodalite (0.76%) and of course the mode of occurrence. The pegmatites fall in two groups namely pulaskites (seven) and nepheline syenite pegmatites (three). Albitite has been defined according to Ashraf and Chaudhry (1976). The Babaji syenite is from nordmarkitic. to soda granitic. Acidic dykes, fenite, lamprophyre, and carbonatite need not be elaborated as they are beyond the scope of this paper.

Nepheline Syenite: The mineral composition of twenty three samples of nepheline syenite alogwith means, standard deviations and correlation co-efficients are given. The nepheline syenite falls into three grain sizes i.e. coarse grained, medium grained and fine grained. The coarse and medium grained varieties are by far the most common. They show hypidiomorphic porphyritic texture. The fine grained varieties are from saccharoidal to hypidiomorphic. Microcline (20.00 to 69.48%), albite (2.00 to 41.78%) and nepheline (5.00 to 39.67%) are three most important minerals of the rock having means and standard deviations respectively as follows:

$X=50.53$ and $S=11.46$,
$X=16.43$ and $S=9.50$,
$X=19.74$ and $S=9.96$.

Except the fine grained varieties microcline perthite occurs as phenocrysts which may look porphyroblastic. It is strongly perthitic and in many instances the crystals look like mixed albite-microcline crystals. It shows slight to moderate alteration to sericite and clay. Albite mostly occurs as subhedral to anhedral crystals. It occurs mostly as small subhedra. In some instances it occurs as bigger crystals which show partial to complete development of chess-board twinning. It may also occur as intergrown (mixed) crystals of albite and microcline. It shows alteration to clay. Nepheline mostly forms subhedral to anhedral crystals and their aggregates, eumorphic grains being rather rare. It also occurs as an interstitial mineral. Other accessory to minor minerals which may occur are sodalite ($X=0.08$, $S=0.40$) cancrinite ($X=0.94$, $S=2.03$), Aegirine ($X=3.71$, $S=3.55$), arfvedsonite ($X=1.79$, $S=2.66$), biotite ($X=2.12$, $S=2.02$), muscovite ($X=1.01$, $S=2.29$), calcite ($X=1.62$, $S=4.00$), apatite ($X=0.01$, $S=0.06$), zircon ($X=0.32$, $S=0.49$), sphene ($X=0.78$, $S=0.81$), ilmenite, melanite (garnet) ($X=0.38$, $S=0.90$), haematite ($X=0.10$, $S=0.33$), magnetite ($X=0.03$, $S=0.15$), pyrite ($X=0.13$, $S=0.33$), and epidote ($X=0.16$, $S=0.55$). The coloured minerals may form diffused streaks imparting the rock from poor to moderare foliation. The fine grained varieties are rare. They do not appear to differ significantly from the medium to coarse grained rocks. However, the present data on the finer grained varieties is insufficient to confirm or reject this possibility.

Microcline shows significant negative correlations with albite, aegirine and calcite and positive correlation with ilmenite. Nepheline shows positive correlation with apatite. Albite shows negative correlation with ilmenite and positive correlation with haematite. Sodalite shows positive correlation with ilmenite. Aegirine shows positive correlation wirh calcite and sphene shows positive correlation with pyrite. Magnetite and pyrite show positive correlations with epidote.

Foyaites : The mineral composition of three foyaites is given. Foyaites are mostly from fine to medium grained hypidiomorphic granular to protoclastic. They are poorly foliated to non-foliated. They are composed mainly of nepheline (44 50 to 55.87%) microcline (5.00 to 25.29%) and albite (9.11 to 38.00%) having means and standard deviations respectively as follows :

$\bar{X}$=51 06 and S=4.82, $\bar{X}$=18.40 and S=9.48,

$\bar{X}$=17.99 and S=14.17.

Nepheline occurs as aggregates of small subhederal to anhedral crystals. It is often fresh but may show slight alteration to clay, sericite and zeolite. Microcline is from poorly to moderately perthitic. It occurs from subhedral to anhedral crystals. Albite occurs from subhederal to anhederal and rather fresh crystals. Microcline occurs as relatively larger crystals. Cancrinite (2.00 to 7.45%) occurs as small aggregates forming anhedral crystals. These may, therefore, be called cancrinite-foyaites.

Other minerals which may be present are aegirine, biotite, zircon, sphene and ilmenite.

Nepheline shows negative correlation with zircon. Microcline shows negative correlation with albite and positive with cancrinite, zircon and sphene. Albite shows negative correlation with cancrinite and positive correlation with sphene. Cancrinite shows positive correlation with zircon and sphene.

Nepheline Syenite Dykes. The mineral composition of five samples of the nepheline syenite dykes with their means, standard deviations and correlation co-efficients are given. They are all foyaites but have been set apart from the nepheline syenite, which are also foyaitic, on the basis of texture and mode of occurrence. From a practical angle their setting apart is warranted because of their relatively higher average nepheline content.

The nepheline syenite dykes can be classified into the relatively finer-grained (from fine to barely medium-grained) hypidiomorphic but subporphyritic to porphyritic texture and relatively coarse grained hypidiomorphic dykes. The former are much more common and show flow structure. Nepheline (20.00 to 30.23%), microcline (45.00 to 57.00%) and albite (5.00% to 13.98%) are the most important minerals having means and standard deviations respectively as follows :

X=24.92 and S=4.03, X=51.94 and S=5.06, X=9.35 and S=3.82.

Microcline mostly occurs as subhedral phenocrysts. Smaller grains also occur. Albite occurs mostly as subhedral to eumorphic laths. It a has composition of upto 6% An. The feldspars show slight alteration to clay and sericite. Nepheline occurs as anhedral to subhedral crystals. Some eumorphic crystals may also occur in some samples. It shows slight alteration to clay. The sample KA-75-AS-31B contains 16.00% cancrinite and may be called cancrinite-nepheline syenite dykes. The other (accessory and minor minerals) are sodalite (X=0.30, S=0.60), Cancrinite (X=3.20, S=6.39), aegirine (X=0.37. S=75), arfvedsonite (X=3 70, S=3.79), biotite (X=3.57, S=1.66), muscovite (X=0.60, S=1.20), apatite (X=0 40, S=0.79), zircon (X=0.60, S=0.79), sphene (X=0 87, S=0.44), ilmenite (X=0.40, S=0.43), melanite (garnet) (X=1.13, S=1.13) and epidote (X=0 26, S=0.52).

Ilmenite shows negative correlation with albite and positive with zircon. Sphene shows negative correlation with sodalite and biotite. Cancrinite shows positive correlations with muscovite and apatite. Aegirine shows positive correlation with epidote. Apatite shows positive correlation with muscovite. Melanite shows positive correlation with ilmenite.

Sodalite-Nepheline Syenite: The mineral composition of eight sodalite nepheline syenite samples alongwith their means, standard deviations and correlation co-efficients are presented. The sodalite nepheline syenite occurs mostly as dykes. They are hypidiomorphic porphyritic. Microcline commonly forms phenocrysts. It ranges from 44.41% to 63.00%. The microcline is from moderately to strongly perthitic. It may show minor alteration to clay and sericite. In the cancrinite-bearing varieties it may be replaced at places by cancrinite. Nepheline ranges from 11.00 to 23.47%. It occurs as relatively smaller grains which are mostly subhedral to anhedral. It is either interstitial or forms small aggregates. In seven out of eight samples albite ranges from 1.41% to 6.00%. Only one sample i.e. KA-76-AK-32B contains 25.00% albite. It mostly occurs as small subhedral laths. Sodalite makes up from 6.99 to 22.14% of the rock. The means and standard deviations of nepheline, microcline, albite and sodalite are as follows respectively:

X=14.68 and S=6.36, X=55.44 and S=5.77, X=6.05 and S=7.33, X=13.63 and S=4.90. Sodalite is a replacement mineral and may enclose nepheline, feldspar, biotite and ore grains.

Four samples do not contain cancrinite. One sample contains 12.23% cancrinite (KA-76-SK-61) and may be called cancrinite-sodalite-syenite. The other three samples contain from 1.40 to 3.10% cancrinite. It replaces feldspar, sodalite and nepheline but also occurs as independent grains and their aggregates. Aegirine is absent whereas arfvedsonite (5.40%) is present in only one sample (KA-76-AS-5B). Similarly zircon is absent and sphene (1.00%) is present in only one sample (KA-76-AK-32B). Other accessory and minor minerals that may be found are biotite (X=4.35, S=3.06), muscovite (X=1.12, S=2.31), ilmenite (X=0.55, S=0.63) sphene (X=0.12, S=0.33), haematite (X=0.18, S=0.34), pyrite (X=0.58, S=0.95) and epidote (X=0.12, S=0.33).

Nepheline shows negative correlations with albite, sphene, ilmenite and epidote. Albite shows positive correlations with sphene and ilmenite. Sodalite shows negative correlation with haematite. Cancrinite shows positive correlation with haematite. Sphene shows positive correlation with ilmenite. Ilmenite shows positive correlation with epidote.

Litchfieldites: The mineral composition of eight litchfieldites is given alongwith means, standard deviations and correlation co-efficients. Litchfieldites occur mostly as dykes. They mostly show from moderately to well developed flow structure which is marked by parallel to sub-parallel alignment of albite laths. They are fine to barely medium grained rocks. They are mostly subequigranular to porphyritic. Albite (44.00 to 60.00%), nepheline (11.00 to 23.62%) and microcline (5.00 to 32.00%) are the main minerals having means and standard deviations respectively as follows :—

(X=53.15, S=5.55), (X=19.05, S=4.71) and (X=15.68, S=8.87)

Albite occurs mostly from fine to medium grained subhedral to eumorphic laths. In specimen KA-76-S-21B albite is from subhedral to anhedral and in specimen KA-76-SK-35 phenocrysts of albite also occur. Albite (except phenocrysts) is mostly upto 0.65 mm. It contains upto 6% An, microcline (upto 1.63 mm) occurring from subhedral to anhedral crystals which are poorly to moderately perthitic. Inclusions of pyribole and albite may be present. Both albite and microcline show alteration to clay and sericite. Nepheline occurs as individual crystals as well as aggregates. It is upto 0.38 mm. It shows slight alteration to sericite and zeolites.

Four out of eight samples studied do not contain pyriboles, Three samples contain arfvedsonite (from 0.50% to 10.00%) and two samples contain 3.00% and 5.00% aegirine. They are from euhedral to subhedral and upto 0.5 mm in length. Small biotite flakes (upto 0.15 mm) are pleochroic from pale yellow to dark brown or brownish green.

Other minerals which may be present are sodalite (X=0.07, S=0.19), cancrinite (X=3.12, S=5.58), muscovite (X=1.00, S=2.64), aegirine (X=1.00, S=1.80), arfvedsonite (X=1.68, S=3.28), apatite (X=0.25, S=0.66), zircon, sphene, (X=1.00, S=1.58), ilmenite (X=1.51, S=1.56), melanite (X=1.25, S=2.16), haematite (X=0.62, S=1.65), pyrite (X=0.25, S=0.66) fluorite, zeolite and astrophyllite.

Nepheline shows negative correlation with haematite. Microcline shows negative correlation with albite and ilmenite, and positive correlation with pyrite. Albite shows negative correlation with muscovite, zircon and pyrite. Sodalite shows positive correlations with aegirine. Arfvedsonite shows positive correlations with apatite, sphene, ilmenite and garnet. Biotite shows negative correlation with muscovite, zircon and pyrite. Muscovite shows positive correlations with zircon and pyrite. Muscovite shows positive correlations with zircon and pyrite. Apatite shows positive correlations with sphene, ilmenite and melanite. Zircon shows positive correlation with pyrite. Ilmenite shows positive correlation with sphene.

Pegmatites : Ten thin sections of unzoned to simply and partially zoned alkali pegmatites were studied. Seven of the thin sections are pulaskitic and three of them are nepheline syenite pegmatites. The sample KA-76-ASA-1 to KA-76-SA-4 represent three zones of a pegmatite. The other samples represent unzoned pegmatites. The means, standard deviations and correlation co-efficients are given. They are all hypidiomorphic and coarse-grained. They show uneven segregations of the constituent minerals. Seven out of ten samples are pulaskitic and only three samples are of nepheline syenite (sensu stricto) which contain from 8.00 to 18.00% nepheline.

Microcline varies from 14.00 to 93.00% (X=50.08, S=25.63). It mostly occurs as big crystals which show strong perthitic growths. Often the intergrowths appear to be mixed crystals of albite and microcline. Nepheline (X=5.49, S=6.66) when present, occurs as aggregates of smaller crystals which are form subhedral to anhedral. Albite (X=32.49, S=18.48) ranges from 1.20 to 57.00%. It mostly occurs as smaller crystals and may form mixed crystals with microcline. Sodalite is absent and cancrinite occurs in only one sample i.e. KA-76-S-12B (0.79%). Calcite, apatite and zircon are lacking. The accessory to minor minerals which may occur are pyriboles (X=2.86, S=4.98; X=0.80, S=1.53), muscovite (X=2.06, S=3.92), biotite (X=1.95, S=1.64), sphene (X=0.50, S=0.92), ilmenite (X=1.09, S=1.96) melanite

(X=0.50, S=1.50), haematite (X=0.25, S=0.60), magnetite (X=0.30, S=0.64), pyrite (X=0.50, S=1.02) and epidote (X=0.10, S=0.21).

The four zones of the simply and partially zoned pegmatites are :

(1) *The wall zone* : It is hypidiomorphic porphyritic (ASA-1). It contains 8% nepheline, 43% albite, 5% biotite, 5% ilmenite, 2% pyrite and 2% haematite.

(2) *Outer Intermediate zone* : Its texture is pegmatitic with uneven segregation of minerals. It contains only 2% nepheline, Albite is 45% and microcline is 30%. Unlike the wall zone it contains 15% aegirine. It also contains 5% ilmenite and 3% biotite.

(3) *Inner Intermediate zone* : Its texture is pegmatitic with uneven segregation of minerals. It is free of microcline. Unlike the other two zones described, it contains 13% muscovite and unlike the outer intermediate zone is free of aegirine. It contains 4% biotite and 5% ilmenite. Unlike the outer two zones described it contains 3% sphene.

(4) *Core* : Its texture is pegmatitic with uneven segregation of minerals. The core shows concentration of nepheline. It contains 5% muscovite and 3% biotite. Albite is 57% and microcline is only 14%.

Going from core inwards the amount of albite increases whereas the amount of microcline decreases. Nepheline first decreases and falls to zero in the inner intermediate zone but then jumps to 18.00% in the core. Biotite occurs in all the zones and the core, its maximum concentration being in the inner intermediate zone.

Microcline shows negative correlations with albite and biotite, and positive correlations with epidote. Albite shows positive correlation with biotite. Biotite shows positive correlation with ilmenite. Muscovite shows positive correlation with sphene.

Four samples of the various zones of the complex zoned pegmatite were studied. The wall zone is composed of nepheline syenite. The intermediate zone is pegmatitic. It is composed of 88% nepheline, 7% cancrinite, 2% sodalite, 1%bioiite1% albite. The core is composed of 20%sodalite, 50%nepheline, 15% cancrinite, 10% albite, 3.% albite, 3% biotite and 2% ilmenite. In addition there is a partially developed biotite zone. It occurs near the wall zone, which contains 70% biotite, 18% ilmenite, 2% haematite, 5% microcline perthite, 3% albite and 2% nepheline.

Carbonatites : Two samples of carbonatites were studied. They are coarse-grained and hypidomorphic. They contain 58% to 60% calcite, 6% mircrocline, 7% to 10% aegirine augite, 7% to 11% arfvedsonite, 15% to 18% apatite and from 0% to 1% ilmenite. The apatite content is of interest.

Fenites : Two fenite samples were studied. The fenite is hypidiomorphic and poikilitic. They contain 3.28 to 10.00% nepheline, 44.00 to 49 74% microcline, 10.00% to 51.26% albite, 0.00 to 4.00% arfvedsonite, 2.00 to 3.02% biotite, 0.0) to 0.43% muscovite, 1.40 to 25.00% calcite, 0.00 to 5.00% apatite and 0.00 to 1.00% ilmenite. The values of the two samples reflect the hetrogeneity of fenites associated with carbonatites of the Koga area.

Lamprophyre : One sample of lamprophyre was studied. It contains 66% pyribole, 7% biotite, 2% quartz, 6% sphene, 6% apatite and 5% magnetite.

Babaji Syenite : Three samples of what is known as the Babaji syenite were studied. It is from quartz syenite to soda granite in composition. It is a coarse grained and hypidiomorphic rock. It contains 65% to 77% microcline 0% to 17% albite, 7% to 20% quartz. Other minerals which may occur as accessories are soda pyriboles, biotite, sphene, apatite, zircon, haematite and ilmenite.

Acidic Dykes : One acidic dyke associated with the Babaji syenite and three dykes associated with nepheline syenite were studied. They contain 5% to 23% microcline, 15% to 30% albite and 15% to 50% quartz. Other accessory to minor minerals are soda pyroxene, biotite, muscovite, sphene, haematite, ilmenite, magnetite and pyrite. The acidic dyke associated with the Babaji syenite differs from those associated with the nepheline syenite in that it has much higher quartz and much lower total feldspar.

Albitite : One albitite was studied. It contains 86% albite, 6% quartz 5% epidote, 1% sphene and 2% ilmenite.

CHEMISTRY

General : A total of forty nine chemical analyses of the Koga nepheline syenite complex were carried out. In addition, two analyses of zoned complex pegmatite, one of albitite, one of Babaji syenite and three analyses of acidic dykes were carried out. Twenty three of the analyses are of nepheline syenite (sensu stricto), seven of nepheline syenite dykes, five of sodalite nepheline syenite, seven of litchfieldites, two of foyaites and five of pegmatites. In the following a brief account of their chemistry is given.

Nepheline Syenite : The averages and standard deviations for important constituents of nepheline syenite are given below :

$\overline{SiO_2} = 58.23$, $S = 3.05$; $\overline{Al_2O_3} = 20.35$, $S = 1.65$; $\overline{Na_2O} = 7.79$, $S = 1.43$; $\overline{K_2O} = 6.06$, $S = 0.82$ $\overline{Fe_2O_3} = 2.97$, $S = 1.15$; $\overline{Na_2O + K_2O} = 13.85$; $\overline{Na_2O} : \overline{K_2O} = 1.29$; $\overline{TiO_2} = 0.19$, $S = 0.36$; $\overline{MnO} = 0.03$, $S = 0.13$; $\overline{MgO} = 0.86$, $S = 0.76$ $\overline{CaO} = 2.02$, $S = 1.60$; $\overline{P_2O_5} = 0.15$, $S = 0.25$, $\overline{H_2O} = 1.44$, $S = 1.28$

The contents of SiO_2 show significant negative correlations with MgO, CaO and H_2O The contents of Na_2O show significant negative correlation with Al_2O_3.

Foyaite : Two chemical analyses of foyaites are given in the following. Since the number of analyses are only two, therefore, correlations cannot be given. The averages for the important constituents are $\overline{SiO_2} = 57.13$, $\overline{Al_2O_3} = 22.27$, $\overline{Na_2O} = 9.98$, $\overline{K_2O} = .07$ and $\overline{Fe_2O_3} = 2.37$, $\overline{Na_2O + K_2O} = 15.05$, $\overline{Na_2O} : \overline{K_2O} = 1.97$, $\overline{MgO} = 1.91$, $\overline{CaO} = 1.39$, $\overline{H_2O^+} = 1.78$.

Nepheline Syenite Dykes : Seven chemical analyses of the nepheline syenite dykes were carried out. The averages and standard deviations from a practical angle for important constituents are given below :

$\overline{SiO_2} = 58.07$, $S = 1.76$: $\overline{Al_2O_3} = 20.82$, $S = 1.64$; $\overline{Na_2O} = 7.98$, $S = 1.26$; $\overline{K_2O} = 6.87$, $S = 1.32$: $\overline{Fe_2O_3} = 1.91$, $S = 0.99$; $\overline{Na_2O + K_2O} = 14.85$; $\overline{Na_2O} : \overline{K_2O} = 1.16$; $\overline{MgO} = 0.81$, $S = 0.71$; $\overline{CaO} = 2.17$, $S = 1.04$; $\overline{P_2O_5} = 0.21$, $S = 0.26$ and $\overline{H_2O^+} = 1.28$, $S = 0.39$.

Since the number of analyses is small, therefore, significant correlation (–ve) is shown only by Al_2O_3 and P_2O_5 But it does not mean that other correlations do not exist in the population.

Sodalite-Nepheline Syenite : Five chemical analyses of the sodalite nepheline syenites were carried out. The averages and standard deviations from a practical point of view for important constituents are given below :

$\overline{SiO_2}$ = 55.92, S = 2.29 ; $\overline{Al_2O_3}$ = 23.46, S = 0.47 : $\overline{Na_2O}$ = 10.68, S = 1.28; $\overline{K_2O}$ = 4.97, S = 0.49, $\overline{Fe_2O_3}$ = 2.32, S = 0.76 ; $\overline{Na_2O + K_2O}$ = 15.65 ; $\overline{Na_2O : K_2O}$ = 2.15 ; $\overline{TiO_2}$ = 0.13, S = 0.23 ; $\overline{MgO}$ = 0.16, S = 0.17, $\overline{CaO}$ = 1.27, S = 0-89 ; $\overline{P_2O_5}$ = 0.04, S = 0.09 and $\overline{H_2O^+}$ = 1.11, S 0.32.

The number of analyses is small, therefore all possible correlations cannot be determined. However, the following correlations were found :

Significant negative correlations between SiO_2, Na_2O and P_2O_5.

Significant positive correlation between TiO_2 and P_2O_5.

Significant positive correlation between Fe_2O_3 and MgO.

Significant positive correlation between K_2O and H_2O.

Significant negative correlation between K_2O and H_2O.

Litchfieldite : Seven chemical analyses of litchfieldites were carreid out. The averages and standard deviations, from a practical point of view, for important constitutents are given below :

$\overline{SiO_2}$ = 58.90, S = 2.36 ; $\overline{Al_2O_3}$ = 21.84, S = 0.94 ; $\overline{Na_2O}$ = 9.56, S = 1.16 ; $\overline{K_2O}$ = 4.70, S = 0.93 ; $\overline{Fe_2O_3}$ = 1.70, S = 0.80 ; $\overline{Na_2O + K_2O}$ = 14.26, $\overline{Na_2O : K_2O}$ = 2.03 ; $\overline{TiO_2}$ = 0.01, S = 0.03, $\overline{MnO}$ = 0-01, S = 0.02 ; $\overline{MgO}$ = 0.25, S = 0.23; $\overline{CaO}$ = 1.99, S = 0.71, $\overline{P_2O_5}$ = 0.15, S = 0.29 and $\overline{H_2O}$ = 1.10, S = 0.52.

Since the number of analyses is small, therefore, all possible correlations cannot be found. However, the following significant correlations were found :

Between TiO_2 and Al_2O_3 (+ve). Between MnO and P_2O_5 (+ve). Between CaO and H_2O (+ve).

Pegmatites : Five chemical analyses of pegmatites were carried out. Averages and standard deviations of the important constituents are as follows :

$\overline{SiO_2}$ = 61.65, S = 1.83, $\overline{Al_2O_3}$ = 21.01, S = 0.94 : $\overline{Na_2O}$ = 8.12, S = 1.72 ; $\overline{K_2O}$ = 6.97, S = 1.26, $\overline{Fe_2O_3}$ = 2.88 and S = 2.11, $\overline{Na_2O + K_2O}$ = 13.00 $\overline{Na_2O : K_2O}$ = 0.88 ; $\overline{TiO_2}$ = 0.14, S = 0.27 ; $\overline{MnO}$ = 0.01, S = 0.03 ; $\overline{MgO}$ = 0.40, S = 0.65 ; $\overline{CaO}$ = 0.55, S 0.38 ; $\overline{P_2O_5}$ = 0.01 S = 0.02 and $\overline{H_2O^+}$ = 0.57, S = 0.22.

Since the number of analyses is small, therefore all possible correlations cannot be given. However, the following correlations were found :

MgO and P_2O_5 (+ve). K_2O and P_2O_5 and (P_2O_5 (+ve). TiO_2 and MnO (+ve).

But these correlations are doubtful due to the truncated distribution of, TiO_2, P_2O_5 and MnO.

PETROGENESIS

The Koga nepheline syenite is not an independent isolated or a local derivative. It is on the contrary a part of the alkaline province stretching from Loe Shulman to Chamla as known presently. (Ashraf and Chaudhry 1978). This province is composed of nepheline syenites, carbonatites, soda granites and alkali porphyries. The members of this province known so far are Loe Shulman nepheline syenite and associated carbonatites. Warsak soda granite, Malakand carbonatites. (Ashraf & Chaudhry 1978), Shewa alkali porphyries, Babaji soda granite and syenites and Koga nepheline syenite and associated carbonatites (Siddiqui, Chaudhry & Shakoor 1968 and E.C.L. 1976). This province is related to a zone of weakness developed south of the Dir-Swat subduction zone.

Some of these rocks may be very young say Pliocene. The relationship between tectonic setting and alkaline rocks is well established. The alkaline rocks tend to form in areas of structural weakness or tectonic quiescence. Such relations have been discussed by Harker (1896) Kuznetsov (1958, 1964) and Sorensen 1970, 1974).

Along this zone were emplaced the alkaline rocks and their relatives and derivatives. Present authors think that this alkaline province is rather poorly studied. Babaji syenite and soda granite are comagmatic. The Shewa porphyries also appear to be related to them. The Chinglai granodiorite gneiss however is much older and belongs to earlier oregenesis. This gneiss is genetically not related to the nepheline syenite.

Siddiqui, Chaudhry and Shakoor (1968) regarded the Koga syenite as a single horse shoe shaped intrusion and derived a sequence of evolution within this intrusion. Detailed field investigations and mapping stretched over a period of one year has changed the picture.

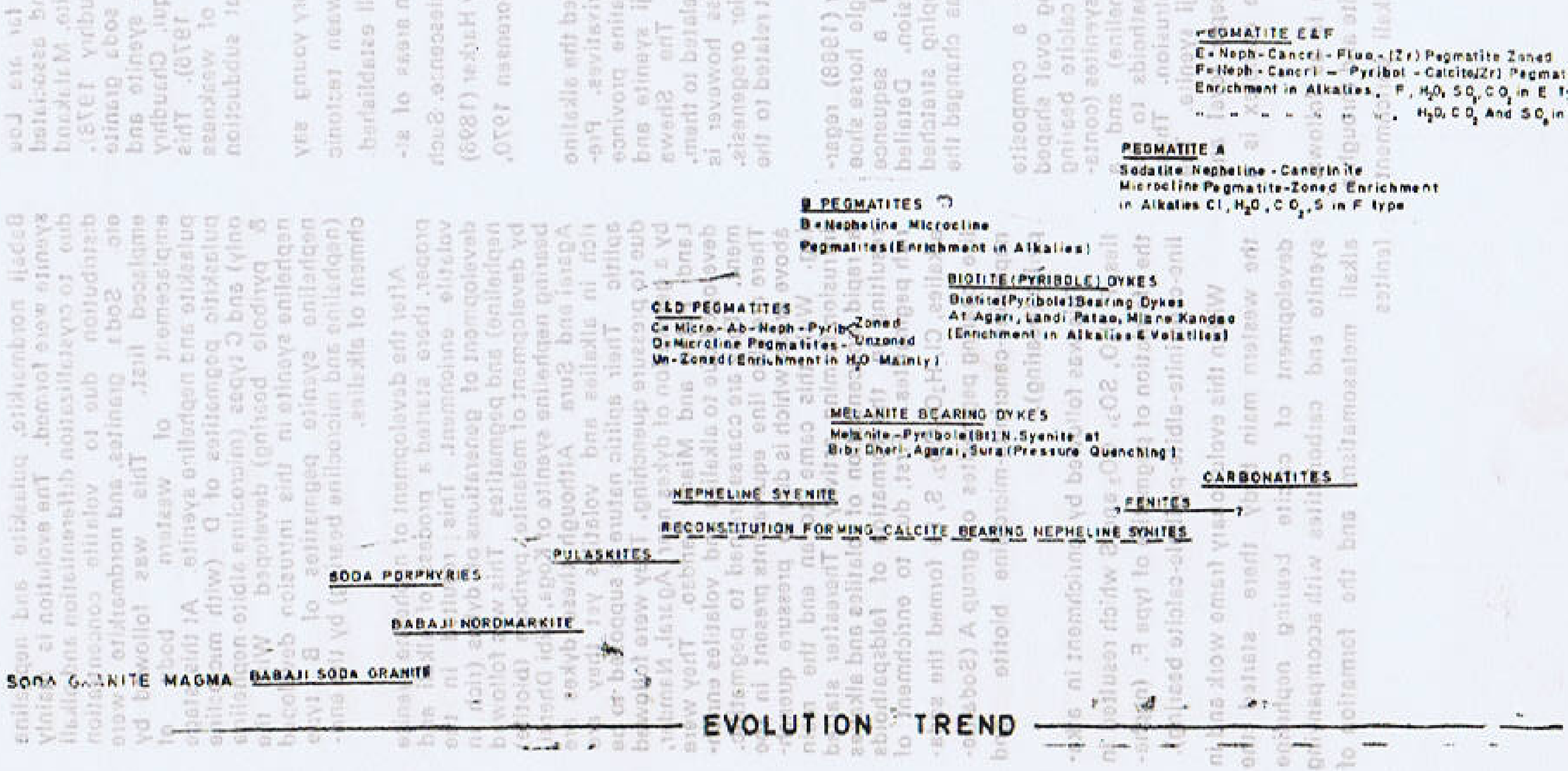
The nepheline syenite is a composite intrusion consisting of an oblong oval shaped intrusion of syenite, pulaskite, calcite bearing syenite and nepheline bearing syenites (containing upto only 15% nepheline) and a number of dykes rich in feldspathoids to the east and northeast of this intrusion. These dykes are emplaced in Babaji syenite. The differentiation took place at deeper level and the present nepheline syenite complex is a result of multiple intrusion.

The sequence of evolution is as follows. Starting from Babaji soda granite and through a progressive evolution to an alkali enrichment Babaji nordmarkite, pulaskite and nepheline syenite were formed. The evolution is mainly due to crystallization differentiation and alkali distribution due to volatile concentration etc. Soda granites, and nordmarkite were emplaced first. This was followed by emplacement of western body of pulaskite and nepheline syenite. At this stage pulaskitic pegmatites of D (with microcline only) and C types (microcline albite-nepheline & pyribole bearing) developed. With the nepheline syenite in this intrusion developed nepheline syenite pegmatites of B type (nepheline and microcline bearing) by the enrichment of alkalies.

After the development of nepheline syenite proper, there started a process of alkali and volatile enrichment. This resulted in the development of generations of dykes (rich in nepheline) and pegmatites. This was followed by development of melanite, pyribole (biotite) bearing nepheline syenite of Koga, Bibi Dherai, Agarai and Sura. Although these dykes are rich in alkalies and volatiles yet they are aplitic. Their aplitic nature is supposed to be due to pressure quenching. They were followed by a generation of dykes near Agarai, Namdar, Landi Patao and Miane Kandao. They were developed due to alkalies and volatiles enrichment. They are coarse grained to pegmatitic. There are also fine equivalents present in the above areas which is due to pressure quenching. With this came to an end the main intrusion forming activity. Thereafter started a rapid concentration of volatiles and alkalies resulting in the formation of feldspathoids rich pegmatites. First, due to enrichment of alkalies, Cl, H_2O, CO_2, S, Fe formed the sodalite bearing pegmatites of group A (Sodalite-nepheline-cancrinite-microcline biotite and pyrite (bearing).

This was followed by enrichment in alkalies, F, H_2O, SO_3, CO_2 and S which resulted in the formation of pegmatite of type F. (nepheline-cancrinite-albite-pyribole-calcite bearing).

Within this evolutionary frame work and in the western main body there started the development of calcite bearing nepheline syenite and carbonatites with accompanying alkali metasomatism and the formation of fenites


PEGMATITE E&F
E = Neph - Cancri - Fluo. - (Zr) Pegmatite Zoned
F = Neph - Cancri — Pyribol - Calcite(Zr) Pegmatite
Enrichment in Alkalies, F, H_2O, SO_3, CO_2 in E Type
" " " " " " H_2O, CO_2 And SO_3 in F.
PEGMATITE A
Sodalite Nepheline - Cancrinite
Microcline Pegmatite-Zoned Enrichment
in Alkalies Cl, H_2O, CO_2, S in F type
B PEGMATITES
B = Nepheline Microcline
Pegmatites (Enrichment in Alkalies)
BIOTITE (PYRIBOLE) DYKES
Biotite (Pyribole) Bearing Dykes
At Agarr, Landi Patao, Miane Kandao
(Enrichment in Alkalies & Volatiles)
C&D PEGMATITES
C = Micro - Ab - Neph - Pyrib - Zoned
D = Microcline Pegmatites - Unzoned
Un-Zoned (Enrichment in H_2O Mainly)
MELANITE BEARING DYKES
Melanite - Pyribole (Bt) N. Syenite at
Bibi Dheri, Agarai, Sura (Pressure Quenching)
CARBONATITES
FENITES
NEPHELINE SYENITE
RECONSTITUTION FORMING CALCITE BEARING NEPHELINE SYNITES
PULASKITES
SODA PORPHYRIES
BABAJI NORDMARKITE
SODA GRANITE MAGMA
BABAJI SODA GRANITE
EVOLUTION TREND

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AN ANALYSIS OF LITHO-TECTONIC ZONES ASSOCIATED WITH THE HIMALAYAN OROGENY, IN NORTHENR PAKISTAN

BY

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Abstract. *The Karakorum Himalayas is characterised by some unique tectonic features which distinguishe it from the rest of the Himalayas. Some of these are ; occurrence of an island are on its north-western margin, existence of two suture zones west of Nanga Parbat—Haramosh antiform, and the absence of the Main Central Thrust, which, in the Central Himalaya demarcates so prominantly the boundary between the Lesser Himalaya and the Himalayan crystalines.*

In this paper, under the light of new tectonic data, an analysis is attempted to differentiate various li ho-ectonic zones in northern Pakistan which were involved in the Himalayan orogeny.

INTRODUCTION

During the past, several geologists have attempted to produce morpho-and lithotectonic classifications of various geographical sectors of the Himalaya in the Indo-Pakistan sub-continent. These schemes, more or less, fitted into Wadia's (1957) four-fold classification of the Himalaya, on the basis of orographic features ; Wadia's divisions from south to north are : (i) The Outer Himalaya, (ii) The Lesser Himalaya, (iii) The Central or Great Himalaya, and (iv) The Inner Himalaya or Ladakh Himalaya.

Among the recent workers, Powell and Conaghan (1973), divided the Central Himalaya into five morphotectonic zones, which from south to north include :

(i) Upper Miocene to Recent molasse of the Indo-Gangetic plain and Siwalik Hills, which is separated by the Main Boundary Thrust from, (ii) a zone of southward directed thrust and nappes of the Lesser Himalayas, (iii) the high Himalaya composed of schists, gneisses and granites, (iv) fossiliferous Cambrian to Eocene sediments of the Tethyan zone, and (v) Cretaceous to Eocene radiolarites and ophiolites - bearing flysch of the Indus-Brahamputra suture.

There are some features unique to certain regions of the Himalayas which are traceable over enormous distance. But in some ways, the tectonic models of the Central and Eastern Himalaya are not consistant with the generalized scheme of the northwestern Himalaya. Some such recently discerned features, which restrict this correlation, are enumerated below.

Recent researches on the regional tectonics carried out in the northern and western parts of Pakistan, under the frame-work of global plate tectonics, have changed the old concept and a new tectonic model has emerged for this region. This change is brought in by the presence of an island a:c located on the northwestern termination of the Himalayas and by the bifurcation of the Indus Tectonic Line into two suture zones, the Northern Mega-shear and the Main Mantle Thrust (Tahirkheli, 1979), west of Nanga Parbat—Haramosh transverse antiform.

The MBT and MCT, the Outer and Inner boundary of the Lower Himalaya, meet slightly west of the Sutlej River and continue northwestward as two adjacent parallel faults, the Krol as the outer thrust and Panja as the inner thrust. Gansser (1934) has combined the two. If so, then the Lesser Himalayas, speaking under geological context, becomes absent from the northwest terminal section of the Himalayas. Thus the MCT, which separates the Lesser Himalaya from the Himalayan crystallines in the Central Himalayas, so for remains obscured in Karakorum ; as a result, some other parameters are to be adopted to demarcate the entity of Lesser Himalayas in Pakistan.

This new development in the tectonic model necessitated to differentiate the major litho-tectonic zones in the northern Pakistan which were involved in the Himalayan orogeny is order to provide a base for correlation with the rest of the Himalayas. In this paper an attempt has been made to decipher various lithotectonic zones in a stretch, between the Shield Belt exposed in the Indus plain in the south, and the northern tip of Karakorum bordering China in the north.

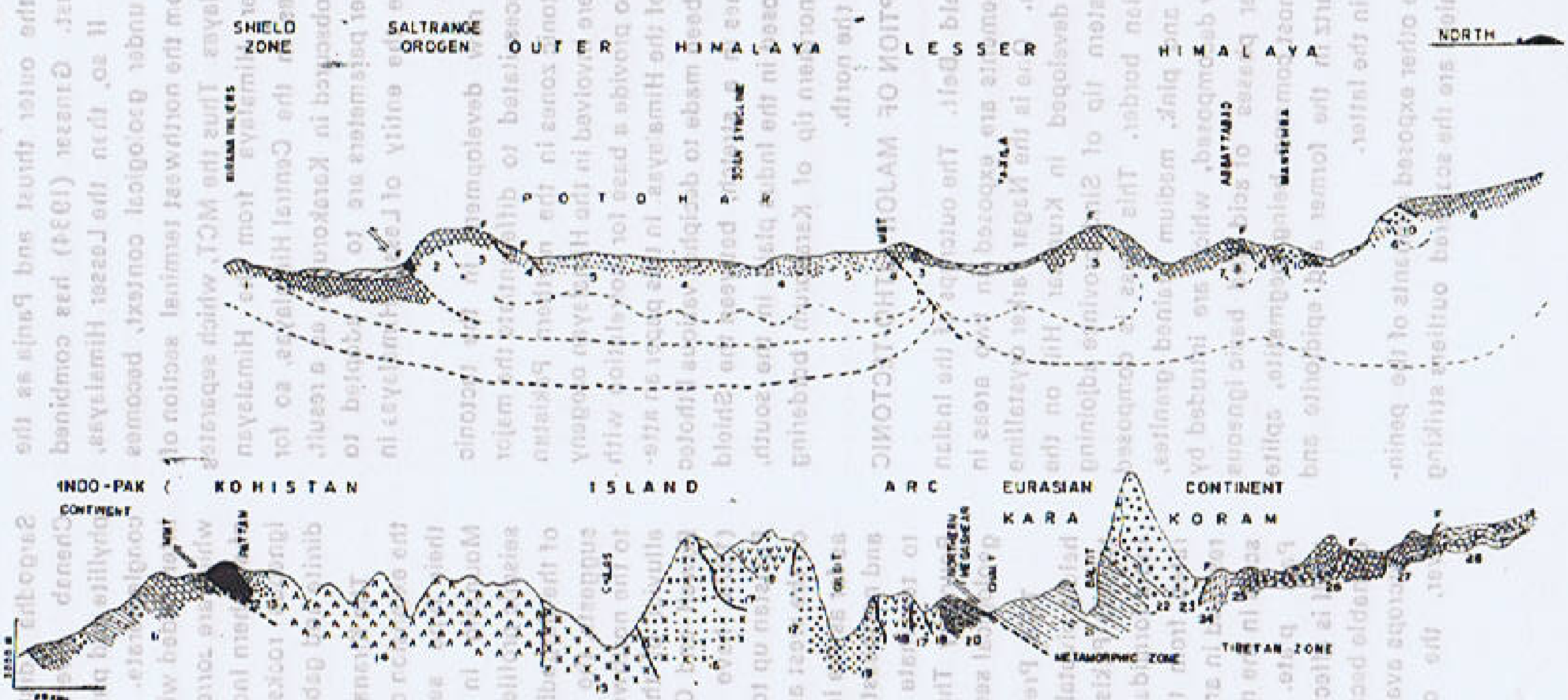
DESCRIPTION OF MAJOR LITHO-TECTONIC ZONES

Shield Belt. The outcrops of the Indian shield elements are exposed in two areas in Pakistan. One is the Nagar Parker crystalline massif, developed in Krunihar Hill on the southeastern tip of Sind province adjoining the Indian border. This mass is composed of grey and pink, medium grained granites, partially decomposed, which are intruded by the later phases of acid and basic igneous rocks, most common being pegmatite, aplite and quartz in the former and epidiorite and gabbro in the latter.

The other exposed remnants of the peninsular shield are the scattered outliers striking E-W and constituting low, deeply weathered hills known as Kirana and Sangla, lying in Sargodha district, between Jhelum and Chenab rivers These consist of slate, phyllite and phyllitic schists interrelated with conglomerate. These metasediments are interbedded with andesite, rhyolite and tuffs which are correlated with the Malani volcanics of southern India. Among the acid and basic igneous rocks, granite, pegmatite, dolerite, dirrite and gabbros are common.

The Kirana outliers are considered to be the extension of Upper Cuddappa system with their type section located in the Aravalli Mountain in southern India. The deep seismic profile shows a subsurface connection of the Sargodha High with the latter which suggests, the extension of the Indian shield to the northwest, concealed under the thick alluvial of the Indus basin in Pakistan. Powell and Conaghan (1973), and Stoneley (1974, have extended the shield belt in Pakistan up to Ornach-Nal and Chaman faults on the west and beneath the Himalaya, atleast as far as the Indus ophiolite belt in the north and northeast. The author considers this belt to terminate in the north along the Main Boundary Thrust as shown in the attached geological section (Fig. 1).

This PreCambrian shield belt in Pakistan held a pivotal position during and subsequent to Indo-Pakistan—Eurasian collision by forming a formidable check to the stresses generated from the north and northwest, which resulted in architecturing the major tectonic scars in the northwestern margin of the Indo-Pak. plate. How much this shield belt itself is affected by this resistance is not discernable because of limited exposures of the outcrops available for structural studies. However, the outcome of limited structural



LITHO-TECTONIC ZONES ASSOCIATED WITH THE HIMALAYAN OROGENY IN N.W. PAKISTAN

BY: TAHIRKHELI

1. SHIELD ROCKS 2. INFRA-CAMBRIAN—CAMBRIAN—UPP PALAEOZOIC FMS. 3. MESOZOIC—LOWER TERTIARY FMS. 4. MURREE FM. 5. SIWALIK GR. 6. HAZARA SLATES 7. TANAKKI BOULDER BED 8. ABBOTTABAD FM. 9. TANAWAL FM. 10. MANSEHRA Gr. 11. BESHAM GROUP WITH FOLIATED Gr. BODIES 12. JIJAL COMPLEX 13. PATTAN GARNET-GRANULITES 14. KAMILA AMPHIBOLITES 15. BAHRAIN PYROXENE GRANULITES 16. DESHAI DIORITES WITH MAFIC BODIES 17. KOHISTAN Gr. 18. GREENSTONE COMPLEX 19. KOHISTAN Gr. WITH BASIC AND MAFIC BODIES 20. CHALT FM. 21. DURMORDU FM. 22. MIGMATITIC GNEISSES 23. KARAKORAM GRANODIORITE 24. PASSU SLATES 25. GUJAL DOLOMITE 26. GIRCHA FM. 27. KILIK FM. 28. MISGAR SLATES

(Fazal Ahmad)

observations made on the isolated outcrops of Kirana, Nashtarabad and Chiniot is as follows :—

(i) The strike of the rocks swings from E-W to NNE-SSW ; local squeezing of beds and sudden shifts in strike direction are not uncommon.

(ii) The dip is usually steep — as high as 70°-80° directed mostly towards north and northwest.

(iii) The structure at Kirana, one of the major outcrops reveals a broad antiform with the axial plane swinging between E and NE.

(iv) Metamorphism is variable but not exeeding beyond chlorite grade.

These minor structural features may represent some of the remnants of alpine orogeny left behind on the northwestern part of the marginal areas of the shield belt in Pakistan.

The rocks from Kirana outliers have been dated by Davies and Crawford (1970) at 870 ± 40 m y.

Salt Range

The E-W trending Salt Range occupies an anomalous position in the physiography of the extra-penisular part of the Indo-Pakistan continent. The orogenic feature is located on the southern-most part of extra-peninsula, where the shield belt comes in contact with the Himalayan off shoots.

The Salt Range exposes litho-stratigraphic units ranging in age from Lower Cambrian to Upper Tertiary. The marine sedimentary equivalents of Gondwana of Permo-Carboniferous—Triassic age (Nilawahan Group and Mianwali Formation) comprising a thick sequence, overlie the Cambrian with a well-marked unconformity. The whole mass rests over the Saline Series of Wynne (1873). or Punjab Saline Series of Gee (1945) which has recently been named Salt Range Formation by Asrarullah (1967).

The Salt Range Formation is exposed on the southern flank of the Salt Range, all along from Khussak in the east to Kalabagh in the west. The western flank of the Salt Range re-entrent, called the Trans-Indus Range, does not show any exposed outcrop of the Salt Range Formation but its subsurface extension underneath this structure is not doubtful. At the type section, the exposed thickness of the Salt Range Formation is about 800 m.

Its subsurface extension, confirmed by drilling is encountered between Adhi in the Potohar, northeast of Islamabad to as far south as Karampur, located about 35 km SE of Multan in the Punjab plain. At Dhariala in the eastern section of the Salt Range, the subsurface thickness encountered in a drill-hole is over 2000 m.

In Karampur well, the Salt Range Formation directly rests over the metasedimentary rocks, having similar lithological denominations as encountered in the Kirana and adjacent outliers representing the shield belt.

The tectonic style of the Salt Range with E-W strike in the eastern limb of the re-entrent and a swing to NE-SW in the Trans-Indus Range is in conformity with the other re-entrents developed in the Himalayan front.

The Salt Range Formation, which overlies the Shield rocks, has about 450 km long N-S subsurface extension in the Punjab plain. Gee (1945) postulated southward thrusting of the Salt Range for 32 Km. but keeping in view the subsurface distribution of the salt bed, the author considers this movement to have affected much larger area as a result of decollemant.

The convexture created in the Salt Range and the sinuous morphological features developed in Kashmir—Hazara—Sulaiman and Kirthar Ranges owe much to slow and asymmetrical creep of the plastic and mobile salt bed over the shield rocks. Armbruster et al. (1978) and Seeber et al. (1977) on the basis of seismo—tectonic studies also consider the Saline bed to be a likely factor for low-strength bedding plane faults responsible for low intensity earthquakes in this region.

Siwalik Group :

The Siwalik Group in the Indo-Pakistan preserves a sedimentary record derived by denudation of the evolving Himalayan system during late orogenic phases.

Potohar is its type section in Pakistan, which is bounded on the north by the Kala Chitta Hills and on the south by the Cis-Indus Salt Range. Wadia (1932) had differentiated this belt of fluvial molasse deposited in the fore-deep along the Himalayan front as Outer Zone or Sub-Ranges of the Himalayas.

These clastics also include the rocks of the older Murree Group, forming thick outcrops on the northeastern edge of Potohar in Murree Hills which constitute their section. Murree outcrops are also associated with the Siwaliks in the Potohar Plateau and are involved in the Main Boundary Thrust, separating the clastics from the Lesser Himalayan rocks.

In Potohar, Martin et al. (1961) have distinguished the following four physiographic units ; (i) central Potohar area (Soan river), (ii) east marginal area (Kahuta—Gujar Khan — Dina), (iii) west marginal area (Khushalgarh—Makhad), and (iv) Hill Tracts area (Khaire Murat—Bakrala ridge etc.).

Gill (1951) has recognised three major zones of deformation across the Siwalik belt which are, (i) A zone of open folding, (ii) A fault zone displaying a number of reversed faults that had steeply toward north, and (iii) a zone with closely spaced strike faults and severly compressed folds terminating at the Main Boundary Fault.

In Pakistan, the Siwalik terrestrial deposits have special geological significance in view of their position within the large scale tectonic frame of the NW Himalaya. Large variations in the rate of sedimentation are related to these tectonics during Neogene and Quaternary which brought rapid morphological uplift. The deformations induced in the Siwaliks strata are shallow and represent the latest phases of Himalayan orogeny.

Palaeomagnetic investigations of the Siwaliks in Potohar under a collaborative programme by the geologists of the Dartmouth College, U.S.A. and University of Peshawar (Johnson et al, 1977, Keller et al, 1977) revealed the structures of Pabbi Hill, Rohtas, Chambal and Mangla—Samwal foldings to be the youngest elements in the area of Pakistan Himalayas foothill belt, having achieved surface expressions during very recent times. Estimated initiation of the deformations and the latest achievement of the surface expression of some of the major structures, of Potohar is given below :

	"Initiation of structure"	"Achievement of Surface expression"
Pabbi	1.2 m.y	0.4 m y B.P
Rohtas	1.7 m,y	0.4 m y B.P
Chambal	2.4 m.y	0.7 m y B.P
Mangla-Samwal	2.7 m y	1.5 m.y B.P

Deformations in the Siwaliks increase towards north in the vicinity of the Main Boundary Thrust, which marks the northern limit of the foredeep. In the south, the southward creep of the Salt Range has affected the marginal areas of the Siwaliks adjacent to the Salt Range, where thrust faults, assymmetrical antiforms and overlapping comprise the major structural features.

MAIN BOUNDARY THRUST ZONE

The Main Boundary Thrust, which demarcates the boundary between the post-collisional Upper Tertiary clastic sediments and the Himalayan crystallines, traverses the southern foothill zone of the Himalayas. This fault has been variously designated in Indo-Pakistan and does not form a single fault line or thrust in every place. It actually consists of many adjoining, truncating or prarallel reversed faults or thrusts.

In Pakistan, two faults, the Panjal and the Murree enter on the east from Kashmir and merge together near the apex of the Hazara—Kashmir syntaxis,

Beyond this point they form a single lineament which traverses the northern tip of the Murree Hills, northern Potohar, through Kohat and extends deep into Kurram Agency before crossing the Pak-Afghanisran border.

The MTB is a northward directed thrust with a variable displacement ranging from 5 to 15 km. In the syntaxial bend, along the eastern and the western limbs the Murrees are thrustover by the Dogra Slates and Hazara Slates respectively. In the Murree Hills, Kala Chitta Range Kohat and Kurram regions, the Mesozoic and the older Tertiary rocks are thrust over the Murreas and Siwaliks along this fault.

In some sections in Kohat and northern Potohar, the MBT represents a picture of high angle reverse fault, and this upsetting appear to have been caused by the southward directed movements during the last phases of Himalayan orogeny. In the northern Potohar this fault is accompanied by numerous parallel and oblique faults. In Murree Hill section, tectonic slices from the older rocks lie within the Murrees along the MBT.

MBT is one of the major megashears located in the Himalayan front which has shared the convergent movements subsequent to Indo-Pakistan-Eurasian collision. According to Mattauer (1975) and Le Fort (1975) the thursting first occurred along the Indus suture at the time of initial collision, which subsequently, some 25 m y. ago shifted to the Main Central Thrust. These movements since last 10 m y. ago have shifted to MBT, as a result some of the epicentres of the large earthquakes are located on this thrust.

LESSER HIMALAYAN ZONE

Lesser Himalayas in the Central Himalaya is situated between the MCT and MCT, and in Pakistan its equivalent should incorporate the mountains of the political districts of Hazara, Swat, Dir, Khyber, Mohmand, Kohat, Attock and Kurram Agency. The elevation of the mountains in this zone ranges from 1200 m.

in the south to as high as 4550 m. (Babu Sar Pass in Kaghan) a.s.l. in the north. The northern boundary of the zone is demarcated, instead by MCT as is the case in the Central Himalaya, by the Main Mantle Thrust in Pakistan.

Nearly three-fourth of the area is underlain by the metasedimentary rocks, intruded by the igneous bodies, the most common being granites. The rest of the area, mostly located in the southern sections in Kala Chitta, Kohat and Kurram, expose thick piles of Mesozoic (Upper Triassic to Cretaceous) and Lower Tertiary (Paleocene and Eocene) rocks. The contact between the sedimentary and the metasedimentary rocks is faulted.

In one section near Lakrai village, on the western tip of the Attock—Cherat Range, the Paleocene rocks are involved in the thrust and on this basis, the fault is considered to be older than MBT. Along this northward directed fault, Palaeozoic (and ? older) metasediments have thrust over the Cretaceous to Eocene sedimentary rocks.

The rocks equivalent to Lesser Himalaya in Pakistam may be divided into two parts, the lower one called the Abbottabad zone, as designated earlier by Fuchs (1975) and the upper one the Kala Chitta Zone.

The Abbottabad Zone is comprised of metasedimentary rocks in which epi-to meso-grade metamorphism dominates in the south, progressively increasing to kata-grade in the north. This zone constitutes the severely tectonized part of the Himalayan belt which inhabits some of the major structural features ; a few of them are, the Hazara syntaxis, the Indus re-entrent, Dargai Klippe, Hazara Thrust system and the deformed sinuous morphological features displayed by the Hazara—Kashmir arc. Besides, this zone reveals some interesting deep crustal dislocations telemetered from Tarbela seismic observatory.

The Kala Chitta Zone is dominantly sedimentary and is located on the southern periphery of the Lesser Himalaya. It extends to the east through the southern fringe of Hazara adjoining Murree Hill and Azad Kashmir and in the west it passes through northern part of Kohat and Kurram. The rocks range in age from Upper Triassic to Eocene. On the south, the Kala Chitta Zone is delimited by MBT and on the north its contact with the metasedimentary rocks is faulted. This fault is usually a thrust which is not clearly demarcated everywhere because of its involvement in the late deformational episodes.

MAIN MANTLE THRUST ZONE

The MMT Zone has been deciphered as one of the suture zones in the northern Pakistan, which separates the Kohistan Island arc from the Indo-Pak. continent. The single Indus Tectonic Line, earlier identified in Tsang Po and Ladakh by Gansser (1974) and other geologists, bifurcates into two lineaments, west of Nanga Parbat—Haramosh loop. One of them is called the Northern Megashear which traverses the northern Baltistan through Machelu Hashupa-Tissar and passes through Gilgit and Chitral along Hini-Chalt-Yasin and Drosh line. The other lineament passes through Dras-Astor, then takes a loop around Nanga Parbat—Haramosh transverse antiform and reappears north of Babu Sar Pass. From here it takes an east—west course, passing through the northern fringe of Hazara, Upper Swat, and southern Dir, before entering Afghanistan. The letter mentioned lineament has been differentiated as the Main Mantle Thrust, a separate Tectonic Zone welding Indo-Pak. plate with the Kohistan arc.

In Hazara, the MMT occupies a high topographic front from the southern terrain, suggesting the northern contact to coincide with upthrown block over the rocks of Hazara and their equivalents in the west, which has been incorporated by the author in the Lesser Himalayan Zone.

Along the MMT, the mafic and calcalkaline rocks of the Kohistan Zone have thrust over the folded and varyingly metamorphosed metasedimentary sequence of Besham Group (Tahirkheli, 1979), which occupies the northern margin of the Indo-Pak. continent. The thrust is southward directed and surficial observations reveal a displacement of 10-15 km, locally in some sections this throw may have further enhanced. The seismic pattern on its underground behaviour telemetered from Tarbela observatory, suggest this lineament to spread in 20-40 km wide zone.

The accessible sections, where this thrust is not much affected by surficial scavengering and can be clearly deciphered, are located, east of Sassi Panyari and near Babu Sar Ulta village in Gilgit region, Jijal, Shangla and Mingora in Swat and near Zulum and Khar villages in Dir.

This megashear has special significance in having association of high density rocks, such as peridotites, mainly harzburgite with websterites, diopsidites and garnet pyroxenites, which are tectonically transported from the upper mantle. Between Jijal and Pattan, in the Indus valley, high pressure granulite facies rocks commonly of garnet – diopsidic pyroxene — Ca/plagioclase — zoisite — rutile are associated with the MMT.

A thick slice of Besham Group has shown glaucophane schists association in the close vicinity of MMT. The noteworthy occurrences are locatad in Shangal and Topsin, which were earlier reported by Shams (1972) and Desio (1974). Recently some more sections containing glaucophane-bearing schists are reported from Babu Sar, northeast of Mingora and east of Zulum. These places contain sporadic showings of glaucophane schists, its thickest development being in Shangla, which are associated with the subduction zone of the Indo-Pak. plate along the MMT.

KOHISTAN ZONE

Gansser (1964) and Desio (1964) had termed Kohistan as a tectonic zone of Karakorum. Due to lack of geological informations, the tectonic status of Kohistan in the framework of NW Himalaya remained uncertain for long. During recent years, researches carried out by Tahirkheli et al (1979) revealed a new picture in which Kohistan has been differentiated as an island arc on the northwestern tip of the Indo-Pakistan Plate.

Kohistan is comprised of dominantly mountainous terrain where the elevation of the mountains rises to over 5000 m. a.s.l. The general trend of the ranges swings between east and north-east which corresponds with the general strikes of the rocks.

Because of high relief, most of the mountains are snow-clad during winter months, as a result the erosional features of Kohistan distinguishes it from the surrounding areas. Ice skittled, Materhorn type sharp peaks with precipitous valleys dominate the general topographic features.

The dominant rock types in Kohistan are comprised of calcalkaline/mafic igneous suite and granites with subordinate volcanics. The metasediments, forming E-W trending isolated linear belts in the vicinity of Kalam, Dir, Chilas and Chalt, show varying degree of metamorphism. The following litho-units have been differentiated in Kohistan (Tahirkheli, 1979).

8. Kohistan Granites, incorporating Ladakh Granodiorite and Swat Granites.

7. Deshai Diorites : Orbicular Diorites, Smoky Diorites, Massive Diorrtes, Gneissose Diorites.

6. Kohistan Complex : Bahrain Pyroxene Granulites
Kamila Amphibolites
Jijal Ultramafics
Pattan Garnet Granulites

5. Yasin Group : Shyok Meta-volcanics, Reshun Group.

4. Dir Group ii. Utror volcanics
i. Baraul Banda Slates

3. Kalam Group iii. Shou Quartzites
ii. Deshan Banda Limestone
i. Karandukai Slates

2. Greenstone Complex

1. Chalt Formation

A detailed description of these litho-units will be beyond the scope of this paper, therefore the readers are recommended to follow them in a special Monograph on the Geology of Kohistan by Tahirkheli and Jan (1979).

The Kohistan Zone, as a result of its interaction as an Island arc with Eurasia and Indo-Pak. continents, has undergone severe deformations that, beside inducing variable metamorphism in its rock assemblage, has created numerous major and minor tectonic scars which have not been properly deciphered so far. The protrusion of Nanga Parbat—Haramosh transverse antiform into Kohistan Zone is the result of the stresses generated after welding of Kohistan with Eurasia and Indo-Pak Plates during the last phases of the Himalayan orogeny.

The metasedimentary deposit, located on the northern margin of Kohistan and discussed elsewhere by the author under Chalt Formation, is relatively more metamorphosed than the rocks of Dir and Kalam Groups. Their grade of metamorphism, in g neral, ranges from epi-to meso, but in some isolated sections in Shigar valley in Baltistan and in the northwest of Nanga Parbat—Haramosh loop kata—grade rocks are also associated. Wadia (1945), on the basis of higher grade of metamorphism and association of graphitic beds, had considered these rocks to be equivalent to Salkhalas underlying the Dogra Slates on the northwestern morgin of Indo-Pak. Plate.

This metasedimentary belt is considered to be much younger to Salkhalas and the author does not think it to be older than Cretaceous. There are three reasons for it being more metamorphosed than the rest.

Firstly, this belt is involved in severe tectonics because of its location between the Northern Megashear and Nanga Parbat—Haramosh loop ; secondly, there are chances of inclusions of tectonic slices from the abducted Dumordu Formation which is comprised of relatively more metamorphosed rocks on Eurasian plate margin ; and thirdly, the effects of contact metamorphism by the younger igneous emanations.

The rest of the metasedimentary outcrops in the Kohistan zone are comprised of slates, mica schists, garnet schists, quartzites and semi-crystalline limestone. The slates have yielded fossils, identified as *Actinocyclina*, *Discocyclina* and *Nummulites Atacicus*.

NORTHERN MEGASHEAR

The northern extent of the Kohistan Zone is delimited by a Megashear which separates it from the Karakorum Zone. This megashear, since the inception of the idea of the Indus Tectonic Line in the Tsang Po area welding India with the Eurasian Plate, is being considered its western extension.

The Northern Megashear is demarcated through Machelu-Hashupa-Tissar in Baltistan, Hini—Chalt—Yasin in Gilgit and passes in the vicinity of Drosh through Chitral before entering Afghanistan. This Megashear forms a southwardly concave arc which corresponds to the general trend of the mountains in this region. This arcuate bend, as considered earlier by Wadia (1932) and Gansser (1964), is the reflection of Hazara—Kashmir syntaxis.

Along this tectonic line the metasedimentary sequence of Dumordu Formation has thrust over the Yasin/Reshun Groups and Greenstone Complex which represent the last remanants of marine sedimentation during Cretaceous in the shrinking Tethys in this region.

The thrust is directed southward and has a displacement of 10-15 km. In some sections, this thrust gives a look of high angle reverse fault which may be the result of subsequent stresses generated during the late Himalayan orogency.

The Northern Megashear is associated with ophiolite suite along the subduction zone. The volcanic rocks, some with well-developed pillow structure indicating oceanic origin, are associated with the Yasin Group and its equivalents in Baltistan and Chitral.

KARAKORUM ZONE

The Northern Megashear separates the Kohistan zone from the Karakorum, which comprises the southern margin of the Eurasian platform. In Karakorum, two litho-tectonic zones are differentiated.

i. The Metamorphic Zone
ii. The Tethyan Zone

These zones have extensions in Chitral and Baltistan, lying respectively, towards west and east of Hunza valley where these observations were made. The Karakorum Range inhibits some of the tallest peaks in the world. In the vicinity of Hunza, the elevations of the mountains ranges from 2400 to 7785 m above sea level. The main floor of the Hunza valley is about 1800 m, in the vicinity of Chalt and culminates to over 3500 m. a.s l. in the north, near the border with China.

The metamorphic zone, lying on the southern margin of the Eurasian continent, obducts the Kohistan Zone along the Northern Megashear. This zone is divisible into two litho-units :

i. Axial Granodiorite Batholith, and
ii. Dumordu Formation

The Dumordu Formation of Desio (1963) was also earlier called Darkot Group by Ivanac et al (1956) and Baltit Group by Stauffer (1968). It is comprised of two lithologies, pelites and carbonates, the former being dominant.

These rocks are comparatively more metamorphosed than the other rocks occupying the marginal area of Eurasian continent. The southward extension of these rocks, as stated earlier, is delimited by the Northern Megashear and on the north their contact with the Karakorum Granodiorite is gradational, which is demonstrated by the tonguing of granodiorite, pegmatite, aplite and lamprophyre bodies in the meta-suite. Besides, large bodies of xenoliths from Dumordu Formation are also found emplaced in the batholith near the contact zone.

Among the common rock types comprising the Dumordu are gneisses, garnet mica schist, garnet amphibolite, staurolite schist, micaceous quartzite, and marble. The author considers these rocks to form one of the oldest units on the southern margin of Eurasian plate.

The Karakorum Granodiorite forms an arcuate bend, following the general trend of the mountains in Karakorum. It starts from Shyok Valley in Baltistan, in the east, and terminates near Mastuj in Chitral, in the west. The granodiorite is medium grained, mostly massive but displaying gneissosity on the margins where the effect of metamorphism is more pronounced. Cumulative result based on the examination of several thin sections, reveal 35-40% quartz, 25-30% plagioclase 25-28% muscovite and biotite with lesser amounts of microcline, orthoclase and myrmekite. Accessories usually constitute less than 1% and consist of ilmenite, magnetite, zircon and apatite. The microscopic texture developed in some minerals, for instance strained quartz, bent plagioclase twin lamellae, and presence of minute garnet crystals point out to some degree of metamorphism, the Karakorum Granodiorite has been subjected to dating, with Rb/Sr method on two samples of granodiorite (Desio 1964), has given an age of 8.6. m.y. This date places it in Pliocene, which suggests its mild metamorphism to be the result of last phases of Himalayan orogeny.

The northern contact of Karakorum Granodiorite is faulted. In Hunza valley, this fault lies between the granodiorite and Passu States. The fault is east-west trending and dips steeply towards south and marks a sharp contact between the rocks.

This fault has a regional status and has been also diagnosed farther east, displacing the similar type of sequence between Alchori and Dassu in Shigar valley and upstream of Machelu in Shyok valley in Baltistan, where the extension of Karakorum Granodiorite has been marked. The fault lies between the slates, considered equivalent to Passu Slates and Karakorum or Axial Granodiorite Batholith. Here also the fault is northward directed at medium to high angles and may have a displacement of 5-10 km. Mattauer el al (1979) have named this fault as Main Karakoram Thrust. Some late acid igneous intrusives associated with the granodiorite cut across the fault and appear to be younger to the fault. It may be mentioned here that some of the earlier workers considered the Axial or Central Gneisses of Karakorum to form a wedge of upthrust basement forming a root of northward directed thrust and nappes of the Lesser Himalayas, which was assigned a Precambrian age.

The Tethyan Zone is separated from the metamorphic zone by Karakorum Granodiorite batholith. It is comprised of sedimentary rocks which yielded Late Palaeozoic fauna. Based on Schnieder's (1957) and Desio's (1972) classifications, the following rock formations are differentiated in this zone :

(i) Passu Slate, (ii) Gujal Dolomite, (iii) Gircha Formation, a complex of argillaceous, arenaceous and calcareous rocks, (iv) Kilik Formation, dominantly calcareous with subordinate argillaceous and arenaceous beds, and (v) Misgar Slates.

The assemblage of competent carbonate and incompetent argillaceous rocks in the Tethyan Zone have behaved varyingly to the regional tectonics, as a result complex nature of structures are developed. Undulatory strikes, squeezed folding, block faulting and thrusting are quite significant structural features displayed by these rocks.

The general tectonic trend in the rocks swings between NW to WNW and is parallel to the tectonic axis of the Karakorum Granodiorite batholith, lying to the south. On the basis of various cycles of igneous emanations and structures, one may work out atleast three phases of orogenic activities during Alpine period, Paleocene, Eocene and Miocene/Pliocene.

Pre-alpine structural elements are present in the Tethyan rocks which have earlier been reported by Desio (1972) also. Those elements seem to point out to an orogeny in the Palaeozoic, which may belong to Hercynian or earlier. According to Desio, these movements have given rise to Upper Hunza Fault and Chalt Fault, which were reactivated during later Alpine orogenic phases. The author considers both of these faults to have originated during the earlier Alpine orogeny; Chalt Fault which is the westward extension of the Indus Suture was created during Kohistan—Eurasia contact sometime during late Cretaceous whereas the Upper Hunza Fault may be as young as Oligocene/Miocene.

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TECTONIC FRAMEWORK OF THE INDUS OIL AND GAS BASIN

By

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Abstract : *The tectonic framework of the Indus oil and gas basin sensu stricto in terms of interrelation ship of its various constituent structural elements, is being considered for the first time. Generally speaking the Indus oil and gas basin is comprised of plateform monoclines in the east and belt of en echelon depressions alongwith their folded flanks in the west.*

A detailed study of geological construction of the Indus oil and gas basin comprising of an area of 275,000 sq. Km , aided with the interpretation of satellite imageries furnishes a great deal of information about various structures existing in the area, otherwise uniddentifiable through conventional geological means of study. It was noticed that most of the structural elements in the study area are demarcated by regional faults, The transitional zones between the platform monoclines and depressions are complicated by meridionally elongated val structures. The Sukkur region is interpreted as an aulacogen. It is established that Sukkur aulacogen is in direct continuation with the Gambay graben, a highly prospective region for oil pools.

INTRODUCTION :

The present paper deals with the tectonic framework of south-eastern Pakistan, stretching between latitude 24°N –32°N and longitude 67° E-73° E approximately. The area under study, satisfying all the three conditions, i. e. generation, accumulation of dispersed hydrocarbons and conservation of oil and gas pools, for a given oil and gas basin, has been named by the author as "Indus oil and gas basin". Geographically it is confined to the lower course of the river Indus. Since, the oil and gas basin occupying the upper course of river Indus is popularly known in the literature as ' Kohat-Potwar oil and gas basin", therefore, it will be appropriate to call the area under review simply as "Indus oil and gas basin."

On regional basis, Indus oil and gas basin may be considered as part of a vast system of deep depressions which have formed in the conjugation of African, Arabian and Indian ancient platforms with the Alpine-Himalayan orogenic belt (Fig. 1). These vast regions of subsidence are distinguished as laterally heterogeneous (Olenin 1977) or folded-platform basins (Sokolov 1977). These are characterized by asymmetric construction' Their one flank is formed of a wide, gently dipping platform monocline and the other presents itself as a narrow folded zone. Deeply submerged parts of these basins are generally compressed against the folded flank.

Folded-platform or laterally heterogeneous Indus oil and gas basin is situated between the alpine mountain ranges in the west and Thar desert in the east. Northern, eastern and southern limits of the basin are defined by the large platform uplifts. In the

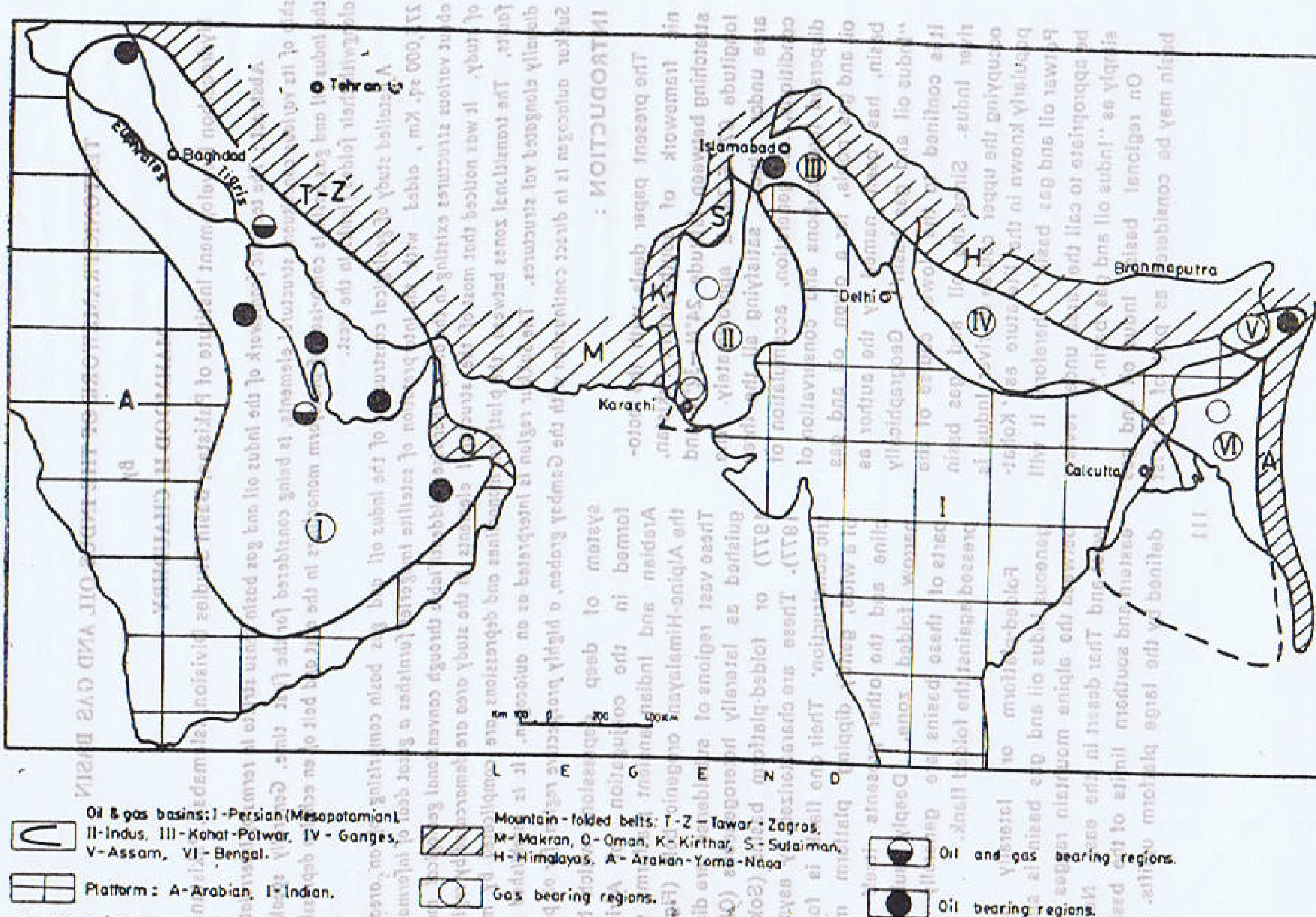

Fig. 1 Schematic map of folded-platform basins of south-western and southern Asia. (After B.A Sokolov, with changes 1973) Mahmood H. Chaudry, 1978

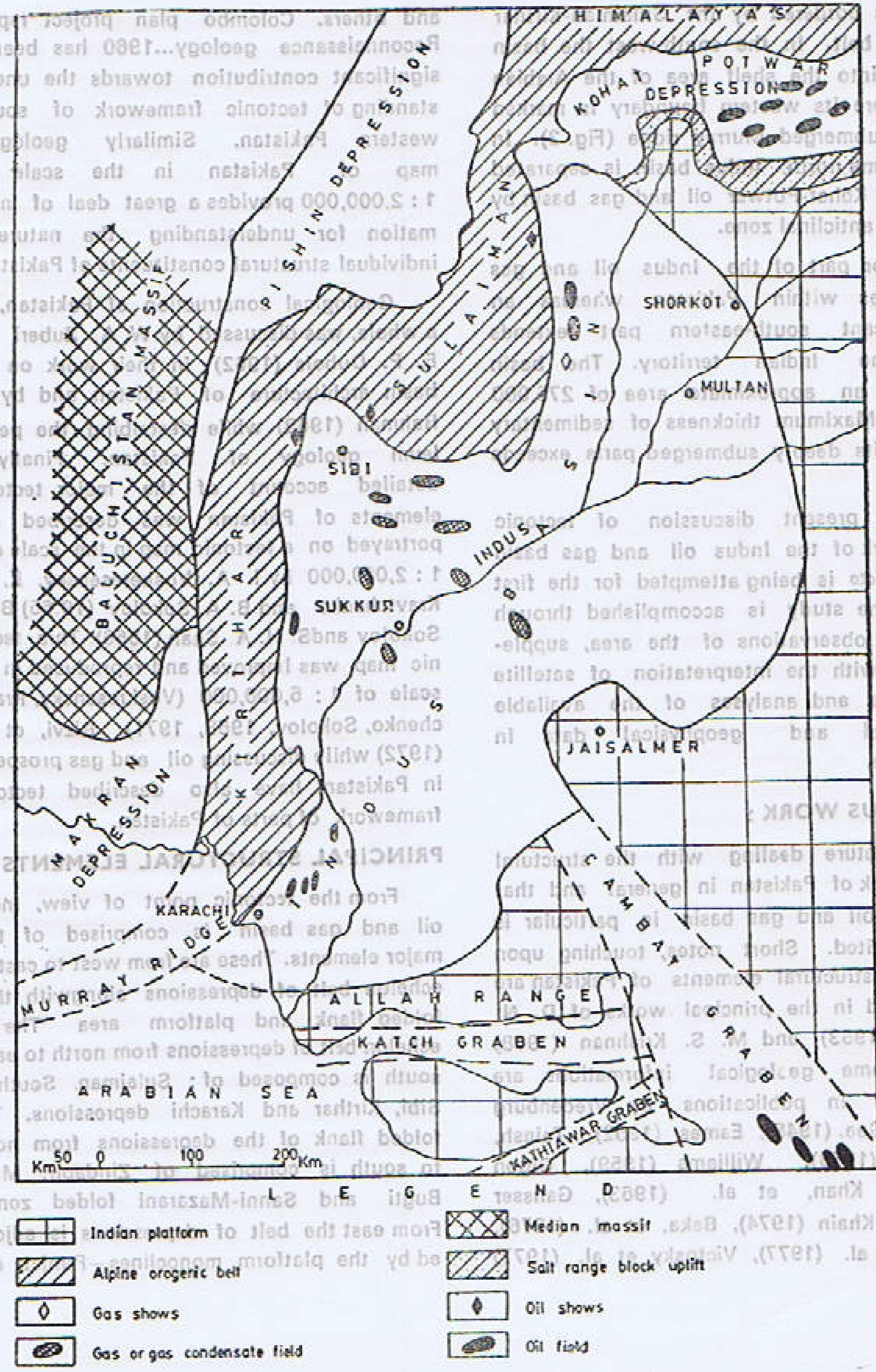

Fig. 2 Structural setting of Indus oil and gas basin. (Mahmood H. Chaudhry, 1978)

west it is bordered by the Sulaiman-Kirthar orogenic belt. In the south-west the basin extends into the shelf area of the Arabian sea, where its western boundary is marked by the submerged Murray ridge (Fig. 2). In the extreme north, Indus basin is separated from the Kohat-Potwar oil and gas basin by the Pezu anticlinal zone.

Major part of the Indus oil and gas basin lies within Pakistan, whereas an insignificant south-eastern part extends over the Indian territory. The basin occupies an approximate area of 275,000 sq. Km, Maximum thickness of sedimentary cover in its deeply submerged parts exceeds 10 km.

The present discussion of tectonic framework of the Indus oil and gas basin *sensu stricto* is being attempted for the first time. The study is accomplished through personal observations of the area, supplemented with the interpretation of satellite imageries and analyses of the available geological and geophysical data in literature.

PREVIOUS WORK :

Literature dealing with the structural framework of Pakistan in general and that of Indus oil and gas basin in particular is very limited. Short notes, touching upon separate structural elements of Pakistan are contained in the principal works of D. N. Wadia (1953) and M. S. Krishnan (1968) also some geological informations are available in publications by Vredenburg (1901), Gee. (1948), Eames (1952), Tainsh, et al. (1959), Williams (1959), Gigon (1963), Khan, et al. (1963), Gansser (1973), Khain (1974), Beka, et al. (1976), Farah, et al. (1977), Victosky et al. (1977) and others. Colombo plan project report, Reconnaissance geology...1960 has been a significant contribution towards the understanding of tectonic framework of south-western Pakistan. Similarly geological map of Pakistan in the scale of 1 : 2,000,000 provides a great deal of information for understanding the nature of individual structural constituents of Pakistan.

Geological construction of Pakistan, as a whole, was discussed by W. A. Zuberi and E. P. Dubois (1962) in their work on the basin architecture of Pakistan and by H. Rahman (1963) while describing the petroleum geology of Pakistan. Finally a detailed account of the major tectonic elements of Pakistan was described and portrayed on a tectonic map in the scale of a 1 : 2,000,000 by I. A. Voskeresensky, K. N. Kravtchenko and B. A. Sokolov (1965) B. A. Sokolov andS. H. A. Shah (1966). This tectonic map was Improved and reproduced in the scale of 1 : 5,000,000 (Voskresensky, Kravtchenko, Sokolov, 1968, 1971). Rizvi, et al. (1972) while discussing oil and gas prospects in Pakistan, have also described tectonic framework of parts of Pakistan.

PRINCIPAL STRUCTURAL ELEMENTS

From the tectonic point of view, Indus oil and gas basin is comprised of two major elements. These are from west to castern echelon belt of depressions alongwith their folded flank and platform area The en echelon belt of depressions from north to easten south is composed of : Sulaiman. Southern Sibi, Kirthar and Karachi depressions. The folded flank of the depressions from north to south is comprised of Zindapir, Mari-Bugti and Sanni-Mazarani folded zones. From east the belt of depressions is adjoined by the platform monoclines --Punjab and

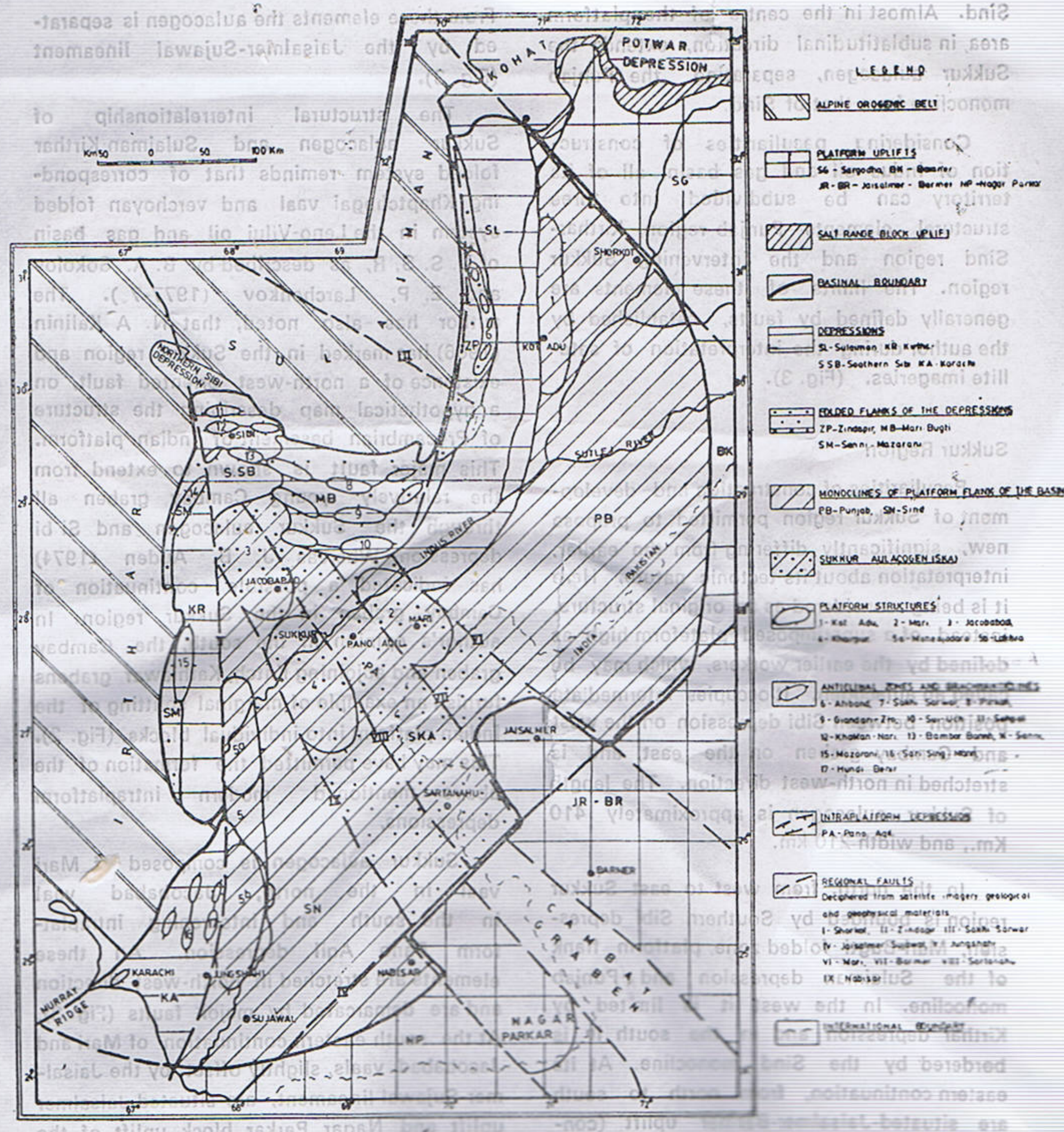

Fig. 3
Principal structural elements of the Indus oil & gas basin (Mahmood H. Chaudhry, 1978)

Sind. Almost in the centre of the platform area, in sublatitudinal direction, extends the Sukkur aulacogen, separating the Punjab monocline from that of Sind.

Considering peculiarities of construction of Indus oil and gas basin, all of its territory can be subdivided into three structural elements—Punjab region, Kirthar-Sind region and the intervening Sukkur region. The limits of these elements are generally defined by faults, established by the author during the interpretation of satellite imageries. (Fig. 3).

Sukkur Region

Peculiarities of construction and development of Sukkur region permitted to propose new, significantly differing from the earlier, interpretation about its tectonic nature. Here it is being considered as an original structure, instead of a superimposed plateform high as defined by the earlier workers, which may be called an aulacogen. It occupies intermediate position between Sibi depression on the west and Cambay graben on the east, and is stretched in orth-west direction. The length of Sukkur aulacogen is approximately 410 Km., and width 210 km.

In the north, from west to east Sukkur region is bounded by Southern Sibi depression, Mari-Bugti folded zone, platform flank of the Sulaiman depression and Punjab monocline. In the west it is limited by Kirthar depression and in the south it is bordered by the Sind monocline. At its eastern continuation, from north to south are situated-Jaisalmer-Barmer uplift (consisting of exposures of Mesozoic and Paleogene sedimentary rocks), Cambay graben and Nagar Parkar uplift of the plateform. From these elements the aulacogen is separated by the Jaisalmer-Sujawal lineament (Fig. 3).

The structural interrelationship of Sukkur aulacogen and Sulaiman-Kirthar folded system reminds that of corresponding Khaptchagai vaal and verchoyan folded system in the Leno-Vilui oil and gas basin of U. S. S. R, as described by B. A. Sokolov and E. P, Larchenkov (1977-7.). The author has also noted, that N. A Kalinin (1966) has marked in the Sukkur region and existence of a north-west oriented fault, on a hypothetical map describing the structure of Precambrian basement of Indian platform. This major fault is shown to extend from the relatively young Cambay graben all through the Sukkur aulacogen and Si bi depression Whereas J. B. Auden (1974) has indicated a possible continuation of Cambay graben in the Sukkur region. In author's opinion in the south, the Cambay graben and adjoining Katch, Kathiawar grabens furnish an example of marginal splitting of the Indian platform into individual blocks. (Fig. 2). This may have permitted the formation of the above mentioned modern intraplatform depressions,

Sukkur aulacogen is composed of Mari vaal in the north, Jacobabad vaal in the south and intervening intraplatform Pano Aqil depression. All these elements are stretched in north-west direction and are demarcated by major faults (Fig 3). At the south eastern continuation of Mari and Jacobabad vaals, slightly offset by the Jaisalmer-Sujawal lineament, are situated Jaisalmer uplift and Nagar Parkar block uplift of the platform. It is worth mentioning, that Cambay graben is in continuation whith Pano Aqil intraplatform depression.

Jacobabad vaal forms the elevated part of the Sukkur aulacogen, relative to which Mari vaal is low lying. Jacobabad vaal consists of two domes; Jacobabad in the north and Khairpur in the south. Thickness of Cretaceous rocks at Khairpur structure exceeds 1.5 km, whereas at Jacobabad structure they completely pinch out and here Jurassic horizons occur at a depth of 1.0 km or so. This characterizes the Sukkur region for shallow occurrence of Mesozoic rocks especially the Lower and Middle.

Most of the Sukkur region is covered by recent sediments, and only near Khairpur city Middle Paleogene rocks are exposed within its confines, Sulaiman-Punjab Region.

Sulaiman-Punjab region is composed of Sulaiman depression alongwith the folded flank-Zindapir, Mari-Bugti folded zones, and Punjab monocline.

SULAIMAN DEPRESSION

It is a large area of subsidence. In the west it is bounded by Sulaiman meganticlinorium and Southern Sibi depression. In the east it conjugates with Punjab monocline and in the south with Sukkur aulacogen. In the north it is separated from Kohat-Potwar depression by the Pezu anticlinal zone.

Two distinct elements are distinguished within the confines of Sulaiman depression. These are: (I) internal folded flank and (II) external platform flank. As compared with the platform flank, folded flank of the Sulaiman depression is much shorter. Platform flank presents itself as a simply constructed monocline.

(I) Internal folded flank of the Sulaiman depression is comprised of two folded zones: (a) Zindapir and (b) Mari-Bugti.

(a) Meridionally oriented Zindapir folded zone forms the western flank of Sulaiman depression (Fig 3). It is approximately 320 km. long and 30 km. wide. In the west Zindapir folded zone is bounded by the Sulaiman meganticlinorium. The contact between the two is marked by the Zindapir fault (Fig. 3).

Zindapir folded zone consists of two en echelon anticlinal zones; Afiband and Sakhi Sarwar. These anticlinal zones are offset by the Sakhi Sarwar fault (Fig. 3). Afiband structure presents itself as a major anticlinal zone with narrow crest and box form. Its hinge, as a whole is plunging towards north. It has a size of 110×10 km. approximately. Four anticlines are distinguished on the axis of Afiband anticlinal zone. These are from south to north Zindapir, Afiband, Rhodo and Dhodak. Cretaceous and Paleogene rocks are exposed in the cores of these structures. Afiband anticlinal zone has a complicate structure. Within its confines are distinguished underthrusted and overthrusted blocks. Elements of analogous construction are known from a number of other regions of the world, for example, in the western folded flank of the Western-Canadian oil and gas basin and in the Tar-Sunjen range of the Northern Caucasus (E O. Brod, et al., 1960).

In the south, Afiband anticlinal zone is en echelon succeeded by Sakhi Sarwar anticline, which has a size of 30×10 km. approximately. Neogene rocks are exposed in the core of the anticline.

(b) Distinctly expressed in relief Mari-Bugti folded zone occurs in the south-west of Zindapir folded zone. It has a size of 150×100 km. approximately. For this structural element of the Indus oil and gas basin, sublatitudinally oriented anticlinal zones are characteristic. The latter are separated from each other by wide, shallow synclines. From north to south, following major anticlinal zones are distinguished; Pirkoh, Giandari-Zin, and Sui-Uch. At these folds rocks of Lower and Middle Paleogene are exposed. The folds have wide, smooth crests with gently dipping northern and steep southern limbs. Generally fold construction approaches to box form.

Mari-Bugti folded zone, due to its expression in relief and construction of folds, can be divided into two parts-Northern and southern zones. Northern zone is characterised by elevated position in relief, expressed as mountain ridges and complicate folds. The anticlinal zones of this part, along the strike, are in continuity with the structures of the neighbouring Southern Sibi depression. The Southern zone is low lying in relief and is characterized by simple fold form.

(II) External platform flank of the Sulaiman depression presents itself as a submeridionally oriented large area of subsidence. It has a size of 470×75 km. approximately. Most of the territory of the platform flank is covered by alluvium. In the upper part, it is filled with Neogene, Upper Paleogene molasses, which is underlain by thick sequences of Mesozoic and Lower-Middle Paleogene marine sediments. Thickness of the molasse complex exceeds 3 5 km. and total thickness of sedimentary filling may be well over 10 km. Mesozoic and Lower-Middle Paleogene rocks sharply thin out in the direction of Punjab Monocline. This provides a sound base to postulate the existence of traps connected with pinch out and unconformities on the platform flank of the Sulaiman depression.

PUNJAB MONOCLINE

Punjab monocline is situated in the north-eastern part of the Indus oil and gas basin. It is bounded in the north-east by Sargodha, in the east by Bikaner and in the south-east by Jaisalmer-Barmer uplifts of the platform. Sukkur aulacogen serves as its southern limiting element. In the west it conjugates with Sulaiman depression. Northern, southern and south eastern boundaries of the Punjab monocline are marked by faults (Fig. 3). Its length exceeds 550 km. and width reaches a maximum of 180 km.

Northern half of the Punjab monocline is comparatively shorter than the southern. The angle of inclination of Mesozoic rocks is in the order of 2-3°. Dip direction changes from south-west in the north, to north-west in the south (Voskresensky, et al., 1971). At the extreme east of the Punjab monocline, basement rocks were penetrated at a depth of approx. 3 km. in the Karampur structure. During the interpretation of the satellite imageries, possible vaal type, submeridionally oriented structural element-Kot Adu (Fig. 3) was noted in the transitional zone between the Punjab monocline and Sulaiman depression.

KIRTHAR SIND REGION

Kirthar Sind Region occupies the southern half of the Indus oil and gas basin. It is comprised of Kirthar depression alongwith its folded flank-Sanni-Mazarani, Southern Sibi depression, Karachi depression and Sind monocline.

KIRTHAR DEPRESSION

Kirthar depression is a narrow, meridionally elongated asymmetric zone of subsidence. It has (I) a narrow, internal folded flank in the west and (II) comparatively wider, external platform flank in the east.

In the west Kirthar depression is limited by Kirthar meganticlinorium and in the east by Sind Monocline, and Sukkur aulacogen. In the north, it is succeeded by Southern Sibi depression. In the south of Kirthar depression, en echelon occurs the Karachi depression. Eastern boundary of the Kirthar depression, as interpreted from satellite imageries, is marked by the Jangshahi fault (Fig. 3).

(I) Internal folded flank of the Kirthar depressions is represented by the Sanni-Mazarani folded zone (Fig. 3). It is made up of two asymmetric anticlinal zones. These are (a) Sanni in the north and (b) Mazarani in the south. Their total length is around 340 km. and width upto 20 km.

(a) Sanni anticlinal zone from the surface is made up of Middle, Upper Paleogene and Neogene rocks. In the north it en echelon joints with Bennh anticline of Southern Sibi depression. Within its confines narrow, comb like, anticlinial fold-Sanni, having a size of approx. 55 × 10 km. is clearly outlined. Structure of the Sanni fold is complicated by faulting and secondary folding.

(b) Within the confines of Mazarani anticlinal zone, meridionally oriented Mazarani fold, having a size of abont 70 × 15 km. is distinctly expressed in relief. In the section, it has a smooth transverse profile. The eastern limb of the fold is complicated by faulting. Rocks exposed on the Mazarani fold are of Neogene age.

(II) External platform flank of the Kirthar depression is a meridionally elongated, narrow, submerged zone and has dimensions of 380 × 40 km. approx. In the north it is filled with Neogene molassic complex reaching a thickness of more than 4 km. (Movshovitch, et al., 1965). This is underlain by Paleogene Mesozoic marine sediments. The total thickness of sedimentary filling exceeds 10 km. Within the confines of platform flank as a result of geological and geophysical studies two local depression are distinguished. These are Dadu in the south and Kachhi in the north. (Voskresensky, et al., 1971, Rizvi, et al. 1972).

SOUTHERN SIBI DEPRESSION

In the present study it is considered, that only the southern, submerged part of the Sibi depression falls within the limits of Indus oil and gas basin. It is, most probably, centroclinal closure of the Kirthar depression. Its size is approximately 120 × 80 km. In the north it is bounded by the Northern Sibi depression, which is, at places, orographically elevated up to 3.5 km. or more above sea level. In the north and south Southern Sibi depression is limited by Sulaiman meganticlinorium and Sukkur aulacogen respectively. Its western boundry with the Kirthar depression is marked by Jungshahi fault (Fig. 3), whereas its eastern extension is limited by the Mari-Bugti folded zone. Southern Sibi depression is filled with molassic complex, exceeding 5-7 km. in thickness.

In the Southern Sibi depression folds are perpendicularly oriented to its main elongation, e g , Sehpal, Khattan-Nari, Bambor-Bannh etc. Fold structure in the south is asymmetric and simple. In the north these are complicated by secondary folding and have steep limbs and deeply submerged synclinal troughs. According to Voskresensky et al., (1971) the folds are developed in Neogene molasse and have a tendency of overturning towards south.

Periclines of folds from the neighbouring zones for a long distance project in the Southern Sibi depression. Thus, for example, western pericline of Pirkoh anticlinal zone of the Mari-Bugti folded zone joins with the anticlinal zone Bambor-Bannh, which, in turn, en echelon joins with the Sanni anticlinal zone of the Kirthar depression.

KARACHI DEPRESSION

The Karachi depression is situated at the southern periclinal termination of the Kirthar meganticlinorium. The length of the Karachi depression is approximately 230 km. and width reaches to a maximum of 100 km. in its southern part. From west and north it is limited by Kirthar meganticlinorium In the east it conjugates with Sind monocline and here its boundry is marked by the Jungshahi fault (Fig. 3). Karachi depression narrows down in the north, where as in the south it opens up into the Arabian sea.

Sedimentary filling of the Karachi depression includes Paleogene and Neogene marine terrigenous sediments reaching a thickness of 5 km. or more, underlain by the Cretaceous and possible Jurassic rocks.

In the section, Karachi depression has an asymmetric profile with the shifting of its axial part, some what towards west. Almost all the anticlinal zones are confined to eastern flank of the Karachi depression. Western flank presents itself as a narrow, simply constructed monocline. Structure of the eastern flank of the depression is complicated by submeridionally oriented asymmetric anticlines. Northern half of the depression relative to the southern is hypsometrically elevated. Here the folds have smooth gentle crests. The cores of the folds are formed of Upper Paleogene rocks.

Southern half of the Karachi depression is submerged. Here rocks of Miocene age are exposed on the surface. Towards further south these are underlain by terrigenous Pliocene sediments. The rocks have principally near horizontal attitude and clearly expressed folds are absent. Some local structures are known in the south-western offshore and south-eastern shelf area.

SIND MONOCLINE

Sind monocline is situated in the south-eastern part of the Indus oil and gas basin. It is limited from north by Sukkur aulacogen, in the east by Nagar Parkar uplift of the platform. In the west Sind monocline conjugates with Kirthar and Karachi depressions. Here its boundary is marked by Jungshahi fault (Fig. 3).

Sind Monocline, as compared with the Punjab monocline, is significantly low lying. In the extreme west structure of the Sind monocline is complicated by meridionally elongated Mohenjodaro-Lakhra vaal, having a size of 300 x 40 km. approx. Northern Mohenjodaro part of the structure (Fig. 3) is marked by the author during the interpretation of satellite imageries. Lakhra part, occupying the southern half of the structure, is complicated by meridionally elongated brachyanticlines. Rocks of Paleogene and Neogene ages are exposed within the confines of the vaal. Nabisar arc is another structural feature situated in the south-east of Sind monocline, where a number of small local folds are outline Northern half of the Sind monocline is submerged relative to Sukkur aulacogen and Mohenjodaro-Lakhra vaal.

Sedimentary cover on the Sind monocline, where a number of small local folds are outlined. Northern half of the Sind monocline is submerged relative to Sukkur aulacogen and Mohenjodaro-Lakhra vaal.

Sedimentary cover on the Sind monocline is formed of Mesozoic, Paleogene and Neogene rocks. These are, for most part of the Sind monocline, underlain by alluvium. On the Sind monocline Mesozoic rocks are fully developed. Paleogene formations show a tendency of sharp decrease in their thickness from west to east.

DISCUSSION AND CONCLUSIONS

The present detailed study of geological construction of Indus oil and gas basin aided by the interpretation of satellite imageries permitted to define its boundaries. It has been noticed by the author that eastern boundary of the basin is marked by Bikaner and Jaisalmer-Balmer uplifts of the platform. Whereas within the confines of the Nagar-Parkar high, limiting the southern extention of the basin, a separate block element bounded by the faults, has been delineated.

The performed studies revealed that the Sukkur region of the platform area provides a classical example of triple junction. It is postulated that Sukkur region through, and only at a later stage, possibly at the end of Jurassic time, it has exprienced an inversion under the effect of lateral compressional movements. This is confirmed by the complete absence of Cretaceous rocks at Jacobabad dome.

Interpretation of the Sukkur region as an aulacogen is of great significance, both from theoretical point of view and for practical purposes. Sukkur region, probably, has a block construction. This is propounded both for the Mari and Jacobabad vaals and for the intra-platform Pano Aqil depression. Such an interpretation also offers solution for the sudden exposures of Middle Paleogene rocks near Khairpur and Mesozoic-Paleogene rocks in the vicinity of Jaisalmer, uplift of individual which have most probably resulted due to the blocks, under the effect of dominant compressional area.

Sulaiman-Punjab and Kirthar-Sind region though situated in the north and south of Sukkur aulacogen. demonstrate a striking similarity in their construction. From east to west these are composed of platform monoclines and adjoining depressions. In both these regions, meridionally oriented vaal structures are disposed in the transitional zones between the platform monoclines and depressions.

Position of Mari-Bugti folded zone, termed by the previous workers as Sui trough (Zuberi and Dubois, 1962) or saddle (Sokolov, and Shah. 1966) is conjectural. This structural element is considered in the present work as a folded flank of the Sulaiman depression. Therefore, it is proposed, that within the confines of Mari-Bugti area both the internal and external flanks of the Sulaiman depression have undergone lateral compressional as well as vertical movements. Thus the present sublatitudinal orientation of the anticlinal zones of Mari-Bugti folded zone is possibly a resultant of an action of a variety of forces. The intensity of compressional forces was more severe from the northern, that is from the rising alpine orogen side. This is confirmed by the complicate folds in the northern and comparatively simple fold forms in the southern parts of the Mari-Bugti folded zone. The latter was not only compressed, but was also pushed forward towards the more mobile aulacogen region.

There is no doubt, that the newly interpreted structures need further work for the precise confirmation of their internal construction. However, it is possible to say that the location of Sukkur aulacogen in continuation of Cambay graben, a highly prospective region for oil pools, provides a reason to carry out such studies by geophysical means and stratigraphic drilling. Similarly vaal type platform structures-Kot Adu and Mohenjodaro-Lakhra could also be prospective for oil accumulation.

They are such disposed, that migrating hydrocarbons from the neighbouring depressions could hardly escape. if intercepted on their way by suitable traps. In this connection Lakhra structure may be cited as an example, which has yielded, though overwhelmed by uncombustible components, gas pools.

An immediate deduction of the above study shows that the several constituent structural elements of the Indus oil and gas basin are demarcated by major faults, which have been interpreted for the first t;me from satellite imagery. It, therefore, confirms that these features viz., platform area, Sukkur aulacogen and depressions need separate treatment, while evaluating their potential in terms of minerals and mineral fuels.

ACKNOWLEDGEMENTS

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A PRELIMINARY STUDY OF TECTONIC ELEMENTS IN DARRA ADAM KHEL AREA, DISTRICT KOHAT

By

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Abstract : *A part of Kohat tribal belt in Darra Adam Khel area (Kohat district) was mapped for geological and structural studies. The area exhibited a tectonic style of typical lateral compressional movements. Two enormous sheets of older allochthonous sediments are overthrusted over younger autochthonous strata in quick succession. A detailed study of geology and mode of deformation of two allochthonous sheets is given along with their possible mechanisms of detachment and tangential displacement.*

INTRODUCTION

The area studied covers approximately 135 square kilometers in Kohat-Potwar depression, lying within longitudes 71°26, 20"-71° 34' 35" East and latitudes 33°36, 40"-33° 0" North.

The area is of moderate relief with surface of rock strata rising approximately 534 metres above sea level from the alluvial tracts to about 1526 metres above sea level in mountain peaks. A network of intermittent streams drains the entire area with major streams occupying mature, terraced valleys. Dominant drainage pattern is dendritic. Alternating hard and soft lithologies make distinct escarpments and strik e valleys in the southern and middle part of the area.

Four times photographic enlargements of original toposheet No. 38 0/6 & 38 0/10 of Survey of Pakistan provided the base for all geological and structural studies. The project was completed as part of requirements for M. Sc. thesis.

STRATIGRAPHY

The rock units exposed in the area range in age from Middle Jurassic to Miocene with sub-Recent to Recent alluvium. The body of rocks consists of structurally complex sequence of sedimentary units that exhibit significant contrasts in their facies and thickness. After the study of inter-relationship between lithology and structure it was evident that Miocene autochthonous strata of Murree Formation are overthrusted by older allochthonous sediments in two successive sheets. Following stratigraphic succession was established in the area :

Autochthonous Sediments

Age	Formation	Characters
Early-Middle Miocene	Murree Formation	Sandstone, purple, dark-greyish-brown, greenish-grey, medium to coarse-grained, conglomeratic ; shale, purple and reddish brown.

Allochthonous Sediments

Age	Formation	Characters
Paleocene	Patala Formation	Shale, greenish grey, calcareous, hard, splintery; intercalations of nodular limestone; uncommon grit and microconglomerates occurrence; Foramanifera common.
	Lockhart Limestone	Limestone, medium to dark grey, finely crystalline, massive, nodular; fetid odour; Foraminifera common.
	Hangu Formation	Sandstone; white, stains rusty brown, reddish, pisolitic laterite near the base; shale reddish brown, ferruginous; intercalations of marl and shale.
		——————Disconformity——————
Cretaceous	Kawagarh Formation	Limestone; light to medium grey, fine grained, medium to thick-bedded, occasionally thin-bedded.
		——————Disconformity——————
	Lumshiwal Formation	Sandstone and quartzose sandstone, greenish grey to brownish green, stains brown, fine to medium grained.
	Chichali Formation	Shale, black, greenish grey, glauconitic; yellow dolomite with bedded chert; fossil fragments on weathered ferruginous surfaces at the base.
		——————Disconformity——————
Jurassic	Samana Suk Formation	Limestone, medium to dark grey, oolitic, medium to thick bedded, occasional dolomitic beds; base not exposed.

TECTONIC ELEMENTS

The most distinctive tectonic elements established after detailed geological and structural studies are two low-angle thrust faults of significant translational movements. Two allochthonous sheets made up of older sediments have thrusted over younger autochthonous infillings one after the other along these bedding plane thrust faults and represent two nappe structures. These nappes possibly resulted as a consequence of "decollement" of the sedimentary cover along some favourable lubricating horizons involving allochthonous series of sediments. Sediments of two allochthonous sheets were deposited with a similar history of formation but differed somewhat in material because the source rocks in two areas were to some extent different. This is evident by significant fasies differences shown by Chichali Formation and Hangu Formation within the two sheets. Thrusting can satisfactorily explain juxtaposition of two varied facies groups now piled one above the other. Even the deformation pattern showed marked contrasts. While folding appearing more intense in the Lower nappe, the rock sequence in upper nappe is frequently disrupted by faulting (generally intensity decreasing away from thrust planes).

AUTOCHTHONOUS TERRAIN

Autochthonous terrain is represented by Murree Formation of Early-Middle Miocene age, Rock strata consists of sandstone and shale of fresh-water origin. Autochthoneus terrain covers both the southern and northern extremities of the area, however outcrops in northern part are more wide-spread and extend further northward into Khyber Tribal Agency. These strata are not intensely deformed as the overthrusted allochthonous sediments. Folds are far more numerous which are generally of isoclinal type.

ALLOCHTHONOUS SEDIMENTS

(a) Kotal Nappe

The first detachment of sedimentary cover occurred at the Lower-Middle Jurassic level and led to the emplacement of first nappe. The thrust blanket of allochthon became detached and rode over a different tectonic terrain. The thrust that provided translational movement to this nappe is referred here as Kotmela Thrust (named after Village Kotmela in Akhurwal area). Kotmela thrust is a low angle bedding plane thrust and abruptly separates underthrusted autochthonous Murree Formation of Middle Miocene age from overthrusted Samana Suk Formation of Middle Jurassic. The sedimentary pile, of which Kotal nappe is built up, consists of rocks of varying competencies interstratified in a sequence of variable but enormous thickness. Rock sequence belonging to this nappe covers bulk of the study area in the southern part whereas in northern part thickness is considerably reduced showing a wedging tendency towards south. The facies of Kotal nappe are dominantly composed of fossiliferous shale, limestone, minor sandstone and dolomite and all these lithologies appear to be deposited in open, marine, shallow water environment with some minor stragnation at certain stratigraphic levels. The principal mode of deformation is a folding phase which seems to be contemporaneous with emplacement of second allochthonous mass. Intensity of folding varies and one finds open gentle flexures to tight folds with axial planes exhibiting all tendencies from vertical to horizontal. Fold axes show a roughly East-West orientation. Few folds are plunging.

Brecciation and contortions of strata along Kotmela Thrust at several places signifies the intestity of movements involved. This thrust has northward dip in southern part and southerly dip in the northern part of the area.

b Zarghun Khel Nappe

A second detachment at Lower Jurassic and Lower Paleocene (?) level led to emplacement of second overthrust sheet, referred here as Zarghun Khel Nappe (Rock strata belonging to this sheet are exposed in the surroundings of Zarghun Khel). The thrust that provided translational movement for this nappe is referred here as Qasim Khel Thrust (named after village Qasim Khel in Zarghun Khel area). Qasim Khel Thrust is also a bedding plane thrust and separates Hangu Formation (Lower Paleocene) of Kotal Nappe from overthrusted Samana Suk Formation (Middle Jurassic age) of so-named Zarghun Khel Nappe. The surface traces of this thrust are markedly curvilinear and at few places this thrust is slightly folded. The extent and importance of translational movements involved could be appreciated in relation to the facies differences shown by various rocks units of Zarghun Khel Nappe Stratigraphic succession is similar to lower Kotal Nappe with the only exception that Upper Paleocene Patala Formation is not exposed, Lockhart limestone being the youngest formation. Dominant lithologies are limestone, shale and sandstone deposited in open marine environment. Rock succession is disturbed by several faults which are of reverse dip slip types. Imbricate structures are observed near villages Ataro Kili, Garhi Sar and around Qasim Khel area.

ASSOCIATED STRUCTURAL ELEMENTS

(*i*) Schuppen Structures

At several places in the area, rock sequence is disturbed by repeated thrusting. All faults are high-angle reverse dip-slip types and run roughly in an east-west direction parallel to major thrusts.

(*ii*) Fenster

Due to erosion of overthrusted Zarghun Khel Sheet, rock units of Lower Kotal Sheet are exposed in middle part of the area and represent a typical fenster.

(*iii*) Klippe

In the southern part, erosion has dislocated two small Klippen of gentle dipping Jurassic limestone which are now resting on autochthonous terrain (Murree Formation) as isolated hillocks.

(*iv*) Inliers/Outliers

These structures were commonly observed in intesly folded rock units of Kotal Nappe east of Kotal Frontier Constabulary Post along N.W F. Road.

CONCLUSIONS

The possible explanation for genesis of these low-angle bedding plane thrusts is that they resulted from decollement of the sedimentary cover. The detachment of sedimentary cover is facilitated by the presence of certain plastic horizons (Soap layers) in a particular succession. The first structure to advance over the autochthon is Kotal Nappe for which there is evidence for detachment at Lower—Middle Jurassic level. It is likely that Shinawari Formation (Lower-Jurassic) which incorporates lithologies such as marls and clays might have acted as soap layer. A second detachment at Lower-Jurassic and Lower Paleocene (?) level led to emplacement of Zarghun Khel Nappe for which Shinawari

Formation as well as Hangu Formation (?) acted as soap layer.

Intensity of deformation varies. Folds and flexures effect the rock units of entire area but folding is more intense in the Kotal nappe. The overriden rocks of Kotal nappe were more folded probably mainly as a result of frictional drag of Zarghun Khel overthrust. Part of the forward movement of overriding thrust sheet probably resulted from the shortening of overriden rocks by this folding. Faulting is very uncommon in the under-thrusted autochthonous strata. Among the allochthonous masses Zarghun Khel Nappe is more intensely fauletd. Tectonic slices (Schuppen zone) are formed along equidistant reverse dip slip faults, most of which are inclined towards same direction (towards the source of stress).

As indicated from inclination of major and minor thrust faults, transport of nappes probably took place from north during Post-Miocene period. The overthrusts and faults can be attributed to the fundamental compression of crust related to collision between Indian and Eurasion plates. Collision type orogenies exhibit nappe and thrust asymmetry toward the plate being consumed. Upon collision the buoyancy of the converging continent prevents the consumption of crustal slices and large nappes and thrusts are produced as it resists subduction.

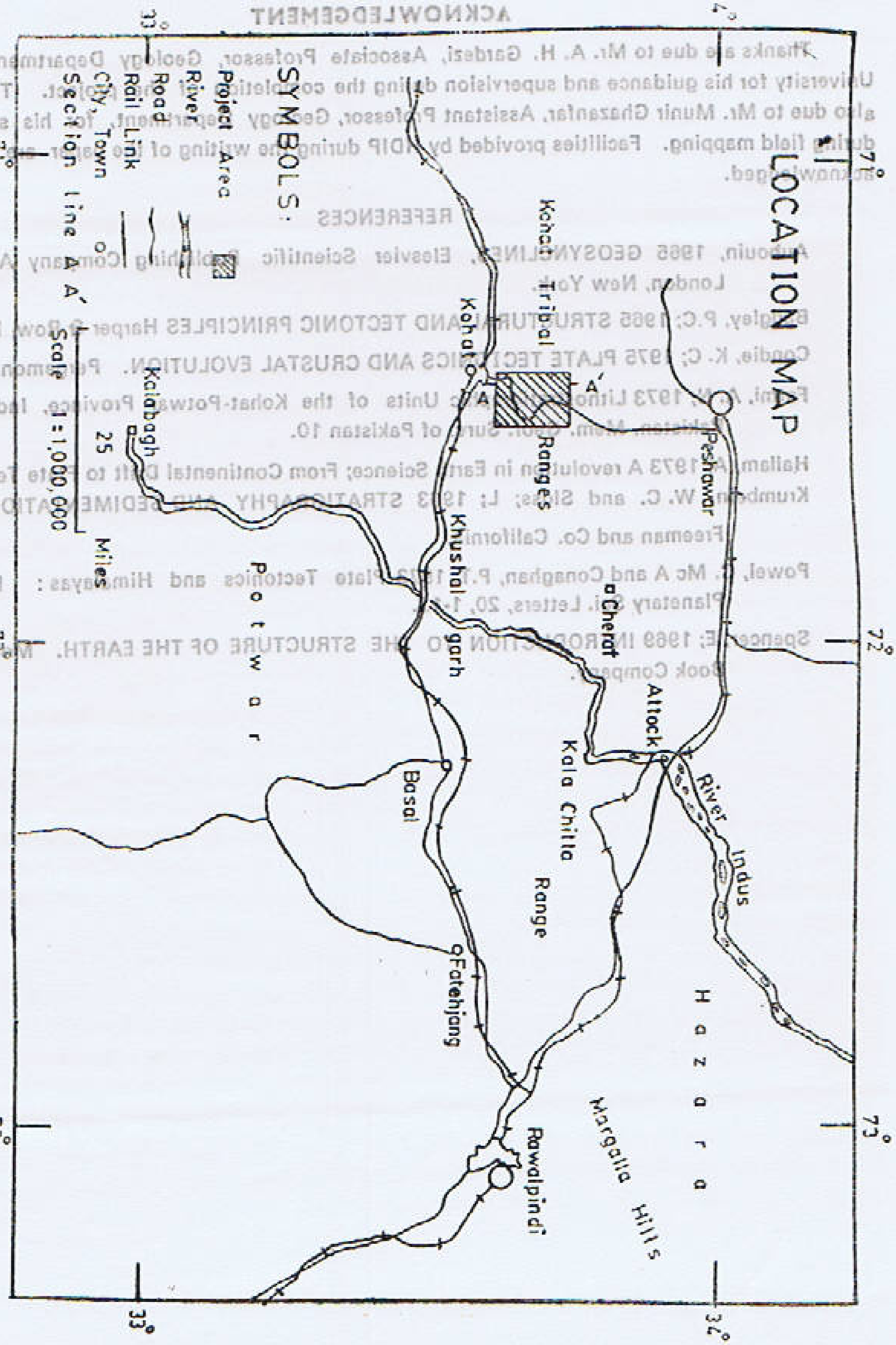

Fig. 1 LOCATION MAP

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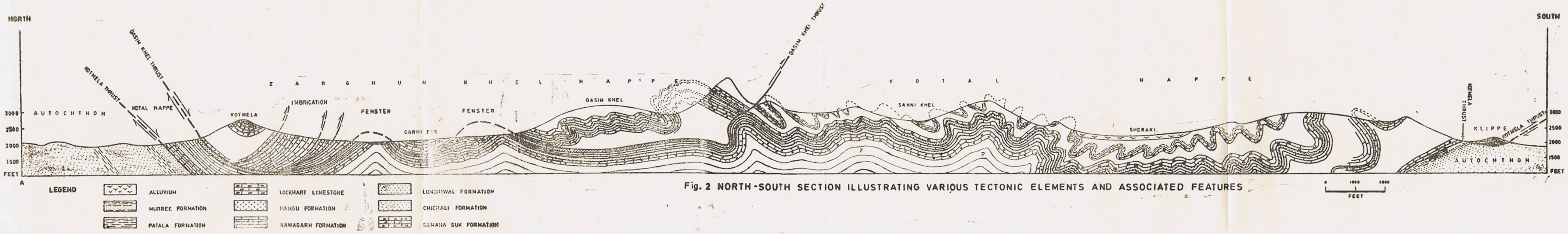

Fig. 2 NORTH-SOUTH SECTION ILLUSTRATING VARIOUS TECTONIC ELEMENTS AND ASSOCIATED FEATURES

A NEW ELEPHANT FROM THE UPPER SIWALIKS OF PABBI HILLS, PANJAB, PAKISTAN

By

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Abstract : *Elephas corrugatus, new species, from Pinjor Zone of the Upper Siwaliks exhibits a comb'nation of primitive and advance dental characters. In a comparison with the known Asiatic elephants, it has proved to be a specialized form It was a short lived abortive offshoot of the species, Elephas planifrons.*

INTRODUCTION

In the year 1965, the author found an elephantine right mandibular ramus bearing last molar from the Pinjor formations of the Upper Siwaliks in Pabbi Hills of Gujrat, Panjab. The molar tooth shows a primitive and advance characters together. On account of fine enamel corrugacy, the name *Elephas corrugatus* has been given to this new elephant species.

SYSTEMATICS

Order Proboscidea

Suborder Elephantoidea

Family Elephantidae

Subfamily Elephantinae

Genus *Elephas* Linnaeus

Elephas corrugatus, new species

Holotype

A damaged right mandibular ramus bearing third molar, U. Z 65/2 (fossil collection in the Department of Zoology, University of the Panjab, Lahore, Pakistan).

Hypodigm

Type only.

Locality

South of village Sardhok, Pabbi Hills. Panjab, Pakistan.

Age

Pinjor zone (Lower Pleistocene) of the Upper Siwaliks.

Diagnosis

Molars broad and subhypsodont. Ridge-plates widely spaced and thin enamelled. Enamel layer finely plicated like that of *Elephas maximus*. Lateral and median sinuses present. Cement abundant, Last molar with ten ridge-plates.

Mandibular ramus quite robust, Vertical ramus broad anteroposteriorly than that of *Elephas planifrons*.

DESCRIPTION

Mandible (Figs. 1-3)

The specimen is compact, hard and well preserved. It consists of a horizontal ramus and a basal portion of the ascending ramus. The horizontal ramus is quite robust,a little bit deeper anteriorly but rounded behind. Posteriorly, the ramus ascends very gradually making a quite rounded contour visible in the lateral view. Having halfworn last molar it can be said that the specimen was belonging to a fairly old individual. Due to the old age, various linings, protuberances and grooves have become prominent. There is only one mental foramen situated at about 80mm below the anteriormost ridge-plate of the tooth. The foramen is elongated downwardly and to some extent forwardly at the anterior face of the ramus, there is a large downwardly elongated vacuity.

Fig. 1. *Elephas Corrugatus*, new species. Crown view of the holotype, U. Z. 65/2. Pinjor zone of the Upper Siwaliks × $\frac{1}{2}$

Fig. 2. *Elephas Corrugatus*, new species. Outer view of the holotype, U. Z. 65/2 Pinjor zone of the Upper Siwaliks × $\frac{1}{2}$.

Fig. 3. *Elephas corrugatus*, new species. Inner view of the holotype, U.Z. 65/2. Pinjor zone of the Upper Siwaliks. × 1/4.

Fig. 4. *Elephas corrugatus*, new species. Crown view of the lower right third molar in U. Z. 65/2. × ½.

This vacuity appears to be just an abnormality and was most probably of no use to the bearer. The tooth alveolus is rounded in outline and is visible at the broken face of the ascending ramus. It is very large and is now filled with sand stone.

The tooth (Fig. 4)

Like the mandibular ramus, the tooth is also heavily built The molar is somewhat broader posteriorly than anteriorly (table I). It was most probably subhypsodont. It is slightly damaged at the antero-external corner. The tooth is in the middle stage of wear. The anterior contour of the tooth suggests that the first preserved ridge-plate is the actual first ridge-plate in succession. The ridge plates are widely spaced but thin-enamelled. Enamel layer is very finely plicated like that of *Elephas maximus.*

In the center, the ridge-plates are expanded antero-posteriorly to form a pre-and a post sinus. In a late wearing stage, the pre-sinus of a ridge-plate fuses with the post-sinus of a preceding ridge plate. Similarly, a pre- and a post-sinus also tend to appear at the lateral margins of the ridge-plates. These lateral sinuses meet anteriorly as well as posteriorly with their respective sinuses of the preceding and the succeeding ridge-plate. Thus on wear, the dentinal matter of the two adjacent ridge plates become confluent at the external border internal broader and in the middle. As a result their intervening transverse valley takes the shape of two cement islets bounded by enamel layer. A thick layer of cement covers the lateral as well as the posterior sides of the tooth. The enamel figures of the posterior ridge-plates suggest that the ridge plates were probably surmounted by 5 conelets. Of these, the outermost and the innermost conelet was comparatively deeply

TABLE I

Mandibular and dental measurements (in mm.) in the holotype (U.Z. 65/2) of *Elephas corrugatus.*

Mandibular depth below the anteriormost end of the tooth (taken from inner side) ...	240
Mandibular depth at the middle of the tooth (taken from inner side)	204
Mandibular depth below the posterior end of the tooth (taken from inner side) ...	231
Basal antero-posterior length of the ascending ramus	225
Maximum crown length of the tooth	244
Transverse width of the third ridge-plate	95
Transverse width of the sixth ridge-plate	95
Transverse width of the seventh ridge-plate	100
Transverse width of the eighth ridge-plate	99
Transverse width of the penultimate ridge-plate	95

clefted. The penultimate ridge-plate is smaller in transverse width as compared to the others. The last ridge-plate is probably abnormal in development. It is semi circular and multituberculated. Its outer tubercles even cover the outer side of the penultimate ridge-plate. The heel is represented by a single conelet.

DISCUSSION

Regarding the number of ridge-plates, it can be related with the species, *Elephas planifrons*. However, other dental characters of U.Z. 65/2 such as very thin and finely plicated enamel and the loxodont sinus do not permit its inclusion in that species. In dental characters, it differs from the Asiatic elephant material included in the species, *E planifrons* or in the Pohlig's (1888) genus, *Archidiskodon* by Falconer (1868), Teilhard de Chardin & Trassaert (1937), Osborn (1942), Hooijer (1955), Chow and Chow (1959) and Chow (1961). Of this material, a posteriorly damaged mandible bearing a second lower molar of either side described as *Archidiskodon tokunagai* by Teilhard de Chardin & Trassaert (op. cit. pl. xi) shows maximum resemblance with the siwalik specimen, U Z. 65/2 Enamel corrugacy and thickness are equally shared by the Siwalik and the Chinese specimen. However, they differ in the development of post-sinus which is absent in the Chinese specimen. Moreover, the tooth is relatively longer than wider in Chinese specimen than in the Siwalik specimen. The other lower molars referred to *Archidiskodon tokunagai* by Teilhard de Chardin and Trassaert (op. cit.) are entirely different from the above said Chinese tooth (pl. xi). It means that Teilhard de Chardin and Trassaert have erroneously grouped two different taxa in one species.

Apart from dental differences, it also differs in size of the mandible and its profile. The jaw bone in U.Z. 65/2 is robust especially at the base of the ascending ramus than those of the *Elephas planifrons* (fig. 5).

It can readily be differentiated from the type and referred material of *Elephas hysudricus* described by various workers such as Falconer (1868), Osborn (1942), Deraniyagala (1944, 1958), Hooijer (1955) and Prasad and Daniel (1968) in having relatively low crown height, small number of ridge-plates and low lamellar frequency. Of the known material of this species, a molar fragment designated as the holotype of *Hypselephas hysudricus sinhaleus* by Deraniyagala (1944), shows maximum resemblance with the specimen under study, Both have strong enamel plications and widely spaced ridge-plates. However, they differ in the development of median sinuses which are absent in the Nagoda specimen but fairly indicated in the Siwalik specimen. Moreover, the Siwalik specimen is relatively much wider than the Nagoda specimen.

The specimen under study also differs from the South Asiatic species, *Elephas namadicus* in having low lamellar frequency. The ridge-plates in the molar tooth of U. Z. 65/2 are widely spaced wheras these are relatively much appressed in those of the type specimen of *Elephas namadicus* described by Falconer & Cautley (1846) In the same character it can easily be discriminated from the Siwalik mammuthine specimens described by Sarwar (1978, 1980).

Infact, thin and finely plicated enamel, loxodont sinus, lateral sinuses, abudance of cement, broad and widely spaced ridge-plates and the lateral jaw contours are the characters of the specimen under study which strongly warrant for the errection of a new species.

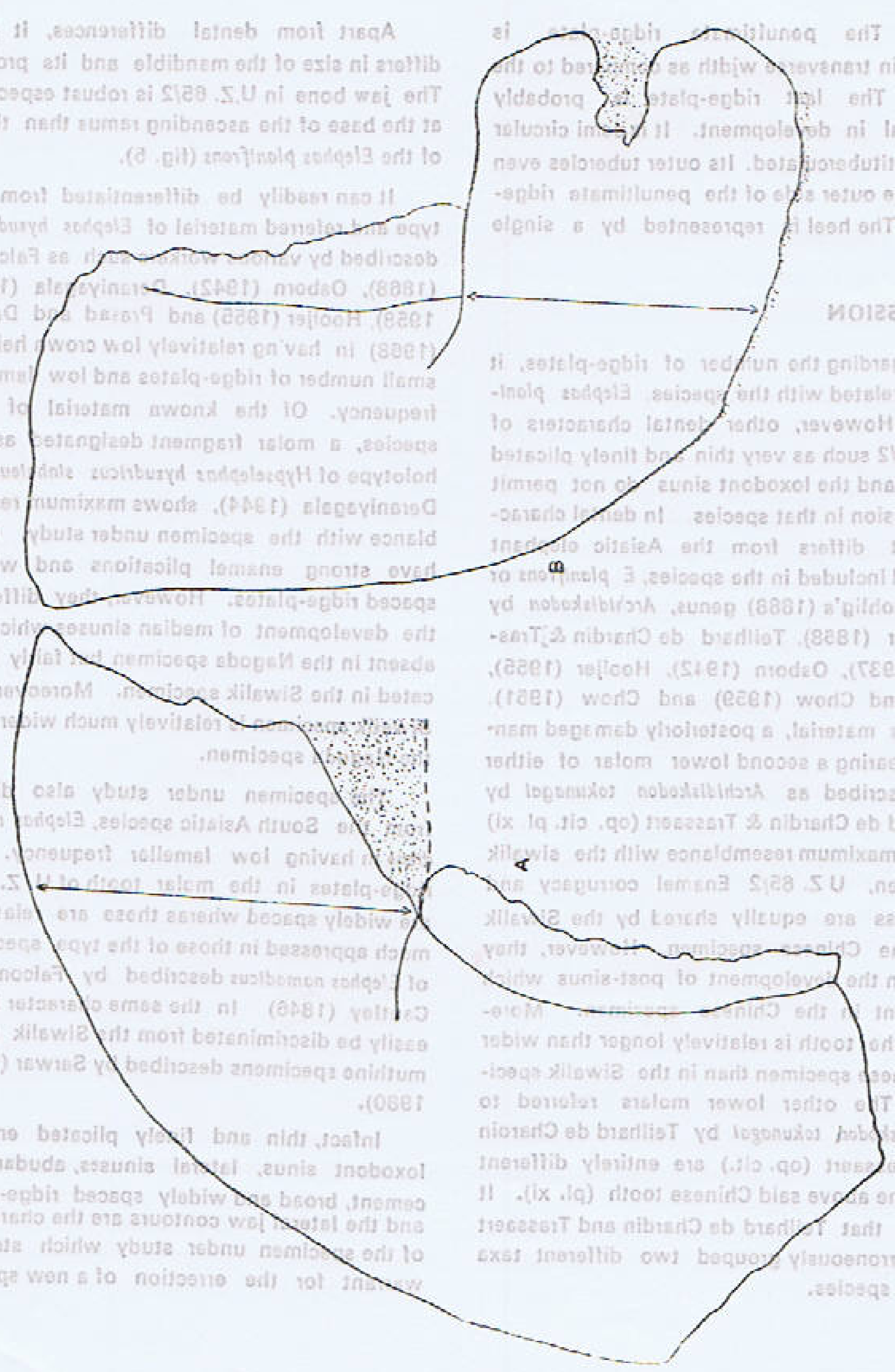

Fig. 5. Mandibular profile of U.Z. 65/2 compared with that of *Elephas planifrons*. Both ½ natural size.
A. Holotype, (U.Z. 65/2) of *Elephas corrugatus*, new species. Outer view.
B. Left mandibular ramus (American Museum No. 19819) of *Elephas planifrons* ref. (labelled as *Archidiskodon planifrons* in Osborn, 1942, p. 958.

Due to strong enamel corrugacy, it is designated as *Elephas corrugatus*. *Elephas corrugatus* is a primitive Siwalik elephant, probably a derivative of the *Elephas planifrons*. Early in its evolutionary history, it evolved some highly specialized characters such as reduction in the enamel thickness, corrugacy and the median and lateral sinuses. Reduction in the enamel thickness and the fine plications in the enamel layer were the characters highly beneficial to the species. But unfortunately, these were not accompanied by the increase in the number of ridge-plates. Probably, this drawback brought about the extinction of the species.

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EVOLUTION OF THE MOLAR RIDGE-PLATES IN ELEPHANTS

By

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Abstract.

The taxonomic importance of the molar ridge-plates in the family elephantidae has been emphasized by many workers such as Osborn (1942), Hooijer (1955), Azzaroli (1966), Aguirre (1969), Maglio (1970, 1973), Maglio and Ricca (1978) and Sarwar (1977, 1978). It is due to the fact that the molar plates have characteristic morphological features in various groups of the family elephantidae. In a transition from Stegodon to Antelephas, the changes happened were the slight increase in the crown height, increase in the cement deposition and the decrease in the enamel thickness. However, there occurred no change in the general shape of the ridge-plate i.e. the ridge-plates were transversely linear in the primitive stegodonts as well as in the Antelephas.

In elephants, primitively, the intervening transverse valleys between the molar plates were stegodontine i.e. V-shaped in lateral view (sarwar, 1978). Such types of ridge-plates are seen in the molars of *Antelephas* (Sarwar, 1979).

In a transition, from *Antelephas* to *Elephas*, the intervening transverse valleys became

A

B

Fig. Ia Posterior fragment of the type tooth of *Antelephas tatrotensis* showing V shaped intervening transverse valley. (From Sarwar, 1979).

Fig. Ib. Lateral view of a molar fragment (U.Z. 67/115) of *Elephas planifrons* showing U-shaped intervening transverse valley. Crown height 84 mm.

U-shaped, the enamel became less thicker and the cemant deposition increased. However, there happened no change in the crown height. Thus, the molars in the early members of the genus *Elephas* are differentiated from those of *Antelephas* on the basis of shape of the intermediate valleys, enamel thickness and the cement deposition (fig Ia & Ib). In this transition also, the ridge-plates remained transversely linear. From this primitive condition, the elephantine ridge-plate underwent various developments. These are for example, the development of pre-sinus, the post-sinus, the pre-and post-sinus together and the lateral sinuses (Sarwar, 1980). Besides this, the ridge-plates may not remain transversely linear and may become wavy. Such a pattern, if not accompanied by the other mandibular or cranial peculiarities, may not be of any significance. However, if it is accompanied by some unusuall developments present in the mandible or the cranium, may be of taxonomic value. The type tooth of *Elephas irshadi* is such an example (Sawar, 1977). The molar plates of a last upper molar (U.Z. 68/739), from the Siwaliks, is still more interesting than that of the type of *Elephas irshadi*. This tooth (figs. 2a & 2b) is in the very late stage of wear and exhibits the morphological features of the last two ridge-plates only. The inner halves of the molar plates are extremely dislocated and are connected with their respective half through a narrow channel. The narrow channel indicates that the two halves of a ridge-plate were, most probably, deeply isolated in unworn condition. Such a dislocation is seen in the molars of *Anancus* among the mastodons. Since, nothing is known about the mandible in which the tooth, U.Z. 68/789, was inserted, this unusuall dislocation of the ridge-plates is of no taxonomic value.

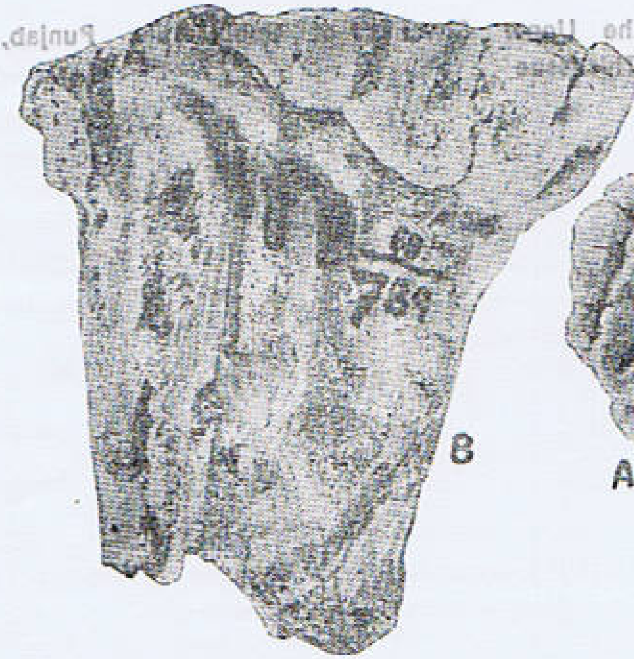

Fig. 2b Side view of a second upper mola (U Z. 68/789) of *Elephas*. Not drawn to the scale.

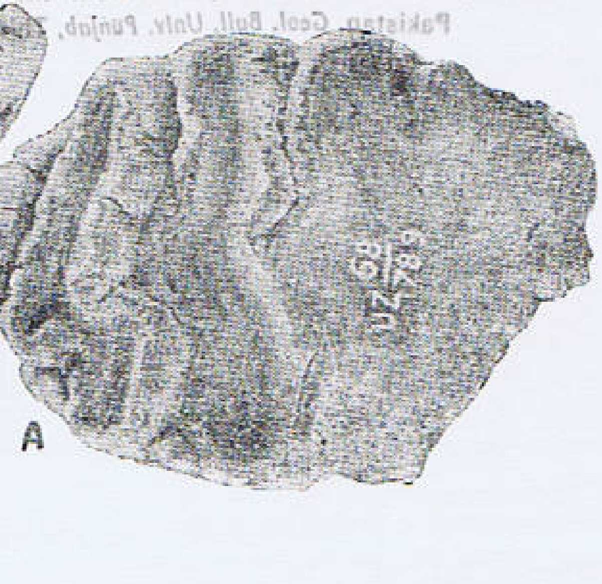

Fig. 2a. Crown view of a second upper molar (U. Z. 63/789) of *Elephas* showing dislocation of the conelets. Not drawn to the scale.

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THE TERTIARY BIVALVES AND GASTROPODS OF PAKISTAN

By

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Abstract

The purpose of this paper is to present a resume of the paleontological research on the Tertiary bivalves and gastropods of Pakistan. The writter (Iqbal, 1972a) presented a detailed account on the subject for the first time during the 13th Session of the Science conference, Scientific Society of Pakistan, March, 1972. Later on a brief paper on the Tertiary bivalve and gastropods of Sind was also published (Iqbal, 1972). The writter (Iqbal, 1974) also presented a paper on the Baluchistan fauna during the Seminar on Development In Geological Sciences in Pakistan, University of Baluchistan, September, 1972. The biostratigraphical research conducted by the writter during 1963 to 1980has given more emphasis to the Tertiary biavalve and gastropod fauna. In most of the cases, the bivalve and gastropod species were found extremely useful in determination of the specific stratigraphical problems and reconstruction of the depositional history of the geological formations in which they occur. Moreover, the world-wide geographical distribution and comparative analysis of the fauna proved helpful in under- standing of the basinal distribution, the possible oceanic connections in between the various in certain geological time, and the genetic relationship between certain species.

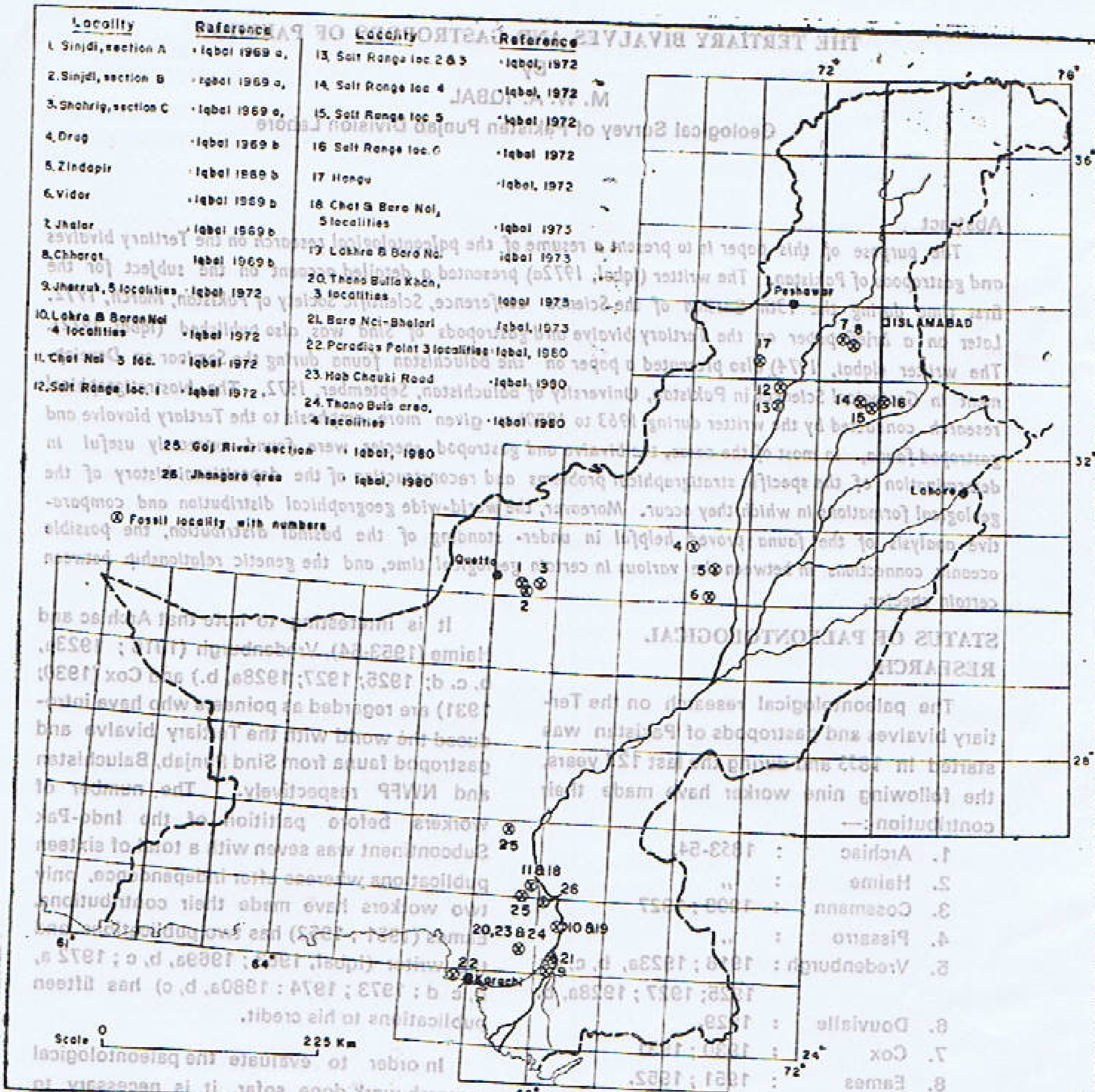
STATUS OF PALEONTOLOGICAL RESEARCH

The paleontological research on the Tertiary bivalves and gastropods of Pakistan was started in 1853 and during the last 127 years, the following nine worker have made their contribution :—

1.	Archiac	:	1853-54.
2.	Haime	:	,,
3.	Cossmann	:	1909 ; 1927
4.	Pissarro	:	,,
5.	Vredenburgh	:	1916 ; 1923a, b, c, d; 1925; 1927 ; 1928a, b.
6.	Douvielle	:	1929.
7.	Cox	:	1930 ; 1931
8.	Eames	:	1951 ; 1952.
9.	Iqbal	:	1963 ; 1969a, b, cd ; 1972a, b, c ; 1973 ; 1974 ; 1979 ; 1980a ; b, c, d.

It is interesting to note that Archiac and Haime (1953-54), Vredenburgh (1916 ; 1923a, b, c. d; 1925; 1927; 1928a, b.) and Cox (1930; 1931) are regarded as poineers who have introduced the world with the Tertiary bivalve and gastropod fauna from Sind Punjab, Baluchistan and NWFP respectively. The number of workers before partition of the Indo-Pak Subcontinent was seven with a total of sixteen publications whereas after independence, only two workers have made their contributions. Eames (1951 ; 1952) has two publications and the writer (Iqbal, 1963 ; 1969a, b, c ; 1972 a, b, c d : 1973 ; 1974 : 1980a, b, c) has fifteen publications to his credit.

In order to evaluate the paleontological research work done sofar, it is necessary to discuss the contributions of the previous workers first and lastly to present an account of the work done by the writer.



Drafted by:- G. Abbas

Prepared by- IQBAL, M W.A.(1981)

FIG — 1

TERTIARY BIVALVE AND GASTROPOD FOSSIL LOCALITIES DESCRIBED BY IQBAL, M.W.A. (1969 a,b; 1972; 1973 & 1980)

PREVIOUS WORK

Archiac & Haime (1853-54) have described 103 new species from Sind and Punjab. Their publication deals with the systematic treatment of the species, assignment of age and correlation with the European froms. This contribution is of great value to the subsequent workers.

Cossmann & Pissarro (1909 ; 1927) have published two monographs in which the fauna from the Paleocene formation is described. The have introduced 85 new species.

Vredenburgh (1916 ; 1923a, b c d; 1925; 1927 ; 1928a, b) has nine publications He made large faunal collection from the Tertiary formations of Sind and Baluchistan and his valuable work includes the systematic description of 230 species of which 221 species are new. Vredenburgh has revised the previously described nomenclature, presented regional correlation, comparison with the European forms and the geological history of the formations.

Douville (1929) has described 35 new species from the Paleocene of Sind. His work consists of one publication centaining discussion on the previously described forms and systematic treatment of the fauna.

Cox (1930, 1931) studied the fauna inom the Tertiary formations of Sind, Baluchistan and NWFP. His valuable work consists of two publications, containing revision of the previously described forms, correction of preemployed names of the species and redesignation according to the zoological nomenclature. Cox has described 35 new species from Sind Baluchistan and NWFP.

Eames (1950 ; 1951) made a large collection from the Eocene formations of Punjab and NWFP. His two publications contain systematic description of 285 forms including 252 new species and revision of previously described fauna.

PRESENT WORK

The biostratigraphical studies of the Tertiary formations based on the bivalve and gastropod fauna carried out by the writer (Iqbal, 1963; 1969a, b, c, d, 1972a, 1973; 1974; 1979: 1980a. *b, c, d*) from the basis of the present work. The writer's humble contribution consists of 15 publications, including research papers, reports, bibliographical work and technical articles.

During 1963 to 1980, the writer has completed the biostratigraphical studies of Khadro and Lakhra formations (Paleocene : Kirthar Province), Hangu Fm., Lockhart Lst., (Paleocene : Salt Range and Kohat Provinces); Ghazij formation (Lr. Eocene: Axial Belt and Sulaiman Province), Margal a Hill Lst. and Chor Gali Fm., (Lr. Eocene : Salt Range & Kohat Provinces) ; Kirthar formation (Mid. Eocene : Kirthar, Sulaiman and Kohat Provinces and Nari & Gaj Formations (Oligo.-Miocene : Kirthar & Sulaiman Provinces).

The faunal collection was made from 46 measured sections, representing 26 major localities (Fig. 1). The systematic description of the fauna includes 129 bivalves, 184 gastropods and 36 new species with uptodate classification and revised nomenclature.

The geographical distribution of the fauna from the type localities in Pakistan was compared with several countries. It was established that between Pakistan and 23 countries of Asia. Africa and Europe there were several common species showing a wellmarked affinity during Paleocene, Eocene and Oligo.-Miocene time. The occurrence of such common forms also suggests the possible oceanic connections inbetween these areas which have been interrupted from time to time.

The writer has also determined several index species representing specific age for the formations in which they occur. On the basis of the fauna and lithology of forma tion regional correlation was made and geological history was reconstructed.

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SOME PHENOMENA WITHIN CONTACT ZONES OF THE HAZARA GRANITIC COMPLEX, N.W. HIMALAYAS, PAKISTAN

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Abstract : *Concise description is given of some important phenomena observed within contact zones between various outcrops of the Hazara granitic complex and the associated metamorphic formations. Briefly, these are recorded as thermal, structural, metamorphic and hydrothermal effects which have important bearing on origin and evolution of the granitic complex with regional implications to other parts of the Himalayas.*

INTRODUCTION

Extensive outcrops of granitic bodies are present along almost the entire length of the Himalayas ; a fact first of all recognised and described by Stolickza (1865). He grouped those together as the "Central Gneiss" and opined that such bodies constituted crystalline backbone of the Himalayas. For the first time, Verchere (1866) proposed an igneous origin for those rocks on the basis of his observations North of the Mansehra town. Later, Wynne (1887) made extensive field investigations within the Mansehra area and suggested a prograde metamorphic origin from the associated argillaceous-arenaceous formaations. This was, however, challanged by Middlemiss (1896) who had reverted to an igneous theory. Thus, an illuminating granite controversy raged during the very initial stages of geological work in the crystalline belt of the Himalayas. However, most of those works suffered from lack of intimate field studies and rigorous laboratory investigations.

After a lapse of 70 years or so, the granitic-metamorphic complexes of the Mansehra and the adjoining areas were brought under extensive revision, including large scale mapping (Fig. 1) and systematic sampling leading to a concept of granitization under the agency of metasomatizing fluids of ultimate igneous origin (Shams, 1961, 1967). The essential details of geological and lithological features of the area were published earlier (Shams, 1969) including publications on some minor members of the granitic rocks (Shams *et al*, 1966 ; Shams, 1980 ; Ashraf, 1974, a, b). The present article aims at describing some of the phenomena observed within the granitic-metamorphic contact zones which have been found to have important bearing on origin of the Hazara granitic complex and similar complexes elsewhere in the Himalayas.

THE THERMAL EFFECTS

The rocks at various contact aureoles of the Hazara granitic complex display prominent effects of thermal metamorphism of metasedimentary formations, which had suffered earlier a regional metamorphism of the Barrovian type. Extensive zones of hornfelses are developed and can be observed along road sections of Chorgali, Chitta Batta, Balhag Utli and Gamian Seri etc., missing,

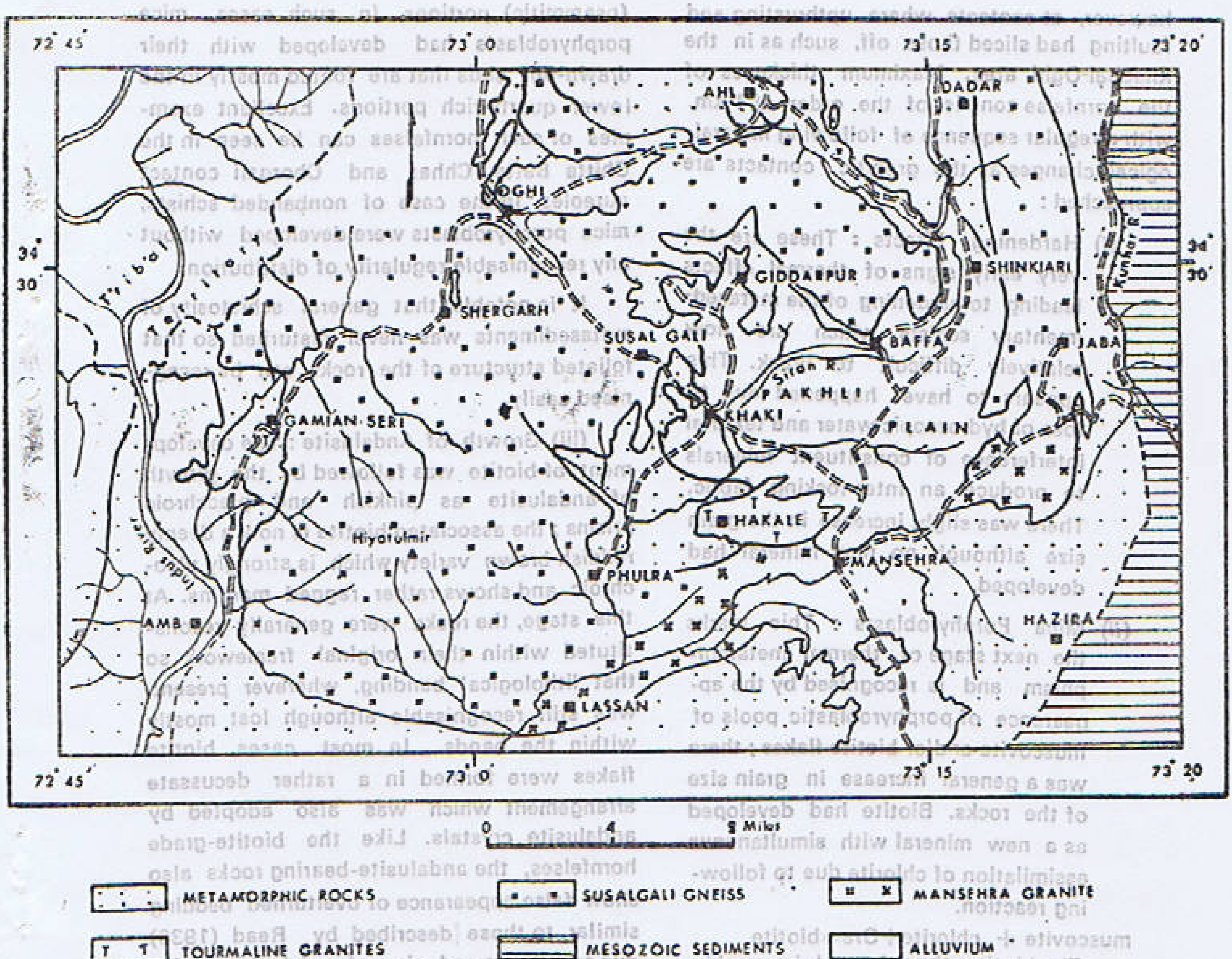

Fig 1 Geological map of the Hazara graintsc complex, NW Himalayas (after Shams, 1967).

however, at contacts where upthrusting and faulting had sliced those off, such as in the Khabbal-Oghi area. Maximum thickness of the hornfelse zone is of the order of 1 km, with a regular sequence of following mineralogical changes as the granitic contacts are approached :

(*i*) Hardening Effects : These are the very early signs of thermal effects leading to hardening of the metasedimentary schists which are now relatively difficult to break. This appears to have happened due to loss of hydroscopic water and textural interference of constituent minerals to produce an inter-locking fabric. There was slight increase in the grain size although no new mineral had developed.

(*ii*) Mica Porphyroblasts : This marks the next stage of thermal metamorphism and is recognised by the appearance of porphyroblastic pools of muscovite and/or biotite flakes ; there was a general increase in grain size of the rocks. Biotite had developed as a new mineral with simultaneous assimilation of chlorite due to following reaction.

muscovite + chlorite + Ore = biotite

The biotite, thus formed, is weakly pleochroic from greenish to pale brown colour and imparts a similar hue to the rocks.

In the case of banded schists (Shams, 1969), thermal metamorphism produced effects of false overturned bedding (Fig. 2) due to coarsing of grain size and darkening of colour towards upper (Pelitic) portions of individual bands as compared with their lower (psammitic) portions. In such cases, mica porphyroblasts had developed with their drawn-out ends that are rooted mostly in the lower quartz-rich portions. Excellant examples of such hornfelses can be seen in the Chitta Batta, Chhar and Chorgali contact aureoles. In the case of nonbanded schists, mica porphyroblasts were developed without any recognisable regularity of distribution.

It is notable that general schistosity of metasediments was never disturbed so that foliated structure of the rocks can be recognised easily.

(iii) Growth of Andalusite : The development of biotite was followed by the growth of andalusite as pinkish and pleochroic prisms ; the associated biotite is now a deeply reddish-brown variety which is strongly pleochroic and shows rather ragged margins. At this stage, the rocks were generally reconstituted within their original framework so that lithological banding, wherever present, was still recognisable although lost mostly within the bands. In most cases, biotite flakes were formed in a rather decussate arrangement which was also adopted by andalusite crystals. Like the biotite-grade hornfelses, the andalusite-bearing rocks also show false appearance of overturned bedding similar to those described by Read (1936) due to amount and size of andalusite grains increasing towards pelitic tops of individual bands.

Andalusite appears to have formed by the following reaction :

muscovite + quartz - andalusite + orthoclase + H_2O.

The andalusite crystals are therefore full of quartz inclusions and are attended by a new generation of orthoclase, which is also studded with tiny quartz grains. Due to non-availability of carbonaceous matter, the familiar "chiastolite cross" was not developed although similar arrangements were occasionally displayed by quartz inclusions.

(iv) Formation of Fibrolite : The development of fibrolite variety of sillimanite appears to have initiated just after growth of andalusite with an overlapping period of genesis ; fibrolite is most prolific in rocks near the granitic contacts. The fibrolite appears to have developed as hair-like slender needles, have grown at (epitaxis ?) or out of biotite flakes and from andalusite ; sometime mats and thin bands were also developed.

At this stage, garnet of the schists also shows evidence of having suffered thermal effects which caused its break-down and release of rods and granules of black ore ; by this stage, the rocks were strongly reconstituted and biotite appeared dark brown.

(v) Metasomatic Effects : These are observed in the rocks at the immediate granite contacts and show hydrothermal alteration of thermal metamorphic minerals. Andalusite and fibrolite were hydrolyzed and were gradually made over to muscovite, occasionally producing pseudomorphs that appear not very much different from "Shimmer" aggregates so extensively found in the marginal facies of the Mansehra granite (Shams, 1969). Simultaneously, there was a prolific growth of feldspar. Garnet had suffered strong alteration to hematite with pseudomorphic tendency. Biotite flakes had faded in colour to light pale-brown while tourmaline and apatite were added appreciably.

Fig. 3 shows the sequence of appearance and ranges of stability of various minerals in the hornfelsed rocks.

(vi) Calcareous Hornfelses : As already described (Shams, 1969), calcareous formations are almost missing in the area except for two locations so far observed near Pattian, North of Phulra, and East of Chitta Batta. As a result of thermal metamorphism, such minerals were formed as wollastonite, epidote, grossularite, augite hornblende and sphene (Shams, 1963).

THE SHEETING EFFECTS

A prominent phenomenon in the contact-zone schists is the occurrence of veins and sheets of granitic-aplitic material, varying in thickness from a few centimetres to many metres and extending for hundreds of metres. Sometime, many sheets are closely emplaced in parallel arrangement. Mostly the sheets follow schistosity planes of the rocks but discordant and even cross-cutting bodies are also present, the latter are mostly related to joint pattern of the host rocks and occur also in the marginal portions of the granitic complex. Rarely, composite bodies are present where an aplitic exterior may contain porphyritic granitic interior or vice versa ; also intersecting sheets of different granularity and composition are present, such as are exposed in the Chorgali section, North of Khaki.

Petrographically, these sheets are of granitic composition, with variations to aplitic nature. The latter class also includes soda aplites, albitities and rare porphyry bodies (Shams, 1980). When intruded into metasediments, a number of chemical effects were produced depending upon composition of the host rock such that pelitic rocks were more reactive as compared with the psammitic material. While granitic-aplitic sheets also contain xenoliths of the host rocks, no prom-

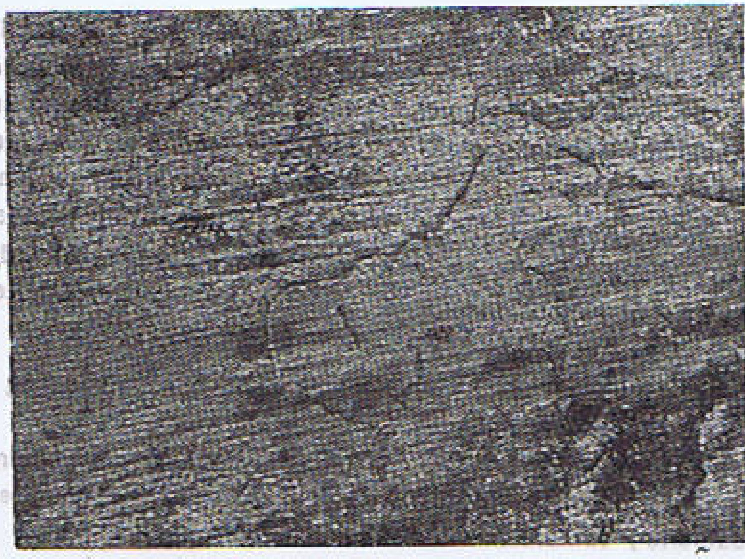

Fig. 2 Hornfelsed schists, showing false over turned bedding.

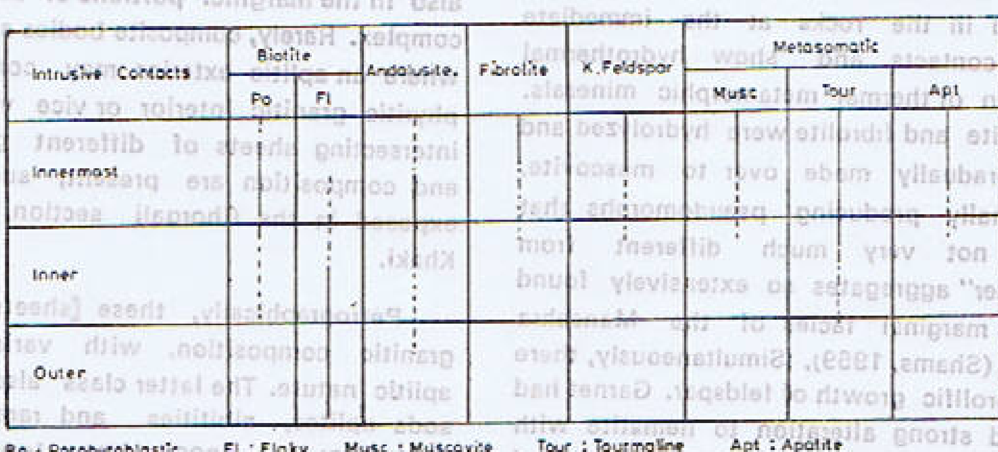

Fig. 3. The sequence and range of stability of minerals in the hornfelsed schists.

inent reaction was produced. The main effects on the meta-sediments were :—

(i) feldspathization of the schists.

(ii) thermal breakdown of the hornfels minerals such as garnet, andalusite and biotite.

(iii) Introduction of volatile constituents in the form of apatite, tourmaline and water.

THE STRUCTURAL EFFECTS

An important category of contact-zone phenomena is related to structural effects recorded on both directions of the contact plane and shed light on structural and tectonic evolution of the granitic-metamorphic complex of the area. For instance, measurements of joint surfaces accros the contact planes show similar pattern (Fg. 4).

Structural changes in the granitic bodies become recognisable as one appreaches their margins from a distance of many hundred kilometres. Megascopic structures of the rocks show development of shear foliation with thin micaceous layers wrapped around augen-shaped areas of feldspar and/or quartz ; near contact, the structure becomes almost mylonitic (Fig. 5). On breaking apart along its foliation plane, the sheared granite shows distinct traces of a lineation marked by smearing of micaceous minerals. In thin sections, these rocks show general fracturing, bending and granulation of constituent minerals and their parallel alignment.

In the case of metamorphic rocks, structural effects are even more conspicuous and can be observed over much greater distance than thermal effects. The most important effect is intense refolding of primary schistosity giving rise to a strain-slip cleavage, the latter had offered new set of planes for tectonic slippage and mineral reorientation. These effects had produced small scale folds, puckers and fine crenulation on schistosity planes of the rocks related to intense slickensiding with attendant lineation.

It is notable that everywhere the superimposed structures in the contact zone granitic and metamorphic rocks, such as lineation, crenulation and microfolds etc., are mutually conformable as well as parallel to the nearby contact planes. Structural effects are also sufered by aplitic and basic minor intrusives, leading to their shearing, boudinage and tear-faulting (Fig. 6). It is also important that many of those minor bodies had suffered movements along such a set of joint system which is mostly oriented diagonal to the nearby contact planes. (Fig. 7). That such a disturbance was post-thermal is proved by disrupted bedding of hornfelsed schists (Fig. 8).

SPECIAL EFFECTS

In addition to various mineralogical and structural changes in the contact zone, following changes are also notable :

(i) Metamorphic Degradation : This effect is seen as breakdown of high grade metamorphic minerals so that biotite, garnet and staurolite show gradual and progressive replacement by chlorite and ore granules. Occasionally, this breakdown was complete enough to produce pseudomorphs. In addition to origin by replacement ; chlorite was also developed extensively in almost all types of metamorphic rocks, thus reflecting a younger wave of phyllonitic metamorphism related to the period of structural involvement of contact zone rocks. The orientation of this chlorite is again conformable to the marginal shear structures.

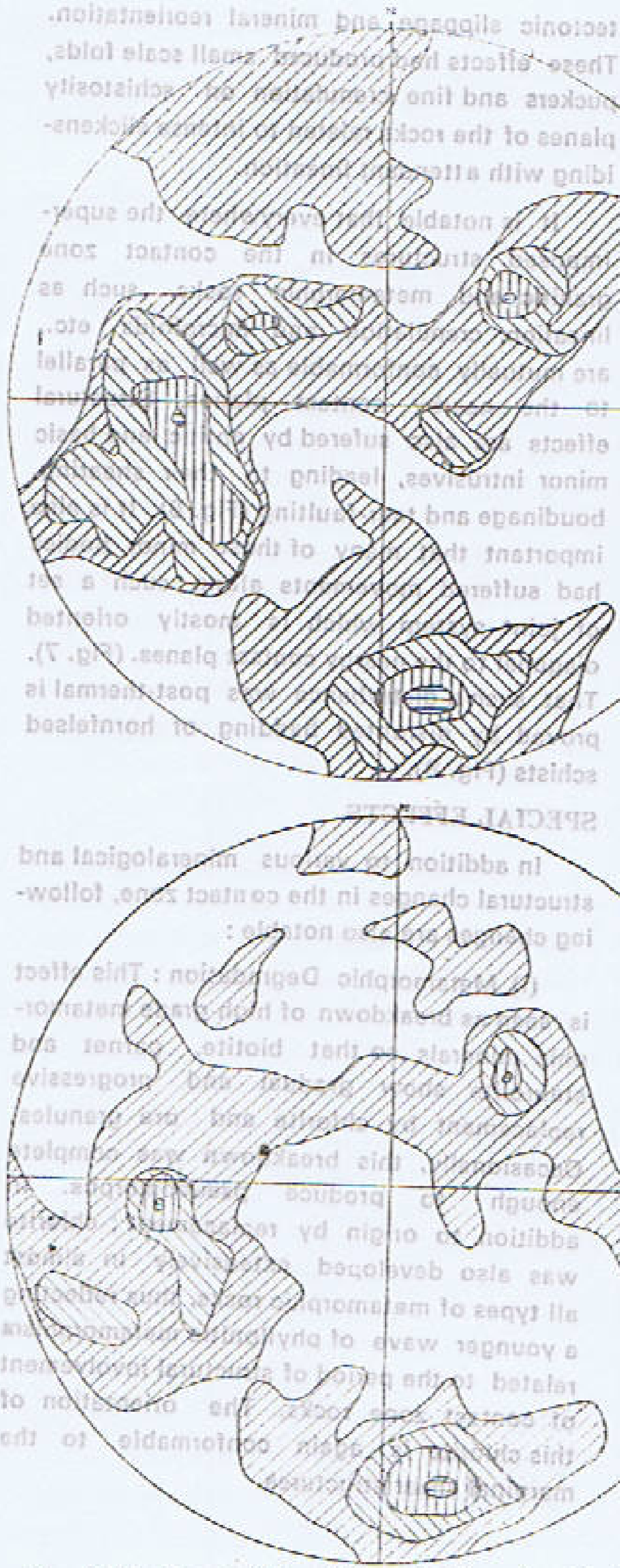

Fig. 4 Equal area (Schmidt) projection of poles to joint planes (800 readings) in the schists (a) and granite (b) in the southern contact zone ofthe Hazara graintic Complex. Contours at 0.5, 1.5, 2.5 and 3.5%.

F g. 5 Mylonitic banding in the cntact zone of Susalgali gneiss, near Chorgali.

Fig. 6 Sheared (a) tear-faulted and bondinaged (b) aplites in the contact zone near Gamian Sari (dj : diagonal joint).

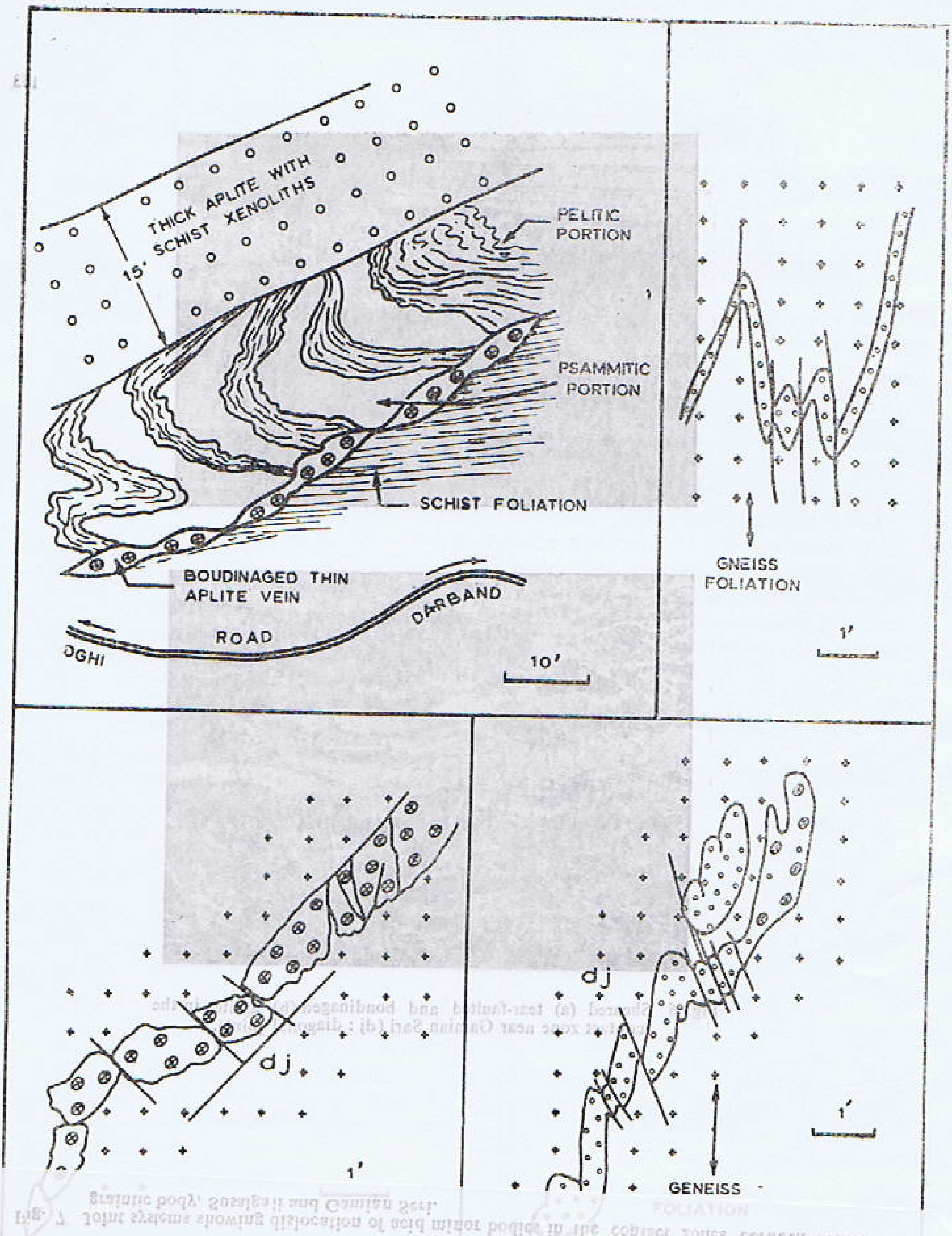
THICK APLITE WITH
SCHIST XENOLITHS
15'
PELITIC
PORTION
PSAMMITIC
PORTION
SCHIST FOLIATION
BOUDINAGED THIN
APLITE VEIN
DARBAND
ROAD
OGHI
10'
GNEISS
FOLIATION
1'
dj
dj
1'
1'
GENEISS
FOLIATION

Fig. 8 Disrupted hornfelsed schists, near Chhar, E. of Mansehra.

(ii) Kyanite Pseudomorphs After Andalusite ; This is a rather rare phenomenon and so far has been observed near Choian and East of Chorgali. This spactacular effect is observed in hornfelsed metasediments wherein big (3 x 1 x 1 cms.) andalusite prism were replaced by bluish coloured kyanite crystals altering to muscovite. The pseudomorphism was so perfect that even interpenetration twinning of original andalusites was preserved. The latter fact points towards absence of any action originating from shearing stress in the Harkerian sense (Harker, 1939) ; rather, an origin by hydrostatic pressures related to granite tectonics was considered as the fundamental cause (Shams, 1965).

DISCUSSION

The variety and nature of various phenomena, as recorded within contact zones of the Hazara granitic complex and the associated metamorphic formations, show the following sequence of events :

1. Pre-granitic regional metamorphism of the geosynclinal argillaceous-arenaceous sediments, causing recrystallization of original minerals and growth of new minerals of Barrovian-type sequence.
2. Thermal metamorphism of the metasediments, forming new minerals, causing thermal breakdown of older minerals and destroying to variable degree the primary fabric of the metasediments.
3. Hydrothermal metasomatism of the hornfelsed metasediments hydrolyzing minerals, with simultaneous appearance of feldspar, tourmaline, apatite etc.
4. Upwelling and expansion of the granitic bodies, producing marginal shear structures and upthrust-faulting at their contacts.
5. Regional phyllonitic metamorphism, partly overlapping the phase (4) above.

From the above, various events in the evolutionary geohistory of the Hazara granitic complex can be grouped as ;

(i) Thermal Type ii) Metasomatic tye iii) Structural type. The basic phenomena were concerned with thermal preparation of the metasediments to become more amanable to the action of metasomatising solutions, the heat having travelled much quicker and farther than the metasomatising solutions. It was as a result of change in chemical, mineralogical and textural composition of the metasediments that new mechanical properties were induced due to granitization. Helped by the pore fluids, the granitic bodies got mobilized under regional stress. Thus, those were elevated into the cores of unchanged metasedimentary formations, now generally met at lower topographical levels due to subsidence and erosion.

In the transformation sequence from metasediments to granitized rocks, the andalusite-bearing granites have an important position. Those are met generally within 1-2 km marginal portion of the granitic complex. Their main differences from the andalusite-hornfelses are the grain size and relative proportions of various essential minerals. During regional study of the Hazara granitic complex (Shams, 1967), andalusite-bearing granites were recognised to present as one stage in the geohistory of the complex, leading to the Mansehra granite composition and ultimately to the Chitti Dheri-type porphyries'

Like the latter, certain pegmatites, aplites and albitite phases of the area were also found to have originated by anataxis. Detailed studies of the acid minor bodies have been published (Ashraf, 1974, a, b, Shams and Rahman, 1966, Shams, 1980).

The tourmaline-bearing granites, such as the Hakale granite, Sukal granite, etc. make a younger group of granites. Among other of their characteristics are the mineralogical zoning, ubiquitous replacement of plagioclase by sodic microcline, variation in size down to thin veins and as smearing on open joint faces. All such bodies were found to have arisen from granitic liquid of anatectic origin. Thus, these rocks represent the ultimate product of granitization of metasediments. Temperature estimations, based on two feldspar thermometry (Shams and Rahman, 1967) gave adequate range for anatexis.

Some of the age data on Hazara granites (Shams, 1967 ; Le Fort et al, 1980 ; Bordet et al. 1971 Jager et al, 1971) show that those were present prior to the Himalyan orogenic episode. Therefore, it is believed that the Hazara granitic complex was present even before the Himalayan orogeny and got mobilized during tectonic evolution of the mountain range. Such a mobilization is found to be responsible for generation of heat, mobility of metasomatising fluids which carried out granitization of the cover rocks, through various stages described earlier. This is thought to be the reason that lithologies of different ages were involved, such as Tanols in the Hazara area, Salkhalas in the Nanga Parbat area, the particular nature of geanitization depended on the particular lithology involved as was proposed by Misch (1949) in the case of the Nanga Parbat granitic area.

The model presented here is considered to be most suitable for application to other granitic-migmatitic complexes of the Himalayas which make thrust sheets and nappes.

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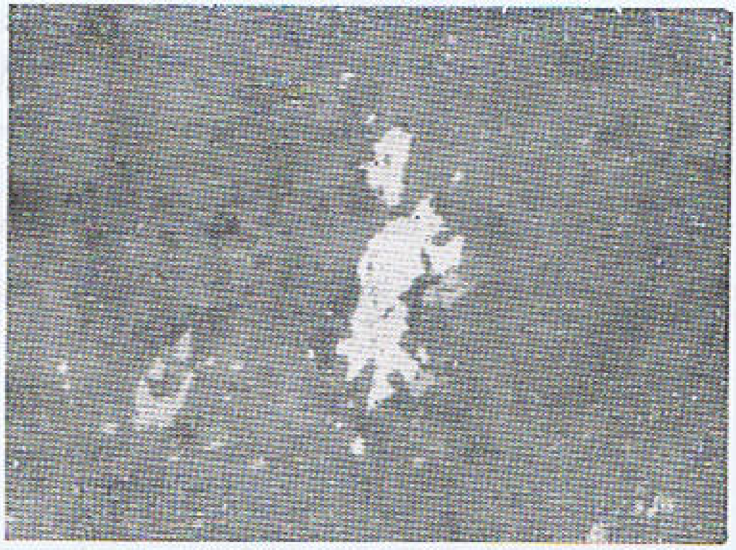

Fig. A 100

Heazlewoodite in a granular aggregate (white) surrounded by serpentine (black)

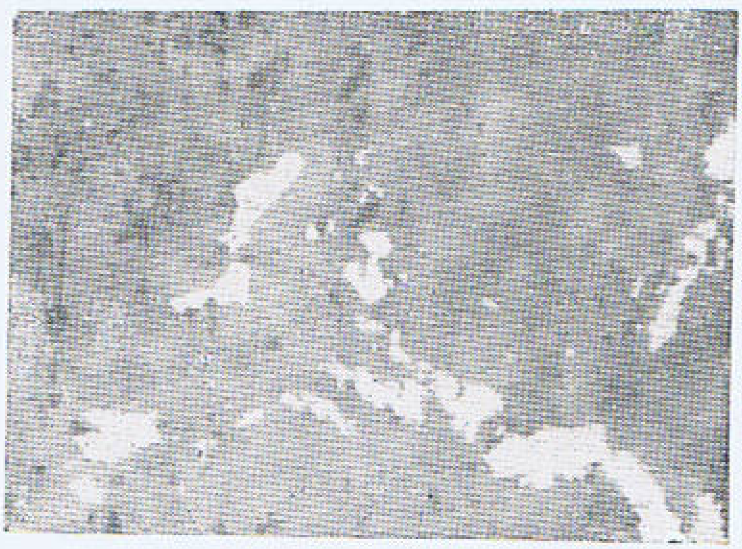

Fig. B 100

Pentlandite (white) in the interstices of serpentine grains (black)

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DINOFLAGELLATES AND POLLEN FROM EOCENE OF PAKISTAN

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Abstract: *Fifteen dinoflagellates taxa, and twenty-seven pollen taxa are recorded from the Eocene of Zao River and Shaplai Khwara sections, Sulaiman Range, Baluchistan, Pakistan. They are represented by eleven dinoflagellate genera and fifteen pollen genera. Although most of the palynomorphs are typical of Eocene age, some reworked palynomorphs from Triassic-Cretaceous are recorded.*

INTRODUCTION

Published work on palynology of the Tertiary material from Pakistan is scanty. The present author recorded, for the first time, several taxa of dinoflagellate cysts, pollen from the Eocene of Zao. River and Shaplai Khwara sections (Fig. 1). Eames (1952) published his work on the lithological subdivisions of the Eocene succession of Zao River and Shaplai Khwara sections. Siddiqui (1971) studied ostracods from these two sections and sub-divided the Eocne strata into several biostratigraphical units, I-V, based on ostracods. A complete succession of the Shaplai Khawara and Zao River area has been provided by him. In general, Shaplai Khwara strata, locally known as Ghazij formations, are Lower Eocene in age. They consist predominantly of shales with intercalations of sandstones, grits, clays, siltstones, marls, etc. These shales are overlain by Kirthar formations, middle to upper Eocene in age. Rocks exposed along Zao River area are Kirthar formations, predominantly consisting of limestones, calcareous shales with intercalations of mudstones, clays, siltstones, marls, etc.

In general, Shaplai Khwara samples (mainly shales) yielded more abundant palynomorphs than Zao River samples (mainly limestones). From the point of view of the preservation of palynomorph assemblages, shales are better preserved material than limestones.

Dinoflagellates are regarded as exclusively marine microplankton, whereas pollen usually predominate in a continental deposit implying a proximity to a land mass. Since almost all the samples, under the present investigation, yielded both dinoflagellates and yollen, it is probable that assemblages recorded on the whole represent a near-shore deposit.

ASSEMBLAGES RECARDED

Dinoflagellate assemblages	Age
Cri$_{\sigma}$roperidinium sp.	early-mid Cretaceous (reworked)
Cordiosphaeridium exihmurum Davey & Williams 1966	Eocene
Homotrilobum sp. 1	Eocene

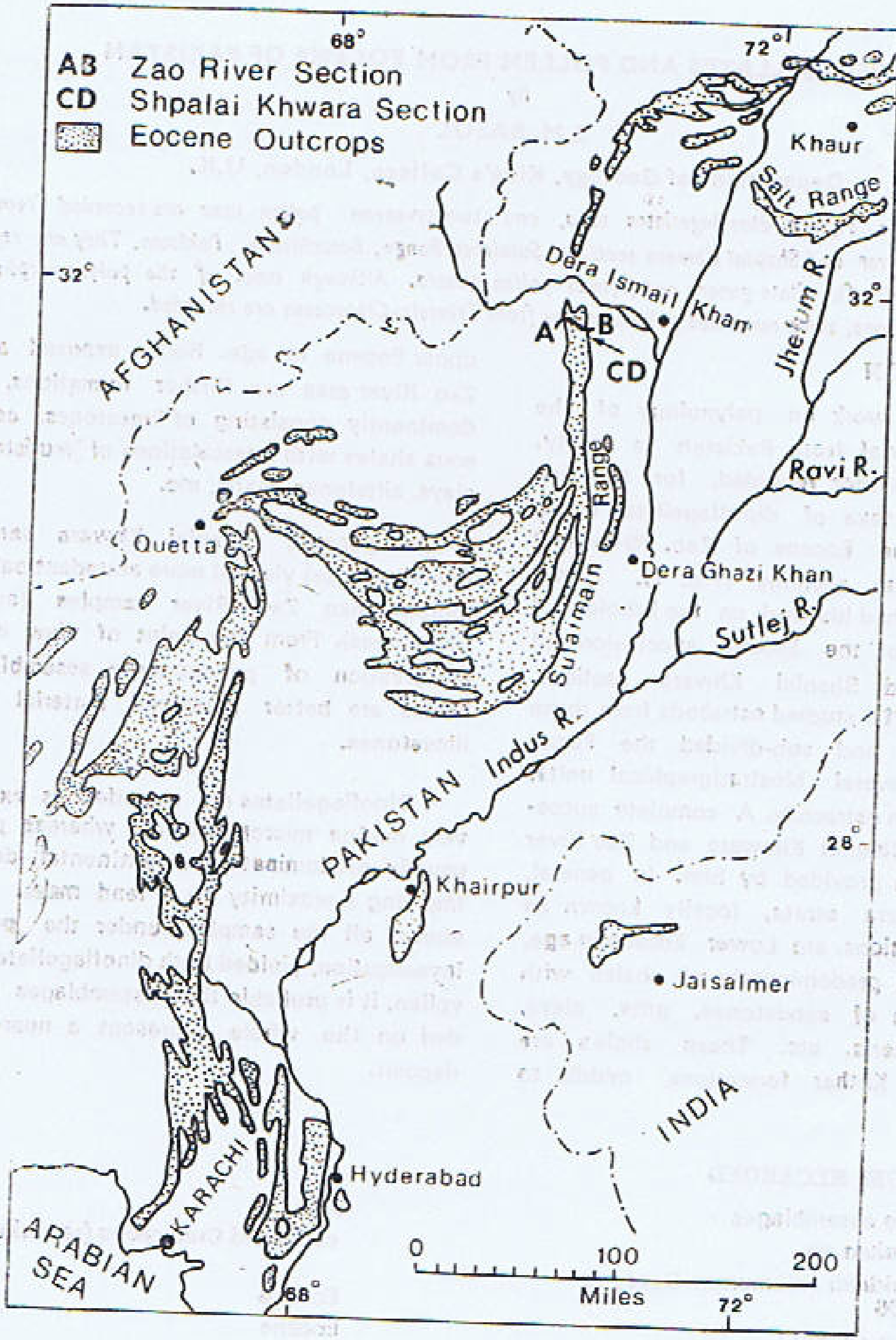

Fig.1 EOCENE OUTCROPS OF PARTS OF PAKISTAN
(After Eames 1952, and Siddiqui, 1971)

Peridium sp.	Eocene
Adnotosphaeridium aemulum Deflandre 1938	Upper Jurassic (reworked)
Cleistosphaeridium sp.	Jurasic (reworked)
Homotriblium sp. 2	Eocene
Spiniferites sp.	Eocene
Spiniferites ramosus var. ramosus Mantell 1950	Eocene
Polystephanephorus sp.	Jurassic (reworkd)
Hystrichosphaeridium tubiferum Ehrenberg 1938 ?	Eocene
Oligosphaeidium anothophorum Cookson & Eisenack 1958	Cretaceous (reworkd)
Cleistosphaeridium diverspinosum Davey, Downie, Sarjeant & Williams 1966	Eocene
Hystrichaeridium sapingophorum Deflandre 1935	Eocene / Jurassic (reworkd)
Chlamydophorella cf. walla Cookson and Eisenachk 1960	Eocene
Pollen assemblages recorded	Eocene
Palmae sp.	Eocene
Polycolpites sp.	Eocene
Tricolpites cf. retriculatus Krutzch	Eocene
Spinozonocolpites sp.	Eocene
Diporites sp.	
Nyssa pollenites	
Neoraistrickia truncatus (Cookson) Potonie 1956	
Laevigatisporites sp.	Eocene
Selixene sp.	Eocene
Cedripites sp. (gymnosperm)	
Tricolporpollenites sp.	Cretaceous
Ericipites sp.	Eocene
Triporate sp.	Eocene
Tilliapollenites sp.	Eocene
Vitreisporites pallidus (Reissinger) Nilsson 1958 (gymnosperm)	
Periporopollenites	Trias
Monoporities sp.	? Eocene
	Eocene

CONCLUSIONS

In this work, a preliminary attempt has been made to document palyonmorph assemblages from the Eocene of Pakistan. This result, in turn, will be useful for further investigations of new material from other areas with a view to eventually establishing a standard set of assemblage zones which will facilitate inter-Eocene correlation and comparison of Eocene material from Pakistan and adjacent areas.

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Plate I

(All figures x 750)

Figure 1	Cribroperidinium sp.
Figure 2	Cordosphaeridium exilimurum
Figure 3	Homotriblium sp. 1
Figure 4	Peridium sp.
Figure 5	Adnotosphaeridium aemulum
Figure 6	? Cleistosphaeridium sp.
Figure 7	Homotribolium sp. 2
Figure 8	Spiniferites sp.
Figure 9	Spiniferites ramosus var. ramosus
Figure 10	Polystephanephorus sp.
Figure 11	Hystrichosphaeridium tubiferum
Figure 12	Oligosphaeridium anothophorum
Figure 13	Cleistosphaeridium diversispinosum
Figure 14	Hystrichosphaeridium sapingophorum
Figure 15	Chlamydophorella cf. walla

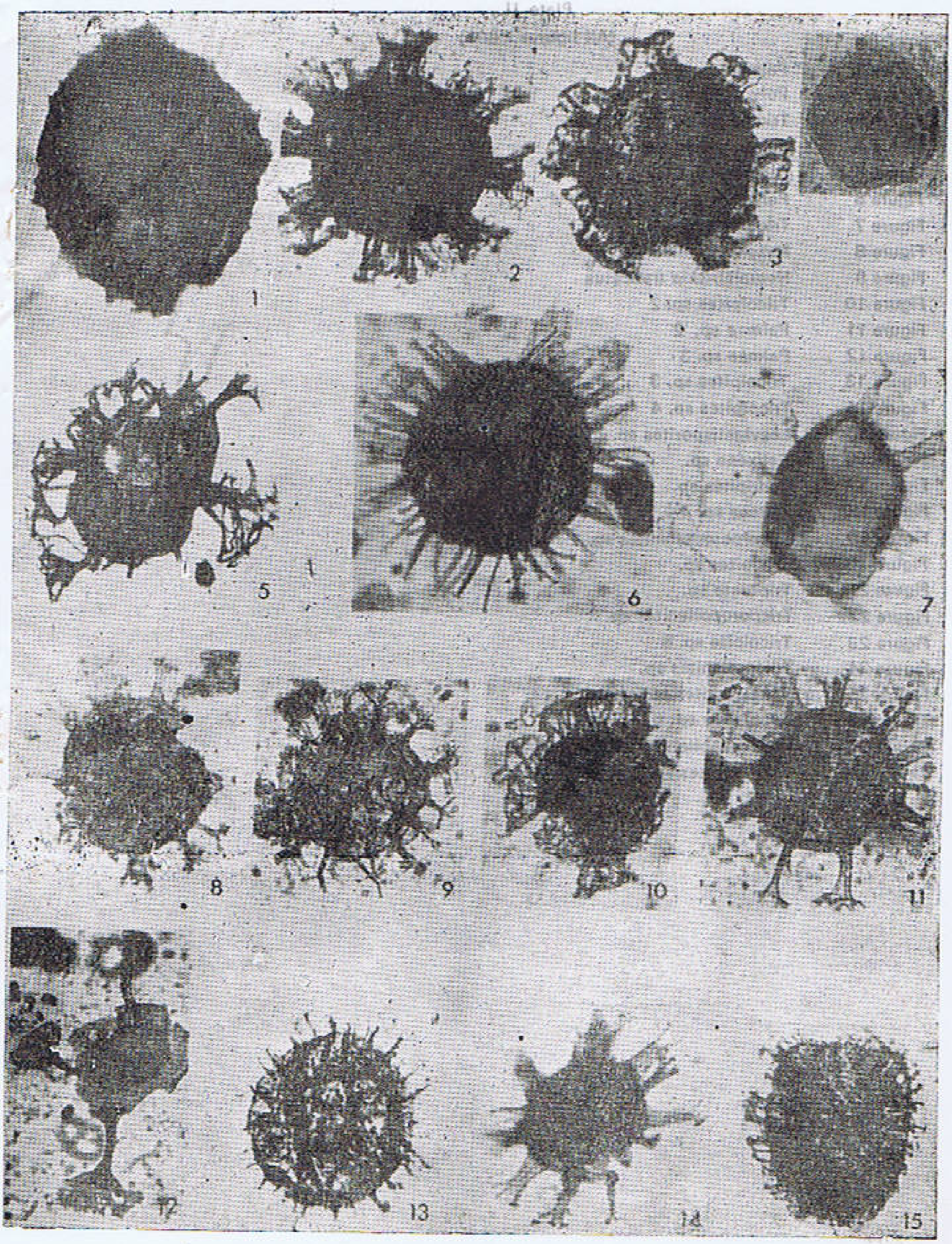
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Plate II

(All figures x 900)

Figure 1	Palmae sp. 1
Figure 2	Polycolpites sp. 1
Figure 3	Tricolpites cf. reticulatus
Figure 4	Spinozonocolpetes sp.
Figure 5	Diporites sp.
Figure 6	Polycolpites sp. 2
Figure 7	Tricolpites sp. 1
Figure 8	Nyssapollenites
Figure 9	Neoraistrickia truncatus
Figure 10	Tricolpites sp. 2
Figure 11	Palmae sp. 2
Figure 12	Palmae sp. 3
Figure 13	Tricolpites sp. 3
Figure 14	Tricolpites sp. 4
Figure 15	Laevigatisporites sp.
Figure 16	Selixene sp.
Figure 17	Cedripites sp.
Figure 18	Palmae sp. 4
Figure 19	Tricolporopollenites sp. 1
Figure 20	Ericipites sp.
Figure 21	Triporate sp.
Figure 22	Tricporopollenites sp. 2
Figure 23	Tricolpite sp. 5
Figure 24	Tiliapollenites sp.
Figure 25	Vitreisporites pallidus
Figure 26	Tricolpites sp. 6
Figure 27	Periporopollenites sp.
Figure 28	Monoporites sp.


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NOTICES, ABSTRACTS AND REVIEWS

PRELIMINARY ACCOUNT OF THE OCCURRENCE OF Ni SULPHIDES IN SERPENTINITES OF SOUCH AREA KAGHAN VALLEY, DISTRICT MANSEHRA, N.W.F.P. PAKISTAN.

Souch area lies between longitude 730 40' —730 40' E and latitude 340 55'—340 59' 30" N. Qadir (1979) has described in detail the Petrology of the area and classified the area into three groups.

1. Metamorphic rocks consisting of garnet mica schist, graphitic schist, marble, amphibolites.

2. Quartzofeldspathic rocks consisting of granite gneiss, pegmatites, aplites.

3. Ultramafics, consisting of dunites, Serpentinites, Pyroxenites, Talc and Carbonates.

The first outcrop of the ultrabasic is at 1½ km. above Lidi a small village on right bank side of river kunhar. Chemical analysis of two serpentinite rock samples showed Ni—0.28 to 0.32 %. The rock under study was weathered to greenish black and fine to medium grain size.

The major minerals are antigorite, chrysotile, olivineforsterite, with small amounts of magnesite, magnetite heazlewoodite and pentlandite. The presence of heazlewoodite (Fig. A) and pentlandite, (Fig. B) was identified by the Ore-microscopic techniques, such as, reflectivity, microhardness and etch tests described by Cameron (1961) and Ramdohr (1969).

These two minerals occur as small disseminated among and molded about silicate minerals, and appears to be a primary accessory of the ultrabasics.

The texture of mineral assemblages and their association favours the Phenomenon of Sulphide-silicate immiscibility and consequent magmatic differentiations in situ. Such sulfide disseminated in ultramafic rocks have been reported by many workers, such as Souch, Podolsky et al (1969), from Sudbury deposits Canada and Woodal and Travis (1969) from kambalden deposits in Western Australia. In these, sulfides grade from minor disseminations in ultramafic rocks to massive ores. The disseminated ores appear to represent an early stage of the process that formed massive ores.

A detail work on the other ultramafic rocks of the area is in progress and will be published soon.

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