T/1. Tahir, M., 1986-85. Geology of Dhamtaur Baghsari Area. Institute of Geology, Punjab University, Lahore, 1-82.

Key words: Geology, lithology, Abbottabad.

T/2. Tahir, M.A., Dastgir, G., Riaz, M. & Ahmad, M., 1996. Landforms of NWFP and FATA. Programme and Abstracts, 8th All Pakistan Geographic Conference, Peshawar, p.11.

Key words: Geography, landforms, NWFP, FATA.

T/3. Tahir, N., 1995. Industrial minerals and dimension stones. Proceedings, International Round Table Conference on Foreign Investment in Exploration and Mining in Pakistan, Islamabad, October 16-18, 1994, 197-204.

Key words: Industrial minerals, dimension stones.

T/4. Tahirkheli, R.A.K., 1959a. Report on lead-zinc deposits near Ushu, Swat State, West Pakistan. GSP, Information Release 9, 7p.

Ushu valley is occupied by metasediments and volcanics of the Kalam Group in the south, followed by a strip of Utror volcanics. But much of the valley contains plutonic rocks ranging from diorite, through quartz diorite to granite of what is now called the Kohistan batholith. The small lead-zinc deposits here are associated with the granitic rocks of the Falaksair area.
Key words: Mineralization, lead-zinc, Swat.

T/5. Tahirkheli, R.A.K., 1959b. Report on kyanite showings near Landaki, Swat State, West Pakistan. GSP, Information Release 12.

Kyanite pockets occur in quartz veins and pegmatites associated with granitic rocks of Swat area. The granites intrude pelitic and calcareous rocks metamorphosed under Barrovian-type conditions. This report describes kyanite showings near Landakai at the border of Malakand Agency.
Key words: Kyanite, Swat.

T/6. Tahirkheli, R.A.K., 1960. Investigations of gold and other placer minerals in the Indus alluvium. GSP, Information Release 14, 9p.

This report furnishes the interim results of field and laboratory studies on samples collected from a selected 25 acre area at amb, and results of analyses of four samples of concentrates from Bunji, Amb, Mian Dheri, and Attock.
The radioactivity of the Indus alluvium at Amb ranges from 0.013 to 0.18 mR/hr with the mantle sand giving slightly higher reading than gravel. Content of uranium in the Indus alluvium at Amb ranges from less than 0.001 to 0.007 percent.
Gold won by the local goldwashers from a ton of sand scrapped from between boulders and cobbles in the gravel bar averages about 0.25 grams. Study of gold washing shows that each working day, a goldwasher collects 3 to 4 pounds of a highly concentrated product containing these heavy minerals, listed in decreasing order of relative abundance; magnetite, ilmenite, garnet, zircon, scheelite, monazite, uranothorite, uraninite, and gold.
Key words: Gold, placers, alluvium, Indus.

T/7. Tahirkheli, R.A.K., 1965a. Economics of Indus River sands. Geological Bulletin, University of Peshawar 2(a), 11-15.

The Indus River has for centuries attracted the attention of the prospectors and geologists because of gold in its alluvials. The goldwashers are still working along the Indus River banks, using primitive methods to extract gold by washing sand and gravel. Recent studies conducted by the author show that an experienced goldwasher extracts about 1.05 grains of gold per cubic yard. The high value minerals left behind in gold tailings are scheelite, uraninite, and cassiterite. An attempt has been made in this paper to evaluate their proportions in the heavy fraction and bulk sands to see whether they can be won economically as co-products of gold.
Key words: Economic geology, gold, Indus River.

T/8. Tahirkheli, R.A.K., 1965b. Recent observations on the undifferentiated Attock Group. Geological Bulletin, University of Peshawar 2(b), 10-23.

Under the light of recent investigations the Attock Slates are found to contain five distinct lithological units which are easily differentiated in the field and belong to different ages. Three of these units are dated to be Upper Mesozoic, one is assigned a pre-Cambrian age and the fifth unit is still under observation and is tentatively placed in the Paleozoic. The argillaceous part of the Attock Group which was previously, considered to be one homogeneous unit is split into two divisions and named "Manki Slates" and "Dag Slates." The later contain fossilized bands of limestone and on the basis of diagnostic fossil (Cerithiopsidea), have been dated to be Upper Cretaceous age. These two slates have got tectonic contact and the older Manki slates are found to have thrust over the younger Dag slates.
Key words: Lithology, slates, Mesozoic, Pre-Cambrian, Attock, Manki.

T/9. Tahirkheli, R.A.K., 1967. Reconnaissance for radioactive minerals in Dardistan, Baltistan and Haramosh in Gilgit agency, West Pakistan. GSP Information Release, 33, 17p, one map.

The eastern and north eastern parts of the Gilgit Agency which constitute Baltistan, Dardistan and Haramosh were reconnoitered for radioactive minerals during the period of July – October 1960. A geological map of the traverse – route was prepared and radioactivity of the rocks exposed was plotted thereon. Samples of sand were collected form the tributaries of Indus river for radiometric and mineralogical study. The radioactivity in the gneissic band in metasediments measured between 0.035 and 0.7 mR/hr. some of the granite intrusions and acid dykes of later phases read 0.03 to 0.07 mR/hr. few sand samples from the tributaries of the Indus yielded relatively high radioactivity, pointing the possibility of uranium mineralization in their catchment areas. These favourable indications of possible mineralization warrant an expeditious programme for having a thorough radiometric check in this area.
Key words: Reconnaissance, radioactive minerals, Baltistan, Dardistan, Haramosh.

T/10. Tahirkheli, R.A.K., 1968a. Size analysis of the Indus River sands, West Pakistan. Geological Bulletin, University of Peshawar 3, 1-9.

In this paper an attempt has been made to evaluate the grade of the sand-size material in the Indus alluvium between Kalabagh and Skardu. The most widely used statistical devices of quartile measures were applied to describe the sediments. Some of the results obtained are comparable with those of similar work carried out in other parts of the world.
Key words: Alluvium, sand, size analysis, Indus River, Kalabagh, Skardu.

T/11. Tahirkheli, R.A.K., 1968b. Stratigraphy of the outcrops exposed along the eastern bank of the Indus at Attock, West Pakistan. Geological Bulletin, University of Peshawar 3, 19-25.

The outcrops exposed on the eastern bank of the Indus at Attock are examined to establish time-rock sequence for correlation. The rocks exposed here represent a typical Mesozoic sequence. No rocks older than upper Triassic (Kingriali Formation) are exposed in this area.
Key words: Stratigraphy, Mesozoic, Indus River, Attock.

T/12. Tahirkheli, R.A.K., 1968c. A new look at the Attock slate series. Geological Bulletin, University of Peshawar 3, 31-32.

A greater part of Attock – Cherat Range, which exposes slates, has been mapped on 1”:1 mile scale map and various lithological units, having separate entity in the series, have been differentiated. This note is intended to provide preliminary results on the stratigraphy of the Attock Slate series – based on the author’s observations.
Key words: Lithology, stratigraphy, slates, Attock-Cherat.

T/13. Tahirkheli, R.A.K., 1969a. Present status of the Attock slate series. Sind University, Science Research Journal, Special No. (Geology Symposium), 51-58.

The Attock slates are divided into twelve mapable units. Descriptions are given for Manki slates, Kingriali formation, Rubbli limestone and Attock slates.
Key words: Lithology, stratigraphy, Attock slates.

T/14. Tahirkheli, R.A.K., 1969b. Another Paleozoic reef discovery in Tangi Ghar, Peshawar District. Geological Bulletin, University of Peshawar 4, 90-91.

The Tangi Ghar spread over some three square miles, and is divided into seven isolated rounded to subrounded hillocks, the highs attaining a height of 1582 feet. The general trend of the ridge is east - west, which conforms to the strike of the rocks, which dip to the north. The major hillock (1982 feet) forms a steep escarpment along the northern edge. The mountain ranges exposed around Tangi Ghar lie at distances varying between 8 and 20 miles; the nearest ones are those of Takhtbai and Mohmand Tribal Territory, lying towards the east and west respectively. Three distinct lithological units are 1) Light to dark gray slate, phyllite and phyllitic schist, 2) Thin-bedded to massive crystalline siliceous limestone, 3) Slate, phyllite and phyllitic schist.
Key words: Lithology, stratigraphy, Palaeozoic, Peshawar.

T/15. Tahirkheli, R.A.K., 1970a. Mineral and minings; Resources base on economic programme of the Peshawar Valley: A study conducted by Economic Department, Peshawar University for Planning and Development, Regional Development Plan, Peshawar, 53-79.

Key words: Mineral resources, mining, Peshawar.

T/16. Tahirkheli, R.A.K., 1970b. Descriptive geological notes on Uch Khattak and Hissar Tang sections in the Attock Range. Geozine, Geology Department, Peshawar University 1, 20-23.

Consult Tahirkheli (1970c) for further information.
Key words: Geology, stratigraphy, Attock-Cherat.

T/17. Tahirkheli, R.A.K., 1970c. The geology of the Attock-Cherat Range, West Pakistan. Geological Bulletin, University of Peshawar 5, 1-26.

The Attock-Cherat Range is exposed in an area of about 50 square miles in Attock district and 360 square miles in the Peshawar district, on both the sides of the Indus River. Around Attock the relief is low; the elevations range from 1300 to 2079 feet which on the other side of the Indus culminate to 4546 and 5033 feet at Cherat and Jalala Sar respectively, which are the commanding heights in the Peshawar Plain. Between Attock and Mir Kalan village, the general trend of the range is east-west which coincides with the strike of the rocks. Beyond this point, the range swings to the south-west and ultimately merges into the Nizampur-Kohat mountains in Darra Adam Khel tribal territory. In the Attock plain the slates are lost beneath the alluvium beyond Kamra hillock till they crop out again in southern Hazara. In the west, the last slate outcrop mapped is exposed near Dag village, beyond which the slates are covered by thick alluvium till they crop out in the Khyber Mountains.
Two types of lithological elements, with a tectonic contact, are exposed in the Attock-Cherat Range. One comprises the Paleozoic metasediments (phyllite, phyllitic slate, slate and crystalline limestone) forming the northern face of the range. They are correlated with the rocks of Khyber in the west, Hazara in the east and Swabi-Lower Swat in the

north. The dominantly sedimentary rocks belonging to the Mesozoic-Tertiary eras, developed along the southern face of the Attock-Cherat Range, may be correlated with the rocks of Samana Range, Kala Chitta hill, Salt Range and Hazara.

The pelites of the Attock-Cherat Range are divided into two parts on the basis of fossil evidences. The older, Manki Slate is of Lower Silurian age and the younger, Attock Shale has been placed in the Middle Jurassic-Cretaceous. Altogether, thirteen mappable lithological units have been distinguished in the Attock-Cherat Range. Of these, four have been placed in the Paleozoic, four in the Mesozoic and five in the Tertiary. The Shahkotbala Formation is the oldest lithological unit exposed in this area and is (?) Upper Ordovician to Lower Silurian in age. No Precambrian rocks have been recorded in the Attock-Cherat Range.

The two major thrust faults running along the northern and the southern fronts of the range traverse the area in the east-west direction. The northern thrust is the result of overturning of the southern flank of an anticlinal fold. Another anticlinal fold skirts the Attock-Cherat Range on the south in the Nizampur valley. The northern limb of this fold is intact. The southern limb is eroded away and is buried under the alluvium. The Attock Shales are folded into assymmetrical parallel isoclinal folds with their axes dipping towards the north. The faulting pattern in the Attock-Cherat Range yielded imbricate type structure, which are conspicuously observed all over the area.

Key words: Geology, stratigraphy, Attock-Cherat.

T/18. Tahirkheli, R.A.K., 1971a. The geology of the Gandghar Range, District Hazara, NWFP, Pakistan. Geological Bulletin, University of Peshawar 6, 33-42.

The Gandghar Range is located on the western tip of the Hazara district, due to its isolated position it could attract a few geologists during the past. In the Geological Map of Pakistan (1964), the Range is partly mapped as Pre-Cambrian and partly Silurian-Devonian.

The Gandghar Range exposes a suite of metasedimentary rocks, comprising of slate, phyllite, phyllitic-slate, schists, quartzite and crystalline limestone. Five lithological units are differentiated which have been correlated with the Palaeozoic sequences of the southern Hazara and the Attock – Cherat Range. The oldest unit is the Mohat Nawan Limestone and the youngest is the Pirthan Limestone, which are respectively homotaxial to the Shahkotbala formation of the Attock-Cherat Range and the Sirban Formation of the Abbottabad Group in the southern Hazara. The former is placed in the Upper Ordovician – Lower Silurian and the latter in the Permo – Carboniferous.

Key words: Stratigraphy, metasedimentary rocks, Hazara.

T/19. Tahirkheli, R.A.K., 1971b. Phosphatic mineralization as a basis for stratigraphic correlations. Geological Bulletin, University of Peshawar 6, 117-119.

The author during geological mapping of Gandghar Range in the western Hazara, Cherat Range east of Peshawar, and the Rajgal area of Tirah in Khyber Agency has located a thick sequence of siliceous dolomitic limestone which was considered identical to Sirbon Formation on lithological grounds. To further authenticate this correlation, the author had collected scattered samples from each section, for chemical examination, to confirm whether phosphorite mineralization of same type as in the Kakul and Sirbon Formation in their type sections, is also present.

Key words: Phosphate, Kakul, Khyber Agency, Gandghar Range.

T/20. Tahirkheli, R.A.K., 1971c. Industrial rock resources of the Kohat District, N.W.F.P West Pakistan. Directorate of Mineral Development, Govt. of N.W.F.P. Information Release 1, 14p.

The rock salt, gypsum and limestone form an important geological horizon in the Trans-Indus Salt Range of Kohat. This belt covers about 2000 square miles area in the eastern part of the district.

At present, only rock salt is being mined, substantial part of which goes for domestic consumption and a fraction supplied to the Industries located outside the district,

This short paper is intended to provide useful geological information to bring the enormous reserves of the Industrial rocks of the Kohat district to some industrial usage.

Key words: Industrial rocks, Kohat.

T/21. Tahirkheli, R.A.K., 1971d. The raw material for refractories in N.W.F.P. and Tribal Territories, Pakistan (West). Directorate of Mineral Development, Govt. of N.W.F.P., Peshawar, Information Release 2, 12p.

Every industry which employs high temperature must utilize refractories. Due to rapid development of refractory-consuming industries in the country, the demand of high refractories is bound to increase.
The common refractories are grouped under fire day, high alumina, silica and basic refractories, Kaolin, quartz, quartzite, bauxite; dolomite, chromite, limestone and olivine are some of the important raw materials available in workable reserves in the N.W.F.P. and the adjoining tribal territories on which refractory industries can be based. This short paper is intended to provide a geological base for planning such industries in this region.
Key words: Refractories, raw material, NWFP.

T/22. Tahirkheli, R.A.K., 1971e. The raw material for refractories in N.W.F.P. and Tribal Territories, (West) Pakistan. The Peshawar Economist 1, 22-35.

Consult the preceding account for further details.
Key words: Refractories, raw material, NWFP.

T/23. Tahirkheli, R.A.K., 1971f. Mineral map of the N.W.F.P. and Tribal area. Directorate of Mineral Development, Govt. of N.W.F.P., Peshawar, Information Release 3.

Several mineral deposits have been discovered in the North-West Frontier Province and the adjacent Federally Administered Tribal Territory. The author shows the location of the minerals of commercial interest in the map.
Key words: Mapping, minerals, NWFP.

T/24. Tahirkheli, R.A.K., 1971g. Phosphate occurrences in Hazara and other contiguous areas of N.W.F.P. and the Tribal Territories. Directorate of Mineral Development, Govt. of N.W.F.P., Peshawar, Information Release 5, 18p.

Key words: Phosphate, Hazara, NWFP.

T/25. Tahirkheli, R.A.K., 1972. A proposed mineral strategy for the N.W.F.P. and the adjoining Tribal belt. Directorate of Mineral Development, Government of N.W.F.P., Peshawar, Information Release 6, 27p.

A number of metallic and non-metallic minerals occur in the accessible areas in the N.W.F.P. and the tribal territories, which do not need much investment to raise an infrastructure for their development and exploitation. Therefore it is advised to first plan mining ventures and mineral industries based on these minerals. A number of mineral based industries have been suggested in various parts of this province where suitable raw material is available.
During future planning for the road and railway extensions in this region, care should be taken to give priority to open up those areas which are potentially favourable for the natural resources, such as minerals, forest, etc.
Bank loans, railway freight concessions, even for the domestic markets along with other technical and economic incentives discussed in this paper, can provide a sound basis for the progressive development of the mining industry in this province. A substantial part of this province remains geologically unexplored and thus needs proper planning to gear up exploration based on modern scientific lines to trace the history of subsurface mineralization of the surficial metallic mineral showings.
The private investment on mineral ventures has become shy because of lack of the above mentioned incentives. Therefore it is in the interest of the government to create favourable conditions to make the mining sector more attractive. This would solve three fold purpose, (a) participation of the private sector in raising the infrastructures, thus sharing a considerable part of the capital cost which otherwise would have to be invested by the government,

(b) to make the minerals located in the far flung interior more competitive in the market, because of relatively low cost of mining venture by the private sector as compared to the public sector, and (c) infusion of technical know-how and inflow of private finances which are directly needed to create a sound footing for the mining industry in this region.
Key words: Minerals, NWFP.

T/26. Tahirkheli, R.A.K., 1974. Alluvial gold prospects in the northwest Pakistan. University of Peshawar, Information Release 7, 48p.

The auriferous alluvials of Chitral, Gilgit, Hunza and the Indus rivers have been discussed in the paper. A goldwashing Industry, based on primitive technique, have flourished for centuries in this region, and even now one can see goldwashers working on wooden sluice, locally called nava. The river alluvials are composed of mantle sand, bouldergravel, cobble-gravel, and pebble-gravel, ranging in size from over 6 feet in diameter to less than 1/256 mm. The assemblage of heavy minerals including gold is relatively higher in the gravel deposit. The mantle sand shows higher concentrations of heavy minerals where the natural accumulates in the form of streaks and thin films occur.
The closely-packed pebble-gravels usually form the favourite sites to wash sands for gold, though in the upper reaches of the mountainous terrain, boulder-gravel and cobble-gravel have indicated reasonably high concentrations of gold.
Among the valuable minerals which would be won as co-product of gold are opaque ore minerals, zircon, garnet, monazite, scheelite, cassiterite, apatite, rutile. In size, over 85 percent of these minerals pass through minus 80 mesh screen. The distribution of gold in the alluvials is erratic. A rough estimate based on nava, washing revealed the following results:
Twenty-eight percent of the alluvials are barren with No gold showings, 58 percent of the alluvials yielded gold worth less than 35 paisas per cubic yard and only 14 percent of the alluvials showed consistent gold occurrences and yielded from 35 to 650 paisas of gold per cubic yard.
The treatment of goldwasher's stage III concentrate
(magnetite-free) in Isodynamic Magnetic Separator revealed the following mineral assemblages in various fractions,
1st fraction - dominantly opaque ore minerals.
2nd fraction - 75-85 percent opaque ore minerals.
3rd fraction - garnet-rich.
4th fraction - gold, zircon. monazite, scheelite, cassiterite, apatite, rutile; recovery of gold is 100 percent.
Key words: Alluvial gold, Indus River, northern Pakistan

T/27. Tahirkheli, R.A.K., 1979a. Geology of Kohistan and adjoining Eurasian and Indo-Pakistan continents, Pakistan. Geological Bulletin, University Peshawar 11, 1-30.

Kohistan constitutes about 36000 square kilometers of territory located between the Indo-Pakistan and Eurasian Plates, on the northwestern tip of the Himalaya. Earlier, Desio (1964) has differentiated this part as a tectonic zone of Karakoram.
Bulk of Kohistan sequence consists of amphibolite, diorites, meta-norites (pyroxene-granulites) and associated volcanic rocks which are considered to be the crust of an ancient calc-alkaline island arc. This sequence has been obducted on to the Paleozoic rocks of the Indo-Pakistan continent on the south and subducted under the Eurasian Platform along the northern megashears.
The northern megashear along Hini-Chalt-Yasin-Drosh was formerly used to be considered the only extension of the Indus suture west of Nanga Parbat. Recent studies by Tahirkheli et al (1977, 77) have brought to light a southern megashear marked by the occurrence of ultramafics and high pressure metamorphic rocks, called Main Mantle Thrust (MMT), which delineates the southern contact of the Kohistan Island arc and the Indo-Pakistan continent. This confirms the bifurcation of the Indus suture into two suture zones, west of Nanga Parbat.
In this paper, an attempt has been made to introduce the geology of Kohistan island arc and the adjoining Eurasian and Indo-Pakistan continents.
Key words: Stratigraphy, structure, Kohistan, Eurasia, Indo-Pak plate.

T/28. Tahirkheli, R.A.K., 1979b. Geotectonic evolution of Kohistan. Geological Bulletin, University of Peshawar 11, 113-130.

Kohistan Zone is located on the north-western tip of the Himalaya and constitutes a tectonic unit in the Indo-Pakistan-Eurasia suture zone between Himalaya and Karakoram. Its characteristics nature distinguishes it from the surrounding well known geological provinces of Hazara and Kashmir on one side and Gilgit, Baltistan and Chitral on the other side. Most of Swat and Dir belong to Kohistan along with the southern part of Gilgit, Chitral and northern Hazara.
The Kohistan Zone is bounded by two megashears: the Hini-Chalt-Yasin-Drosh fault lying to the north, which extends into Baltistan through Tissar-Hashupa in Shigar Valley and Machelu in Shyok Valley. Another is recently deciphered Main Mantle Thrust traversing the southern periphery of Kohistan.
In addition, there exists a series of late thrust tectonic features, the two prominent among them being the Hazara syntaxial bend located on the south and a dominant Naze of Nanga Parbat – Haramosh massif on the northeast, which was considered by Wadia to be a horst of the Indian Peninsula, but the author interprets it as a transverse antiform fold.
These major tectonic features, located in the vicinity of the Kohistan Zone, have played a major part in the evolution of its structural history. A chronological account of various tectonic episodes is presented in this paper.
Key words: Tectonics, Kohistan, MMT, Himalaya.

T/29. Tahirkheli, R.A.K., 1979c. An indepth analysis of Pakistan's mineral policy with special reference to northern region. Geological Bulletin, University of Peshawar 12, 41-54.

Since the creation of Pakistan all the Governments have shown keen interest in the development of mineral resources for which various steps were taken to accelerate and generate momentum in the development of minerals. Inspite of these efforts no concrete results were achieved.
The author being a member of the advisory committee on planning for mineral resources has observed some pitfalls which directly or indirectly created sluggish environment which caused the retardation in the development and exploitation of mineral resources. In this paper the author has attempted to shed light on the impediments in order to generate a healthy climate for strengthening the base to raise structure in which the mineral could get a square deal for their economical and commercial exploitation. This paper was presented in a seminar held at Lahore and had a limited circulation. The publication of this paper in this bulletin is intended for its wider publicity both in private and public sector in order to create awareness for skittling the loopholes faced by the mineral-based industry.
Key words: Mineral resources, Mineral policy, Pakistan.

T/30. Tahirkheli, R.A.K., 1980a. Major tectonic scars of Peshawar vale and adjoining areas, and associated magmatism. Geological Bulletin, University Peshawar 13, 39-46.

The Vale of Peshawar, spread in about 1800 sq. km area, constitutes an important tectonic zone in the northwestern margin of the Indo-Pakistan plate. It is surrounded by well carved mega-tectonic features, which originated during post collisional alpine orogenic episodes, starting from Late Cretaceous and lasting till Early Pleistocene. The main tectonic evolutionary history of the Vale is syngenetic to these episodes, though some pre-alpine tectonic scars have also been distinguished.
Ten major fault tectonics have been described in this paper, out of which six located within the Vale and the remaining four occur in the adjoining areas. An attempt has been made to decipher these tectonic scars and to delineate associated magmatism in the Vale of Peshawar.
Key words: Tectonics, magmatism, Peshawar Valley.

T/31. Tahirkheli, R.A.K., 1980b. The Main Mantle Thrust: Its score in metallogeny of northern Pakistan. Geological Bulletin, University of Peshawar 13, 193-198.

Major shear zones in the collisional orogens like the ones exposed in Pakistan, can create important pathways for the movement of the mineralized solutions along with magmatic emanations. The Main Mantle Thrust (MMT), which has come to limelight recently, constitutes one of the important major tectonic scars on the northwestern terminus of

the Himalaya. It extends for over 500 km across the northern part of Pakistan, welding the Indo-Pakistan plate with the Kohistan island arc. Several magmatic bodies, some of them of batholithic dimensions are associated with this megashear.
In this paper an attempt has been made to focus upon the magmatic environments associated with MMT to discern various episodes of metallic mineralizations and their localizations in the subducted Indo-Pakistan marginal mass, obducted Kohistan mass and in the main Mantle Thrust zone.
Key words: Metallogeny, Shear zones, MMT, Himalaya.

T/32. Tahirkheli, R.A.K., 1980c. An extended domain of the Yasin group in the Karakorum and Hindu Kush. Wadia, Institute of Himalayan Geology, Dhera Dun, India, 2p.

The Yasin group is a Late Cretaceous, highly fossiliferous, group of sedimentary and volcanic rocks. Many authors have described its fossil assemblages and stratigraphy from the type area Yasin. This paper shows the extension of the group laterally into Kohistan up to Chalt in Hunza valley and beyond.
Key words: Stratigraphy, Yasin group, Cretaceous, Karakoram, Hindukush.

T/33. Tahirkheli, R.A.K., 1981a. Geological zonation of Karakorum and southern Hindu Kush in Pakistan. National Centre of Excellence in Geology, University of Peshawar, Special Issue 1.

For further information, consult Tahirkheli (1982 and 1992-93).
Key words: Geology, tectonics, Hindu Kush, Karakoram.

T/34. Tahirkheli, R.A.K., 1981b. Geological complexion of unfossiliferous Lesser Himalayan sequence in Pakistan; a review. In: Sinha, I. (ed.), Contemporary Geoscientific Research in Himalayas 1, 21-30. Singh, Dehra Dun.

Key words: Tectonics, unfossiliferous, Lesser Himalaya.

T/35. Tahirkheli, R.A.K., 1981c. An analysis of litho-tectonic zones associated with the Himalayan orogeny, in northern Pakistan. Geological Bulletin, University of Punjab 16, 98-110.

The Karakorum Himalayas is characterized by some unique tectonic features, which distinguish it from the rest of the Himalayas. Some of these are; occurrence of an Island arc 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 prominently the boundary between the Lesser Himalaya and the Himalayan Crystallines.
In this paper, under the light of new tectonic data, an analysis is attempted to differentiate various litho-tectonic zones in northern Pakistan, which were involved in the Himalayan orogeny.
Key words: Tectonics, MMT, MKT, MCT, Himalaya.

T/36. Tahirkheli, R.A.K., 1982. Geology of the Himalaya, Karakoram and Hindukush in Pakistan. Geological Bulletin, University of Peshawar 15, 1-51.

The northern segment of Pakistan hosts three of the best known mountain chains of the world, namely, the Himalaya, Karakoram and Hindu Kush. Among them the Lesser Himalaya received more attention by the earlier workers because of an easy access, but the other two were landlocked and remained isolated till 1960's, when the Karakoram Highway patched them with the modern amenities.
Inspite of manifold problems, the geologists remained attracted to this segment of the Central Asia and continued their relentless efforts from the mid 1970's to bring this unsympathetic but enchanting terrain within the fold of geological investigation. Some of them intruded this terrain along with the climbing and scientific expeditions and a few made solo efforts, which paved a good base to provide a best possible geological account on this area. In this regard, the author gratefully acknowledges the pioneering efforts of these stalwarts who for the sake of science faced all kinds of hardships while taming this terrain and have emerged with wealth of information which enabled their

successors to continue smoothly. The author's first acquaintance with the geology of the Karakoram-Hindu Kush was cherished in 1957 while accompanying the Kyoto University (Japan) scientific expedition. Subsequently, this visit was fostered into a permanent feature during which a mapping program was initiated. Since, 1964, after being transferred from the GSP to Peshawar University, this work was accelerated and more attention was given to mapping of the virgin terrain lying blank on the first geological map of Pakistan, published in 1964. This work has helped to discover a new crustal section intervening the Indo-Pakistan and the Eurasian plates, which now is well known as the "Kohistan Island Arc". Although some geological base was attained by the Karakoram-Hindu Kush, yet their existed a vacuum to provide a comprehensive coherent regional geological interpretation to this terrain under the context of plate tectonics. The presence of the Kohistan Island arc juxtaposed between the two mighty continents produced a mosaic other than exiting in the rest of the Himalaya, which further aggravated this problem.

These shortcomings greatly handicapped a regional geological correlation with Ladakh and northeastern Afghanistan with which the Karakoram and Hindu Kush respectively, are geographically linked.

To answer and arrest these problems, the best course to be adopted for their solution was to conduct a geological mapping program. Firstly, to knit together the observations made by the earlier workers lying dispersed in the isolated valleys and secondly to supplement this with fresh data to augment and up to date the already known informations on the geology of this region.

To achieve these objectives, a new geological map of the Karakoram and Hindu Kush has been introduced, a stratigraphic scheme of each geological domain has been devised which partly overlaps those produced by the earlier workers and diagrammatic sketches of all the important sections in the Himalaya, Karakoram and Hindu Kush giving a regional bias to their geological setup have been added. Besides, a regional correlation based on the new observations is attempted through with meager published literature available to the author from across the border. This is first attempt to present a regional geological mosaic of approximately 165000sq. Km area in the northern Pakistan, which was cradled by the tectonic emerging from the Indo-Pakistan-Eurasian collision and culminated during the attainment of structural configurations by the Pamir Knot, Nanga Parbat-Haramosh loop and the Hazara-Kashmir syntaxis.

The author is well aware of the shortcomings because of limitations in observations made by the author, lack of published literature and inaccessibility to nearly one-third of the area. However, it is hoped that this humble contribution will be helpful to bridge the geological gap existing between the Himalaya, Karakoram, Hindu Kush and the adjoining areas across the border.

Key words: Tectonics, geology, Himalaya, Karakoram, Hindukush.

T/37. Tahirkheli, R.A.K., 1983. Geological evolution of Kohistan island arc on the southern flank of the Karakorum-Hindu Kush in Pakistan. Bollettino di Geofisica Theorica Applicata (Pamir-Himalaya) 25, 351-364.

The Kohistan island arc covers approximately 36000 sq. km in the Northern part of Pakistan. It is bounded by two sutures, namely, the Main Karakorum Thrust (MKT) and the Main Mantle Thrust (MM1) which tectonically differentiate it from the Eurasian and the Indo-Pakistani plates respectively.

In the Himalaya, ophiolitic rocks mark the suture between and Eurasian and Indian continents. But in Pakistan along the southern flank of the Karakorum and the Hindu Kush an approximately 40 km thick complex of calc-alkaline plutonic/volcanic and metasedimentary rocks is emplaced between the two sutures and is considered to represent a complete cross–section of an island arc. On the north, this arc is subducted under the Eurasian marginal mass (Baltit Group and Chitral Slates) along the MKT and on the south is obducted onto the Indo-Pakistan plate (unfossiliferous lesser Himalayan sequence) along the MMT.

This arc had evolved due to intraoceanic subduction subsequent to the northward movement of the Indo-Pakistani plate which began during Late Jurassic. Its first contact with Eurasia, based on sedimentation and faunal evidences, is postulated during Late Cretaceous-Early Tertiary time and subsequently the second contact with the Indo-Pakistani plate occurred during post Paleocene.

However, Klootwijk et al. (1979), based on paleomagnetic data from Ladakh, considers the Ladakh arc to have collided first with the Indian plate during Late Paleocene-Early Eocene and with Eurasia during Eocene-Oligocene time.

Key words: Metasediments, evolution, Kohistan island arc, Karakoram, Hindukush.

T/38. Tahirkheli, R.A.K., 1985. Recent additions of the geotectonic net of northern Pakistan. Proceedings, First Pakistan Geological Congress, Lahore, 82-91.

The northern region of Pakistan comprises a variety of litho-tectonic domains, namely northwest Himalaya, Kohistan island arc, Karakoram plate and Hindukush Range. This contribution presents the new contributions to the already complex geology, structure and tectonics of the region.
Key words: Tectonics, Himalaya, Karakoram.

T/39. Tahirkheli, R.A.K., 1986. An overview of the major tectonic and geologic elements of the Himalaya and Karakoram in northern Pakistan. Geological Society of America Annual Meeting, 18.

In north Pakistan, there are three distinct geological domains, comprising NW Himalaya (Indian plate), Kohistan island arc, Karakoram-Hindukush Eurasian block. These are separated by major sutures, the Main Mantle Thrust (or Indus suture) in the south and the Main Karakoram Thrust (or Shyok suture) in the north. There are other major faults, including the Main Boundary Thrust.
Key words: Tectonics, Kohistan, Himalaya, Karakoram.

T/40. Tahirkheli, R. A. K., 1987. Shontargali thrust: an analogue of the main central thrust (MCT) in the NW Himalaya in Pakistan. Geological Bulletin, University of Peshawar 20, 209-214.

The Main Central Thrust (MCT) is one of the three principal megashears of the Himalayan orogenic belt which is formed as a result of collision between the Indian and Eurasian plates. Present studies in the substreams of the Kel Nala, one of the tributaries of the Nilam river in Kashmir and in another section located in Baloshbar area about 12 Km south of Astor in close vicinity of the Nanga Parbat massif, have revealed a new megashear which in stratigraphic, tectonic and metamorphic settings appears to be an analogue of the MCT in the NW Himalaya. This megashear is named Shontargali Thrust and like MCT, separates the Salkhala series of the Lesser Himalaya from the Nanga Parbat Gneisses of the Great Himalaya in Kashmir and Hazara in Pakistan.
Key words: Tectonics, MCT, Shontargali Thrust, Himalaya.

T/41. Tahirkheli, R.A.K., 1988. Presence of the Main Central Thrust in the tectonic domain of northwestern Himalaya in Pakistan. Geological Bulletin, University of Peshawar 21, 131-140.

The tectonic model of the northwestern Himalaya remained obscure for years for lack of demarcation of the Indus Suture Zone (ISZ) and Main Central Thrust (MCT) which are the two important tectonic features of the rest of the Himalaya. The problem of the ISZ was solved about a decade ago by locating two suture zones, the main Mantle Thrust (MMT) and the Main Karakoram Thrust (MKT) with an intervening Kohistan island arc (Tahirkheli et al., 1976, 1979). The location of MCT remained a debatable issue because of its discontinuity beyond west (Simla) Himalaya towards northwest in Kashmir and northern Pakistan. As a result, the Main Boundary Thrust and the Panjal Thrust in Kashmir and NW Himalaya, respectively, were considered as analogues of MCT.
This paper discusses a newly discovered deep level thrust named “Shontargali Thrust” which on the basis of geographic location and tectono-stratigraphic setup, compares favourably with the Main Central Thrust.
Key words: Tectonics, Shontergali Thrust, MCT, Himalaya.

T/42. Tahirkheli, R.A.K., 1989. Whether newly discovered Shontargali Thrust is an analogue of MCT in the Northwestern Himalaya in Pakistan. Kashmir Journal of Geology 6 & 7, 23-28.

Shontargali Thrust is a newly discovered megashear in the northwestern domain of Himalaya. A brief introduction to its broad geological aspects is intended in this paper. It geographic location is at the base of Nanga Parbat massif, Higher Himalaya. It has been investigated for a stretch of about 50 km in Barai steam, a tributary of

Neelam=Kishenganga river in Kashmir and in Mir Malik steam, a tributary of Astor river, in Gilgit Agency. Both of these streams follow the strike of the thrust.
In the Shontargali Thrust, the Salkhala series Jatog Fm. is thrust over by the Nanga Parbat gneisses Central crystalline Vaikritta Group. The thrust has a northeast-southwest strike and dips between 250-350 towards east. In more tectonized sections, the angle of dip could be more. The Shontargali Thrust zone, between 3-5 km wide, is highly deformed giving rise to squeezed recumbent or reclined folds. Imbrication in the footwall zone of the thrust is manifest in highly deformed sections which usually give rise to duplex structures. The presence of mylonite and migmitite point to ductile deformation which is frequently noticed in the footwall zone of the thrust. On the basis of its geographic location and grade of metamorphism of the associated rocks, couple with its stratigraphic and tectonic settings, the author considers the Shontagali Thrust as an analogue of the Mian Central Thrust (MCT) in the northwest Himalaya in Pakistan.
Key words: Tectonics, MCT, Shontargali Thrust, Himalaya.

T/43. Tahirkheli, R.A.K., 1990. Tectonic zonation of the northwestern Himalaya in Pakistan. Abstracts, 2nd Pakistan Geological Congress, University of Peshawar, 6-7.

The tectonic zonation of the NW Himalaya in Pakistan, for years, could not be spelt out adequately because of the absence of the major tectonic scars which are so prominently manifest in the rest of the Himalaya. Recent studies on this problem have added a new dimension to the interpretation of the tectonic frame of this region by locating the extension of the Indus Suture Zone (ISZ) and the Main Central Thrust (MCT) in the NW Himalaya in Pakistan.
The ISZ, west of Ladakh, bifurcates into two sutures with a sandwiched Island arc. The northern suture which welds the Kohistan arc with the Eurasian plate is called the Main Karakorum Thrust. The southern suture juxtaposes the Kohistan arc with the Indo-Pakistan plate and is named the Main Mantle Thrust. Nowhere in Pakistan, the Eurasian Plate comes in direct contact with the Indo-Pakistan plate.
The two sutures and the Kohistan Island arc have been given due attention in several papers published within the country and abroad. But the extension of the MCT is a new addition which completes the regional tectonic net for correlation of the tectonic Zonation of NW Himalaya with the rest.
The analogue of the MCT in NW Himalaya is called the Shontargali Thrust and is mapped in the Kel stream, a tributary of the Kishanganga-Neelum river in Kashmir and the Mir Malik stream, a tributary of Astor river in Gilgit Agency. On the basis of geographic location, stratigraphic setting, tectonic frame and mode of deformation of the rocks involved, the Shontargali Thrust appears as an analogue of the MCT in the NW Himalaya in Pakistan.
Key words: Tectonics, stratigraphy, MCT, Himalaya.

T/44. Tahirkheli, R.A.K., 1991. Tectono-stratigraphic zonation of the northwestern Himalayas in Pakistan. Abstracts, 1st Postgraduate Training Course in Plate Tectonics, Punjab University, Lahore, p.7.

Consult the preceding account.
Key words: Tectonics, MCT, stratigraphy, Himalaya.

T/45. Tahirkheli, R.A.K., 1992a. Shontargali Thrust: The Main Central Thrust (MCT) of northwestern Himalaya, Pakistan. In: Sinha, A.K. (ed.) Himalaya Orogen and Global Tectonics. Shiva Printers Derhra Dun, 107-120.

For further information, consult Tahirkheli (1987, 1988, 1989).
Key words: Tectonics, Shontargali Thrust, MCT, Himalaya.

T/46. Tahirkheli, R.A.K., 1992b. Shontargali thrust: An addition of new megshear akin to the Main Central Thrust, in the northwestern Himalaya tectonic domain. Abstracts, First South Asia Geological Congress, Islamabad, 42-43.

For further information, consult Tahirkheli (1987, 1988, 1989).

Key words: Tectonics, Shontargali Thrust, MCT, Himalaya.

T/47. Tahirkheli, R.A.K., 1992-93. Tectono-metamorphic domains of the Karakoram in Pakistan. Regional Postgraduate Training Course in Plate Tectonics, Punjab University, 24-25.

The Karakoram constitutes the southern marginal mass of Eurasia which is tectonically delineated from the Himalaya-Kohistan/Ladakh arc by the Main Karakoram Thrust, the northern suture. Its northern, eastern and western boundaries are shared respectively, by Kun Lun-Wakhan (SE Pamir), southern Tibet, east of Shyok and the eastern Chitral along Yarkun River. On the basis of tectono-metamorphic settings, the Karakoram terrain is divisible into three east-west trending linear belts:
(1) The southern Preheroynian marginal crystalline mass, (2) The central magmatic domain, and (3) the northern Permian-Jurassic Karakoram microplate.
The southern marginal mass is comprised of metasediments ranging from slate, phyllite, various types of schists, para-gneisses, flaggy quartzite, conglomerate, medium crystalline limestone and very coarse grained marble. The grade of metamorfacies level, but in more tectonized sections, this level could rise· to kyanite and sillimanite grade. The reeks are named Chitral Slate in Chitral, Darkut Group in the Yasin valley, Damurdu Formation and Baltit Group in the Hunza valley. The ages assigned to these rooks by various authors are, Cretaceous by Calkin et al., (1981), PermoCarboniferous by Ivanac et al., (1956), Permo-Triassic by Desio (1975), Triassic by Pudsey et al., (1985) and Precambrian by Tahirkheli (1982).
The central magmatic domain in the Karakoram is named Axial Karakoram Batholith and constitutes a composite assemblage of hornblende granodiorite, granites, pegmatites, aplites and vein quartz belonging to pre- and post-tectonic phases. The radiometric dates (Debon et al., 1987) place various magmatic phases in three broad categories: Middle Cretaceous (ca 110-95 Ma), Palaeogene (ca 43 Ma) aud Hiocene (ca 15-9 Ha).
The upper Hunza valley (UIN) sequences of the northern Karakoram microplate investigated along the Karakoram Highway reveal the following sequential order (Tahirkheli et al., 1990): Gircha Formation, Passu Slate, Dih Quartzite, Gujal .Dolomite and Shanoz Conglomerate. This is a modified stratigraphic scheme, earlier presented by Desio et al. (1972). Their age ranges from Permian (on faunal basis) to Cretaceous (Shanoz Conglomerate) on lithostratigraphic correlation with the Reshun Conglomerate in Chitral. This miorcplate is Gondwanic (Gaetani et al., 1990) and is accreted on to Eurasian margin during pre-Main Karakoram Thrust (MKT) accident.
On the basis of lithostratigraphic, tectonometamorphic and biostratigraphic evidences, it appears that there existed two paleogeologic domains in the Karakoram. The northern one on faunal support is assigned a Permo-Jurassic age (Gaetani et al., 1990) and the southern one has a pre-Devenian/Ordovician basement. In a tectonic scenario of the Karakoram with the northern Karakoram mioroplate, it will be problematic to find an adjustable place for the southern mass. The northern Karakoram mioroplate has two neighbours Kun Lun and Quingtong mioroplates which have their ancestors located in Eurasia. The lithostratigraphic and tectonometamorphic frames of the southern mass of the Karakoram relate it sympathetically with the Kabul and Lhasa mioroplates, lying on its east and west respectively.
Key words: Tectonics, metamorphism, Karakoram.

T/48. Tahirkheli, R.A.K., 1995. A macro-overview of geology of Pakistan. Proceedings, International Round Table Conference on Foreign Investment in Exploration and Mining in Pakistan, Islamabad, October 16-18, 1994, 47-55.

Key words: Geology.

T/49. Tahirkheli, R.A.K., 1997. Tectono-stratigraphic framework of the Hindukush Rang in Chitral, Pakistan. Abstracts, 3rd Pakistan Geological Congress, University of Peshawar, 68-69.

The rock formations encountered in the Chitral domain of Hindukush are:
i. The Chitral Slates are dominantly pelitic ranging from slates to various types of schists along with para-gneisses, interbedded flaggy quartzites, medium crystalline limestone and conglomerate. Two principal mapable lithologies incorporated in the Chitral Slates are Kaghozai Greenschists and Gahirat Marble. Diorite, dolerite and amphibolite intrusions in the basic realm and pegmatite, aplite and vein quartz in the acid are common. Based on

lithostratigraphic correlation with their counterparts in the west, (in Nuristan) in Afghanistan and in the east in the Karakoram and Ladakh, the Chitral Slates are placed in the Precambrian-Lower Palaeozoic.
ii. The Broghil Formation is composed of medium crystalline limestone, siliceous dolomitic limestone, flaggy quartzites and interbedded siliceous slates. About 5 meters thick bed of siliceous dolomitic limestone bed has yielded conodont fossils on the basis of which this sequence has been assigned and Ordovician age.
iii. The Shogran Formation at its stratotype is about 900 m thick and is divisible into three faunal units; a lower crinoidal massive dolomite, a middle coral-bearing thick bedded dolomite along with interbedded black shales and upper flaggy quartzite and thin bedded limestone with brachiopods. A lower to upper Devonian age is assigned to Shogram Formation.
iv. The undifferentiated Turikho Group constitutes a thick sequence of dominantly argillaceous rocks with subordinate crystalline limestone, quartzos sandstone and conglomerate along with host of acid and basic sills and dykes. These rocks have been mapped in different sections as Lun shales, Sirikol Shales, Khandhot Shales, Wakhan Slates and Fusilina Limestone. Some limestone beds in the Mastuj valley have yielded fossils, on the basis of which Permo-Carb, Triassic and Jurassic ages have been assigned to the rocks of this group.
v. The Reshun Formation is divisible into three litho-stratigraphic units. The lower one is medium crystalline, thick bedded to massive Krinj Limestone, followed by Awi Conglomerate with larger part of its clasts derived from the underlying limestone and from the Chitral Slates. The top bed consists of maroon marly shales. Some Orbitolina-bearing pebbles conglomerate along with Hippurites in Krinj Limestone in Lutkho valley places Reshun Formation into the Cretaceous.
vi. The Tirich Mir Granites occur in isolated plutons intruding Turikho Group of rocks and constitute an assemblage of quartz diorite, granodiorite, monzogranite and granite. Rb/Sr radiometric age on granodiorite has yielded an age of 115 my.
vii. The westward termination of the Axial Karakoram batholith in the Hindukush of Chitral is marked by three east-west trending plutons located within the Chitral Slates. The Buni Zorn pluton west of Sor Laspurf among them, is the largest. Granodiorite and granites are its main constituents with basic and acid sills and dykes occurring as minor intrusions. Radiometric dates on granodiorite and granites of Karakoram batholith range from 96 to 15 my. The four major tectonic scars in the Chitral area are, (a) Reshun Fault, (b) Ayun Fault, (c) Tirich Fault and (d) Shishi Koh Fault. The last one is regarded to demarcate the northern Himalayan suture, namely the Main Karakoram Thrust. Tirich Fault in the northern domain has indicated some basic igneous and metavolcanic signatures and could mark a boundary between Hindukush and Southern Pamir Block.
Key words: Stratigraphy, tectonics, Hindukush, Chitral.

T/50. Tahirkheli, R.A., Asif, M.K. & Tahirkheli, T., 1992. Regional geological framework of the Karakorum in Pakisatn. In: Zheng, D., Zhang, Q. & Pan, Y. (Eds.), Proceedings of international symposium on the Karakorum and Kunlun mmountains. China Meteorological Press, Beijing, 54-71.

The 600x150 km Karalorum Range covers about 90,000 km^2 area of Pakistan, China and India. It comprises three linear belts, from S to N, 1: Southern Pre-Hecynian (Precambrian-Early Paleozoic) crystalline marginal mass which is delineated from the Kohistan arc and Himalaya by the Main Karakorum Thrust; 2: The central magmatic domain of batholithic dimension. It comprises pre-tectonic phases of Late Cretaceous age and post-tectonic phases emplaced in Miocene, and 3: The northern Hercynian (Pero-Cretaceous) sedimentary belt, referred to in the paper as the Upper Hunza Valley sequence.
Key words: Tectonics, Northern Karakoram plate, Main Karakorum Thrust, Hunza

T/51. Tahirkheli, R.A.K., Baqri, S.R.H. & Dawood, H., 1992. A new status of the pelitic sequences in the upper Hunza valley in Karakoram, Pakistan. Abstracts, First South Asia Geological Congress, Islamabad, p.43.

Briefly describes the pelitic rocks (e.g., Misgar slates) that cover large areas in northern Hunza valley, in the central Karakoram Range. For further detail, See Tahirkheli, SUN, Pan et al., 1990.
Key words: Pelitic sequence, slates, Hunza, Karakoram.

T/52. Tahirkheli, R.A.K. & Jan, M.Q. (Eds.), 1979a. Geology of Kohistan, Karakoram Himalaya, northern Pakistan. Geological Bulletin, University of Peshawar, 11, 187p.

This volume contains a compilation of 11 papers on geology of Kohistan. Contributors include R.A.K. Tahirkhelli (2), M.Q. Jan (4), M.A. Khalil and A.G.K. Afridi (1), M. Majid (1), J. Khan (1), M.S. Badshah (1), F.A. Shams and S. Ahmad (1), and regional geological map by Tahirkhelli and Jan. the papers are summarized in appropriate places.
Key words: Ultramafics, metamporphism, Island arc, Tectonics, Kohistan, Himalaya.

T/53. Tahirkheli, R.A.K. & Jan, M.Q., 1979b. A preliminary geological map of Kohistan and the adjoining areas, N. Pakistan. Geological Bulletin, University of Peshawar 11.

This is the first compilation of the geological map of northern Pakistan, where much of the blank area shown on the Geological map of Pakistan (Bakr & Jackson, 1964) was also covered. The terrain is divided into Eurasian, Kohistan island arc, and Indian plate domains. Major thrust faults, i.e., Main Karakoram Thrust, Main Mantle thrust and Main Boundary Thrust, are also shown on the coloured map.
Key words: Geological map, Indian plate, Kohistan, Karakoram.

T/54. Tahirkheli, R.A.K. & Jan, M.Q., 1984. The geographical and geological domains of the Karakoram. In Miller K.J. (eds), The International Karakoram Project, Volume 2, 57-70. Cambridge University Press.

This paper deals with some of the existing geographical and geological problems of the Karakoram and the authoress presents their views for their solution and better understanding.
The western and eastern boundaries of the Karakoram with the Hindukush and the Himalaya, respectively, still remain an unsettle issue. The authors on the basis their observations have extended the western boundary to the high ranges forming the main divide between the Gilgit and the Yarkun rivers, lying southwest of Mastuj between 72o and 73o E. In the north this boundary passes slightly east of Broghil between Long. 73o and 74o E.
In the east, the limit of the Karakoram has been stretched deep into Ladakh; and the eastern extent of the Deosai-Ladakh range with its eastern boundary with the Himalaya.
Under the context of plate tectonics, the rock sequence established by authors in the western section of the Karakoram (Hunza valley), from south to the north as follows:

Kohistan Island Arc Mass Chalt Ophiolite Yasin Group	Ladakh Granodiorite
Main Karakoram Thrust	
Asian Karakoram Granodiorite	Darkut Group
FAULT	
The rock sequence of the Tethyan folded belt lying towards north of the Main Karakoram Range	

Key words: Tectonics, geology, geography, Karakoram.

T/55. Tahirkheli, R.A.K., Jan, M.Q. & Majid, M. (Eds.), 1980. Proceedings of the International Committee on Geodynamics. Geological Bulletin, University of Peshawar, 13, 213p.

This is a compilation of 23 papers by international experts on the geology and geodynamics of the Himalayan region, especially northern Pakistan. Individual papers are annotated in appropriate places in this volume.

Key words: Geodynamics, Himalaya

T/56. Tahirkheli, R.A.K., Jan, M.Q. & Mian, I., 1971a. Graphite occurrence in Spinkia area, Tirah, Khyber Agency, Directorate of Mineral Development, Govt. of N.W.F.P., Peshawar, Information Release 4, 10p.

For details consult the following account.
Key words: Metamorphic rocks, graphite, Khyber Agency.

T/57. Tahirkheli, R.A.K., Jan, M.Q. & Mian, I., 1971b. Hydrothermal graphite in Tirah, Khyber Agency. Geological Bulletin, University of Peshawar 6, 114-117.

During recent years, some samples of graphite from Tirah, Khyber Agency, which were analysed in various laboratories in Pakistan, have yielded over 50 % fixed carbon. This created special interest for the authors to conduct investigations concerning the origin and economic potentials of the mineralization. The graphite is located near Spinkai (Lat. 330 55 ½, Long. 700 41′) in Tirah tribal territory and is accessible through Chora, Bazar, Bara and Rajgal Valleys. The area can also be approached from Kohat via Sra Mela and Maidan. The mineralized area is along the northern slope of Bijor Sar (ca. 9,000 feet) at an elevation of about 6,500 feet.
Key words: Metamorphic rocks, graphite, Khyber Agency.

T/58. Tahirkheli, R.A.K., Jan, M.Q. & Mian, I., 1975. A geological traverse through Tirah, Khyber Agency, NWFP, Pakistan. Geological Bulletin, University of Peshawar 7 & 8, 79-88.

This short paper presents the results of a geological traverse conducted through the northern part of Tirah in Khyber Agency during the last week of July, 1971. The rocks encountered between Lala China and the Rajgal area are, Lala China Slaty-shale, Chura Kandao Limestone, Walai Limestone, China Limestone, Spinkai Limestone, Mughalbagh Shales, Paleocene Limestone and Murree sandstones and shales; the latter two units are well developed in the Bara and Rajgal valleys, west of Bazar.
The Palaeozoic sequence, besides Lala China and Chura Kandao (Khyber Pass), were encountered at two places; in a Khwar about 3 miles upstream of Mughalbagh and in Baraghat nala in the Rajgal area. Four differentiable mapable units from bottom to top are; Lwarai Mela Limestone, Baraghat Slate, Barai Quartzite and Spinkai Limestone, which have been placed as members of the Rajgal Formation. Acid igneous intrusions consisting of granite and granite-gneiss with pegmatite and aplite veins lie in contact with the upper part of Spinkai Limestone. Graphite mineralization occurs in the granite and granite-gneiss near the contact of the Spinkai Limestone.
Key words: Reconnaissance, mapping, Palaeozoic, Khyber Agency.

T/59. Tahirkheli, R.A.K. & Kamal, M., 1981. Whether tectono-magmatic regimes offer any prospects for primary uranium mineralization in northern Pakistan. Geological Bulletin, University of Peshawar 14, 95-100.

The northern segment of Pakistan inhabits some of the loftiest mountain systems of the world. Nearly forty per cent of the rocks covering the surface area in this terrain are igneous, out of which over seventy per cent belong to the acid igneous domain. The Late Mesozoic – Cenozoic orogenic events had brought into being some of the major lineaments, which have regional dimensions. Magmatic emanations associated with these shears belong to several generations; some of them belonging to the late phases have indicated metallic mineral associations. A few known primary uranium mineralizations in this region are associated with some of these magmatic episodes. This paper discusses the tectono-magmatic environment of the northern Pakistan and delineates the metallogenic zones under the context of plate tectonics – where favorable conditions may exist for finding primary uranium mineralization.
Key words. Tectonics, magmatism, uranium mineralization, Gilgit-Baltistan

T/60. Tahirkheli, R.A.K. & Majid, M., 1977. Geology of the Tanawals in the southwest Tanawal and Gandghar Range, Hazara, Pakistan. Geological Bulletin, University of Peshawar 9 & 10, 1-21.

In the Hazara Paleozoic sequence, the Tanawal Formation overlies the Hazara Slates and underlies the Abbottabad Formation. A pebbly bed marks the contact between the Hazara Slates and the Tanawals, which is not persistant, but elsewhere in Kashmir and the Central Himalayan sections gradational contact has been reported by the earlier worker.

The Tanawal comprise dominantly of arenaceous rocks which constitute quartzite, quartzitic schist and quartzitic sandstone with interbedded arenaceous slaty shales, slates, phyllitic slates and conglomerate which are intruded by the igneous rocks. Among the quartzose rocks, arkosic wacke, suabarkose, arenites and quartz arenites are differentiated. Amphibolites, epi-diorites, porphyritic micro-tonalite, dacite, rhyo-dacite, pegmatite and quartz veins are the igneous rocks which occur in the Tanawals as sills, dykes and veins.

The Tanawals are unfossiliferous. Their sympathetic stratigraphic relationship with the fossiliferous Paleozoic rocks in Kashmir, Central Himalaya and Swabi – Lower Swat areas, suggest for them a Devonian – Lower Carboniferous age. The discovery of Hyolothids of Cambrian age near the contact of overlying Abbottabad Formation and Hazira shales will depress the age of the Tanawals to Precambrian. However, this fossil find is very localized and appears to have been derived from the older horizon and incorporated in these rocks.

Key words: Stratigraphy, Palaeozoic, Hazara.

T/61. Tahirkelli, R.A.K., Mattauer, M., Frost, F. & Tapponnier, P., 1977. Donnees nouvelles sur la suture Inde-Eurasie auo Pakistan. Colloques Intrenacionale, CNRS (Himlaya Science de La terre) 268, 209-212.

Consult the following for further information

Key words: Sutures, India-Eurasia.

T/62. Tahirkelli, R.A.K., Mattauer, M., Frost, F. & Tapponnier, P., 1979. The India-Eurasia suture zone in northern Pakistan: synthesis and interpretation of recent data at plate scale. In: Farah, A. & Dejong, K.A. (eds) Geodynamics of Pakistan. GSP, 125-130.

In north Pakistan, there are three distiunct geological domains, comprising NW Himalaya (Indian plate), Kohistan Mountains, and Eurasian block. These terrains are separated by major faults. The authors were amongst the earliest ones to propose that the Kohistan terrain is a sandwich of an island arc between Eurasia in the north and Indian plate in the south. Its northern boundary is delineated by a regional fault that they named as the Main Karakoram Thrust, and its southern boundary with the Indian plate delineated by what they called the Main Mantle Thrust.

Key words: Sutures, tectonics, Kohistan, Indian plate, Eurasian plate.

T/63. Tahirkheli, R.A.K. & Riaz, M., 1991. Tectono-stratigraphic implication in extending the Panjal thrust, west of the Hazara-Kashmir syntaxis. Geological Bulletin, University of Pakistan 24, 25-32.

The Panjal Thrust (PT) is one of the principal tectonic scars of the Lesser Himalayan domain in Kashmir. Its type section is located in the Panjal Range from where it extends northeast wards along the eastern flank of the Hazara-Kashmir syntaxis and terminates at its apex. In the Panjal Thrust the Precambrian Salkhalas thrust over the Permo-Triassic Panjal Group. This tectonostratigraphic setup is retained by this thrust throughout its course in Kashmir. During recent years, some geologists have extended this thrust west of the syntaxis through Galiat, Abbottabad, Gandghar Range, and terminated it across the Indus in the Attock-Cherat Range. The tectono-stratigraphic and lithostratigraphic frames of these sections are not akin to the ones displayed in the Panjal Thrust sections in Kashmir. This controversial aspect of the Panjal Thrust has been studied to ascertain whether the western counterparts of the Panjal Thrust west of the Hazara-Kashmir syntaxis has any justification to be correlated with its tectono-stratigraphic net displayed in Kashmir.

Key words: Tectonics, stratigraphy, structure, Panjal thrust, Hazara-Kashmir-syntaxis.

T/64. Tahirkheli, R.A.K., Sun, D., Pan, Y., Deng, W., Zhang, Y., Baqri, S.R.H. & Dawood, H., 1990. Review of stratigraphy of the upper Hunza valley (UHV), NW Karakoram, Pakistan. Geologcial Bulletin, University of Peshawar 23, 203-214.

Recent collaborative work of Pakistani and Chinese scientists has established five mapable stratigraphic units which, from old to young, are: i. Gircha Fm., ii. Pak-China Friendship Fm (Dih Fm.), iii. Passu Slate, iv. Gujal Dolomite, and v. Shanoz Conglomerate. A NNW-SSE trending Sost Anticline is the major structure in this area which bifurcates the stratigraphic net of this valley. The oldest formation exposed in the core of Sost Anticline is Gircha Fm. The base of the Gircha Fm is not exposed in UHV. The age of stratigraphic sequence in the UHV, based on fauna, ranges from Late Permian to Late Cretaceous-Early Tertiary.
Key words: Stratigraphy, structure, Hunza valley.

T/65. Tahirkheli, T., 1998. Geochemistry, mineralogy and petrology of the sulfide mineralization and associated rocks in the area around Drosh, north Pakistan. Ph.D. thesis, NCE geology, University of Peshawar.

Copper mineralization in the Drosh-Shishi area is localized in the upper crust of the Kohistan arc terrane in Chitral, northern Pakistan. It is confined to the Gawuch Formation in the area, comprising variably metamorphosed volcanics and sediments intruded by the plutons of diorite and granodiorite composition. The metavolcanics of the Gawuch Formation and the diorite-granodiorite minor plutons have calc-alkaline compositional characteristics. In comparison, the metavolcanics of the Darosh Formation, occupying the top of the succession, are island-arc tholeiites. Copper mineralization in the area is related to hydrothermal activity and is mainly associated with altered diorites and quartz veins. It occurs in different forms; in the quartz veins, along the foliation planes, in dissemination and as supergene enrichment. Tetrahedrite, chalcopyrite, pyrite and galena are the dominant ore minerals along with subordinate amounts of sphalerite, magnetite, malachite and azurite. Fluid-inclusion studies indicate that the salinity of the hydrothermal solution is <26 equivalent wt% NaCl and the homogenization temperature is in the range of 160 to 350°C. Oxygen isotope data suggest that the quartz in the mineralized quartz veins has $\delta\ ^{18}O$ values ranging from 14.49 to 18.32 per mil with mean value of 16.63 ‰. This, when combined with the homogenization temperature obtained from the fluid-inclusion studies, indicates involvement of magmatic fluids ($\delta\ ^{18}O$ =5.79-9.62‰) in the formation of quartz veins and associated copper mineralization.
The lead isotopic compositions of three galena samples suggest that $^{206}Pb/^{204}Pb$ ranges from 18.728 to 18.793, $^{207}Pb/^{204}Pb$ from 15.658 to 15.728 and $^{208}Pb/^{204}Pb$ from 39.040 to 39.285. These Pb-isotope ratios yield model ages of 42 – 140 Ma with the μ values of 9.86 to 10.01. The minimum age (i.e., 42 Ma) is in close agreement with 40Ar-39Ar age of the Lowari pluton, which is considered to be the source of hydrothermal solutions. The lead isotopic composition of studied galena samples indicate involvement of lead derived from older sources. These sources could be the arc volcanics or pelagic sediments of oceanic crust of Neotethys or the continental crust of the subducting Indian plate. It is concluded from these studies that the copper mineralization in Drush-Shishi area was produced by the hydrothermal activity related with syntectonic dioritic magmatism.
Key words: Geochemistry, mineralogy, petrology, sulfide mineralization, Chitral.

T/66. Tahirkheli, T., Khan, M.A. & Mian, I., 1990. A- type granites of Warsak, Khyber Agency, N Pakistan: Rift-related acid magmatism in the Indian plate. Geological Bulletin, University Peshawar 23, 187-202.

Three varieties of granite from Warsak have been analysed for their geochemical composition, particularly trace elements. Two of the three varieties contain aegirine and riebeckite and are thus peralkaline. The third variety comprises biotite and muscovite with rare garnet, and varies between meta- and peraluminous compositions. Irrespective of these differences in mineralogical and major-element characteristics, there is a close match in incompatible trace elements between all the three varieties of granite from the studies area. A close scrutiny of the trace-element composition reveals A-type nature of the Warsak granites. Palaeozoic fragmentation of Gondwana,

involving breakaway of India, may be responsible for the generation of the Warsak A-type granites and other similar granites in the Peshawar plain at Ambela, Shewa-Shahabazgarhi, Malakand and Terbela.
Key words: Geochemistry, petrology, granites, magmatism, Indian plate.

T/67. Tahirkheli, T., Khan, M.A. & Mian, I., 1993. The Warsak basic rocks: Initial- rift stage continental tholeiites of Permo-Triassic "Panjal" affinity. Geological Bulletin, University of Peshawar 26, 17-33.

A suite of basic rocks, comprising microgabbros, dolorites, metabasalts and volcaniclastic sediments, occurs associated, both in space and time, with the alkaline granites at Warsak near Peshawar. Detailed geochemistry, mainly based on trace elements, suggests that the magmatism responsible for the Warsak basic rocks was tholeiitic in composition and was erupted/intruded in a within-plate continental setting. Furthermore, the Warsak basic rocks have geochemical composition closer to rift volcanics rather than the plateau basalts.
The Warsak basic rocks, in this study, have been identified to be related with the suite of tholeiitic basalts commonly encountered as dykes and sills in the Lower Palaeozoic or older rocks of northern part of the Indian plate. The volcanic and volcaniclastic component in the Warsak area is directly correlatable with the Karapa greenschsit in Ambela area, and the amphibolite marker horizon in the upper part of the Marghazar Formation of Lower Swat, which are in turn correlatable with the Permo-Triassic Panjal volcanics of Kaghan and Kashmir.
Key words: Geochemistry, petrology, granites, magmatism, Indian plate.

T/68. Tahirkheli, T., Khan, M.A. & Shah, M.T., 2001. Geochemistry and petrogenesis of igneous rocks in Drosh-Shishi area, Chitral, Northern Pakistan. Abstracts, 4th Pakistan Geological Congress, Islamabad, p.11.

Drosh-Shishi area is localized in the upper crust of the Kohistan arc terrane in Chitral, northern Pakistan. It comprises two groups of igneous rocks, metavolcanics and diorites. Metavolcanics occur as two stratigraphic entities i.e. Gawuch and Drosh formations. Gawuch Formation comprises of variably metamorphosed volcanics and sediments intruded by the plutons of diorites and granodiorite composition.
The metavolcanics of Gawuch Formation are divided into two types: porphyritic and fine-grained to glassy. The former vary from fresh to highly altered and commonly dissected by quartz and calcite veins. Volcanic rocks belonging to the Drosh Formation are massive to weakly foliated, fine-grained and commonly altered. In composition, they are mostly andesitic. Three varieties of diorites are distinguished in Gawuch Formation on the basis of texture and degree of alteration, 1) diorites, 2) altered diorites, and 3) gneissose diorites. Geochemistry involving major and trace elements have been used to characterize the petrology and tectonic setting of igneous rocks of the area. Detailed geochemistry suggests that the magmatism responsible for diorites and volcanics of the Gawuch Formation was cab-alkaline, while that of Drosh Formation was tholeiitic in composition. Detailed treatment in terms of mantle-normalized trace element patterns and discrimination diagrams suggest that diorites and the two groups of volcanics, despite differences in their petrological character, originated with a 3trong subduction component.
Key words: Geochemistry, petrogenesis, Chitral, Kohistan arc.

T/69. Tahirkheli, T., Shah, M.T. & Khan, M.A., 1997. Mineralogical isotopic and fluid inclusion studies of copper mineralization in Drosh-Shishi area, Chitral, northern Pakistan. Nation. Symp. Econ. Geol., (Abstract) p.9-10.

Key words: Geochemistry, mineralogy, copper, Chitral.

T/70. Tahirkheli, T., Shah, M.T. & Khan, M.A, 1997a. Lead isotopic signature of the hydrothermal copper mineralization in Drosh-Shishi area, Chitral, Northern Pakistan. Abstracts, 3rd Pakistan Geological Congress, University of Peshawar, p.69.

For details consult the following account.

Key words: Geochemistry, mineralogy, isotopes, lead, Chitral.

T/71. Tahirkheli, T., Shah, M.T. & Khan, M.A., 1997b. Lead isotopic signature of the hydrothermal copper mineralization in Drosh-Shishi area, Chitral, Kohistan arc terrane, Northern Pakistan. Geological Bulletin, University Peshawar 30, 209-217.

Copper mineralization in Drosh-Shishi area is a part of the upper crust of Kohistan arc terrane in Chitral, northern Pakistan. It is generally confined to the Gawuch formation in the area. This formation comprises of variably metamorphosed volcanics and sediments intruded by plutons of diorite and granodiorite. Copper mineralization is related to the hydrothermal activity and is mainly associated with altered diorites and quartz veins.
The lead isotopic ratios of three samples of galena from quartz veins in Drosh-Shishi area were determined. 206Pb/204Pb from 18.728 to 18.793, 207Pb/204Pb from 15.658 to 15.728 and 208Pb/204Pb from 39.040 to 39.285. These lead-isotopic ratios yield wide range of model ages of 42 to 140 Ma. This mineralization is very young in terms of age and have μ values of 9.86 to 10.01. The studied galenas have comparable Pb-isotope ratios to that of Rossie-Type veins of USA and Canada and are more radiogenic to the conformable massive sulfides and less radiogenic to Mississippi Valley-Type sulfide deposits. The Lead isotopic data further suggest that the lead in galena may have been derived from the arc volcanics or pelagic sediments of ocean crust of Neo-Tethys or continental crust of Indian plate and may have relation with orogeny.
Key words: Geochemistry, copper mineralization, isotopes, lead, Chitral.

T/72. Tahirkhelli, T., Shah, M.T. & Khan, M.A., 1998. Oxygen Isotopic Signature of the Hydrothermal Copper Mineralization in Drosh-Shishi Area, Chitral, Pakistan. Acta Mineralogica Pakistanica 9, 111-116.

Copper mineralization in Drosh-Shishi area is a part of the upper crust of Kohistan arc terrane in Chitral, northern Pakistan. It is generally confined to the Gawuch Formation in the area. This formation comprises of variably metamorphose volcanics and sediments intruded by plutons of diorite and granodiorite. Copper mineralization is related to the hydrothermal activity and is mainly associated with altered diorites and quartz veins.
Nine samples of mineralized quartz veins in Drosh Shishi area were analyzed for oxygen isotopic ratios. The δ18O value of quartz veins range from 14.49 to 18.32% with a mean value of 16.63%. The δ18O value of the mineralizing fluid of the area has been calculated at the man temperature (255oC) as determined by fluid inclusion studies. The estimated δ18O value of the mineralizing fluid ranges from 5.79 to 9.62% with a mean value of 7.98%. This indicates the involvement of magmatic fluids in the formation of quartz veins and associated copper mineralization in the investigated area.
Key words: Geochemistry, oxygen isotopes, copper mineralization, hydrothermal, Chitral.

T/73. Tahirkheli, T., Shah, M.T. & Khan, M.A., 2000. Mineralogical, isotopic and fluid inclusion studies of copper mineralization in Drosh-Shishi area, Chitral, Northern Pakistan. In: Hussain, S.S. & Akbar, H.D. (Eds.), Proceedings, National Symposium on Economic Geology of Pakistan, 1997, Islamabad, 59-71.

Key words: Geochemistry, mineralogy, isotopes, copper, fluid inclusions, Chitral.

T/74. Tahirkheli, T., Shah, M.T. & Khan, M. A., 2000. Genesis of copper mineralization in the western Kohistan island arc terrane, NW Himalaya-Hindukush, N. Pakistan. Abstract Volume, 15th Himalaya-Karakoram-Tibet Workshop, Chengdu, China, 410-411.

Key words: Mineralogy, copper, Kohistan island arc, Himalaya, Hindukush.

T/75. Tahirkheli, T., Shah, M.T. & Khan, M.A., 2000. Copper mineralization in the western Kohistan island arc terrane, NW Himalaya-Hindukush, N. Pakistan. Abstracts, Third South Asia Geological Congress, Lahore, 175-177.

The Kohistan Terrane in N. Pakistan straddles the suture zone between the collided Indian and Eurasian plates in the NW Himalayas of N. Pakistan. Initiated as an intra-oceanic island-arc crust in Neotethys, the terrane accreted with the southern margin of the Karakoram Plate in the Late Cretaceous (- 90 Ma). Continued subduction at its southern margin resulted in Andean type magmatism and tectonics , until collision with the Indian Plat in the Early Eocene. Whereas much of the central and eastern Kohistan expose Cretaceous volcanic and sedimentary rocks of intra-oceanic island arc setting, the western Kohistan in Swat, Dir, Chitral and upper Ghizer valleys preserves remnants of the Late Paleocene-Early Eocene volcanism and sedimentation of Andean type setting. These volcano-sedimentary lithologies in western Kohistan are geographically divisible into two, separated by the Lowari Pluton; 1) Dir-Swat Belt, 2) Drosh-Shamran Belt. Late Paleocene Early Eocene siliceous volcanics termed Utror Volcanics and Shamran Volcanics are common in the two belts and so are the plutons intrusive into these volcanics (Late Stage-II of the Kohistan Batholith). The difference is in the sedimentary successions present in the two belts. Whereas in the Dir-Swat belt, the sedimentary succession comprises Baraul Banda Slate Formation, deposited in deep-water fore-arc setting and contemporaneous in age with that of the nearby Utror Volcanic Formation (-55-60 Ma), the sediments in the Drosh-Shamran belt are distinctly red beds of fluvial origin (the Purit Formation) those overlie unconformably on top of the Shamran Volcanics and their equivalents. Copper mineralization in western Kohistan is associated with the both volcano-sedimentary belts described above. In the following we outline salient features of copper mineralization in the belts.

Copper Mineralization in Dir-Swat Belt:

In Dir-Swat belt copper mineralization is confined to the Eocene Utror Volcanic Formation. Greenschist facies metavolcanics host the mineralization in quartz veins, shear zones, sphalerite-bearing copper -rich zones and copper and iron-bearing chloritized zone. Chalcopyrite is the main copper-bearing phase along with subordinate amounts of pyrite, bornite, and chalcocite. Malachite and azurite occur as supergene enrichment. High $\delta^{18}O$ values for mineralized quartz veins (average 10.1 %) and the mineralized metavolcanics (8.1-10.3%) suggest involvement of isotopically heavy fluids ($\delta^{18}O$ =5.9 %) probably related with the late-stage (post-Early Eocene-Stage II) intrusives of the Andean-type Kohistan Batholith. A chemical gain-loss comparison between the mineralized and unmineralized rocks suggests that the mineralizing fluids induced enrichment of elements like Cu, Zn, Pb, Mo, As, Cd, Ag, and Au in the former.

Copper Mineralization in Drosh-Shamran Belt:

The copper mineralization in the Drosh-Shamran belt, unlike the Dir-Swat belt, is localized in the Late Cretaceous volcano-sedimentary sequence (i.e., Gawuch Formation) rather than the Eocene Sharman Volcanic Formation that is equivalent and probably cogenetic with the Utror Volcanic Formation. Within the Gawuch Formation, mineralization is particularly is particularly intense in the granodiorites that occur as minor intrusives within the metavolcanics of the Gawuch Formation. A marble band of 2 to 3 meter thickness occurring at the contact of the Gawuch Formation and overlying fluvial sediments of the Purit Formation is most mineralized, suggesting entrapment of migrating mineralizing fluids. Tetrahedrite, galena, chalcopyrite and pyrite are the dominant ore minerals along with subordinate amounts of sphalerite, magnetite, limonite, malachite and azurite. $\delta^{18}O$ in the mineralized quartz veins is high (14.49 to 18.32%) that is even higher than those in Dir. The $\delta^{18}O$ of the mineralizing fluid is calculated to be at average 7.98%, that falls in the range of values known for magmatic liquids (i.e., 5-9%). The localization of mineralization in the Late Cretaceous Gawuch Formation suggests that mineralization, unlike in the case of the Dir mineralization, may be of any age between Late Cretaceous and Late Eocene. However, the two plutons close to the mineralized zone indicate ages younger than Early Eocene. The Lowari pluton that separates the Dir-Swat Belt from the Drosh Shamran Belt yields a ^{40}Ar-^{39}Ar cooling 'age of 45 Ma while the Mirkhani pluton in the Drosh area intrudes Eocene Shamran Volcanic formation. Therefore there is great probability that copper mineralization in the Drosh Shmaran Belt is Post-Early Eocene, related with the late phases of the Kohistan Batholith.

Conclusions:

The two principal copper mineralization zones in western Kohistan, at Drosh and Dir are localized in volcanic lithologies of different ages, Late Cretaceous and Early Eocene, respectively. Both are however characterized by high $\delta^{18}O$ values suggesting role of magmatic fluids in their origin. Late phases of Kohistan Batholith are considered to be the source of these fluids in both cases.

Key words: Mineralogy, copper, Kohistan island arc, Himalaya, Hindukush.

T/76. Tahirkheli, T., Shah, M.T. & Khan, M.A., 2001. Mineralogical, isotopic and fluid inclusion studies of copper mineralization in Drosh-Shishi area, Chitral, Northern Pakistan. Journal of Asian Earth Sciences 19, p.66.

Key words: Geochemistry, mineralogy, isotopes, copper, fluid inclusions, Chitral.

T/77. Tahirkheli, T., Shah, M.T., Khan, T. & Khan, M.A., 1996. Fluid inclusion studies of the copper-bearing quartz veins in Gowuch Formation, Drosh-Shishi area, Chitral, northern Pakistan. Geological Bulletin, University of Peshawar 29, 51-57.

Copper mineralization, generally confined to the Gowuch Formation, in Drosh-Shishi area is part of the upper crust of Kohistan arc terrain in Chitral, northern Pakistan. It is related to the hydrothermal activity and is mainly associated with altered diorites and quartz veins. It occurs in different forms; within quartz veins, along foliation planes, in dissemination and as supergene enrichment. Fluid inclusion studies indicate that the salinity of the hydrothermal solution is 12.28-13.40 equivalent wt% NaCl and the homogenization temperature ranges from 160 to 350^{o} C. This suggests that the copper mineralization is related to the late stage vein formation as a result of diorite and granodiorite intrusion.
Key words: Geochemistry, mineralogy, copper, fluid inclusions, Chitral.

T/78. Takahashi, Y., Kausar, A.B., Takahashi, Y. & Khan, T., 1993. Field relationship between the rock units of the Chilas complex, Chilas, northern Pakistan. Proceedings of Geoscience Colloquium, Geoscience Lab, GSP, Islamabad 4, 41-50.

The Geoscience Laboratory, Geological Survey of Pakistan has started a joint collaborative project with JICA experts who were mainly despatched from the Geological Survey of Japan **on** the Chilas Igneous Complex in Chilas area as one of the technology transfer programs for the Geoscience Laboratory established under a grant in aid project by JICA, Japan.
The survey in Chilas area is being carried out jointly by experts of both the countries. For the 1991 work, the first phase, the GSJ despatched a survey team consisting of 3 geologists during a period from Nov. 4 b Nov, 19, 1991 (Kubo *et* al., 1992. For the 1992 work, the second phase, the JICA despatched a team consisting of 2 geologists from Oct. 27, 1992 to Nov. 23, 1992. During 1991, 1 geologist and during 1992, 2 geologists from Geoscience Laboratory participated in this research programme.
The primary purpose of this research is to focuss on the following points:
1. Relationship between the gabbro-norite and ultramafic-mafic bodies.
2. Variation of rock facies within the Chilas igneous complex
3. Relationship between ultramafic and mafic rock facies.
4. Layered structure in ultramafic and mafic units.
5. Finding out original flow structure in gabbro, norite-gabbro, and gabbro-norite and then interpreting the younging direction.
Key words: Petrology, Chilas complex, Kohistan arc, Himalaya.

T/79. Takahashi, Y., Khan, T., Takahashi, Y., Kausar, A.B. & Kubo, K., 1996a. Mode of plagioclase twining of two plutonic bodies in Kohistan terrane, northern Pakistan. Journal of Mineralogy, Petrology and Economic Geology 91, 242-249.

Mode of plagioclase twinning is examined 'in the Chilas complex and Kohistan batholith, which are large plutonic bodies in the Kohistan terrane, northern Pakistan . The frequency of C twins, which are defined as all laws other than albite and pericline twin s, is mostly 10 to 20% in the tonalite and granodi orite of the Kohistan batholith. These values characterize igneous rocks.
Frequency of C twins in the Chilas complex is low (0 to 5%) in the eastern part and high (20 to 30%) in the central part. The former repre sents metamorphic features and the latter igneous features. These features result from the

difference of the erosional surface of the complex and explain the petrological discrepancy that the complex is deduced to have been metamorphosed to the granulite facies, but that it locally intruded and gave thermally altered effect to the surrounding amphibolite.
Frequency of pericline twin is almost the same in both bodies. This consistency may be developed by a result of the same tectonic event, i.e., collision between the Indian plate and the Kohistan terrane.
Key words: Mineralogy, plagioclase, twining, plutonic, Kohistan terrane.

T/80. Takahashi, Y., Khan, T., Takahashi, Y., Kausar, A.B. & Kubo, K., 1996b. Mode of plagioclase twining of two plutonic bodies in Kohistan terrane, northern Pakistan. In: Kausar, A.B. & Yajima, J. (Eds.), Geology, Geochemistry, Economic Geology and Rock Magnetism of the Kohistan Arc. Proceedings of of Geoscience Colloquium, Geoscience Lab, GSP, Islamabad 15, 69-82.

Consult Takahashi et al (1996a) for further information.
Key words: Geochemistry, mineralogy, plagioclase, twining, plutonic, Kohistan terrane.

T/81. Takahashi, Y., Kubo, K., Takahashi, Y., Sawada, Y., Kausar, A.B., Khan, T. & Khan, I.H., 1994. The Chilas Igneous Complex in Kohistan island arc, Northern Pakistan. Abstact voume Symposium on Himalayan Geology, 3–9 Sept. 1992. Matsue, Japan.

For details consult the following account.
Key words: Mineralogy, petrology, Chilas complex, Kohistan island arc.

T/82. Takahashi, Y., Kubo, K., Takahashi, Y., Sawada, Y., Kausar, A.B., Khan, T. & Khan, I.H., 1994. The Chilas Igneous Complex in the Kohistan Island Arc, Northern Pakistan. Journal of Geological Society of Nepal 10, Abstract Volume, 9th Himalaya-Karakoram-Tibet Workshop, Kathmandu, 140.

The Chilas Igneous Complex is one of the major geological unit in the Kohistan Island Arc Region, of which southern end is bounded by the Main Mantle Thrust (MMT) and northern end is by the Main Karakoram Thrust (MKT) (Searle, 1991). The Chilas Complex is 60-km wide and elongated 300-km almost parallel to the MMT and MKT. It is intruded into the amphibolite (Kamila Amphibolite), which develops widely on the southern half of the Kohistan Island Arc Region. The Complex is composed mainly of gabbronorite and contains several masses of ultramafic-mafic complex as large xenolith. Ar/Ar and K/Ar ages of the hornblende from the Complex are at around 80Ma, which may date cooling through 500oC, the hornblende blocking temperature (Treloar et al., 1989). The Complex consists of host gabbronorite and several masses of ultramafic-mafic complex (UMC). Both of them are deformed together exhibiting foliations, which form several antiforms and synforms striking WNW-ESE, subparallel to the igneous body. Some structures of deformation on the Chilas Complex are discussed.
Key words: Mineralogy, petrology, Chilas complex, Kohistan island arc.

T/83. Takahashi, Y., Takahashi, Y., Kausar, A.B., & Kubo, K., 1994a. Modes of plagioclase twinning in the Chilas complex and Kohistan batholith, northern Pakistan. Proceedings of Geoscience Colloquium, Geoscience Lab, GSP, Islamabad 9, 51-58.

The ratios of perilcline twins in the twinned plagioclase of Chilas complex (CC) and Kohistan batholith (KB) are overlapped, suggesting that these are deformed under same physical conditions. The ratio of C twins (all twins other than albite and pericline) in the KB are more than those in the CC. The ration of C twins in the KB are more than 8%, indicating their igneous origin. The ratio of C twins of the CC is less than 5%, indicating metamorphic origin. It is noted that the CC has been emplaced at depths first and subsequently metamorphosed, which is characterized by low ratio of C twins. On the other hand the KB show high ratio of C twins suggesting comparatively shallow depth of emplacement and lack of metamorphism after emplacement.

Key words: Mineralogy, Plagioclase, twining, Chilas complex, Kohistan batholith.

T/84. Takahashi, Y., Takahashi, Y., Kausar, A.B., Khan, T. & Kubo, K., 1994b. Contrasting frequency of plagioclase twinning in two plutonic bodies in Kohistan terrane, Northern Pakistan. Abstract International joint Symposium IGCP Projects 283–321–359 in Japan (Hokkaido Univ.), From Paleo-Asian Ocean to Paleo–Pacific Ocean, 75–79.

Key words: Mineralogy, Plagioclase, Twining, Plutonic, Kohistan terrane.

T/85. Takahashi, Y., Mikoshiba, M., Kubo, K., Kausar, A.B., Khan, T.K., Takahashi, Y. & Shirahase, T., 1998. Geological relationship between the Chilas complex and the Kamila amphibolite belt, northern Pakistan-Implications for the tectonic development of the Kohistan island arc. Geological Bulletin, University of Peshawar 31, Abstract Volume, 13th Himalayan-Karakoram-Tibet International Workshop, 192-193.

The Kohistan terrain in the western Himalaya, northern Pakistan, is regarded as a tilted island arc type crust sandwiched between the Asian and Indian continental crusts [I]. The Kohistan island arc is bounded along the south by Main Mantle Thrust (MMT), and along the north by Northern Suture (or Main Karakoram Thrust, MKT), which can be divided into some geological units.
The Chilas complex is a huge basic intrusion about 50km wide and elongates 300-km almost parallel to the MMT and the MKT, which is composed mainly of gabbronorite and several masses of ultramafic-mafic anorthosite association [21. It has been interpreted as the magma chamber root zone of the Kohistan island arc [3]. On the other hand, the Kamila amphibolite belt is composed of highly deformed amphibolite-facies meta-plutonic and meta-volcanic rocks with calc-alkaline geochemistry [41 situated to the south of the Chilas complex. Geological relationship between the Chilas complex and the Kamila amphibolite belt is not yet confirmed, although they are main constituents of lower crust in the Kohistan island arc. Some people consider that the Chilas complex and the Kamila amphibolite were originally same, but the Chilas complex was metamorphosed to granulite facies and the Kamila amphibolite belt to amphibolite facies [5,6]. On the other hand, it is considered that the Chilas complex and the Jijal complex are lower crusts of different island arcs and they are separated by the Kamila shear zone (Kamila amphibolite belt) [6]. Accordingly, northern part of the Kamila amphibolite belt is hydrated and recrystallized product from the gabbronorite of the Chilas complex.
The geological relationship between the Chilas complex and the Kamila amphibolite belt is fundamentally important to consider the geologic development of the Kohistan island arc, because they are main constituents of lower crust in the Kohistan island arc. In this paper, we present detailed geological and geochemical data around the boundary between the Chilas complex and the Kamila amphibolite belt and discuss on the relationship between them.
In the Swat valley, the Chilas complex is bounded on the south by the Kamila amphibolite belt. Around the boundary several xenoblocks of the Kamila amphibolite are observed in gabbronorite of the Chilas complex and gabbronorite dikes of the Chilas complex occur in the Kamila amphibolite. At the lower reaches of Miandam River which is a small branch of Swat River coming from the east, a xenoblock (about 2O*5m) of the Kamila amphibolite occurs in gabbronorite of the Chilas complex. The amphibolite and gabbronorite are just contact to each other and a foliation develops in both the amphibolite and gabbronorite which is oblique to the lithologic boundary. The amphibolite is composed mainly of hornblende and plagioclase, in which original plutonic texture still persists. Under the microscope, hornblende and biotite are aggregates of fine crystals exhibiting a decussate texture, which indicates thermal effect. On the other hand, the gabbronorite is composed mainly of plagioclase, clinopyroxene and orthopyroxene with minor hornblende and biotite, which is slightly deformed, but there is no evidence of thermal effect. Therefore, it is evident that the Kamila amphibolite was intruded by gabbronorite of the Chilas complex and suffered contact metamorphism and after that a foliation was formed in both the gabbronorite and amphibolite by ductile deformation, which may be related to the collision of Kohistan to the Asian continent.
The eastern part of the Chilas complex is bounded on the north by amphibolite. At the upper reaches of Khanbari River, which is a small branch of Indus River coming from the north, gabbronorite of the Chilas complex and amphibolite are just contact to each other. The amphibolite is composed mainly of hornblende and plagioclase, in which original plutonic texture still persists. Under the microscope, hornblende and biotite are aggregates of fine crystals exhibiting a decussate texture. On the other hand, the gabbronorite is composed mainly of plagioclase,

clinopyroxene and orthopyroxene with small amount of biotite and hornblende, which is slightly deformed. Therefore, it is evident that the amphibolite was intruded by the gabbronorite of the Chilas complex and suffered contact metamorphism. The northern amphibolite may correspond to the Kamila amphibolite, because these features are just like those in the Swat River. It is important to note that the Chilas complex is a large intrusive body in the Kamila amphibolite belt.
Key words: Tectonics, petrology, Chilas complex, Kamila amphibolite, Kohistan island arc..

T/86. Takahashi, Y., Takahashi, Y., Kausar, A.B. & Mikoshiba, M., 1996. Geology and geochemistry of eastern part of the Chilas complex, northern Pakistan- Implications for the tectonic development of the Kohistan island arc. In: Kausar, A.B. & Yajima, J. (Eds.), Geology, Geochemistry, Economic Geology and Rock Magnetism of the Kohistan Arc. Proceedings of Geoscience Colloquium (Geoscience Lab, GSP, Islamabad) 15, 183-205. (Also published in the Proceedings of Geoscience Colloquium (Geoscience Lab, GSP, Islamabad) 14, 39-61)

Geological and geochemical studies of the eastern part of the Chilas complex, Northern Pakistan have been carried out by GeoLab research team. On the basis of the results, a model of tectonic development of the Chilas complex is proposed. The Chilas complex is composed mainly of gabbronorite and several masses of ultramafic-mafic association (UMA). The UMA is composed mainly of olivine (with or without clinopyroxene) cumulate (dunite, wehrlite) and plagioclase clinopyroxene-orthopyroxene cumulate (two pyroxene gabbro), with minor amount of clinopyroxene-orthopyroxene cumulate pyroxenite). Geochemistry of the gabbronorite is suitable to island arc non-cumulate, and the UMA is suitable to island arc cumulate. Major element geochemistry of the gabbronorite and the UMA is explained by cumulate and noncumulate model. Rare earth element and trace element geochemistry of the gabbronorite indicates island arc type feature, and the UMA indicates its cumulate character.
Key words: Geochemsirty, tectonics, Chilas complex, Kohistan island arc.

T/87. Takahiuhi, Y., Khan, T., Takahashi, Y., Kausar, A.B.,& Kubo, K. 1996. Mode of Plagioclase Twinning of two Plutonic Bodies in Kohistan Terrane, Northern Pakistan.

Mode of plagioclase twinning is examined in the Chilas complex and Kohistan batholith which are large plutonic bodies in the Kohistan terrane, northern Pakistan. Frequency of C twins, which are defined as all the other laws than albite and pericline twins, is mostly 10 to 20 % in tonalite and granodiorite of the Kohistan batholith. These values represent igneous character. Frequency of C twins in the Chilas complex is low (0 to 5 %) in eastern part and high (20 to 30%) in central part. The former represents metamorphic feature and the latter igneous feature. These features result from the difference of the erosional surface of the complex and explain the petrological discrepancy that the complex is deduced to have been metamorphosed to the granulite facies but that it locally intruded and gave thermal effect into the surrounding amphibolite. Frequency of the pericline twin is almost the same in both bodies. This consistency of the frequency may be developed due to the same tectonic event, i.e., collision between Indian plate and Kohistan terrane.
Key words: Plagioclase, twinning, plutonic bodies. Kohistan Terrane.

T/88. Talent, J.A., 1976. Provincialism in the Himalayan region. Seminar on Himalayan Geology, New Delhi.

Key words: Palaeontology, Himalaya.

T/89. Talent, J.A., 1999. Bibliography of Phanerozoic palaeontology and stratigraphy of Pakistan. Abstract volume International Geological Corr, Program 421 Meeting. North Gondwana Biogeography, Bioevent Patterns in relation to Crustal Dynamics, Peshawar, Pakistan, 35-65.

Key words: Palaeontology, stratigraphy.

T/90. Talent, J.A. & Bhargava, O.N., 1999. Silurian of the Indian subcontinent and surrounding regions. Abstract book, Peshawar meeting IGCP 421 (8-26 September 1999), 27 National Centre of Excellence in Geology, University of Peshawar.

Consult the following for further information.
Key words: Palaeontology, stratigraphy, Silurian.

T/91. Talent, J.A. & Bhargava, O.N., 2003. Silurian of the Indian subcontinent and surrounding regions. New York State Museum Bulletin 493, 221-239.

An overview of the Silurian of the Indian subcontinent and adjacent regions, illustrated by ten stratigraphic columns, underscores uncertainties in precise correlation. Silurian sequences with some biostratigraphic control are documented from the Dasht-e-Nawar region, Afghanistan; the Peshawar Basin, Pakistan; central Nepal; southernmost Tibet; and Shan State, Myanmar (Burma). Near-shore, primarily siliciclastic sequences with reef developments in the western Himalaya, that range from Late Ordovician to Middle and, conceivably, younger Silurian, are not tightly constrained biostratigraphy. Similar sequences in the central Himalaya, often referred to as the Muth Quartzite and regarded as broadly Devonian, are largely Silurian, but need renewed study. The Paleozoic of Bhutan, assumed by some to include Silurian rocks, appears to have a Middle Cambrian-late Devonian hiatus. There is urgent need for a multi-pronged re-investigation of these Silurian and associated late Ordovician and Devonian sequences, particularly if transgression-regression patters and changes in paloegeography are to be documented adequately.
Key words: Palaeontology, stratigraphy, Silurian, Indian subcontinent.

T/92. Talent, J.A., Conaghan, P.J., Mawson, R., Molloy, P.D. & Pickett, J.W., 1976. Intricacy of tectonics in Chitral (Hindu Kush): Faunal evidence and some regional implication. Abstracts, Himalayan Geology Seminar, Delhi, 13-17 September, 1976, 76-77. Geological Survey of India, Calcutta.

Key words: Palaeontology, tectonics, Chitral, Hindukush.

T/93. Talent, J.A., Conaghan, P.J., Mawson, R., Molloy, P.D. & Pickett, J.W., 1982. Intricacy of tectonics in Chitral (Hindu Kush): faunal evidence and some regional implications. Himalayan Geology Seminar, 1976, Section IIA. Geological Survey of India, Miscellaneous Publication 41, 77-101.

Key words: Palaeontology, tectonics, Chitral, Hindukush.

T/94. Talent, J.A., Gaetani, M., Mawson, R., Molloy, P.D. & Conaghan, P.J., 1999. Early Ordovician and Devonian Conodonts from the Western Karakoram and Hindu Kush, Northernmost Pakistan. Abstracts, IGCP 421, North Gondwanan mid-Palaeozoic Bioevent/Biogeography Pattern in Relation to Crustal Dynamics, Peshawar Meeting, p.28.

For details consult the following account.
Key words: Palaeontology, conodonts, Ordovician, Devonian, Karakoram, Hindukush.

T/95. Talent, J.A., Gaetani, M., Mawson, R., Molloy, P.D. & Conaghan, P.J., 1999. Early Ordovician and Devonian Conodonts from the Western Karakoram and Hindu Kush, Northernmost Pakistan. Rivista Italiana Paleontologia i Stratgrafia 105, 201-230.

Extensive tracts of Devonian and older sedimentary and igneous units occur within the axial region of the western Karakoram Block of northernmost Pakistan over a distance in excess of 200 km between the headwaters of the Karambar valley in northwestern Gilgit Agency to southwestern Chitral. Conodont data indicate that the oldest sedimentary unit so far discriminated within this belt, the Yarkhun Formation, includes horizons of Ordovician (Arenig) age, consistent with an earlier-presented acritarch-based Arenig age for part of the same unite. Conodont data from the "Lun Shale", a stratigraphic potpourri with little known Silurian and Devonian tracts, demonstrate the presence of Early Devonian (early Emsian) horizons. The Shogram Formation, widely distributed through the region, spans an appreciable interval of the Middle and Late Devonian mid-Givetian through until at least early Famennian. A major lacuna in sedimentation may be present, represented by all or most of the earlier half of Frasnian time. A biostratigraphically and possibly biogeographically important new species, Icriodus homeomorhphus, is described; it is encountered in horizons of early Famennina age (Late triangularis Zone to? Early crepida Zone).
Key words: Palaeontology, conodonts, Ordovician, Devonian, Karakoram, Hindukush.

T/96. Talent, J.A., Goel, R.K., Jain, A.K. & Pickett, J.W., 1988. Devonian and supposed Devonian of India, Nepal and Bhutan: a commentary. Courier Forschungsinstitut Senckenberg, 106, 1-57.

Key words: Devonian, India, Nepal, Bhutan.

T/97. Talent, J.A. & Mawson, R., 1979. Palaeozoic-Mesozoic biostratigraphy of Pakistan in relation to biogeography and the coalescence of Asia. In: Farah, A. & DeJong, K.A. (Eds.), Geodynamics of Pakistan. GSP, Quetta, 81-102.

An overview of Paleozoic-Mesozoic biostratigraphy of Pakistan, especially the northern mountainous region, is given providing, inter alia, preliminary reports of the presence of unequivocal Ordovician 9NE Chitral), Silurian (Peshawar district), and carboniferous sequence (S Khyber and NW Gilgit agencies); all systems from Proterozoic to recent are now known to be represented in Pakistan. Comparison of Paleozoic and Mesozoic faunas from Pakistan with approximately coeval faunas from elsewhere in Asia underscore; 1. The provincial heterogeneity of Asia through these time intervals, though only preliminary comments are made on the change within these patterns due to coalescence of the various continental blocks. 2. That the only region of Pakistan with surety not formerly part of Gondwanaland is a narrow strip of the northern mountain region stretching through Chitral, Gilgit (N of the Ghizar valley) and Hunza, i.e. N of the Upper Shayok-Hini (or Chalt)- Drosh-Kunar fault. 3. The zoogeographic integrity of Paleozoic and perhaps Mesozoic faunas south of this lineament, and its E-W extension in Afghanistan beyond the 'Kabul vortex', the hari Rud or Herat fault zone, is in accord with these areas having been once part of Gondwanaland; conversely, the contrast between faunas from these areas and faunas from regions north of the above lineaments is taken as testimony to the latter not having been parts of Gondwanaland. 4. Nevertheless, there are still insufficient published palaeontologic data to be able to comment on the history of fragmentation, dispersal and reamalgmation of the various bits and pieces of the old portions of Gondwanaland west of the Bela-Quetta-Muslimbagh-Waziristan 'Axial Belt', but the prospects are exciting and the Mesozoic molluscan faunas may yet yield useful biographic as well as chronologic data for this exercise.
Key words: Palaeozoic, Mesozoic, biostratigraphy, coalescence.

T/98. Talent, J.A. & Mawson, R., 2001. Bibliography of Phanerozoic palaeontology and stratigraphy of Pakistan. Geological Bulletin, University of Peshawar 34, 1-81.

The stratigraphy and palaeontology of Pakistan covers almost all intervals of geologic time, Precambrian to Recent, some more elegantly than others, especially Permian and younger sequences from the southern two-thirds of Pakistan. Palaeozoic sequences of pre-Permian age are restricted to northern Pakistan where metamorphism has tended to obliterate fossils, and where tectonic complexity-especially frequent thrust faulting-often obscures relationships and, in the absence of fossils, ages may remain controversial and stratigraphic relationships problematic. Palaeontology, taking advantage of occasional "windows of opportunity" with materials which have escaped severe deformation, will continue to have an important role in unravelling the structure of this vast region.

The foundations of the stratigraphy and palaeontology of Pakistan go back to the remarkable pioneering work of. W. T. Blanford, A. B. Wynne, C. L. Griesbach, W. Waagen, F. Noetling and C. S. Middlemiss in the 19th century, to the work of H. H. Hayden and E. W. Vredenberg early in the 20th, to the labours in Hazara of D. N. Wadia and the exemplary mapping by E. R. Gee in the Salt Range 50-70 years ago and, in more recent time, the impact of the sustained energies of R. A. K. Tahirkheli.
Remarkable work was achieved, often under conditions for which the word adverse would be an understatement. E. W. Vredenberg comes to mind, with camel and violin, collecting his way across Baluchistan-a palaeontologist analogue perhaps of artist-violinist J. A. D. Ingres ... G. E. Pilgrim early in this century, and expanded by recent work by a galaxy of vertebrate palaeontologists, especially by P. D. Gingerich, L. L. Jacobs, M. Pickford and D. R. Pilbeam. These faunas are now chronologically constrained by integrated high-precision stratigraphic/sedimentary and magnetostratigraphic investigations undertaken by several people, among them D. W. Burbank, G. D. Johnson, and N. D. Opdyke, working in highly effective collaboration with the Geological Survey of Pakistan and with numerous staff and postgraduate students of the University of Peshawar. The origin of this bibliography derives from the discovery that less than 25 % of the geological literature published in Pakistan is cited in GEOREF, the main source for obtaining a swift coverage of the literature published on a specific topic or specific region. The situation is least satisfactory with regard to literature on vertebrate palaeontology; this has been poorly covered by both GEOREF and Biological Abstracts, though the Zoological Record is useful in helping fill this lacuna. Our compilation is not exhaustive; it expands on a preliminary version issued to participants in the First Pakistan Palaeontological Convention and 6th international meeting of IGCP 421, North Gondwana mid-Palaeozoic bioevent/biogeography patterns in relation to crustal dynamics held at the University of Peshawar in September 1999. There are few references to unpublished reports and postgraduate theses. Not included are numerous articles in which stratigraphy has been incidental to economic geology, mineralogy, structural, tectonic or petrologic presentations, notably for the Kohistan Terrane and the Nanga Parbat Syntaxis (e.g. Khan et al., 2000). Numerous citations of such literature can be found in the excellent overview of the geology and tectonics of Pakistan by A.H. Kazmi & M. Qasim Jan (1997). Useful for older literature and for literature on areas adjoining Pakistan to the east and west are the Bibliography of Indian Geology by La Touche (1917), the Bibliography on Himalayan Geology by Kapoor et al. (1976) and the Bibliography on the Geology of Afghanistan by Kastner (1971). Many of the cited references have not been checked against the original publications-a mammoth task beyond the means of compilers without access to all relevant libraries in Pakistan and India. Because most titles provide a clear indication of content, no attempt has been made to annotate the bibliography. It is hoped, nevertheless that even casual perusal of it will draw attention to many publications, including some long forgotten, which include important data and opinions.
Key words: Bibliography, Phanerozoic, palaeontology, stratigraphy.

T/99. Talent, J.A., Mawson, R. & Khan, F.R., 1999. Mid-Palaeozoic of Pakistan, Conodont-based perspectives. Abstracts, IGCP 421, Errachidia Meeting, 42-43.

Key words: Palaeozoic, conodonts.

T/100. Talent, J.A., Molloy, P.D. & Morante, R.J., 1988. The Devonian of Pakistan. In: McMillan, J., Embry, A. & Glass, D. (Eds.), Proceedings of 2nd International Symposium of the Devonian System, Calgary 1987,

Key words: Devonian.

T/101. Tandon, A.N. & Srivastava, H.N., 1975. Focal mechanism of some recent Himalayan earthquakes and regional plate tectonic. Bulletin of Seismological Society of America 65, 963-969.

Focal mechanism solutions of 12 recent earthquakes along the northern boundary of the Indian-Eurasian plates, from Hindukush to Burma, have been determined assuming the double-couple hypothesis. It has been found that the majority of earthquakes are of thrust type with the pressure directions acting at right angles to the faults/mountains, but, for a few of the earthquakes the orientations of the pressure directions are almost along the strike of the faults.

Such observations could be partly explained in terms of the concept of “flake tectonics” as proposed for continent-continent collisions. A number of earthquakes in the eastern Himalayas and Burma show normal dip-slip or predominantly strike-slip movements. These anomalies call for further refinements of the plate theory in this zone of complicated deformation.
Key words: Earthquakes, seismology, tectonics, Himalaya.

T/102. Tandon, S.K., Thakur, V.C. & Jain, A.K., 1974a. Tilloids from N.W. Pakistan. Geological Magazine 111, p.568.

This note refers to a recent letter in this journal by Kempe (1973) wherein he has recorded a “Tilloid” occurrence near Warsak and advanced the line of the known Himalayan localities of subcontinental tillites more than 200 km. It may be pointed out lltat the gmelli; of the Himalayan diamicts i.9 still an open question. Rallan (1913) recognized the Manjir Conglomerate (Chamba Tillites of Powell & Saxena, 1971) to be part of a flycsh sequence. In recent years, a debate has also ensued on the origin of the Blaini Conglomerate and related formations (Bhargava, 1972; Bhattacharya &. Niyogi, 1971; Casshyap, 1969; Gaur &. Dave, 1971; Niyogi &. Bhattacharya, 1971; Rupke, 1968; Saxena & Pande, 1969; Valdiya, 1970, 1973). We may also add that many of these controversial 'tillite' horizons form part of different tectonic units and may not all be the Stratigraphic equivalents. The premise of Kempe (1973) regarding the extension of the Himalayan tillite localities has thus to be viewed in the above framework.
Key words: Tilloids, Mulagori, Warsak.

T/103. Tandon, S.K., Thakur, V.C. & Jan, A.K., 1974b. Tilloids from Pakistan. Reply by Kempe, R.D.C., Geological Magazine 111, 568-569.

Tandonl, Thakur & Jain refer above to the tilloids from NW Pakistan (Kempe, 1973), suggesting that this Himalayan diamict should be treated as one of several of which the true origin is still in dispute. I entire1y agree. My objective in drawing attention to this unusual rock:, which I referred to as a tilloid [which] may thus be the most northwesterly of the known sub-continental tilloids, was in the hope that it would be visited and examined by those who, unlike myself, are familiar with Indian and other tillites and are thus in a better position to decide in such cases on the origin of the rock.
Key words: Tilloids, Mulagori, Warsak.

T/104. Tanoli, S.K., 1990. Shallow marine sediments of the Patala Formation of Paleocene age, Kohat area, Pakistan. Geological Bulletin, University of Peshawar 23, 111-121.

The Patala Formation in Kohat area consists of four lithofacies which are; PF1 sandstone with shale interbeds, PF2 shale and siltstone with limestone interbeds, PF3 shale with interbeds of siltstone, and PF4 shale and marl interbeds. These facies were deposited in shallow marine shelf environments ranging from upper shoreface to offshore possibly middle to outer shelf environments.
Facies PF1-PF4 in general depict deposition in a continuously deepening or transgressive conditions. The lateral variations in lithology within the Patala Formation are suggested to be mainly related to the local variations in paleogeographic setting.
Key words: Sediments, Paleocene, Patala formation, Kohat.

T/105. Tanoli, S.K., Gandapur, M.A. & Mahsood, S.K., 1978. Geology of the part of area northwest of Kohat, North West Frontier Province, Pakistan. M.Sc. Thesis, University of Peshawar, 50p.

Key words: Mapping, stratigraphy, Kohat.

T/106. Tanoli, S.K., Rashid, S.M., Qamar, B., Awad, M. & Jabeen, N., 1990. Depositional environment of the Patala Formation of Paleocene age, Kohat area. Abstracts, 2nd Pakistan Geological Congress, University of Peshawar, p.19.

The Patala Formation in Kohat area is divisible into four lithofacies which are; PF1 sandstone with shale interbeds, PF2 shale and siltstone with limestone interbeds, PF3 shale with interbeds of siltstone, and PF4 shale and marl interbeds. These facies are interpreted to have been deposited in shallow marine, ranging from upper shoreface to offshore, shelf environments. Facies PFI-PF4 in general depict deposition in a more or less continuously deepening basin. The lateral variations in lithology within the Patala Formation are suggested to be mainly related to the local variations in paleogeographic setting.
Key words: Sediments, Paleocene, Patala formation, Kohat.

T/107. Tarar, R.N., 1982. Water resources investigations in Pakistan with the help of LANDSAT imagery-snow survey (1975-1978). International Association of Hydrol. Sci. Publ. 138, 177-190.

Key words: Remote sensing, LANDSAT imaging, hydrology, water resources.

T/108. Tariq, S., 1984. Geology of Jawan Pass, Khabal village, Swat. M.Sc. Thesis. Geology Department, Peshawar University, 120p.

Key words: Geology, Jawan pass, Swat.

T/109. Tariq, S., 1992. Geology and clay mineralogy of Patala Formation in Salt Range and Kalachitta Range with reference to Paleo-Environments. M.Phil. Thesis, University of Peshawar, 177p.

The Patala Formation was studied in Salt Range and Kala Chitta range. About 99 samples were collected to investigate clay mineral composition and to understand the paleo-environments and diagenetic/ sedimentological control of the clay minerals. The samples from the Salt Range representing the southern end of the Potwar basin contain mostly kaolinite _illite and a mixed-layer clay mineral (a mixture of general illite/montmorillonite). The chlorite mineral was detected only in five samples from the Nilawahan area (central Salt Range).
The samples from the Kala Chitta Range (Khawri Khawar section) contain mostly illite, chlorite and mixed-layer clay mineral. The kaolinite was found in 12 samples. It was concluded that the illite, chlorite mineral are the detrital clay –minerals which were brought into the depositional basin through erosional and sedimentological processes from a source rock exposed in the south.
The kaolinite from both localities, was found to be partly diagenetic and partly of detrital origin. The mixed-layer clay mineral was observed to be of diagenetic origin. The kaolinite in Khawri Khawar section (Kala Chitta Range) was interpreted as detrital mineral. The comparison of clay composition from the Salt Range and Kala Chitta Range (Khawri Khawar section) indicated that kaolinite decreases in the samples of Kala Chitta Range while illite and chlorite show increase. The mixed-layer clay mineral did not Show any significant variations. The decrease of kaolinite in Kala Chitta Range samples was interpreted as a sedimentological/ depositional control.
The crystalinity indices of illite and kaolinite Show a decrease in crystallinity in the samples from the Kala Chitta Range as compared to the Salt Range samples. It is 0.77 for kaolinite, 0.37 for illite in Kala Chitta Range, and 0.26 for kaolinite and 0.19 (average} for illite in Salt Range. The decrease in crystallinity of illite and kaolinite again verify the transportation of kaolinite and illite from south to north of the depositional basin which was the direction of deepening of the basin.
Key words: Clay, mineralogy, Patala Formation, Salt Range, Kalachitta.

T/110. Tariq, S., 2001. Environmental geochemistry of surface and subsurface water and soil in Peshawar basin, NWFP, Pakistan. Ph.D. thesis, NCE geology, University of Peshawar.

Peshawar Basin is situated at the southern foothills of Himalayas between the longitude 71° 15' and 72° 45' E and latitude 33° 45' and 34° 30' N in the North-West- Frontier Province (NWFP) of Pakistan. Major cities of the basin are Peshawar (capital), Mardan, Charsadda and Nowshera. The E-W flowing Kabul river and its tributaries irrigate the basin and join the Indus at the eastern exit. Peshawar Basin is surrounded by mountain ranges of Khyber in west

and northwest, Attock-Cherat in south and Swat in the northeast. The basin is filled with Quaternary sediments ranging from Pleistocene to recent in age. These sediments overlie rocks of Paleozoic age. The Quaternary sediments of the Peshawar Basin are physio-graphically classified as Peshawar Piermont-sediments, Peshawar lacustrine sediments and Peshawar flood plain/ stream channel sediments.
The sediments present in the foot-hills of the mountains in the western (Khyber Range) and southern Attock-Cherat Range) part of the Peshawar Basin are coarse deposits of sand and gravel. However, the sediments of the central part of the basin contain relatively large proportion of fine material and are characterized as the lacustrine sediments. On the basis of existing lithologies the aquifer of Peshawar Basin has been classified as Peshawar Piedmont aquifer and Peshawar Lacustrine aquifer. The Peshawar Piedmont aquifer has further been divided in to Khyber mountain range piedmont aquifer, Attock-Cherat Range Piedmont aquifer and Lower
Swat Range Piedmont-aquifer.
Fast growing urbanization and industrialization in and around the major cities is threatening the air as well as the surface and subsurface water systems of the Peshawar Basin. In the cities, air is consistently polluted by vehicular emanations, industrial effluents and metals-born dust, which ultimately make their way to surface and underground water. This study is part of a large project concerning surface and groundwater and soil pollution of major and trace elements and heavy metals. The isotopic data of surface and groundwater of the Peshawar Basin has also been evaluated in order to identify the sources of pollution.
The hydro-physical and chemical parameters of the water of Peshawar Basin determined during the present study include pH, Temperature (T) electrical conductivity (Ee), total dissolved solid (TDS) calcium (Ca), magnesium (Mg), potassium (K), chromium (Cr), nickel (Ni), copper (Cu), cobalt (Co), lead (Pb) cadmium ((Cd), bicarbonate (HC03), sulfate (S04) and chloride (Cl). Surface and groundwater of all the aquifers and rivers respectively have been classified as normal alkaline fresh water and alkaline earth fresh water with higher contents of alkalies. This suggest that the cations and anions have played an important role in categorizing the waters of the Peshawar Basin. On the basis of physical parameters (i.e., pH, T, Ee and TDS), the water of all the rivers and aquifers of Peshawar Basin can be generally classified as "fresh", however, "Slightly saline" water is also present at various places. The groundwaters of some areas have pH in acidic range and have high S04 contents suggesting the contamination through coal and sulfide seems having metal sulfides. These areas of unsuitable drinking water have been delineated during this study.
In order to establish the chemical contamination in the water of the various aquifers of Peshawar Basin, the above mentioned parameters have been compared among various aquifers and also with the permissible limits of US-EPA and WHO.
Various cations (e.g., Ca, Na, K, and Fe) anions (e.g. S04, Cl, HCO3) and trace elements (e.g., Cu, Pb, Zn, Ni, Cr, Co and Cd) in the drinking water of Peshawar are generally within the permissible limits set by US-EPA and WHO. However, Ca, Mg, Na, K, Fe, Pb. Cr, S04, Cl, and HC03 at some places exceed the permissible limit. This could generally be attributed to the compositional changes in the lithology of the area. The oxygen isotopic characteristics of both surface and groundwaters of the Peshawar Basin have been determined. The three rivers, Kabul, Swat and Indus have distinct 18O signature with Indus river being the most depleted, Swat river being the most enriched and Kabul river midway between the two. The oxygen isotopic data for the underground water system of the Peshawar Basin indicate that the aquifers in the Peshawar Basin are recharged both by rainwater and waters from the Kabul and Swat rivers. In this respect the Kabul river remain dominant over the Swat river. This data also indicate that the shallow waters in the basin are more contaminated than the deep water. This suggests that there are chances that any pollution in the surface water can very easily be transferred to the underground water. This study also indicate that the soils of Peshawar Basin have higher contents of few major elements such as MgO, CaO, Na20, K20 and trace elements such as Cu, Pb, Cr and Ni when compared with the normal soil elsewhere in the world. This could possibly be correlated with the surrounding rocks (ultrabasic to acidic nature) of Peshawar Basin.
It is evident from this study that though the waters of the piedmont aquifers are safe both for agricultural and drinking purposes but still the special measures shall be taken to protect the underground water of the area from contamination if the industries are to be established in these areas of the Peshawar Basin in future. In this regard, some recommendations are also given at the end.
Key words: Geochemistry, groundwater, Peshawar basin.

T/111. Tariq, S., Baqri, S.R.H. & Rehman, O., 1997. The distribution of clay minerals in Patala Formation of the Kala Chitta and Salt Ranges: Implications for paleoenvironments. Abstract volume, 12th Himalaya-Karakorum-Tibet International Workshop, Rome, Italy, 227.

During the Paleocene, the predominantly shaly rocks of the Patala Formation were deposited in an extensive Potwar Basin, stretching from the Salt Range to the Kala Chitta Range. Ninty nine samples were collected to investigate the clay mineral composition and to understand the paleoenvironments and diagenetic sedimentational control of the clay minerals in the basin. The samples from the Salt Range, representing the southern end of the Potwar Basin, contain mostly kaolinite, illite, and a mixed-layer clay mineral consisting of illite and montmorillonite. Chlorite was studied only in samples from the NW area of the central Salt Range. The samples from the Kala Chitta Range contain mostly illite, chlorite and mixed-layer clay mineral.
Kaolinite found in twelve samples. It is concluded that the illite-chlorite mineral and the detrital clay minerals were brought into the depositional basin through erosional and sedimentational processes from a source rock exposed in the south. The kaolinite was found to be partly diagenetic and partly of detrital origin. The mixed-layer clay mineral was observed to be of diagenetic origin. The kaolinite in Kala Chitta Range is interpreted as detrital mineral. The crystallinity of kaolinite and lute minerals were also studied in samples. The comparison of clay minerals composition from the Salt Range and Kala Chitta Range show that kaolinite decreases while illite and chlorite increase with depth towards north in the samples from the Kala Chitta Range. The mixed-layer clay mineral does not show any significant variation. The decrease of kaolinite in Kala Chitta Range samples was interpreted as related to a sedimentational/depositional control, because comparatively coarse grained kaolinite was deposited in abundance in shallower parts and hardly transported into the deeper parts of the basin towards north. The fine grained illite-chlorite minerals were transported and deposited in abundance in the deeper part of the basin. The crystalinity indices of illite and kaolinite show a decrease in crystallinity in the samples from the Kala Chitta Range as compared to the Salt Range samples. It is 0.77 mm for kaolinite, 0.37 mm for illite in Kala Chitta Range, and 0.26 mm for kaolinite and 0.19 for illite in Salt Range. The decrease in crystallinity of illite and kaolinite minerals again varify the transportation of these minerals, and deepening of the depositional basin from south to north.
Key words: Sediments, clay, Paleocene, Patala formation, Kalachitta, Salt Range.

T/112. Tariq, S., Baqri, S.R.H. & Rehman, O., 1998. The distribution of clay minerals in patala formation of the potwar basin: implications for palaeo environments. Geological Bulletin, University of Peshawar 31, Abstract Volume, 13th Himalayan-Karakoram-Tibet International Workshop, 193-195.

During the Paleocene, the predominantly shaly part of the Patala Formation was deposited in Potwar Basin, stretching from the Salt Range in the south to the Kala Chitta Range in the north. The paleoenvironments interpreted by the diagenetic sedimentational control of the clay minerals in the basin by analyising the clay mineral composition in 99 samples. The samples contain kaolinite, illite, chlorite and a mixed-layer clay mineral of illite/ montmorillonite. It is concluded that the kaolinite/ illite and chlorite minerals are the detrital clay minerals, brought into the depositional basin due to erosion of the source rocks exposed in the south of partly diagenetic origin. The clay minerals composition from the south to north show that the kaolinite decreases while illite and chlorite increase. The decrease of kaolinite in Kala Chitta Range is most likely due to sedimentational/ depositional control, because coarse-grained kaolinite was deposited in abundance in shallower parts and hardly transported into the deeper parts of the basin towards north. The fine-grained illite and chlorite minerals were transported and deposited in abundance in the deeper parts of the basin. No significant variation observed in mixed-layer clay mineral. The crystalinity indices of illite and kaolinite decrease in the Kala Chitta Range as compared to the Salt Range. The decrease in crystallinity in clay mineral again verify the transportation, and deepening of the depositional basin from south to north.
Key words: Clay, Paleocene, Patala formation, Potwar basin.

T/113. Tariq, S., Hamidullah, S. & Shah, M.T., 1998. Preliminary environmental geochemistry of surface and subsurface waters from Peshawar Basin, north Pakistan. Geological Bulletin, University of Peshawar 31, Abstract Volume 13th Himalayan-Karakoram-Tibet International Workshop, 195-196.

The Peshawar Basin is semi-circular low-lying broad depression (≅8000 km^2) situated at the southern margin of foot hills of Himalayas and north-west of the Indus Plain. Unplanned urbanization and industrialization due to a very high rate of population increase have affected the major cities of N.W.F.P., particularly those situated in Peshawar

Basin. Air is highly polluted in the major cities and industrial estates and both surface and underground water are also facing a significant threat. This study is part of a large project concerning with the investigation of surface and subsurface water pollution related to major and trace elements, particularly heavy metals in Peshawar Basin. Here we present the major element chemistry of the various types of water from the basin. On the basis of stratigraphic correlation five types of semi-confined aquifers, namely, Khyber piedmont aquifer (west and south-west), Attock-Cherat piedmont aquifer (south and south-east), Lower Swat-Bunner piedmont aquifer (north and north-east), floodplain and lacustrine aquifers in the central part of the basin have been identified. A total of 112 water samples collected from surface (river) and subsurface water (shallow, dugwell; deep, tubewell) have been analyzed. Majority of the surface and subsurface water samples appear to be hydrogencarbonatic (Ca-Mg-HCO_3 type) and sulfatic (Cl-SO_4 type) of the alkaline earth fresh water with high contents of alkalies.
Sodium-chloride (NaCl) and magnesium-sulfate ($MgSO_4$) are the major ionic pairs in these waters. Based on the major ions comparison with Quality Standards of Drinking Waters, most of the waters of the Peshawar Basin are classified as normal waters. Few dugwells (shallow water) from the Khyber and Attock-Cherat piedmont aquifers (Zahairabad and Ghari Chandan respectively), a dugwell and two tubewells from lacustrine aquifer of the central part of the basin (Amman Kot) indicate relatively higher concentration of sodium, calcium, magnesium, potassium, iron, chloride, sulfate, and total dissolved solid (TDS) as compare to the standard Maximum Contaminant Level (MCL) of potable water. The high concentration of these radicals at these locations, in the basin, can be attributed to, a) the presence of evaporites at the depth, e.g. gypsum, limestone, dolomite and halite etc., b) water logging and salinity, c) greater use of fertilizers. Therefore no contamination from a source related to industrialization and urbanization was found in waters of these areas.
Key words: Geochemistry, environment, water, Peshawar basin.

T/114. Tariq, S., Shah, M.T. & Hamidullah, S., 2001a. Stable isotopic composition of surface and subsurface water from Peshawar basin, north Pakistan. Journal of Asian Earth Sciences 19, p.66.

Key words: Geochemistry, isotopes, water, Peshawar basin.

T/115. Tariq, S., Shah, M.T. & Hamidullah, S., 2001b. Environmental geochemistry of surface and subsurface water from Peshawar basin, north Pakistan. Journal of Asian Earth Sciences 19, p.67.

Key words: Geochemistry, environment, water, Peshawar basin.

T/116. Tassy, P., 1983. Les Elephantoides Miocenes du plateau du Potwar, groupe du Siwalik, Pakistan; 1, Introduction, cadre chronologique et geographiqe, Mammutides, Amebelodontides. Annales de Paleontologie 69, 99-136, 235-297, 317-354.

These three papers give details of the Siwalik Miocene Elephantoides of the Potwar Plateau. Information is also given on chronological framework, geography, Mammutides and Amebelodontides.
Key words: Palaeontology, elephantoide, Miocene, Siwalik, Potwar.

T/117. Tauxe, L. & Opdyke, N.D., 1982. A time framework based on magneto stratigraphy for the Siwalik sediment of the Khaur area, northern Pakistan. Palaeogeography, Palaeoclimatology, Palaeoecology 37, 43-61.

The magnetostratigraphy of eleven new sections in the Khaur area of northern Pakistan is presented. All specimens have been subjected to thermal demagnetization. The sections, taken in adjacent ravines incising the Siwalik formations nearly penpendicular to strike, form a temporal framework in which to interpret the biological and lithological information. A composite section is constructed from several long sections and is correlated to the magnetic polarity time scale (Chron 6 to Chron 15), providing absolute age information for the biostratigraphic zonations of Barry et al. (1982). Detailed sections along the strike of major stratigraphic marker beds document an

isochronous horizon and form the basis for paleoenvironmental reconstructions. The preservation of a polarity transition in fluvial sediments suggests continuity of sedimentation on a time scale of 10^3–10^4 years.
Key words: Magnetostratigraphy, sediments, Siwaliks.

T/118. Teichert, C., 1967. Nature of Permian glacial record, Salt Ranges and Khisor Range, West Pakistan. Neues Jahrbuch fur Geologie und Palaontolgie, Abhandlungen, 129, 2: 167-184.

Key words: Glacial deposits, Permian, Salt Range, Khisor Range.

T/119. Teichert, C., 1981a. Permian glaciation in Pakistan. Geological Society of Australia, Abstracts, 3, p.17.

Key words: Glaciation, Permian.

T/120. Teichert, C., 1981b. Permian glaciation in Pakistan. In: Harland, W.B. & Hambrey, M.J. (Eds.), Earth's Glacial Record, 278-286. Cambridge University Press.

Key words: Glaciation, Permian.

T/121. Teichert, C. & Stauffer, K.W., 1965. Palaeozoic reef discovery in Pakistan. GSP, Records 14(3), 1-10.

Consult the following account for further information
Key words: Reefs, limestone, Silurian, Devonian, Palaeozoic, Nowshera.

T/122. Teichert, C. & Stauffer, K.W., 1965. Palaeozoic reef in Pakistan. Science 150(3701), 1287-1288.

A Silurian, and perhaps Devonian, limestone belt in northern West Pakistan contains the first Paleozoic reefs found on the Indo-Pakistan subcontinent. The belt contains a rich fauna entirely new to Pakistan. Its presence indicates that this area was inundated in Silurian and Devonian times by seas bordered by reefs or containing reef platforms.
Key words: Reefs, limestone, Silurian, Devonian, Palaeozoic, Nowshera.

T/123. Templeton, R.S.M., 1973. Ideas on the tectonics of the Afghan-Pakistan geosyncline. Geological Survey of Pakistan. Geonews, 3, 7–8.

Key words: Tectonics, geosyncline, Afghan-Pakistan.

T/124. Teng, J.W. & Lin, B.Z., 1984. Earthquake activity and tectonics of the Himalaya and its surrounding regions. In: Miller, K.J., The International Karakoram Project, 1, 221-235. Cambridge University Press.

Using teleseismic data from the Himalaya and surrounding regions plus observations from local seismic networks located on both side of the Yarlung Zungbo River during 1975-1979, both large and small earthquake fault plane solutions are obtained, and the relationship between the seismicity of the plateau and plate tectonics is investigated. Shallow earthquakes are dominant on the Qinghai-Xizang (Tibet) Plateau, whilst intermediate earthquakes are common at the east and west extremities of the arc. In the central part of the arc intermediate depth shocks are rare. According to the fault plane solutions the directions of compressive stress are mainly north and northeast, i.e., basically perpendicular to the strike of the arcuate system. The extremely thick crust and other geophysical data

fields in this regions suggest that the stress field is caused by the collision and compression of the Indian and the Eurasian plates.
Key words: Tectonics, seismicity, Himalaya.

T/125. Terai, Y., Niida, K. & Khan, S.R., 1998. Origin of ultramafic rocks in the Jijal Complex, Kohistan, Pakistan. Abstract volume 105th Annual Meeting, Geological Survey of Japan, p.201.

Key words: Ultramafics, Jijal, Kohistan, Himalaya.

T/126. Terra, H. de, 1935. Geological studies in the northwest Himalaya between the Kashmir and Indus Valleys. Connecticut Academy of Arts and Sciences, Memoirs, 82, 18-76.

Key words: Mapping, petrology, Kashmir, Indus, Himalaya.

T/127. Thakur, V.C., 1983. Granites of western Himalayas and Karakorum structural framework, geochronology and tectonics. In: Shams, F.A. (ed.), Granites of the Himalayas Karakorum and Hindu Kush. Institute of Geology, Punjab University, 327-339.

Key words: Tectonics, geochronology, structure, granites, Himalaya, Karakoram.

T/128. Thakur, V.C. (ed.), 1992. Geology of Western Himalaya. Pergamon Press, Oxford. Physics and Chemistry of the Earth 17 & 18, 1-363.

This monograph gives a comprehensive account of various aspects of the geology of the western Himalaya. Brief references are also made to northern Pakistan. Following introduction, there is a detailed discussion of the outer Himalayan Zone (including Potwar Plateau); Lesser Himalayan Zone (including Attock-Cherat Kala Chitta and Salt Ranges, Nowshera and Hazara region and western syntaxis); Higher Himalayan Zone (including Nanga Parbat, Hazara, Besham, Swat and Kaghan region); Tethys Himalayan Zone; and Trans Himalaya (including Karakoram and Kohistan region. The final chapter deals with tectonic synthesis followed by a comprehensive bibliography spread over 35 pages.
Key words: Tectonics, potwar, Attock-Cherat, Salt Range, Nanga Parbat, Kohistan, NW Himalaya.

T/129. The Aerosol Magnetism Research Team, 1996. Application of rock magnetic method to atmospheric aerosol discrimination: A preliminary observation in Pakistan. Extended Abstracts, International Seminar on Paleomagnetic Studies in Himalaya-Karakoram Collision Belt and Surrounding Continents, November 20-21, 1996, Islamabad. Geosciences Lab, GSP, Islamabad, 107-108.

Key words: Rock magnetism, atmospheric aerosol.

T/130. Theobald, W., 1877a. On the occurrence of erratics in the Potwar, and the deduction that must be drawn therefrom. Geological Survey of India, Records 10(3), 140-143.

For further information, consult Theobald 1880 below.
Key words: Potwar, India.

T/131. Theobald, W., 1877b. Remarks, explanatory and critical on some statements in Mr. Wynne's paper on the Tertiaries of the North West Punjab in Records 10(3). Geological Survey of India, Records 10(4), 223-225.

For further information, consult Theobald 1880 below.
Key words: Tertiary, Punjab, India.

T/132. Theobald, W., 1879. On a marginal bone of an undescribed tortoise, from the Upper Siwaliks, near Nila, in the Potwar, Punjab. Geological Survey of India, Records 12(4).

Key words: Palaeontology, Siwaliks, Potwar, Punjab.

T/133. Theobald, W., 1880. On some Pleistocene deposits of the northern Punjab and the evidence they afford of an extreme climate during a portion of that period. Geological Survey of India, Records 13(4), 221-243.

Theobald provided fairly detailed information about the geographic distribution, lithology and size of the Punjab erratics. Many blocks are located on the east bank of the Indus River in the territory between Indus and Haro rivers and the Grand Trunk Road, particularly near Attock, south of Haji Shah, near Attock city, and Lawrencepur. More blocks occur further north near old Tarbela village, and in the valley of the Dor River, and also on the eastern bank of the Indus river south of the Kala Chitta Range near Nara, Jand and Pindi gheb. The blocks are mostly of granite, gneiss, basalt, and limestone, and range from angular to surrounded in shape, with dimensions up to 20 m3. The blocks rest on a terraced surface suspended some 10 m above the present course of the Indus, about 300-400 m above sea level. Based on lithology, the boulders are considered to have been brought from the north. Theobald states that the erratics were carried and deposited directly by the glaciers or by fallen ice blocks in the ancient Indus and looks upon them as proof of the expansion of the Pleistocene glaciers as far as the foot of the mountain range, below 600 meters.
Key words: Pleistocene, climate, Punjab.

T/134. Theobald, W., 1881. The Siwalik group of the Sub-Himalayan region. Geological Survey of India, Records 14(1), 66-125.

Key words: Siwaliks, Himalaya.

T/135. Thewissen, J.G.M., Gingerich, P.D. & Russell, D.E., 1987. Artiodactyla and Perissodactyla (Mammalis) from the early-middle Eocene Kuldana Formation of Kohat (Pakistan). University of Michigan, Contributions from the Museum of Paleontology, 27, 247-274.

Chorlakki, yielding approximately 400 specimens (mostly isolated teeth and bone fragments), is one of four major early-to-middle Eocene mammal localities on the Indo-Pakistan subcontinent. On the basis of ungulates described in this paper we consider the Chorlakki fauna to be younger than that from Barbora Banda older than the Kalakot fauna, and possibly comparable in age to the Ganda Kas/Lammidhan fauna. Artiodactyis are abundant in the Chorlakki fauna. Two families are represented: Dichobunidae and Raoellidae. A new dichobunid. *Pukibune chorlakkiensis* n. gen. et sp.. and a new raoellid. Indohyus *majar* n. sp.. are described. A new diagnosis of Raoellidae is given here. Perissodactyls are rare at Chorlakki. However a few elements identified as isectolophid tapiroids brontotheriids and hyracodontids are known.
Raoellidae is endemic to the Indo-Pakistan subcontinent and may be related to European Dacrytheriidae. Pakistan dichobunids too seem to have European affinities. The perissodactyls are possibly more closely related to Eocene taxa from the rest of Asia than to those from Europe.
Key words: Palaeontology, Mammalia, Eocene, Kuldana Formation, Kohat.

T/136. Thewissen, J.G.M., Hussain, S.T. & Arif, M., 1994. Fossil evidence for the origin of aquatic locomotion in archaeocete whales. Science 263, 210-212.

Recent members of the order Cetacea (whales, dolphins, and porpoises) move in the water by vertical tail beats and cannot locomote on land. Their hindlimbs are not visible externally and the bones are reduced to one or a few splints that commonly lack joints. However, cetaceans originated from four-legged land mammals that used their limbs for locomotion and were probably apt runners. Because there are no relatively complete limbs for archaic archaeocete cetaceans, it is not known how the transition in locomotory organs from land to water occurred. Recovery of a skeleton of an early fossil cetacean from the Kuldana Formation, Pakistan, documents transitional modes of locomotion, and allows hypotheses concerning swimming in early cetaceans to be tested. The fossil indicates that archaic whales swam by undulating their vertebral column, thus forcing their feet up and down in a way similar to modern otters. Their movements on land probably resembled those of sea lions to some degree, and involved protraction and retraction of the abducted limbs.
Key words: Palaeontology, mammalia, Eocene, Kuldana Formation, Kohat.

T/137. Thewissen, J.G.M., Hussain, S.T., Arif, M., Aslan, A., Madar, S.I. & Roe, L.J., 1997. The origin of the modern orders of mammals within the context of Paleogene deposition in the northern Pakistan. Abstracts, 3rd GEOSAS Workshop on Siwaliks of South Asia, Islamabad. GSP, Records 109, 80-84.

One of the greatest enigmas of the evolution of life is the origin of the modern orders of mammals. Many recently mammal orders appear in the fossil record abruptly, and no morphologically-similar ancestors are known. Krause and Maas (1990) have proposed that Indo-Pakistan could be the birth place for many of these orders and that investigation of Paleocene and Eocene sediments of the subcontinent could solve these enigmas. Collaborative investigations of teams from Howard University, the Northeastern Ohio Universities College of Medicine (NEOUCOM), and the GSP have resulted in significant collections of Eocene mammals, elucidating the origin of several orders of modern mammals. The most primitive artiodactyl in the world is Diacodexis and one of its species, D. pakistanensis has been found in Kohat District (Thewissen et al., 1983). Thewissen and Hussain (1990) suggested that it is the most primitive member of its genus. Spectacular fossil discoveries have been made with respect to the origin of cetaceans (whales and their relatives). The oldest known cetaceans, so called pakecetids, are known from Punjab and NWFP (West, 1980; Gingench and Russell, 1981). Important new fossil material of these animals has been found in the Kala Chitta Hills, allowing a better understanding of the evolution of underwater hearing (Thewissen et al., 1992) and the ability of whales to drink sea water (Thewissen et al., 1 996B). A complete skeleton of another cetacean, Ambulocetus natans from Punjab, is the only cetacean known to preserve much of the hands and feet of the ancestral cetaceans and allows the study of locomotion of amphibious whales (Thewissen et al., 1994, l996A). Anthracobunids, a group only known from Pakistan and India, played an important role in the origin of siremans and proboscideans (Wells and Gingerich, 1981; West, 1981), and true siremans have been recovered in several areas of Punjab (Gingerich et al. 1995). New fossil material for Eocene primates (Thewissen et al., in press) and hyaenodontid creodonts, may solve important biogeograpliical questions of these orders of mammals, and some of the earliest rodents are known from NWFP (Hussain et al., 1978).
Understanding of the depositional environment of Punjab and NWFP is of great importance in the recovery of early mammals. The Cretaceous-Tertiary Boundary of the Kohat-Potwar Province (Punjab and NWFP) is characterized by an unconformity which is commonly expressed as a taterite near the northern edge of the Potwar Plateau. Paleocene deposits of the Kohat-Potwar Province are marine and can be more than 1000m thick (Meissner and Rahman, 1973). These deposits have been interpreted as documenting a continental shelf and deep sea basin sequence (Wells, 1983), and Gardezi et al (1976) identified Paleocene clastic deposits that may document a more near-shore environment. Beck et al. (1995) interpreted the Paleocene rocks as having been deposited immediately after the collision between the Indian and Asian continents. This is consistent with magnetostratigraphic data (Klootwijk et al., 1994).
In the early Eocene, shallow water sedimentation dominates, resulting mainly in extensive limestone deposits that are part of the Ghazij Group of Pivnik and Wells (1996). In the Potwar Plateau area, these include the Margala Hill and Chor Gali Formations which are generally considered to be Ypresian in age (Fatmi, 1973).
Early Eocene marine sedimentation is followed by deposition of continental sediments that are the regressive part of the Laki sequence. These are usually referred lower Kuldana Formation in Punjab or the Mami Khel formation in North-West Frontier Province. Meissner et al. (1974) recovered Foraminifera indicating an early Eocene age for these beds in Kohat District. The lower Kuldana Formation consists mainly of red muds, but occasional indurated conglomerates and sandstones are also present. It is the Kuldana Formation that has yielded most of the important paleontological discoveries of Eocene Indo-Pakistan.

The faunas of the two lithologies of the lower Kuldana Formation differ. Most of the collections described by Dehm and Oettingen-Spielberg (1958) were collected in the muds. The fauna here contains a large number of perissodactyls, especially tapiroids and brontotheres. Wells (1984) interpreted these muds as overbank deposits.
The conglomerates of the lower Kuldana Formation are laterally restricted (several meters) and thin (usually less than 1 m beds). Individual grains are cemented by calcite and commonly show concentric rings in cross-section. They have been interpreted by Wells (1983) as soil nodules that were reworked into channels representing lag deposits. Wells (1984) proposed that the nodules were formed in soils during alternating warm-wet and warm-dry conditions, and that occasional torrential rains may have concentrated them into channels. The faunas found in different conglomerates vary greatly, but are generally different from those of the muds in the low numbers of perissodactyls, especially brontotheres.
Howard-GSP Locality 62 in the Kala Chitta Hills is an example of a conglomerate. The preservation of the fossils is unusually good (Asian and Thewissen, in press), fossils from this site include such delicate elements as braincases and scapulae. This suggests that no high-energy transport has taken place. On the other hand, no articulated elements are known from this locality, suggesting that all soft tissues were destroyed before diagenesis. Pakicetids and anthracobunids are the most common taxa among the recovered mammals, and perissodactyls are extremely rare. Freshwater fish and aquatic turtles are also common, and it is likely that the depositional environment of Locality 62 is aephemeral pond. Asian and Thewissen (in press) proposed that the sediments at this locality were deposited in a short time, possibly less than 1,000 years.
Another fossiliferous conglomerate occurs near Barbora Banda in Kohat District. The fauna at this site consists nearly exclusively of two forms. By far the most common is Diacodexis pakistanensis, but some individuals of an isectolopkid tapiroid are also known (Thewissen et al., 1983). Articulated partial skeletons are common for both taxa at this locality (Thewissen and Hussain, 1990). Wells (1983, 1984) studied the genesis of this conglomerate and suggested that a catastrophic flood swept a group of animals in to a channel and buried them with soil nodules that were eroded from the floodplain. Some scavenger activity is also apparent (Thewissen and Hussain, 1990).
Lower Kuldana sediments are followed by a variety of thin beds including varicolored shales, limestones (sometimes dolomitic), and silts. These beds are sometimes described as the upper Kuldana Formation (Wells, 1983), or included in the Mami Khel formation (Meissner et al., 1974; Pivnik and Wells, 1996). We follow Shah (1977) and include the Mami Khel clays in the Kuldana Formation. There is a quick succession of different lithologies, including both freshwater and mare beds. Given the differences in depositional environment, faunal variation is significant. Terrestrial faunas include primates, hyaenodontids, mesonychians, and brontotheres, whereas aquatic faunas include anthracobunids and cetaceans. Wells (1984) interpreted the upper Kuldana deposits as representing coastal plain and near shore deposits, including brine pools, freshwater lakes, marshes, lagoons and bays. There is also evidence for paleosol development (Aslan and Thewissen, in press).
The top of the Kuldana Formation is conformable with the overlying Kohat Formation. A thick (approximately 1 m in the Kala Chitta Hills) mud with many bivalves and gastropods marks the boundary between the formations. It is underlain by green silts with occasional marine snails and bivalves. The vertebrate fauna of silts and oysterbed includes cetaceans, sirenians, bony fishes, and sharks. Abundant plant remains occur in some sites, and induration varies. These deposits represent the transition from paralic to restricted marine environments (Wells, 1984). Arnbulocetus was found at a locality near the top of the Kuldana Formation.
The Kohat Formation consists of grey muds and limestones with locally abundant benthic foraminifera. Shah (1977) proposed a later Early or early Middle Eocene age for the Kohat Formation. The Kohat Formation is topped by an unconformity after which Miocene freshwater sediments of the Murree Formation are deposited. The base of the Murree Formation commonly consists of a conglomerate that includes reworked Eocene rocks (the Fatehjang Beds).
Key words: Palaeontology, Mammals, Paleogene, Eocene.

T/138. Thewissen, J.G.M., Hussain, S.T. & Arif, M., 1996. New Kohatius (Omomyidae) from the Eocene of Pakistan. Journal of Human Evolution, 32, 473-477.

Further information not available to the authors.
Key words: Palaeontology, Eocene.

T/139. Thewissen, J.G.M., Madar, S.I. & Hussain, S.T., 1996. Ambulocetus natans, an Eocene cetacean (Mammalia) from Pakistan. Courier Forschungs-Institut Senkenberg, 190, 1-86.

Key words: Palaeontology, Mammals, Paleogene, Eocene.

T/140. Thewissen, J.G.M., Roe, L.J., O'Neil, J.R., Hussain, S.T., Sahni, A. & Bajpai, S., 1996. Evolution of cetacean osmoregulation. Nature 381, 379-380.

Key words: Palaeontology, Cretaceous.

T/141. Thewissen, J.G.M., Russell, D.E., Gingerich, P.D. & Hussain, S.T., 1983. A new artiodacyl (Mammalia) from the Eocene of North-West Pakistan. Dentition and classification. Proceedings of the Koninklijke Nederlandse Adademie voor Wetenschappen, Series B, 86, 153-180.

Key words: Palaeontology, Mammals, Eocene.

T/142. Thomas, H., 1977. Un nouveau bovide dans les couches a Hominoidea du nagri (Siwalik moyens, Miocene superieur), Plateau du Potwar, Pakistan, Elachistoceras khauristanensis gen. Et sp. Nov. (Bovidae, Artiodactyla, Mammalia). Bulletin de la Societe Geologique de France, serie VII, 19, 375-383.

Key words: Palaeontology, Miocene, Potwar, Siwaliks.

T/143. Tilman, H.W., 1949. Two Mountains and a River. Cambridge University Press, Cambridge. 233p. 18 plates, 6 maps.

A scarce book, this is one of the classic mid-twentieth century texts for mountaineers, explorers and adventurers, in which the author treks and climbs including Kashgar, Tashkurghan, Rakaposhi, the Kukuay Glacier, The Fainyor Nallah, Muztagh Ata, Kashgar, the source of the Oxus, Sarhad, Gilgit, and Ishkashim (where the author was arrested!), and others. The book has the noted Tilman qualities, sense of place, descriptive powers, never-failing humor, affection for many kinds of men, and a not too intolerant hate for a few. A unique work by a noted traveler, writer, and raconteur.

<u>From the dustjacket:</u>

When a couple of years ago Mr Tilman left with us a MS. of his book *Mount Everest*, 1938, he arranged for his own executors to deal with proofs, pictures, maps and index, and went out of civilization. He returned to England some months later. Few of his friends knew what he had been up to. This new book, *Two Mountains and a River*, now reveals everything.

It appears that he and two Swiss mountaineers went together to the Gilgit region of the Himalaya with the ambitious project of an attack on Rakaposhi (25,550 ft.). Rakaposhi beat them.

After defeat Tilman went on alone to Chinese Turkistan, having an appointment with an old Everest colleague, Mr E. E. Shipton, British Consul at Sinkiang, for a private attempt on the *Father of Ice-Mountains* which Sven Hedin had four times attempted. They did not reach the summit of their mountain, both got frost-bitten toes, and they had to give up that part of their ambition; but they did some heavy travelling among strange towns, which provided Tilman with just the travel copy he handles and photographs best.

Finally, Tilman alone took an alternative return route, which included a crossing of the frontier of Afghanistan (for which he had no visa) where he had an anxious and angering setback, being arrested as a spy by strange Afghan officials, and handed on under guard from town to town, until his final release.

The book has the Tilman qualities, sense of place, descriptive powers, never-failing humour, affection for many kinds of men, and a not too intolerant hate for a few. It is risky to say that Tilman reminds one of Borrow, but there is no doubt that this book will maintain his unique reputation as a traveller, writer, and raconteur.

Divided into the following sections:

- Food and equipment
- Karachi to Abbottabad
- The approach march

- Gilgit - arrival and departure
- The Jaglot approaches
- The two ridges
- The Dainyor Nallah
- The Kukuay glacier
- Chalt to Misgar
- Misgar to Tashkurghan
- Muztagh Ata
- To Kashgar
- Another way home
- The Oxus source
- Sarhad to Ishkashim - open arrest
- Ishkashim - close arrest
- Destination unknown
- Faizabad and freedom

Key words: Travel, Books.

T/144. Tilman, H.W., 1951. China to Chitral. Cambridge University Press, Cambridge.

A story of travel into China's mysterious inner massif where mountains rival Everest's height and the native tribesmen still have a time-suspended life unchanged since Genghis Khan's Golden Horde swept the civilized world. Tilman, a young Englishman, started out from Shanghai, took some easy stages by plane, then descended to earth and oxcart, then truck, to cross the deep interior into Sinkiang or Chinese Turkestan-the long, fabulous back of the beyond that lies north of the Himalayas. There he observed curiously costumed tribesmen, Turkish-bazaar towns, curly-roofed houses designed to keep devils out, and he achieved the ascent of some of the world's highest- and roughest- mountains. This hasn't a magic text to speed it along, but some maps, along with 69 photographs, will attract the travelogue fancier.
Key words: Geography, Chitral.

T/145. Tilton, G.R., Bryce, J.G. & Mateen, A., 1998. Pb-Sr-Nd isotope data from 30 and 300 Ma collision zone carbonatite in northwest Pakistan. Journal of Petrology 39, 1865-1874.

We present isotope data for the synorogenic Sillai Patti and Loe Shilman (30 Ma) and the pre-orogenic Koga and Jhambil (300 Ma) cabonatites, of the Indus Suture Zone. They younger carbonates are foliated-banded sheet-like bodies in the metamorphosed belts of the Higher and Lesser Himalaya, within the Indus Suture Zone. They appear to be collision related and have no relationship to the silicate rocks in the complex. The initial isotope ratios are: ε_{Nd}-3.1 to –3.8; $^{87}Sr/^{86}Sr$ 0.70463-0.70486 (ε_{Sr} +2.4 to +5.6); $^{206}Pb/^{204}Pb$ 19.01-21.35; $^{207}Pb/^{204}Pb$ 15.54-15.67; $^{206}Pb/^{204}Pb$ 38.29-40.63. The pattern is alytical given that carbonatites generally yield positive ε_{Nd} and negative ε_{Sr}. The Nd, Sr, and least radiogenic Pb isotope ratios also fit the pattern of carbonatites from the East African Rift, suggesting derivation from similar sources. In that case a lithospheric source for the 30 Ma Pakistan carbonatites was probably transported with the Indian Plate during migration from East Africa to the collision with the Asian content. Intrusion of the carbonatites into rocks of the Himalayan orogenic zone apparently affected only the Pb isotopes on some of the plutons. Nd, Sr and Pb isotope patterns for the 300 Ma Pakistan plutons fit those for most intra-plate carbonatites, with positive ε_{Nd} and negative ε_{Sr}, showing that neither transport nor collision noticeably disturbed their isotope patterns.
Key words: Carbonatites, metamorphism, Loe Shalman, Sillai Patai, Indus Suture, Himalaya.

T/146. Tipper, G.H., 1921. Orpiment mines in Chitral. Geological Survey of India, Records 54(1): 16-17.

Key words: Mining, Chitral.

T/147. Tipper, G.H., 1922. Chitral. In Fermor, L.L., General report for 1921. Record of the Geological Survey of India 54, 55-57, Calcutta.

This general report of the Geological Survey of India also has geological information on Chitral.
Key words: Chitral

T/148. Tipper, G.H., 1924. Chitral. In Pascoe, E.H., General report for 1923. Record of the Geological Survey of India 56, 44-48, Calcutta.

This general report of the Geological Survey of India also has geological information on Chitral.
Key words: Chitral

T/149. Tipper, G.H., 1923/1924. Geology of Chitral. Geological Survey of India Records 60/61,

The report describes the geology and rocks of the Chitral area.
Key words: Geology, Chitral.

T/150. Tipper, M.H., 1905. Report on penetration of Malakand Tunnel. Geological Survey of India, Records 35, 35p.

Key words: Chitral

T/151. Tiratsoo, E.N., 1947. The search for oil in northwest India. Oil Weekly 125(10), 10-12 & 15-16.

This and the following contribution are not available to the authors. But, hopefully, they contain information on the oil wells that occur in the area of this report; hence the papers are included in this compilation of ours.
Key words: Hydrocarbons, India.

T/152. Tiratsoo, E.N., 1951. Oil fields of Asia and Africa, Pakistan and India. Petroleum Geology. Methuen & Co. London, 156-159.

Key words: Hydrocarbons, Asia, Africa, Pakistan, India.

T/153. Tiratsoo, E.N. 1979., Natural Gas, Gulf Publishing Co., Houston, Texas, p.1-360.

Key words: Hydrocarbons.

T/154. Tohma, M., 1959. On the mineral resources in West Pakistan. Mining Geology, Geological Society of Japan 9, 249-260.

Key words: Mineral resources.

T/155. Tonarini, S., Villa, I.M., Oberli, F., Meier, M., Spencer, D.A., Pognante, U. & Ramsay, J.G., 1993. Eocene age of eclogite metamorphism in Pakistan Himalaya: implications for India-Eurasia collision. Terra Nova 5, 13-20.

This eclogite occurs in the upper part of Kaghan valley, and is derived from mafic protolith. It gives an Eocene age of metamorphism. Implications on the tectonics of the burial of the precursor rocks, very high pressure metamorphism, and uplift of the eclogite are discussed.

Key words: Eclogites, metamorphism, Eocene, Himalaya.

T/156. Tongiorgi, M., Milia, A. de, Le Fort, P. & Gaetani, M., 1994. Palynological dating (Arenig) of the sedimentary sequence overlying the Ishkarwaz Granite, upper Yarkhun valley, Chitral, Pakistan. Terra Nova 6, 595-607.

A sedimentary sequence overlying a granite pluton near Ishkarwaz (upper Yarkhun valley, Chitral, Pakistan; Karakorum Microplate) contains abundant, but poorly preserved, acritarchs probably referable to the late early Arenig-early late Arenig interval. The palynological assemblages of Karakoram show a marked similarity to the cold water Peri-Gondwana assemblages; i.e. to those of Li Jun's Arbusculidium-Coryphidium-Sttiafofheca 'Mediterranean' Bioprovince. Biogeographical and geological comparisons suggest that, before the accretion of Cimmerian microplates to the Eurasian continent, the Karakorum Microplate was located along the northern margin of Gondwana in a latitude intermediate between the Mediterranean region and South China (Yangtze Platform).
Key words: Ishkarwaz granite, palynology, Yarkhun, Chitral.

T/157. Torossian-Brigasky, W. & Hammer, V.M.F., 1996. Die “Turkishgrunen Steine” von Nagar in Nord-Pakistan. Mineralien Welt 7, 47-51.

Quartz of turquoise-green colour is described from Nagar in North Pakistan. The deposit is at 3400 m altitude.
Key words: Gems, semi-precious minerals, Nagar, Karakoram.

T/158. Treloar, P.J., 1989. Imbrication and unroofing of the Himalayan thrust stack of the North Indian plate, north Pakistan. Geological Bulletin, University Peshawar 22, 25-44.

The northern part of the Indian Plate in North Pakistan is dominated by a crustal scale south-verging thrust stack composed of a number of thrust nappes, each of which is stratigraphically distinct. Major nappes recognized in the Swat to Kaghan area of north Pakistan are the Besham, Swat, Hazara, Banna, Lower Kaghan and upper Kaghan nappe. Metamorphism was synchronous with early ductile stages of Himalayan deformation, the metamorphic pile being subsequently disrupted during the development of the thrust stack which marks the last phase of southeasterly directed Himalayan thrusting. Within each nappe the metamorphic grade increases upwards, an overall inversion that represents post-metamorphic imbrication within individual nappes, synchronous with the main phase of nappe stacking, rather than an originally inverted metamorphic gradient. As a result of this “within-nappe” imbrication each thrust slice within any particular nappe contains rocks of a higher metamorphic grade than those in the slice below, with sharp metamorphic breaks across the imbricating thrusts as well as across the major shears that bound the individual thrust nappes. Exhumation and unroofing of the rocks within the thrust stack was rapid. The assembly of the stack triggered rapid erosion, record in the Oligocene and Miocene molasse basins, and regional extension that included significant northward extension within the Main Mantle Thrust zone. Cooling ages imply that peak metamorphism was completed by 40 Ma ago, or within 15 to 20 Ma of collision; that the post-metamorphic thrust stack had been assembled by 25 Ma age, and that much of the subsequent exhumation was completed by 18 Ma ago.
Key words: Tectonics, structure, stratigraphy, metamorphism, Indian plate, Himalaya.

T/159. Treloar, P.J., 1990. Collision processes in the NW Himalaya: Evolution of the Indian plate thrust stack, Pakistan Himalaya. In: Abstract volume, 5th Himalaya-Karakoram-Tibet Workshop, Milano, p.62.

In NW Pakistan Himalayan collision was between the Kohistan Island Arc (accreted to Asia about 100 Ma ago) and the Indian Plate, with Kohistan thrust south over India along the Main Mantle Thrust (MMT). In the crystalline internal zones of the Indian Plate, metamorphism, at temperatures of up to 650^{o}C, was synchronous with ductile simple shear regionally developed in the MMT footwall. The metamorphic pile was subsequently imbricated within a crustal-scale south-verging thrust stack formed of a number of internally imbricate nappes, each lithologically distinct. The thrusts, which imbricate these nappes each, have higher-grade rocks in their hanging wall than in footwalls generating an overall inversion of the metamorphic sequence. It is stressed that this inversion results from

a post- metamorphic disruption of the metamorphic pile rather than from an originally inverted metamorphic gradient.
Internal zone evolution can hence be divided into two periods of deformation, each of which resulted in a, subsequently eroded, topographic high: an early period of thickening of India under Kohistan culminating in the metamorphic peak and a second phase of post-metamorphic stacking. Ar-Ar, K-Ar, Rb-Sr and fission track geochronology enables us to date these different events. The first period predates 40 Ma (the time of cooling back through the hornblende blocking temperature). Thermal modeling suggests that the crustal thickening, which drove the metamorphism, must have predated 60 Ma, which is earlier than the normally accepted timing of Himalayan collision. Post-metamorphic stacking of the internal zones was largely accomplished between 35 and 25 Ma ago subsequent to which this second topographic high was exhumed by a combination of extension in upper levels of the Indian plate and the overlying MMT zone, and rapid erosion reflected by molasses deposition in the foreland basins. Eocene and Miocene molasses sequences respectively date the erosion of these two mountain fronts. Since 25 Ma the crystalline zones have acted as rigid block transported southward over the foreland basin sequences.
Shortening estimates can be derived for different structures within the internal and external zones, geochronological date allowing us to date both when these structures were operative and the rates at which they accommodated shortening. Although total shortening across the zone is of the order of 500-kms, giving a time-averaged rate of ca. 1cm/yr, shortening rates varied throughout the post-collisional period. Within the internal zones the two deformation periods were separated by a phase of little or no apparent shortening. Shortening rates of 2 to 4 cm/yr can be estimated for the period of post-metamorphic stacking. Within the external zones similar variations can be observed. There is, however, little evidence of shortening between 25 and 12 Ma, after which shortening rates, as recorded by sequentially developed structures, varied from <1 to ca. 5 cm/yr.
Key words: Tectonics, metamorphism, MMT, Indian plate, Himalaya.

T/160. Treloar, P.J., 1991. P-T-t paths of metamorphism, Pakistan Himalaya: implications for crustal subduction and staking. Abstract Volume, 6th Himalaya-Karakoram-Tibet workshop, Auris, France, 93-94.

One of the main contributions that metamorphic petrology can make to our understanding of the tectonic evolution of orogenic belts is by contributing hard data pertaining to the P-T-t paths of crustal thickening, metamorphism and exhumation. This involves a consideration not just of thermodynamically calculated metamorphic Ps and Ts, but the use of inclusion suite thermobarometry and the forward modeling of P-T trajectories based on chemical zonations. Such trajectories, when coupled with microstructural analysis of farbric-porphyroblast relationships and Ar-Ar and fission track mineral cooling chronologies, enable the construction of well-defined P-T-t-deformation.
Within the crystalline internal zones of the Indian Plate, west of the Nanga Parbat syntaxis, fabric-porphyroblast relationships demonstrate that metamorphism was synchronous with early stage of ductile deformation. This deformation was related to the development of the first Himalayan mountain front. It is now well established that this metamorphic pile was subsequently deformed within a post-metamorphic thrust stack which contains a number of individual thrust nappes, each with tectonically controlled metamorphic inversions. This period of post-metamorphic thrust stack, which contains a number of individual thrust nappes, each with tectonically controlled metamorphic thrust staking documents the development of a second Himalayan mountain front.
In the Upper Kaghan, Hazara and Swat nappes forward modeling of garnet zonation profiles in low variance assemblages, as well as changes in inclusion suite parageneses from core to rim (especially ilmmenite in garnet cores and rutile in garnet rims in rocks saturated with plagioclase and kyanite), both indicate that the main period of metamorphic mineral growth was along a path of increasing T and P. maximum Ps of 9 to 12 kbar are routinely recorded, with ΔPs during metamorphism of $\geq$6 kbar. These substantial syn-metamorphic pressure increases reflect thickening of the Indian Plate crust during active subduction beneath Kohistan.
Within the Upper Kaghan and Swat nappes, near rim Ca zonation in garnets and the mantling of matrix rutile by ilmentite testify to a phase of pressure decrease, although still at elevated pressures, which must represent early stages of exhumation of the deeply buried rocks. This exhumation is recorded in the late Eocene molasse sediments of the Murree Formation. That no extensive down temperature and pressure cooling p0ath recorded in the zonation profiles suggest extremely rapid cooling that can only have been accommodated by rapid unroofing such as uplift-driven erosion and upper crustal extension on the hanging wall of a major S-verging thrust located beneath the currently exposed crystalline rocks. That this cooling, from >600oC, was rapid is indicated by mineral cooling ages that date cooling through 500^{o}C at ca. 40 Ma. In passing we may not that this early timing of metamorphism and post-metamorphic cooling is inconsistent with a combination of the normally accepted timing of Himalayan

collisions and one-dimensional conductive models of the thermal evolution of thickened crust. They imply that either Himalayan collision was earlier than normally predicted, or that frictional processes of heating are more important in deformation zones than hitherto suggested.
Apart from the growth of calcic rimes on garnets in the garnet and staurolite zones of the Hazara nappe there is little evidence for metamorphic overprinting during post-metamorphic stacking. These calcic rims are, though, important. Modeling across the zonations demonstrate that they record abrupt pressure increases, equivalent to about 10-kms of new tectonic burial. Inside the rim regions, the garnets record normal growth patterns relating to metamorphism during development of the first mountain front. The calcic rims relate to tectonic thickening during the second mountain building phase. Within the post-metamorphic stack, the ductile nature of the shear fabrics and K-Ar geochronology suggest that temperatures were>350oC throughout the period of stacking.
Within the post-metamorphic stack there is a systematic increase in metamorphic pressure from the structurally lowest to the structurally highest nappes. This is most clearly shown in the Kaghan Valley where pressures range from ca. 5 kbar in the lowermost nappes to eclogite conditions in the highest ones, as David Spencer has recently, and most excitingly, shown. This is convincingly firm evidence that, following subduction-related metamorphism, the subducted slab was acutely telescoped, largely by crustal scale thrusting that was entirely confined to sequences on the MMT footwall. That the uppermost nappes are essentially composed of cover sequences has important implications for processes of cover basement decoupling during continental subduction. Displacement amounts for those rocks originally most deeply subducted, and now structurally uppermost in the internal zones, must have been substantial and imply that total shortening amounts for the Indian Plate are well in excess of the 500-km or so generally assumed.
Consequently the full metamorphic story for the Indian Plate internal zones involves: pre 50 Ma, and associated with the growth of the first mountain front, syn-subduction metamorphism (were the heat for this metamorphism not largely driven by frictional heating the collision and crustal thickening must have pre-dated 60 Ma); rapid, pre-40 Ma, exhumation-driven, cooling; pre-25 Ma, and during the growth of the second mountain front, the telescoping and stacking of the cooled and partly exhumed subducted slab with tectonic metamorphic inversions; a second phase (pre-15 Ma) of extension and erosion-driven cooling.
Key words: Tectonics, orogeny, metamorphism, P-T-t path, Indian platen, Nanga Partbat syntaxis.

T/161. Treloar, P.J., 1992. Tectonic of the Himalayan collision between the Indian Plate and the Afghanistan Block: Regional Implication. Abstract Volume, 7th Himalaya-Karakoram Workshop, Department of Earth Sciences, Oxford University, England, 132.

The tectonic history of Afghanistan is complex but can be simplified into deformations related to two main orogenic events. In the earlier of the two, the Triassic to Jurassic aged Kimmerian orogeny, blocks of Gondwanan affinity were sutured to the Asian Plate. Two ophiolitic sutures (Hari-rud and Panjao) can be traced eastward into, respectively, the Jingsha and Banggong sutures of Tibet. A calc-alkaline arc sequence, developed on the southern part of the Asian Plate aensu stricto, to the north of the Herat Fault, represents the magmatic products of the subducted intervening oceanic plate. Subsequent to the Kimmerian the Afghan block behaved as a part of Greater Asia.
Prior to Himalayan collision, subduction of the Tethyan oceanic plate beneath Afghanistan saw the development of volcanic arc plutonic sequences of Late Cretaceous age within the Helmand and SW Pamir blocks of the Afghan continental margin, and within the Nuristan extension of the Kohistan-Ladakh island arc. These plutons, and associated volcanics, represent the western end of the Trans-Himalayan batholith.
An important ophiolite emplacement event occurred during the Paleocene. This included emplacement of the Khost, Muslimbagh, Zhob and Waziristan oph2.olltes onto the western margin of Greater India, as well as ophiolite emplacement onto the Kabul block. The Kabul Block is interpreted here as being of great significance in the pre-Himalayan tectonic evolution of the NW Himalaya. Not only were ophiolitic units emplaced onto it from the northwest, but subsequent to the ophiolite emplacement events, the Kabul block remained separated from Greater India by oceanic crust to its east and southeast. Eocene to OligoCefle flysch sediments of the Katawaz basin were deposited onto this oceanic crust subsequent to the ophiolite emplacement events. The Kabul block therefore appears to represent a sliver of continental crust separated from Greater India by a narrow slice of oceanic crust.
Timing of Himalayan collision is uncertain, but there is an increasing body of data which suggests that peak metamorphism in the NW Himalaya must have predated 40 Ma ago, and that metamorphism and leucogranite emplacement may have been as early as 51 Ma ago. If these ages predate true India-Asia collision, as seems likely, then we need to find a mechanism by wh3.ch the northern margin of Greater India may have been telescoped and

thickened prior to India-Asia collision. Such a mechanism could involve the collision of the leading edge of India with an independent slice of continental crust, subsequently subducted beneath Kohistan and southern Asia. The Kabul Block may be the southwestern, and only remaining exposed, part of this strip of continental crust. The early metamorphism may, therefore, represent thermal relaxation following this pre-Himalayan collision between India and "Kabulistan".

True India-Afghanistan collision did not take place until the mid- to late-Oligocene, the oceanic crust and overlying flysch sediments, that separated the Kabul Block from the Indian Plate, remaining intact until then. Dating of this collision is derived from the ages of: molasse sediments that postdate thrusting in the Sulaiman Ranges of West Pakistan; flysch sediments folded within the Katawaz Flysch Basin; Paleogene sediments deformed in basins within the Herat Fault zone; and Oligocene sediments and volcanics folded during deformation of the Farah Block of Afghanistan. Significant counter-clockwise rotation of northern Afghanistan took place as, following oblique collision, Afghanistan climbed onto the western margin of the Indian Plate.

The degree to which continental extrusion, accommodated by strike-slip faulting, has taken place in Afghanistan following the Oligocene is uncertain. The Herat and Chaman Faults cannot have acted together to accommodate such expulsion as the former was mainly active during the early Miocene, and the latter after that. Instead, much of the shortening consequent on collision and the continued indentation of India into Asia may currently be being taken up by the northwestward thrusting of the Hindu Kush Mountains over the Afghan-Tadzhik Basin.

Key words: Tectonics, deformation, Indian late, Afghan block, Himalayan collision.

T/162. Treloar, P.J., 1995a. Pressure-temperature-time paths and the relationship between collision, deformation and metamorphism in the North-west Himalaya. Geological Journal 30, 333-348.

For details consult the following account.

Key words: Tectonics, deformation, metamorphism, Himalaya.

T/163. Treloar, P.J., 1995b. P-T-t Paths and the relationship between collision, deformation and metamorphism in the NW Himalaya. Abstract Volume, 10th Himalaya-Karakoram-Tibet Workshop, (ETH Zurich) Switzerland.

In recent years, an increasing amount of attention has been given to the thermal controls of metamorphism and the P-T-t paths followed by evolving regional metamorphic terrains. One-dimensional models of conductive heat transfer within orogenically thickened crust clearly demonstrate that in the absence of the sudden injection of heat through magmatic processes, time-scales over which prograde regional metamorphism occurs should be measurable in tens of millions of years. As such, it has become commonplace to consider that the regional metamorphism of thickened crust is a lengthy process, with short lived regional metamorphic episodes being limited to regions, possibly of limited extent, that are characterised by the magmatic advection of heat from the mantle to the crust. In this paper I wish to explore mechanisms which may explain why areas of apparently large regional extent, can undergo regional metamorphism over short time-scales but in the absence of any magmatic heating. An area ideal for this study is the chlorite- to sillimanite-grade metamorphic pile developed on the leading edge of the Indian Plate in northern Pakistan, in the NW Himalaya.

Early Tertiary tectonic and metamorphic evolution of the Indian Plate in N Pakistan.

Within the NW Himalaya, collision was between the leading edge of the Indian Plate and the Kohistan-Ladakh island arc. The Kohistan arc, sutured to Asia at between 100 and 85 Ma ago (Treloar et al 1989a), was the last exotic terrain to be accreted to the Asian Plate prior to Tertiary collision between the Indian and Asian Plates. Prior to collision between the Indian Plate and Kohistan, a series of ophiolitic sheets were obducted onto the northern and western margin of the Indian Plate. Structural data from various ophiolites suggest ophiolite emplacement to have taken place about 65 Ma ago (Searle 1986, Beck et al 1995). When collision between the Indian Plate and the Kohistan island arc commenced, Kohistan was obducted onto the leading edge of the Indian Plate along the Main Mantle Thrust (MMT), a major north-dipping thrust fault that is the true westward continuation of the Indus-Tsangpo Suture Zone. Within the crystalline internal zones, the Indian Plate can be divided into three lithostratigraphic units. At the base is a Proterozoic complex comprised of biotite gneisses intruded by undeformed granites. Hornblende and zircon ages from the gneisses are about 1850 Ma (Treloar & Rex 1990a, b). The gneisses are overlain by a series of late Precambrian to early Cambrian sediments intruded by the Cambrian Mansehra granite, and which underwent a Paleozoic low grade metamorphism (Baig et al 1989). Unconformably overlying these units is a sequence of pelites, calc-pelites, marbles and amphibolites which constitute the Carboniferous to Triassic Panjal Sequence of the Kaghan Valley and the Alpurai Schist sequence of the Swat Valley Di Pietro et al 1993, Greco & Spencer 1993). These units must have been overlain, prior to collision, by a sequence of Mesozoic to Eocene continental margin limestones and sandstones, up to 4km thick.

Metamorphism on the footwall of the MMT, within the Indian Plate cover sequences, was synchronous with ductile deformation associated with collision with Kohistan (Treloar et al 1989b, c, d; DiPietro 1991). Spiral garnets, garnets with curving inclusion trails, and garnets with inclusion trails discordant to developed crenulation cleavages are all consistent with growth of metamorphic porphyroblasts early in the deformation history. Subsequent to the main phase of metamorphism, the metamorphic pile was disrupted within a S-vergent thrust stack which imbricated thrust nappes composed of basement rocks with thrust nappes composed of cover rocks. Within individual nappes, N-dipping thrusts placed rocks of a higher metamorphic grade on top of rocks of a lower metamorphic grade, thus generating a tectonically inverted metamorphic sequence, with metamorphic grade increasing both northward and structurally upward. The thrusts and shears which controlled this stacking disrupted the peak metamorphic assemblages and thus post-date the main phase of metamorphism. Although Tertiary cooling ages are readily retrieved through hornblende and mica Ar-Ar data from the Upper Kaghan, Swat and Hazara nappes, there is no evidence for a substantial Tertiary heating of the basement rocks, from within which undisturbed hornblende Ar-Ar spectra yield ages of ca 1850 Ma (Treloar & Rex l990a, b). This implies either that the cover sequences, metamorphosed during the early Tertiary, were transported great distances during the post-metamorphic thrust stacking, or that the early Tertiary metamorphism was restricted to the upper part of the Indian Plate.

Geochronologic data from a variety of sources indicate that peak metamorphism predated 47Ma with cooling back through 5000C by 40 Ma (Treloar et al 1989a; Treloar & Rex 1990a, b; Zeitler & Chamberlain 1991; Tonarini et al 1993; Smith et al 1994). By contrast, timing of Himalayan collision between the Indian and Asian plates is poorly constrained although most reasonable estimates place it at between 65 and 50 Ma ago (Klootwijk et al 1992; Patriat & Achache 1984). However the timing of collision is defined, there is still an absolute maximum of 15 Ma between initial collision and the attainment of peak metamorphic conditions within the leading edge of the Indian Plate in Pakistan. This is insufficient to permit the attainment of middle amphibolite-facies temperatures by purely conductive heating of cold rocks following continental thickening, unless they had extremely high internal heat generating properties. Possible solutions to this dichotomy are either that the metamorphism predated the Tertiary collision of India, which appears unlikely, or that the driving force for metamorphism involved more than simply conductive heating following crustal thickening. Here I wish to assess the second of these possibilities.

Metamorphism in the Indian Plate. Metamorphic conditions have been derived for much of the internal zones of the Indian Plate exposed to the west of the Nanga Parbat syntaxis (Treloar et al 1989b, c; DiPietro 1991; DiPietro & Lawrence 1991; Pognante & Spencer 1991). For the Swat region, kyanite-grade rocks were metamorphosed at 625 + 500C and 9 + 2 kb. For the Hazara area, staurolite-grade rocks were metamorphosed at 480~620a(2 and 5-10kb, and kyanite-and sillimanite- grade rocks at 600-7400C and 7-12 kb. Kyanite- and sillimanite-grade rocks of the upper Kaghan Valley, on the hanging wall of, the Batal Thrust, were metamorphosed at ca. 650 + 500C and 9 + 2 kb. In addition, eclogitic rocks within the Upper Kaghan nappe yield P-T estimates of 650 + 500C and 14.5 + 2.5 kb. In the Lower Kaghan Valley, on the footwall, and to the south of, the Batal Thrust garnet-grade rocks yield P-T estimates of 540 + 400C at 10 + 2 kb.

Pressure-temperature-time (PTt) paths have been estimated for rocks from each of the major thrust nappes. Within the Swat region, garnet cores contain an assemblage including zoisite, calcite and ilmenite, and garnet rims contain an assemblage that includes kyanite and rutile. The transition from ilmenite in garnet cores to rntile in garnet rims and in the matrix is consistent with a pressure increase from core to rim. For the Hazara and Upper Kaghan region, PTt paths have been calculated through forward modelling of garnet zonation profiles. Calculated core to rim paths invariably involve increasing pressure trajectories, with little evidence from marginal rim compositions for a significant late pressure decrease.

Thus, in North Pakistan, metamorphism of the Indian Plate sedimentary cover was along a path of increasing pressure, synchronous with ductile shearing, consistent with metamorphism having occurred during active subduction of the leading edge of continental India beneath Kohistan. Peak metamorphism of the cover sediments was achieved by no later than 50 Ma, with cooling back through 5000C at 40 Ma. Subsequently, the rocks were stacked within an imbricate thrust pile within which higher grade rocks are always stacked on top of lower grade rocks. Any model that attempts to explain the metamorphic history of this part of the Indian Plate has to be able to account for the rapidity of heating and subsequent cooling, the syn-metamorphic path of increasing pressure, the subsequent tectonic stacking of the metamorphic sequence; and why, on the footwall of the MMT, it is largely the cover, and not the basement, sequences that show the effects of Tertiary metamorphism.

A Model for the early Tertiary thermal evolution of the NW Indian Plate.

Much of the numerical modelling of the thermal evolution of metamorphic terrains has been involved with explanations for the evolution of inverted thermal gradients across crustal-scale structures. Within 1 -dimensional systems, it is easy to generate an inverted thermal gradient across a thrust fault by assuming instantaneous thrusting. However, such an instability will decay within a few Ma due to conductive heat transfer across the fault. Using 2-dimensional modelling, it can be shown that, at thrust displacement rates of < 5cm a' and in the absence of dissipative shear heating, conductive cooling during thrusting would prevent the development of an inverted thermal gradient, even in the immediate vicinity of the fault (Ruppel & Hodges 1994). Even at thrust rates of >5cm aL a steady state temperature inversion cannot be maintained due to cooling of the hanging wall block by continued underthrusting of cold layers on the top of the footwall block: the so-called subduction refrigeration effect (Peacock 1987). To preserve a record of the inverted thermal gradient, it is necessary to accrete the metamorphosed footwall rocks onto the base of the hanging wall, and then to tectonically uplift them. By contrast, dissipative shear heating can generate an inverted temperature gradient on the footwall of the thrust, but with the temperature maximum on the thrust plane itself (Molnar & England 1990; England & Molnar 1993). The effects of dissipative shear heating will override any incipient cooling of the upper block, within which a stable geothermal gradient will be achieved after initiation of faulting at a time determined by the displacement rate along the fault and the thermal diffusivity.

The possible effects of dissipative shear heating along the fault that separated Kohistan from the Indian Plate have been modelled using equations 23 to 30 of England & Molnar (1993). Shear stresses have been calculated, using dips of 15 and 30o for the fault surface and displacement rates along the fault of 10 and 15 cm a-', for two different sets of P-T conditions (725o at 10 Kb and 650oC at 10 Kb) that equate to kyanite to sillimanite bearing rocks of the Hazara nappe and the kyanite-bearing rocks of the Swat nappe respectively) and thus approximate to temperatures attained in the uppermost part of the Indian Plate on the footwall of the MMT. Derived shear stresses are a function of the angle of dip of the subduction thrust and the convergence rate, with high dips and high convergence rates favouring high shear stresses. The relatively low angles of dip of the subduction thrust are taken to account for the fact that buoyant continental, rather than dense oceanic, crust was being subducted beneath Kohistan. Displacement rates are based on early Eocene convergence rates between India and Asia. For these input parameters, shear stresses developed along the thrust at depths of 25 to 50 km are in the order of 57 to 116 MPa.

Using the calculated shear stresses, temperature gradients developed on both the hanging wall and footwall of the thrust can be retrieved. A steady state geotherm of Ca. 20ºC km-1 will be attained in the hanging wall within about 5 Ma of the initiation of thrusting. For the footwall, and for depths of 35 km, a negative geothermal gradient of between -83 and -178oC km-1 will be attained. Thus, if the effects of dissipative shear heating along the MMT are considered, it is clear that at about 5 Ma after initiation of collision significant negative thermal gradient could have been established beneath Kohistan in the Indian Plate rocks on the footwall of the MMT, with temperatures on the immediate footwall > 550ºC.

Discussion.

Given the likely inverted gradients that developed during thrusting, it becomes possible to construct an approximate model for metamorphism on the footwall of the MMT, which might have developed within approximately 5 Ma of the initiation of collision between India and Kohistan. As the major isogradic reactions are temperature dependent, the temperature inversion developed on the footwall of the MMT should be matched by a metamorphic inversion. In order to be preserved, such inverted metamorphic sequences need to be accreted to the base of the over-riding fault block and brought rapidly back towards the surface. To do this the main zone of shearing has to step downward into the footwall so that the initially metamorphosed rocks can be uplifted on the hanging walls of new thrusts developed on their footwall. This accretion process is likely to achieve a thrust-type imbrication of the metamorphosed zone as a result of which rocks metamorphosed deeper within the thrust zone will be stacked on top of rocks metamorphosed at shallower levels within the thrust zone. These imbricating faults will be sub-parallel to the master fault, although with an anastomosing geometry, will stack higher pressure (and thus higher temperature/grade) rocks on top of lower pressure (and thus lower temperature/grade) rocks, and will tectonically thicken the metamorphic complex.

A number of predictions arise from this model. Firstly, the metamorphic pile will be relatively thin and concentrated in the upper part of the footwall block. This means that, as in N. Pakistan, the main metamorphism will be concentrated in the cover sequence of the downgoing plate, with the basement rocks insulated from the thermal effects of the thrust-related metamorphism. Secondly, to be preserved, the rocks that underwent rapid metamorphism during active shearing on the thrust footwall must be brought rapidly back towards the surface, and hence, as in N. Pakistan, will show rapid post-peak metamorphic cooling histories and only a brief residence at high temperatures and pressures. Thirdly, the thrust imbrication that develops during accretion and uplift should stack high-grade rocks on top of lower grade rocks, as is seen in N. Pakistan, thus re-inforcing the original syn -thrusting inverted metamorphic gradient. In the internal zones of N. Pakistan, there is no evidence for older rocks being stacked upon younger rocks. Rather, the geometry is of rocks that had been deeper in the subduction zone being stacked upon rocks that have never been as deep. This implies that deeper rocks accreted onto the hanging wall first with increasingly shallower packages accreted onto their base during their tectonic exhumation. Exhumation of the metamorphic tectonites developed on the immediate footwall of the MMT would have been by a combination, firstly, of imbrication of the metamorphic rocks during their accretion onto the footwall of the MMT, and, secondly, by uplift of the MMT and the imbricated metamorphic rocks on the hanging walls of S-vergent thrusts developed as deformation stepped downward into the Indian Plate. This uplift would have been accompanied by erosive unroofing of Kohistan. The imbrication of the metamorphic rocks during accretion onto the MMT footwall thus provides a mechanism for producing a regional metamorphic signature of large areal extent, as a thin metamorphic “aureole” becomes tectonically thickened by intense subsequent imbrication.

The thermal models presented here are clearly approximations. At the subduction rates used here a zone with inverted thermal gradient could also be modelled on the MMT footwall through simple one-dimensional thermal modelling. However, it is clear that dissipative shear heating may be a significant factor in controlling metamorphism within thrust systems, and provides a mechanism by which areas of apparently large regional extent can undergo regional metamorphism over short time scales, but in the absence of any magmatic heating.

Key words: Tectonics, collision, deformation, metamorphism, Himalaya.

T/164. Treloar, P.J., 1995c. Short time scale events: are they the key signature of early stages of orogenesis? A framework for discussion. Abstract Volume, 10th Himalaya-Karakoram-Tibet Workshop, (ETH Zurich) Switzerland.

That the Himalaya form a wonderful (scenically and scientifically) open air laboratory within which to study orogenic processes is indisputable. What is maybe more debatable is the extent to which they form an ideal basis on which to build analogies for the evolution of old orogenic belts. If we accept the broad tenets of the Law of Uniformitarianism, it is obvious that modem day processes should form the key by which we understand the past. This is clearly demonstrated by recent papers by de Wit et al (1992) and Windley (1993) which utilise modern tectonic processes as analogues for Archaean and Proterozoic tectonism in the Limpopo Belt. As an example, I admit to a Tibetan analogy for the late Archaean tectonic evolution of the Limpopo Belt and adjoining Zimbabwe and Kaapvaal cratons (Treloar et al 1992), a model relatively uncritically accepted by southern African geologists, yet one with such serious flaws that it has to be viewed as untenable (Treloar & Blenkinsop, in press). One of the problems in applying Tibetan-Himalayan analogies to the Archaean, for instance, is in the time scales involved. In many cases, the errors on geochronologically dated apparently simultaneous events are almost as large, or even greater than, the total elapsed time since the initiation of the India-Asia collision!

Two features really form the gist of this discussion: time scales and rates of orogenic processes. Through a combination of isotope, fission track, palaeomagnetic and palaeontologic dating techniques it is now possible to constrain the timing of most of the critical events within the history of the Himalayan orogeny, and the rates at which those events took place. Ironically, the least well constrained event is the timing of initial collision between India and Asia (mais, c’est la vie!). What this chronology tells us is not only that a tremendous amount has happened within a relatively short time scale (< ca. 60 Ma), but that it happened quickly. Given that the initial India-Asia convergence rate was in the order of 20 cm a4, this may not be surprising, but it does raise a number of questions.

As a young metamorphic petrologist I, amongst many others, was influenced by the seminal papers of England & Richardson (1977) and England & Thompson (1984). Amongst the first to attempt to model the thermal evolution of tectonically thickened crust, these papers demonstrated the efficiency of purely one-dimensional conductive thermal relaxation of thickened crust in driving regional metamorphism and the fact that for most thickened crustal sections metamorphic P-T-t paths are of a “clockwise~ sense (if one assumes that pressure on the P axis of a P-T plot increases upwards. Geophysicists would likely describe these, probably correctly, as counterclockwise paths!) What these early attempts at thermal modelling showed, and this may be the critical message that struck home to a thousand hearts, is that time scales of regional metamorphism are LONG, measurable in many tens of millions of years. An unstated implication of the England & Thompson models, as well as other similar ones, is that regional metamorphism should be, BY DEFINITION, static. Thickening of the metamorphic pile occurs synchronously with deformation, but the peak metamorphic temperatures are attained many millions of years later. There is geochronological support for this. Both Burton & O’Nions (1991) and Vance & O’Nions (1992) have shown that growth periods of individual garnets may be measurable in terms of up to about 10 million years. However, the exciting, seminal and sometimes controversial work of Tim Bell and his colleagues (Bell 1985, Bell et al 1986, Bell and Johnson 1989, 1992) poses a major question to this simple assumption. Bell will aver that porphyroblast growth in metamorphic rocks is synchronous with deformation. If we look at papers that describe metamorphic tectonites from the Himalaya, what do we see? Spiral garnets, garnets with curving inclusion patterns etc (e.g. Treloar et al 1989a, b). Whether one wishes to resort to "Zwartian" or "Bellian" classifications of porphyroblast-matrix relationships, these textures have to be consistent with syn-deformational growth of metamorphic porphyroblasts, the only thing that is logically not predicted by standard one-dimensional thermal modelling.

Let us take as an example, the early Tertiary metamorphism of the leading edge of the Indian Plate in the NW Himalaya of N Pakistan. It is clearly demonstrable that peak metamorphism there had occurred by between 47 and 50 Ma (Zeitler & Chamberlain 1991, Tonarini et al 1993, Smith et al 1994) and that subsequent cooling back through 5000C was achieved by 40 Ma (Treloar & Rex 1990a, b). Depending on how one constrains the timing of collision, peak metamorphism was within between 5 and 15 Ma of initial India-Asia collision. What price long time scales of regional metamorphism now? In a parallel paper to this (Treloar, this volume) an answer to this conundrum is provided, which builds on the numerical experiments of Molnar & England (1989) and England & Molnar (1993) in invoking dissipative shear heating as the driving thermal impetus for early Tertiary regional metamorphism in the NW Himalaya.

But, this rapid Early Tertiary regional metamorphism is not the only short-lived event that we recognise within the Himalaya. In no particular order of importance or chronology the following far-from-exhaustive list includes:

The synchroneity of thrusting along the Main Central Thrust, extension along the Zanskar Shear Zone/South Tibetan Detachment Zone granite generation and emplacement within the High Himalayan Crystallines (HHC) at about 22 to 20? Ma (references to numerous to mention! but see Searle et al., 1993, England & Molnar 1993). The near synchroneity of metamorphism, melting and granite emplacement within the HHC (a above) uplift and erosion of the HHC and deposition of derived sediments within the Himalayan foreland basins (Najman et al 1993) and the Bengal Fan (Copeland & Harrison 1990) and beyond (France-Lanord et al 1993). The rapid late Oligocene to early Miocene cooling of the internal zones of the Pakistan Himalaya (from > 350º to < 100ºC in <8Ma in direct response to erosional and extensional unroofing of the pile (Treloar et al 1991).

The rapid (instantaneous?) late Miocene uplift of the Tibetan plateau (England & Houseman 1988).

The rapid uplift of the Nanga Parbat (Zeitler 1985, Treloar et al 1991) and Hazara syntaxes (Bossart 1988).

Lateral variations in the rapid rate of sediment accumulation in the foreland basins. In Kohistan, there is a possible linkage between probably short-lived regional scale metamorphism and lower arc melting and massive advective heat input from the mantle associated with emplacement of the Chilas body at ca 85 Ma.

There have to be many more examples of rapid metamorphism, sedimentation, exhumation, which as a group of Himalayan geologists we can identify, in discussion, at this meeting. It is true that it is not only just in the Himalaya that short-lived events are important in crustal evolution. As an example, emplacement of granitoid plutons into the Mesozoic arc developed along the western margin of continental South America in the Chilean Andes was not a continuous process. Instead a number of distinct short-lived pulses of pluton emplacement have been identified by precise hornblende Ar-Ar geochronology. Essentially pluton emplacement was controlled by intermittent periods of extensional activity within the trench parallel Atacania Fault system (Grocott et al 1994). When the fault system was not in extension, no space was available within the crust for magmas to stall and create plutons, hence periods of plutonism are separated by distinct periods of volcanism. Similar, highly responsive, relationships between changes in regional deformation and magmatic styles have been identified elsewhere (Glazner 1991). Harte & Dempster (1987) and Ridley (1989) have argued that lateral changes in metamorphic history and style within orogenic belts are a function of active tectonic boundaries, across which there may be significant lateral heat fluxes, and that prominent metamorphic zones within orogenic belts may be the product of tectonic boundary conditions and thus not necessarily representative of the overall thermal history of the belt. They inferred that these tectonic boundary zones and associated heat fluxes may be long-lived. However, Himalayan examples demonstrate that this may not necessarily be the case.

I do not wish to deny that there are a plethora of data that support the thesis that orogenic deformational and metamorphic features are long-lived. Particularly relevant here are the way that granulite terrains show evidence for long time-scales of high temperature, static annealing and metamorphism (Mezger et al 1990). It is clear that any overthickened crust, if left long enough, would follow the one-dimensional conductive thermal relaxation paths of England & Thompson (1984) and, over a long time scale, heat up and experience a long term, static regional metamorphism. There is little doubt, in my mind, that rocks currently located at depths of >40 km below the topographic surface in Tibet and the Himalaya are currently following the path of purely conductive heating and regional metamorphism. My picture of the lower crust beneath Tibet and the Himalaya is of zones of slowly heating isotropic granulites separated by fine-grained mylonitic shear zones. Dissipative heating along these shear zones may contribute fundamentally to the evolving thermal budget in these deep crustal regions. The significance of the above probably comes down to two points. Firstly, the role of shear zones, thrusts and faults in controlling many of

the processes witnessed within the Himalayan belt. These include crustal thickening, uplift, tectonic exhumation, space creation for pluton emplacement, a dissipative shear heating contribution to metamorphism, fluid access for retrogression and/or melt fluxing, all of which processes will •be enhanced by high displacement rates. Secondly, that short-lived events within the Himalaya are important due to high convergence rates, and hence rapid displacement rates along shear zones and faults at all crustal levels. Implications of this include the following. Are short-lived events of less importance in orogenic belts in which strain rates are lower? Will short-lived events within the Himalaya-Tibet region become less significant as the convergence rate between India and Asia decreases? To answer these questions we probably need to consider what the late stages of orogeny involve and what will the Himalaya-Tibet region look like fifty or a hundred million years hence. Most of the features that we see now will have been re-distributed as sediment in the oceans to south and east. The thickened crust which currently underlies the High Himalaya and Tibet will probably have returned to a more normal crustal thickness by a number of processes (delamination, extension, but increasingly dominantly through isostatically driven erosion) such that rocks now at depth will be exposed at surface. Those rocks will show evidence for a long thermal history at depth, consistent with England & Thompson’s (1984) early models. Evidence for the shear zones which accommodated much of the Tertiary thickening will be limited to annealed granoblastic rocks with little microstructural information, and the Ar and fission track cooling histories will tell us little about the major orogenic processes. It is probable that preserved deformation features will be dominated by those generated during the later stages of orogeny, when convergence rates, and hence strain rates, were lower.
My contention, which we should discuss at this meeting, is that, although over the duration of an orogeny, it may appear that long time scales of metamorphism, magmatism, erosion and uplift are the norm (and if we look at orogens such as the Appalachians, the Cadomian or the Caledonides where we see the roots of the eroded orogen this may appear a sensible conclusion) the reality is that short lived, and possibly localised, thermal, magmatic, metamorphic, erosive and sedimentary processes that result from short-lived faulting (thrusting and extensional) events (brittle at surface, ductile at depth) characterised by high displacement rates, are an important contributor to early stages of orogeny. Thus, if it is these short-lived, rapid events which dominate early orogenic processes the Himalaya are only really a true analogue for the early stages of orogenies characterised by high convergence rates, and we should not attempt to force too far analogies that explain the waning, late-stage orogenic processes recorded in many of our deeply eroded orogenic belts.
Key words: Tectonics, orogeny, Himalaya.

T/165. Treloar, P.J., 1997. Thermal controls on early-Tertiary, short-lived, rapid regional metamorphism in the NW Himalaya, Pakistan. Tectonophysics 273, 77-104.

During Tertiary collision in the NW Himalaya, the leading edge of the Indian Plate was subducted beneath the Kohistan island arc along the Main Mantle Thrust (MMT). Metamorphism within Indian Plate cover sediments was synchronous with ductile shearing, and took place along a path of increasing pressure during subduction beneath the island arc. Initial collision cannot have pre-dated 65 Ma and probably shortly pre-dated 50 Ma. Radiometric data constrain the metamorphic peak as shortly post-dating 50 Ma. As, firstly, initially subducted units are now probably located beneath Tibet, secondly, the subduction thrust separating the Kohistan arc terrane from the Indian Plate was probably cooled by continued underthrusting and, thirdly, the heat-producing Indian Plate cover sediments were delaminated from the basement during collision, metamorphism was more rapid than can be predicted by purely conductive models of thermal relaxation. Although dissipative shear heating along the MMT doubtless contributed to early stages of heating of the footwall rocks, the temperatures attained in the footwall are too high to support the shear stresses required to generate them solely through shear heating. A model is derived to account for both the rapid regional metamorphism and the equally rapid post-metamorphic cooling. Dissipative shear heating along the MMT generated an early inverted thermal profile in the upper units of the Indian Plate. As the hanging wall mafic rocks have a low thermal conductivity, they would have acted as a thermal reflector and the heat would have been conducted away only slowly. As footwall temperatures increased through the brittle-ductile transition, the role of dissipative shear heating decreased and continued heating became a function of internal heat generation within the footwall rocks, together with hanging wall thermal reflectivity. The metamorphic inversion was reinforced by imbrication of the metamorphic stack as it accreted onto the MMT footwall during early stages of uplift and exhumation. Dissipative shear heating within thrust systems provides a potentially important mechanism by which areas of large regional extent can undergo regional metamorphism over short timescales, in the absence of magmatic heating.
Key words: Tectonics, thermal modelling, Early Tertiary, metamorphism, Himalaya.

T/166. Treloar, P.J., 1999. Exhumation of high-grade Indian Plate rocks in North Pakistan: Mechanical implications of a multi-phase process. Terra Nostra 99 (Abstract Volume, 14th Himalaya-Karakoram-Tibet Workshop, Kloster Ettal, Germany), 157-158.

Although syn-convergent extension has been described from many compressional orogens, evidence that it may partition into multiple discrete phases is less clear, even though extension is predicted as continuing for as long as shortening once a critical crustal thickness is attained. Geochronological and structural data from the Indian Plate of North Pakistan, to the west of the Nanga Parbat syntaxis, as well as from the structurally overlying Kohistan arc, permit construction of a model for Indian Plate exhumation that demands two discrete, short-lived phases of rapid exhumation separated by long periods of erosive exhumation with low unroofing rates. Here, the evidence for this is summarized, and the mechanical implications assessed.

Data collated from a variety of sources date peak metamorphism in the Indian Plate internal zones, that post-dated thrusting of Kohistan onto the Indian Plate along the Main Mantle Thrust, at c. 47 ± 3 Ma at T'> 6000C and P of 10 - 15 kbar (see review in Treloar, 1997). That maximum pressures were higher yet is indicated by the recent discovery of coesite in the Kaghan eclogites (O'Brien et al., this volume). Metamorphism was followed at c. 40 Ma. by rapid decompression-related cooling to ca 5000C (Treloar & Rex 1990; Tonarini et at. 1993), much of it probably between 43 - 40 Ma at a cooling rate of 500C Ma. This cooling resulted from rapid exhumation of all the metamorphic rocks; not just the highest pressure ones. That all of the earliest formed metamorphic rocks were partially exhumed at this time, and that the highest pressure rocks are located in cover sediments rather than basement gneisses excludes the application of a simple Chemenda-type model for this period of exhumation and cooling (c.f. Anczkiewicz et al., 1998). Instead of uplift being driven by the rapid rise of a positively buoyant, deeply subducted basement slice, it is more likely to have involved accretion of metamorphosed cover rocks onto the base of the arc and uplift of the whole sequence on the hanging wall of structurally underlying south-vergent thrusts. K-feldspar Ar-Ar data from southern Kohistan date rapid cooling there at ca 40-42 Ma (Krol et at., 1996). This indicates that the Eocene-aged cooling and exhumation consequent on uplift was largely accommodated by extension in the upper, brittle, parts of the over-riding Kohistan arc slab. Although synchronous erosion of the Kohistan slab is recorded in the base of the Murree Formation in the Hazara syntaxis (Bossart & Ottiger, 1989), it is unlikely to have been fast enough to accommodate the extremely rapid cooling indicated by the Geochronological data.

A period of slow cooling in the upper Indian Plate followed until ca. 22 Ma when ductile through to brittle extensional displacement was initiated along N-vergent structures developed along the Main Mantle Thrust (MMT), and in rocks immediately above and below. This extension, coeval with renewed deposition in the foredeep, resulted in ca 300^0C cooling at a rapid rate of ca 600C M&' in rocks on the MMT footwall (Burg et at., 1996; Vince & Treloar, 1996). Both of the discrete exhumation events can be linked to short-lived phases of ductile thrusting at the, then active, base of the thrust wedge. In the former case, this imbricated the metamorphic complex on the MMT footwall. In the latter, it transported the metamorphic complex south along the Panjal Thrust. Each thrust event had the effect of thickening the thrust wedge and can be coupled with the development of north-vergent extensional faulting in the upper part of the thickened crust. In the former case, the locus of brittle extensional faulting was at a high level within the Kohistan arc. In the later, extensional faulting, which spanned the ductile to brittle transition, developed within the Main Mantle Thrust zone. Both extensional events are coeval with sedimentary pulses within the foredeep. This suggests that they are the direct result of the erection of a topographic high as a result of ductile thrusting and imbrication at the base of the evolving thrust wedge. Extensional faulting in the Pakistan Himalaya, developed near the brittle-ductile transition, is a mechanical consequence of the requirement to maintain the critical taper of a wedge being thickened by ductile processes at its base. Not only does thrusting propagate downward within the wedge, but extension also steps downward following the brittle-ductile boundary. Periods when extension is dominant over erosion are the result of over-thickening of the orogenic wedge, possibly due to short-lived high rates of thrusting at the base of the wedge. Since the Miocene, the Pakistani topographic high has been reduced by erosion rather than extension. Although thrusting has continued at the base of the wedge, growth of high mountains has been retarded by the presence of an Eocambrian salt layer within which the basal thrusts are now located. As a result, critical taper of the wedge is now maintained by out-of-sequence thrusting at the rear of the wedge, rather than thickening at its frontal base.

Key words: Tectonics, exhumation, metamorphism, Himalaya.

T/167. Treloar, P.J., Brodie, K.J., Coward, M.P., Jan, M.Q., Khan, M.A., Knipe, R.J., Rex, D.C. & Williams, M.P., 1990. The evolution of the Kamila shear zone, Kohistan, Pakistan. In: Salisbury, M.H. & Fountain, D.M (Eds.), Exposed Cross-Sections of the Continental Crust Kluwer Academic, the Netherlands, 175-214.

The Kamila Shear Zone is a deep to mid crustal structure developed within the Kohistan island arc complex of North Pakistan prior to Himalayan collision: between Kohistan and India. Meta-gabbros of the Chilas complex were transported southwards across the shear zone onto a stack of high pressure rocks that had been assembled in the hanging wall of the Tethyan subduction zone. The shear zone is constituted by an anastomosing array of amphibolite facies ductile high strain zones within which fabric intensity varies although mylonitic zones are common. Shear criteria and kinematic indicators have a consistent SW-vergence. Little microstructural evidence for the high temperature ductile shearing is preserved, fabrics having been over-printed by post-deformational processes of recrystallisation, annealing and grain growth. A subsequent history of exhumation during decreasing temperature is documented by a progressive sequence of down temperature retrogression and deformation in superimposed shear zones which predominantly affected coarse grained rocks unaffected by the earlier crystal plastic deformation. The shearing involved dominantly cataclastic amphibolite to greenschist facies deformation culminating in lower greenschist facies shearing and mylonitisation, and the development of a distributed network of minor cataclastic and gouge-filled fault rocks.
Key words: Deformation, metamorphism, shear zone, amphibolite, Kamila, Kohistan.

T/168. Treloar, P.J., Broughton, R.D., Williams, M.P., Coward, M.P. & Windley, B.F., 1989. Deformation, metamorphism and imbrication of the Indian Plate, south of the Main Mantle Thrust, north Pakistan. Journal of Metamorphic Geology 7, 111-125.

South of the Main Mantle Thrust in north Pakistan, rocks of the northern edge of the Indian plate were deformed and metamorphosed during the main southward thrusting phase of the Himalayan orogeny. In the Hazara region, between the Indus and Kaghan Valleys, metamorphic grade increases northwards from chlorite zone to sillimanite zone rocks in a typically Barrovian sequence. Metamorphism was largely synchronous with early phases of the deformation. The metamorphic rocks were subsequently imbricated by late north-dipping thrusts, each with higher grade rocks in the hanging wall than in the footwall, such that the metamorphic profile shows an overall tectonic inversion. The rocks of the Hazara region form one of a number of internally imbricated metamorphic blocks stacked, after the metamorphic peak, on top of each other during the late thrusting. This imbrication and stacking represents an early period of post-Himalayan uplift.
Keywords: Metamorphism, deformation, tectonics, Besham, MMT.

T/169. Treloar, P.J. & Coward, M.P., 1991. Indian plate motion and shape: constraints on the geometry of the Himalayan Orogen. Tectonophysics 191, 189-190.

Sea-floor palaeomagnetic data that reflect variations in rate and vector of Indian Plate movement and rotation suggest that initial collision between India and Asia occurred at about 50–55 Ma ago. As the pre-collisional Indian Plate was diamond shaped, with the northern margin comprised of two oblique boundaries, collision was earliest where these boundaries meet, or in what is now the northwest Himalaya. Oblique convergence along each of these two boundaries would generate rotation of thrust sheets as they climb on to the Indian Plate. The oroclinal shape of the main Himalayan chain to the east of the northwest Himalayan syntaxes reflects a combination of the effects of oblique convergence, post-collisional anticlockwise rotation of the Indian Plate, and the pinning of the main thrusts at their northwestern terminations by crust thickened during the earliest collisional stage. The Indian Plate rotation enhances a strike-slip component of movement along the western oblique margin, with the transpressively sinistral Chaman fault zone now acting as a continental escape structure.
Key words: Plate movement, Himalayan orogeny, geometry, Indian plate.

T/170. Treloar, P.J., Coward, M.P., Chambers, A.F., Izatt, C.N. & Jackson, K.C., 1991. Thrust geometries, interferences and rotations in the northwest Himalaya. In: McClay, K. (ed.), Thrust Tectonics. Chopman and Hall, London, 325-342.

In North Pakistan the dominant transport direction throughout Himalayan collision has been to the S or SSE. Southward propagation of thrusts within the thickened Indian Plate has, however, been impeded by interference with SW-verging thrusts in Kashmir, at the western end of the main Himalayan oroclinal chain. As a result of this interference, thrusts within both the Pakistani and Kashmiri systems have become pinned at their lateral terminations. Lineation and palaeomagnetic data document substantial rotations of whole thrust sheets, of up to 40° around the pinned terminations, anticlockwise in Pakistan and clockwise in Kashmir. Although such rotations are best seen within the Pliocene to Recent structures of the external zones, similar rotations can be determined within Oligocene structures in the internal zones. The NW Himalayan syntaxes are crustal scale folds which have grown within the zone of convergence between the two thrust systems. The main Himalayan thrust system is interpreted as having been pinned within the Himalayan chain, rather than at its western termination, due to early thickening of the northwestern Indian Plate having acted as a mechanical impediment to the lateral propagation of the main Himalayan thrusts.
Key words: Tectonics, plate rotation, thrust geometry, Himalaya.

T/171. Treloar, P.J., Coward, M.P., Williams, M.P. & Khan, M.A., 1989. Basement-cover imbrication south of the Main Mantle Thrust, North Pakistan. In: MacFarlane, A., Sorkhabi, R.B. & Quade, J. (Eds.), Himalaya and Tibet: Mountain roots to mountain tops. Geological society of America Special Papers 232, 137-152.

India collided with the northern Kohistan/Asian plate at about 55 Ma. Subsequently, Asia has overridden India, developing a wide range of thrust slices at the top of the Indian plate. Balanced sections in the imbricated sedimentary cover of the Indian plate indicate a minimum displacement of more than 470 km since collision. This requires the Kohistan region to the north to be underlain by underthrusted middle to lower Indian crust, the internal ductile deformation and thickening of which accounts for the main overall crustal thickening beneath Kohistan. In the Besham area of north Pakistan, a stratigraphy can be documented for the northern part of the Indian plate that includes basement sequences of quartzo-feldspathic gneisses of the Besham Group, and of Precambrian schists of the Tanawal Formation intruded by the Swat-Mansehra granite. The basement rocks are unconformably overlain by carbonate-rich Paleozoic sedimentary rocks. Sedimentary rocks of both the basement and cover sequences were metamorphosed at an early stage of the Himalayan deformation during tectonic burial associated with crustal thickening. Structures just south of the suture related to this crustal thickening include a sequence of ductile mylonites thickened by thrust-related folding, a folded thrust stack involving basement rocks imbricated with cover strata, and late cross-folds. Much of the thickening of the Indian plate in the footwall of the Main Mantle Thrust can be related to the necessary changes in thrust wedge shape as it climbs through the crust.
Key words: Tectonics, imbrication, metamorphism, Himalaya.

T/172. Treloar, P.J., George, M.T. & Whittington, A.G., 2000. Cross-cutting mafic sheets from Indian plate gneisses in the Nanga Parbat Syntaxis: their significance in dating crustal growth and metamorphic and deformation events. In: Khan, M.A., Treloar, P.J., Searle, M.P. & Jan, M.Q. (Eds), Tectonics of the Nanga Parbat Syntaxis and the Western Himalaya. Geological Society, London, Special Publication 170, 25-50.

Indian plate, granulite facies, migmatitic basement gneisses exposed within the Nanga Parbat syntaxis host a t least two generations of mafic sheets. In the southern part of the syntaxis, concordant sheets yield Palaeo-Proterozoic model ages of 2.2-2.6 Ga, which probably date early stages of continental growth. In the northern part of the syntaxis the sheets include a suite of discordant, silica-saturated or oversaturated sub-alkaline basalts extracted from a slightly depleted sub-continental mantle. Nd model ages and an imprecise Sm-Nd isochron yield an age of emplacement at between 1.6 and 1.8 Ga. That these dykes crosscut granulite facies migmatitic fabrics implies that peak metamorphism in the Indian plate gneisses was, at latest, Meso-Proterozoic and not Tertiary in age. Zircon and

amphibole ages published elsewhere suggest that this metamorphism was probably c. 1850 Ma in age. That the basement gneisses were refractory by the Tertiary has implication for the derivation of leucogranite sheets during the Neogene. Although the gneisses experienced a Tertiary-aged metamorphism, it was to lower temperatures than the Meso-Proterozoic metamorphism. Unless the gneisses were rehydrated during the Tertiary, the leucogranites need to have been soured from more fertile rocks underplating the granulite facies basement complex.
Key words: Mafic sheets, granulite, metamorphism, deformation, Nanga Parbat, Indian plate, Himalaya.

T/173. Treloar, P.J. & Izatt, C.N., 1993. Tectonics of the Himalayan collision zone between the Indian plate and the Afghan Block: a synthesis. In: Treloar, P.J. & Searle, M.P. (eds) Himalayan Tectonics. Geological Society of London, Special Publications 74, 69-87.

For details consult Treloar 1992.
Key words: Tectonics, deformation, Indian late, Afghan block, Himalaya.

T/174. Treloar, P.J., O'Brien, P.J. & Khan, M.A., 2001. Exhumation of early Tertiary, coesite-bearing eclogites from Kaghan valley, Pakistan Himalaya. Journal of Asian Earth Sciences 19, p.68.

The preservation of coesite in ultra high pressure eclogites now at surface raises questions about the structural mechanisms by which they were exhumed. As UHP rocks metamorphosed early in an orogenic cycle probably come to surface through more than one exhumation phase, often few structures remain that relate to the early part of the exhumation path that brought them to "mid"-crustal depths. Here, part of that early path is revealed for coesite-bearing eclogites from the Indian Plate internal zones of N. Pakistan. Metamorphism, at 725 ± 25°C, 28 - 30 kbar, at c. 50 Ma, shortly post-dated subduction of the leading edge of continental India beneath Kohistan.
Structural restorations, field and petrographic data, show the eclogite-bearing rocks are flanked by thrusts below and extensional shears above and that thrusting, extension and the amphibolite to greenschist facies transition were synchronous. The eclogites lie immediately above a top-side-S thrust, S-C' fabrics related to which are overprinted by greenschist facies albite porphyroblasts. The dominant microstructures, though, are S-C' shear bands, penetratively developed throughout the eclogite facies metasedimentary sequences, which document a phase of pervasive top-side-N extension. Hornblende crystals locally parallel stretching lineations related to this extension. Albite porphyroblasts up to 10 cm in diameter overgrow extension related fabrics, although elsewhere they are flattened and stretched within those fabrics.
Top-side-S thrusting predated cooling through the amphibolite greenschist transition at 40 Ma, at which time the pervasive top-side-N extension was operating. This implies exhumation from metamorphic peak to greenschist facies within a few million years. It is likely that both the thrust and extensional sense shear zones represent the late-stage of a deformation continuum which commenced at UHP and brought the eclogites back to "mid" crustal levels. Subsequent Miocene extension brought the rocks near to surface.
Key words: Tectonics, eclogites, Kaghan valley, Himalaya.

T/175. Treloar, P.J., Petterson, M.G., Jan, M.Q. & Bignold, S.M., 1995. A re-evaluation of the Stratigraphy and Early Evolution of the Kohistan Arc Sequence: Implications for Magmatic and Tectonic Arc Building Processes. Abstract Volume, 10th Himalaya-Karakoram-Tibet Workshop, (ETH Zurich) Switzerland.

The NW Himalaya are atypical of the Himalayan chain due to the separation of the Asian and Indian Plates by the Kohistan-Ladakh island arc. The arc was initiated during the mid-Cretaceous, offshore of Asia above a N-dipping subduction zone. The arc was sutured to Asia along the Shyok (or Northern) Suture at between 102 and 85 Ma (Treloar et al 1989). Thickening of the arc along S-vergent shear zones accompanying suturing. Subduction of Tethyan oceanic crust beneath the arc continued until about 55 Ma ago when Indian Plate continental rocks began to be underthrust beneath the arc along the N- dipping Main Mantle Thrust (MMT). Most of the penetrative shearing deformation within the arc is related to Cretaceous suturing to Asia rather than the early Tertiary collision with India (Treloar et al 1990). Extrusive volcanic activity spanned the mid-Cretaceous to Eocene, with the last phases of volcanism postdating the initiation of collision with continental India. On the basis of geochemical and geochronological data, granitoids of the Kohistan batholith, intrusive into the volcanic sequence, have been divided into three. Stage 1 plutons, predate suturing of Kohistan to Asia. Post-suture stage 2 and 3 plutons, dated at 85 to 26 Ma, show a change from gabbroic to granitic types with time (Treloar et al 1989). Petrogenetic and structural models suggest that the infant arc was an extract from Cretaceous mantle and that the subsequent magmatic evolution was a function of the tectonic history. Sr and Nd isotope data document a change in magma source following suturing to Asia and associated arc thickening. The early post-suturing gabbro-diorites have a dominantly mantle-derived isotopic signature. With time, however, magmas emplaced into the arc show evidence for an increasing crustal input as the immature crust of the lower arc began to melt. The crust to mantle input ratio increased with time, such that the last stage magmas were entirely crustally derived (Petterson & Windley 1990; Petterson et al 1993). The full sequence thus shows characteristics that change from those of the juvenile stages of an island arc through those of a thickened volcanic arc accreted to a continental margin, to those of an arc underplated by continental crust.

Here we wish to present new field and structural data which enables us to redefine and clarify the stratigraphy of, and order of events within, the Kohistan arc; to this stratigraphy with an evaluation of the newly available geochemical data, not all of which is consistent with the hypothesis that the arc represents a simple calc-alkaline subduction related system, to derive a model for the tectono-magmatic evolution of the infant arc; and to comment on processes that may be generally relevant to early arc development.

A REVISED ARC STRATIGRAPHY.

We have mapped four sections across the southern part of the Kohistan arc: along the Indus Gorge from the MMT northward to the schists that outcrop to the north of the Chilas complex; a north-south section through Chilas that crosses the Indus Valley section; and along the Swat and Dir valleys from the MMT to north of the Chilas complex. The field relations that we recognise define the nature of the contacts of the Chilas body and this, together with the recognition of a regionally extensive sequence of sedimentary and volcanic rocks to the north of the Chilas body, enable us to redefine the basal arc stratigraphy.

The Kamila amphibolite belt. The southern margin of the arc is marked by a series of ultrabasic layered intrusions of which the Jijal body is the best known. The belt separates the Jijal and Chilas bodies, and can be divided into two. The southern part of the belt is marked by the variably sheared rocks of the Kamila Shear Zone, the only major crustal scale structure within the arc (Treloar et al 1990). The belt contains a mixture of variably deformed meta-basalts and meta-gabbros, although the ratio of meta-basaltic to meta-plutonic material varies both along and across strike. Metamorphic grade is of amphibolite facies, with metamorphism synchronous with shearing. Hornblende Ar-Ar cooling ages of ca. 85 Ma from sheared rocks indicate that the main phase deformation and metamorphism is probably linked to suturing with Asia. On the basis of trace element and rare earth data that the mafic rocks can be divided into two (Khan et al 1993): a Ti-rich HFSE and HREE enriched subset and a Ti-poor HFSE and HREE depleted subset. The Ti-rich subset have remarkably flat REE and incompatible trace element diagrams. This chemistry is untypical of subduction-related magmatism, and is transitional between E- and N-type MORB. These basalts have an oceanic rather than a subduction-related affinity and closely resemble intra-oceanic plateau basalts such as the Ontong-Java, plateau basalts of the Pacific. By contrast, the Ti-poor subset have a transitional tholeiitic to calc-alkaline chemistry with a negative Nb anomaly and LILE/HFSE ratios more typical of subduction zone magmas and represent the early stages of development of a calc-alkaline arc constructed on the magmatically thickened oceanic crust.

The Jaglot schist belt. We identify schists, interbedded with volcanics, outcropping immediately N of the Chilas gabbro-norites wherever we have been able to access that contact. This belt of rocks extends from E to W right across the arc, and we identify it as a major Kohistan-wide stratigraphic unit located to the N of the Chilas complex which has not previously been formally defined. We propose that it be termed the Jaglot Schist Group. On the S side the Group is intruded by the Chilas gabbronorites, on its N it is overlain by the Chalt volcanics. The Jaglot schist group is bimodal with greenschist facies metabasalts, sometimes pillowed, and volcaniclastic schists interbedded with metasedimentary schists. The schists are dominantly quartz-rich pelites with some psammitic and calc-silicate horizons. The sediments are similar to greywacke dominated lithologies, and probably represent input of terrigenous material into medium to deep water marine basins. Turbidity currents formed graded units. Where basalts crop out, they tend to dominate with a low proportion of sedimentary material. Sedimentation is evidence for crustal stretching and basin development in close proximity to a subaerial source for abundant amounts of terrigenous material. Such a setting would be consistent with a model of basaltic volcanic eruptions within an arc basin which was acting as a depo-centre for both sedimentary and volcanic rocks. Thus we favour deposition within a medial to distal basin developed behind the main frontal arc during active uplift and erosion of the arc. Basalts with both ocean plateau type and subduction type signatures outcrop within the belt, suggesting that the transition to full arc magmatism occurred during deposition of the Jaglot Group. In both the Indus and Dir Valley sections pillows have been strongly stretched. The schists everywhere carry a strong tectonic fabric and are intruded by Stage 1 plutons (a mixture of gabbro-diorites and granodiorites), which have also been strongly deformed. The most southerly of the deformed stage 1 plutons crop out within half a kilometre of the northern margin of the Chilas body.

The Chalt, Hunza, Western and Shamran volcanics. Volcanic rocks crop out to the N of the schist belt along the northern margin of the arc over an area, which extends from the Hunza Valley east to Chitral. These form what has been previously termed the Chalt Formation. On the basis of geochemistry we divide this volcanic terrane into two: the Cretaceous Chalt or Hunza Valley volcanics, sensu stricto, which outcrop mainly in the E in the Hunza Valley, and the Western and Shamran Volcanics in the W. The Hunza Valley volcanics are overlain by the Yasin Group of turbiditic sediments, fossils within which yield Albian-Aptian ages (Pudsey 1986). The Chalt volcanics are strongly deformed with, in the Hunza Valley, stretched pillows common. There is a bimodal distribution into basaltic to andesitic lavas and rhyodacitic lavas, although the latter are volumetrically minor. Basalts and andesites of the Chalt volcanics have a tholeiitic trend and high MgO (6-15%), Cr and Ni contents with chemistries typical of bomnites and, in extreme cases, basaltic komatiites. They have negative Nb-anomalies, high LILE/HFSE ratios and (Ce/Y)N ratios close to unity, all similar to low-K tholeiites (Petterson et al 1990). The Western volcanics are calc alkaline in type, with high LILE/HFSE ratios, negative Nb anomalies and Ce/Y ratios consistent with high LREE/HREE ratios (Petterson et al 1990). They can be correlated geochemically with the Shamran volcanics which yield an Eocene Ar-Ar hornblende age of 58 + 1 Ma (Treloar et al 1989) and both the Utror volcanics (Sullivan et al 1993), and the Drosh volcanics.

The Dir Group. Eocene volcanic rocks of the Dir Group outcrop in the Dir and Kalam regions. The Dir Group is divided into the volcaniclastic Baraul Banda Formation and the Utror Volcanics, and comprises a diverse assemblage of coarse volcaniclastic material, basa1tic-andesit~ flows and porphyroclastic material. The lavas consist of a variably altered suite of tholeiitic to calc-alkaline lavas that range in composition from basaltic andesite to high silica rhyolite. They show selective enrichment of LIL elements with respect to the HFS elements, and LREE enrichment relative to the HREE with Ce/Yb ratios in the range 2.3 to 9.9 (Sullivan et al 1993). These trends are typical of subduction related volcanics. The Dir Group overlies granitic plutons dated at ca 75-78 Ma and is intruded by younger plutons dated at 45-48 Ma (Treloar et al 1989). Deposition of the Dir Group was as a marine fore-arc sequence following collapse of the continental margin.

The Chilas complex which marks the core of the arc, is a massive body of, locally layered, calc-alkaline gabbro-norites up to 50km wide and 300km long. The calc-alkaline magmas are similar in trace element composition to those of the low-Ti, HFSE depleted plutons within the amphibolite belt, in that they display a distinct negative Nb anomaly and high normalised LILE/HFSE ratios. The gabbro-norites were probably derived from partial melting of a mantle diapir emplaced during initial stages of arc splitting (Khan et al 1989, 1993). On its northern margin, the Chilas body is intrusive into meta-sediments intercalated with metavolcanics of the Jaglot Schist Group. The intrusive nature of the contact is clearly indicated by the presence of abundant schist xenoliths within the northern part of the Chulas body. Unlike the rocks of the schist belt to the north and the amphibolite belt to the south, both of which were strongly deformed and sheared during the crustal thickening event which postdated suturing of the arc to Asia, rocks of the Chilas complex are generally undeformed although cut by isolated narrow shear zones. Locally, though, the gabbronorites are intensely deformed. No granodiorites are intrusive into the gabbronorites. U-Pb ages on zircon separates from Chilas gabbronorites in Upper Swat fall on a concordia of 84 Ma which would be consistent with a post-suturing emplacement of the Chilas Complex.

DISCUSSION.

To construct a model for the evolution of the Kohistan arc which has general relevance to early arc evolution scenarios, we need to consider the relative timing of volcanic and plutonic events, the significance of the changes in magma chemistries, the role of the repetitive switching from extension to compression in controlling magmatism, the effects of suturing of the arc to Asia in the late Cretaceous with subsequent arc thickening.

On field criteria, geochemistry and geochronology, we can identify a number of distinct, units within the Kohistan arc. Although the contact between the Jaglot Schist Group and the Kamila Belt volcanics and intrusive gabbroic rocks is never exposed, the two being always separated by the Chilas gabbro-norite body, we argue that they are lithologically distinct. The greywackes present in the former are absent in the latter, and the mafic plutons present in the latter are absent in the former. On the basis of consistent northward dips within the volcano-sedimentary sequences, we argue that Kamila Amphibolites underlie the basalts and turbiditic sediments of the Jaglot schist belt. The mid-Cretaceous Chalt volcanics overlie the Jaglot Schist Group. The Western, Shamran and Utror volcanics, postdate suturing and are thus younger than the other three units.

Within the arc, we can define a number of geochemically distinct magma types in both the volcanic and intrusive sequences. The volcanic rocks of the Kamila Belt show a change from oceanic plateau to subduction type chemistry with time. The tholeiitic type, transitional between N-MORB and E-MORB, with High TiO_2 contents, low

LILE/HFSE ratios and flat REE and spidergram patterns, are typical of ocean plateau basalts and we interpret this basement volcanic sequence one of oceanic crust magmatically thickened within an intraoceanic setting. These are superceded by a calc-alkaline type with high LILE/HFSE and LREE/HREE ratios which include the bulk of the basic rocks in the Kamila ampbibolite belt, and the Chilas gabbro-norites. A third type are the low TiO2, high MgO low-K boninite and basaltic komatiites of the tholeiitic Chalt volcanics. This is a chemistry typical of extensional regimes. Fourthly, are the more silicic calc-alkaline magmas of the Kohistan batholith and of the basalts, andesites and rhyolites of the Utror and Western volcanics, which have high LILE/HFSE ratios. It is clear that, although the batholithic granitoids and some of the volcanic rocks are calc-alkaline in type with subduction zone type chemistries, many of the pre-suture volcanic rocks are not so. The first true calc-alkaline arc type rocks are the second stage low-Ti basalts within the Kamila amphibolite belt and the calc-alkaline plutons intrusive into the Kamila volcanics. Early parts of the Kohistan sequence are, therefore, NOT arc related. The timing of the final transition from ocean (plateau) to subduction related arc magmatism is uncertain but we infer it to have been during deposition of the Jaglot Schist Group.

There is clear evidence for at least three phases of rifling within the arc. The first of these involved the development of the back-arc(?) or intra-arc(?) basin within which the Jaglot Schist Group was deposited. It is likely that the sediments of the schist belt have an arc source, the remnants of which are visible in the plutonic rocks of the Kamila amphibolite belt. Thus the sediments and basalts of the schist belt may be contemporaneous with the later stage calc-alkaline plutonism of the amphibolite belt which marks the initiation of true arc style calc-alkaline activity. This period of crustal stretching probably continued until the extrusion of the Chalt volcanics and deposition of the turbiditic Yasin Group, with the peak of rifling being represented by extrusion of the primitive boninitic rocks of the Clink volcanic sequence. A second rifting event was linked to the emplacement of the Chilas body. The size of the Chilas complex and the transition from calc-alkaline gabbro-norites to the tholeiitic UMA association are both consistent with emplacement of the body into a tensional environment. The deformation state of the complex suggest emplacement after arc suturing to Asia. The third phase of rifling was accompanied by deposition of the Eocene Dir Group.

Rifling phases were separated by compressive phases. One such was related to suturing of Kohistan to Asia, accompanied by arc thickening. That thickening of the arc accompanied suturing is indicated by the deformed nature of the Stage 1 plutons but not of the Stage 2 plutons. The Kamila Shear Zone, deformation within which is dated as pre-80 Ma, is the major regional expression of this shortening. A second phase of compression is documented from the Dir area. Here, early Stage 2 batholiths (75-78 Ma) were eroded and exhumed prior to the unconformable extrusion of the Utror Volcanics onto their eroded surfaces and the subsequent intrusion of further plutons into the Dir Group at 48-45 Ma. For significant granite emplacement to take place within a volcanic arc, the over-riding plate must be in a state of either orthogonal tension or of transtension with plutonism inhibited during compressive phases. The clear hiatus in plutonism within the arc between 75 and 50 Ma would be consistent with a period of compression, during which intrusion was inhibited and regional uplift and erosion occurred, separating periods of extension or transtension. At about 55 Ma, arc regional extension replaced compression as the dominant strain with the resultant development of the fore-arc basin into which the Baraul Banda Slates and Utror Volcanics were deposited.

Thus we suggest a tectonic model within which the magmatic evolution of the Kohistan arc can be viewed. Arc evolution of the Kohistan was dominated by extensional tectonics with periods of tension separated by significant phases of shortening during which plutonism would have been inhibited. The earliest magmatism was related not to subduction driven arc growth but to magmatic thickening of oceanic crust, possibly within an ocean plateau setting. The earliest stages of arc growth were located on this magmatically thickened oceanic crust. Once subduction was initiated, extension in the back-arc developed, possibly in response to roll-back of the subduction zone. This extension included the development of the basin in which the Jaglot sediments were deposited and the extrusion of the boninitic Chalt volcanics, which may represent melting of upwelling asthenosphere beneath the zone of lithospheric thinning. This first phase culminated with melting of the lower arc crust generating the Stage 1 plutons of the Kohistan Batholith immediately prior to suturing of the arc to the Asian Plate. Subsequently, the arc returned to a state of active (trans?)-tensional rifling during which the Chilas Complex was emplaced. The thermal and magmatic history of Kohistan shows the initiation of the Stage 2 plutonism at about 85 Ma, essentially synchronous with the emplacement of the Chums Complex at about 84 Ma. Amphibole Ar-Ar data date regional cooling through ca 5000C at about 80 Ma. We infer that emplacement of the Chilas body, as a result of asthenospheric upwelling resulting from active extension and rifling in the arc, and the associated massive advection of heat from the mantle to the base of the arc crust, would have had a significant thermal effect on the volcanic rocks of Kohistan. In particular, sufficient heat may have been released to melt the base of the arc in the Kamila belt, drive the widespread regional metamorphism and initiate deep arc melting and subsequent stage 2 pluton creation. The cessation of this

period of extension is dated by erosive exhumation of the Stage 2 batholiths in the Dir and Swat region although what caused this is uncertain. Renewal of extension at c. 60 Ma, involving fore-arc collapse, resulted in extrusion of the Shamran and Dir volcanics and the deposition of the Baraul Banda Formation in a major extensional basin at about 60 Ma.
Key words: Tectonics, stratigraphy, magmatism, Kohistan arc, Himalaya.

T/176. Treloar, P.J., Petterson, M.G., Jan, M.Q. & Sullivan, M.A., 1996. A re-evaluation of the stratigraphy and evolution of the Kohistan arc sequence, Pakistan Himalaya: implication for magmatic and tectonic arc-building processes. Journal of the Geological Society of London 153, 681-693.

New field mapping and structural data, combined with published geochemical data, from the Kohistan arc in the NW Himalaya, enable a re-evaluation of the arc stratigraphy. Key lithological units and their relationships are more clearly defined, permitting the construction of a revised magmatic-tectonic history for the arc. The oldest units are transitional oceanic-type basalts, which form the basement to the subduction related sequence. Arc-type gabbroic sheets and plutons intrude the oceanic basalts; together these form the Kamila Amphibolite Belt. Metasediments and basaltic lavas were deposited, within an extensional basin, onto the Kamila Amphibolite Belt basement. This sequence, exposed across the arc, forms a distinct stratigraphic unit which is formally defined here as the Jaglot Group. Sediment-charged turbidity cements transported material into the basin, whilst submarine eruptions contributed the basaltic component. This period of extension culminated in the eruption of high-Mg boninites of the Chalt Volcanic Group which overlie the rocks of the Jaglot Group. The earliest granitoids of the Kohistan Batholith predate suturing and intrude the Jaglot and Chalt sequences. At c. 100 Ma Kohistan sutured to Asia, suturing being accompanied by thickening of the arc with the development of major intra-arc shear zones and a penetrative, regionally developed steep cleavage. At c. 85 Ma intra-arc rifting permitted the emplacement into the arc of the voluminous gabbronorites of the Chilas Complex which clearly intrudes the Kamila Amphibolite Belt to the south and the Jaglot Group to the north. The Chilas Complex has been regarded as part of the pre-suturing, juvenile arc sequence. Field evidence summarized here show this to be not so. Heat advection associated with emplacement of the Complex caused amphibolite facies regional metamorphism, melting of the lower arc and plutonism. Some of the resultant granitoid pluton were unroofed and eroded during a compressional phase at between 80 and 55 Ma, before emplacement of further plutons and extrusion of basaltic through to rhyolitic volcanic rocks at between 55 and 40Ma. At least three phases of extension and rifting, each separated by short lived phases of compression, characterized arc evolution. Much of the magmatism is controlled by extensional tectonics within the overriding plate of the kind commonly associated with a retreating subduction zone.
Key words: Geochemistry, structure, Himalaya, Kohistan Island arc.

T/177. Treloar, P.J., Potts, G.J., Wheeler, J. & Rex, D.C., 1991. Structural evolution and asymmetric uplift of the Nanga Parbat syntaxis, Pakistan Himalaya. Geologisches Rundschau 80, 411-428.

The Nanga Parbat syntaxis, in the NW Himalaya, is a still growing crustal-scale north-trending antiformal structure in the core of which Indian Plate gneisses have been uplifted from beneath the overthrust rocks of the Kohistan island arc. Isotopic and fission track geochronology show that uplift rates within the syntaxis have increased to present day rates of > 6 mm/yr. Uplift has been accommodated by a combination of initial northwest verging thrusting on the western margin of the syntaxis, followed by crustal scale folding within the syntaxis and latterly by dextral reverse faulting on the western margin. This thrusting, folding and faulting is the effect of deformation at the north-western lateral tips of the main Himalayan thrusts where they interfere with the south-southeast verging thrusts of the northwest Himalaya.
Key words: Structure, metamorphism, Nanga Parbat sytaxis, Himalaya.

T/178. Treloar, P.J. & Rex, D.C., 1990a. Cooling and uplift histories of the crystalline thrust stack of the Indian Plate internal zones west of Nanga Parbat, Pakistan Himalaya. Tectonophysics 180, 323-349.

Amphibole and mica K-Ar, Ar-Ar and Rb-Sr geochronology for the crystalline internal zones of the Indian Plate define both an extensive pre-Himalayan thermal history and a post-Himalayan metamorphism cooling history. South of the Main Mantle Thrust, near Besham, hornblende Ar-Ar ages from basement gneisses record an ca. 1850 Ma mid-Proterozoic thermal event. Hornblende, muscovite and biotite cooling ages from cover sequences metamorphosed during the Himalayan orogeny are 35 ± 4, 30 to 24, and 29 to 22 Ma respectively. The mica ages, together with those derived from zircon and apatite fission track data (Zeitler, 1985) demonstrate a rate of cooling, of about 30°C/Ma, during the late Oligocene to early Miocene that was greater than that either before or since. This rapid cooling was initiated during the post-metamorphic evolution of the Indian Plate south-verging crustal-scale thrust stack, during which cover sequences metamorphosed during the Himalayan orogeny were imbricated with basement rocks thermally unaffected during that event. Most of the cooling, which happened during the stripping of some 10 ± 2 km of overburden, reflects exhumation due to a combination of erosion, recorded in the Miocene molasse sediments of the foreland basin, and major crustal extension within the MMT zone. Both erosion and extension were the direct consequence of the evolution of the thrust stack.
Key words: Geochronology, metamorphism, amphibole, Nanga Parbat sytaxis, Indian Plate, Himalaya.

T/179. Treloar, P.J., & Rex, D.C., 1990b. Cooling histories and their tectonic implications for the Indian plate crystalline thrust stack of northern Pakistan. In: Crystal Dynamics and path way. Symp. 21–24 Feb. 1990, Bochum, Germany.

For further information, consult the preceding account.
Key words: Tectonics, Indian plate, cooling history.

T/180. Treloar, P.J. & Rex, D.C., 1990c. Post-metamorphic cooling history of the Indian Plate crystalline thrust stack, Pakistan Himalaya. Journal of the Geological Society, London, 147, 735-738.

A post-metamorphic Himalayan cooling history for the crystalline internal zones of the northern Indian plate is defined by amphibole and mica K-Ar and Ar-Ar geochronology. Hornblende, muscovite and biotite cooling ages from cover sequences metamorphosed during the Himalayan orogeny are 35–40, 30 to 23, and 29 to 23 Ma respectively. The mica ages, together with those derived from zircon and apatite fission track data demonstrate a cooling rate of about 30°C/Ma during the late Oligocene to early Miocene. This rapid cooling was initiated during the post-metamorphic development of the Indian Plate south-verging crustal-scale thrust stack. Most of the cooling occurred during the stripping of some 10 ± 2 km of overburden through a combination of erosion, recorded in the Miocene molasse sediments of the foreland basin, and major crustal extension within upper levels of the Indian Plate and the Main Mantle thrust zone. Both erosion and extension were the direct consequence of the evolution of the thrust stack.
Key words: Structure, metamorphism, Nanga Parbat syntaxis, Himalaya.

T/181. Treloar, P.J., Rex, D.C., & Williams, M.P., 1991. The role of erosion and extension in unroofing the Indian plate thrust stacks, Pakistan Himalayas. Geol. Mag., 128, 465–478.

In north Pakistan cooling history data show that metamorphism within the Indian Plate predated 40 Ma, and that the post-metamorphic thrust stack developed within the crystalline internal zones had cooled to less than 100 °C by c. 18 Ma. Much of this cooling occurred during late Oligocene to early Miocene time and can be equated to substantial unroofing of the metamorphic pile. This unroofing was by a combination of erosion, recorded in Lower Miocene molasse deposits within the foreland basins, and by large scale hinterland (northward) directed extensional normal faults developed within the upper parts of the Indian Plate and within the Kohistan-India suture zone and operative as late as 20 Ma. As up to 20 km of material was removed during exhumation, substantial uplift must have been synchronous with exhumation. Part of this may be accounted for by isostatic rebound of the thickened Indian Plate, and part by uplift in the hanging wall of major south-verging thrusts developed at the base of the crystalline pile.
Key words: Metamorphism, Indian plate, erosion, exhumation, Himalaya.

T/182. Treloar, P.J., Rex, D.C., Guise, P.G., Coward, M.P., Searle, M.P., Windley, B.F., Petterson, M.G., Jan, M.Q. & Luff, I.W., 1989. K-Ar and Ar-Ar geochronology of the Himalayan collision in NW Pakistan: constraints on the timing of suturing, deformation, metamorphism and uplift. Tectonics 8, 881-909.

Mica and hornblende K-Ar and Ar-Ar data are presented from each of the three crustal components of the Himalayan collision zone in North Pakistan: the Asian plate, the Kohistan Island Arc, and the Indian plate. Together with U-Pb and Rb-Sr data published elsewhere these new data (1) date the age of suturing along the Northern Suture, which separates Kohistan from Asia, at 102-85 Ma; (2) establish that the basic magmatism in Kohistan, which postdates collision along the Northern Suture, predates 60 Ma, and that the later granite magmatism spanned a range of 60-25 Ma; (3) show that uplift amounts within Kohistan are greater toward the Nanga Parbat syntaxis than away from it and that rate of uplift near the syntaxis increased over the last 20 Ma to a current figure of about 5.5 mm a year; (4) show that much of southern Kohistan had cooled to below 500øC by 80 Ma and that the major deformation which imbricated Kohistan probably predated 80 Ma and certainly predated 60 Ma and was related to the Kohistan-Asia collision rather than the Kohistan-India one; (5) imply that uplift along the Hunza Shear in the Asian plate together with imbrication of the metamorphics in its hanging wall took place at about 10 Ma and was associated with breakback thrusting in the hanging wall of the Main Mantle Thrust; (6) suggest that the Indian plate has a lengthy pre-Himalayan history with an early metamorphism at about 1900 Ma, major magmatism at 500-550 Ma and early Jurassic lithospheric extension or inversion; and (7) show that the Indian plate rocks were metamorphosed shortly after the collision within Kohistan, which occurred at circa 50 Ma, and subsequently cooled back through 500øC at circa 38 Ma and 300^0C at 30-35 Ma with ages of cooling through 200^0 and 100^0C (as determined by fission track data) locally controlled by Nanga Parbat related uplift tectonics.
Key words: Geochronology, collision, suturing, deformation, metamorphism, Himalaya.

T/183. Treloar, P.J., Rex, D.C., Guise, P.G., Wheeler, J., Hurford, A.J. & Carter, A., 2000. Geochronological constraints on the evolution of the Nanga Parbat syntaxis, Pakistan Himalaya. In: Khan, M.A., Treloar, P.J., Searle, M.P. & Jan, M.Q. (Eds) Tectonics of the Nanga Parbat Syntaxis and the Western Himalaya. Geological Society, London, Special Publication 170, 137-162.

New amphibole, muscovite and biotite Ar-Ar and K-Ar data and zircon and apatite fission track data are presented from the western margin of the Nanga Parbat syntaxis as well as from the Indus and Astor valley section which cross the syntaxis. Amphibole data date a regional cooling through 500°C at 25±5 Ma and are inconsistent with earlier suggestions that the peak of regional metamorphism was Neogene in age, although there is no doubt that some rocks were still at upper amphibolite facies temperatures as recently as 5 Ma. The data can be used to constrain structural models for syntaxis uplift. After an initial phase of crustal-scale buckling, bodily uplift of the syntaxis was along subvertical shear zones developed along its margins, although with a significantly higher time-averaged strain rat for shears developed along the western margin than along the eastern margin. The latter may be antithetic to the former. These shears were operative from 10 to <1 Ma. In the southwestern part of the syntaxis, this subvertical uplift was superseded, since 6 Ma, by uplift along moderately SE-dipping NW-vergent shears on the hanging wall of which are located Neogene-aged migmatites.
Key words: Tectonics, metamorphism, geochronology, Nanga Parbat, Himalaya..

T/184. Treloar, P.J., Rex, D.C. & Hurford, A.J., 1992. Geochronology of the Indus Gorge Section through the Nanga Parbat Syntaxis: Constraints on uplift history Abstract Volume, 7th Himalaya-Karakoram Workshop, Department of Earth Sciences, Oxford University, England, 92.

The Indus Gorge provides a constant altitude east-west section across the north-trending Nanga Parbat syntaxis. The syntaxis is a structural half window, within the core of which Indian Plate gneisses are updomed from beneath a cover of overthrust volcanics of the Kohistan-Ladakh island arc complex. This section provides an opportunity for detailed, structurally constrained, sampling for both P-T-t path analysis and geochronology. Here we present data

from this traverse that enable us to constrain the uplift history of the syntaxis. 70 samples were collected for analysis by hornblende and mica Ar-Ar and K-Ar techniques, and by zircon and apatite fission track techniques. When those data of Zeitler (1985) and Zeitler and Chamberlain (1989) are included we have a copious, closely spaced data set.
A marked break in cooling ages occurs across the western margin of the syntaxis. This margin is marked by the Raikot-Sassi Fault Zone, a complex fault system with an overall oblique sense of displacement that includes both right lateral and thrust type displacements. The data imply that significant displacements have occurred along this zone within the last 1 to 2 Ma.
The eastern margin is marked by neither a significant fault zone nor a marked step in cooling ages. Instead cooling ages gradually decrease westward across the margin into the syntaxis, a decrease explained by exhumation during the growth of a large scale antiformal fold located within the syntaxis. Hornblende and mica ages are both younger within the western half of the syntaxis than in the eastern half. This is consistent with the recognition of a series of domal structures within the syntaxis not all of which grew synchronously. Within the Indus Gorge section, the data are consistent with the growth of an antiform within the eastern part of the section before 5 Ma ago, and the subsequent growth of a similar structure, at Ca. 3 Ma ago, in the western part of the section.
Neither zircon nor apatite ages show this age difference from east to west, indicating that folding may have become of secondary importance to uplift controlled by faulting along the eastern margin after about 2 Ma ago. Although a combination of early folding followed by later oblique slip thrusting along the western margin may explain the uplift and cooling history of the Indus Gorge section, it may be unwise to extrapolate this model without qualification to the rest of the syntaxis. The internal structure of the Syntaxis is best modeled as a series of nested domes. More detailed geochronology is required to demonstrate the extent to which these developed diachronously as well as their temporal relationships to thrusting along the western margin.
Total exhumation and overall uplift rates are difficult to quantify given the vertical telescoping of isotherms due to rapid uplift and unroofing, and the emplacements as recently as 2 Ma ago, of leucogranite dykes and bodies to high structural levels. However, due to the constant altitude of the Indus Gorge section, the antecedent nature of the river and the magnitude of the unroofing indicated by the cooling history data, we feel confident that exhumation amounts approximately equal bulk uplift amounts. As such, it is hard to escape the conclusion that fold amplification was exponential, or that recent uplift rates have been as high as 6mmyr-1, as suggested by Zeitler (1985).
Key words: Geochronology, metamorphism, Indus gorge, Himalaya.

T/185. Treloar, P.J. & Searle, M.P., 1990. Himalayan Geology. NERC News. 15, 11-14.

Key words: Geology, Himalaya.

T/186. Treloar, P.J. & Searle, M.P., (Eds.), 1993. Himalayan Tectonics. Geological Society, London, Special Publications, 74

This contribution contains refereed and edited papers on various aspects of the Himalayan tectonic. The papers are presented under the headings: Karakoram and Afghanistan, North and West Pakistan, Tethyan Himalaya, High Himalaya, Main Central Thrust Zone, and Main Boundary Thrust, Lesser Himalaya, and Beyond. Individual papers are presented in appropriate places in this document.
Key words: Tectonics, Himalaya.

T/187. Treloar, P.J., Searle, M.P., Khan, M.A. & Jan, M.Q., 2000. Tectonic of the Nanga Parbat Syntaxis and the Western Himalaya: an introduction. In: Khan, M.A., Treloar, P.J., Searle, M.P. & Jan, M.Q. (Eds) Tectonics of the Nanga Parbat Syntaxis and the Western Himalaya. Geological Society, London, Special Publication 170, 1-6.

Often described as a natural laboratory, the Himalaya are probably the ideal place in which to study ongoing continent-continent collision. This volume focuses on the geology of the northwestern part of the Himalaya which provides the most complete and best-exposed transect across the range. Here, in northern Pakistan and in Ladakh in northwest India, the full profile across the south Asian continental margin, and the north Indian margin is superbly exposed in mountains reaching as high as K2 (8611 m) and Nanga Parbat (8125 m). The south Asian geology is exemplified in the Karakoram and Hindu Kush ranges along the north and northwestern frontiers of Pakistan. The unique Kohistan-Dras island-arc terrane is sandwiched within the Tethyan suture zone between India and Asia. Rocks of the northern margin of the Indian Plate are exposed in both the Zanskar and the Pakistan Himalaya. The northern sedimentary carbonate platform of the Indian Plate, magnificently exposed in the mountains of Zanskar and Ladakh, is largely missing in Pakistan where the Kohistan arc has been obducted southward onto the metamorphosed rocks of the internal crystalline zones of the Indian Plate. The Nanga Parbat syntaxis represents an orogenic bend developed within a convergent zone in the thrust belt where the south-vergent thrusts of the central and eastern Himalaya swing around through 300 degrees.

The history of geological research in the Himalaya extends back to some of the earliest explorers and climbers who visited the region. Two significant problems have affected mapping of the topography and geology of the Himalaya. The first of these is the sheer logistical problem of attaining access to extremely rugged terrain. The second is a political problem. In the NW Himalaya, access to rocks along the disputed border between India and Pakistan is largely forbidden to foreigners. Similarly, easy access northward across the Chinese-Pakistan border has only been possible since the opening of the Khunjerab Pass in 1986. It is arguable that prior to the Russian invasion of Afghanistan in 1980, the geologically best known of the Himalayan nations was Afghanistan, largely through the detailed mapping of Wittekindt & Weipper (1973) and Wolfart & Wittekindt (1980). Since then, advances in understanding of the geology of Afghanistan have been limited to re-interpretations based on satellite imagery or increases in knowledge of the geology of surrounding states such as Pakistan. As a result of these problems, many regions of the Himalayan chain remain poorly mapped or completely unmapped. Containing many new maps, this volume goes part of the way towards addressing this shortfall.

Despite the problems of access, the Himalaya and adjoining mountain ranges continue to be a magnet to earth scientists. The geology of northern Pakistan was largely unknown until about 20 years ago. Until then much of what was known of the region was due to the work of the Geological Survey of India, especially Hayden (1915) and Wadia (1931, 1932). Some aspects of the geology were summarized in volumes that dealt with the geology of the whole of prepartitioning India (e.g. Wadia 1919). Some geology was carried out by geologists attached to major expeditions to the Karakoram (e.g. Desio 1930; Auden 1938). However, really detailed regional scale work truly commenced only in the 1970s during which R. A. K. Tahirkelli from the University of Peshawar carried out much pioneering work in the northern part of the Indian Plate, the Hindu Kush and Karakoram mountains of the southern part of the Asian Plate and what is now recognized as the Kohistan arc. This work was summarised in 1982 in a superbly illustrated Geological Bulletin of the University of Peshawar (Tahirkelli 1982) as well as in Tahirkelli et al. (1979). A then useful summary of the broader effects of the Himalayan orogeny was given in Farah & De Jong (1979). In 1980 the Karakoram Highway (KKH), that stretches from Islamabad in Pakistan through to Kashgar in China, was opened and this stimulated an extraordinary influx of geoscientists into the region. The KKH straddles not just the northern margin of the Indian Plate and the southern margin of the Asian Plate, but also the Cretaceous Kohistan island arc sandwiched between the two. An early synthesis of the geology along the Pakistani section of the KKH was given in the proceedings of an international expedition that traversed the KKH immediately on its completion (Miller 1982). A recent literature audit showed that between 1980 and 1997, over 200 papers had been authored or coauthored on the region traversed by the KKH by British, French and German geoscientists alone. A complete reference list up to 1996 and synthesis of the geology of N. Pakistan is given in Kazmi & Jan (1997). This volume builds upon this recent explosion of geological knowledge.

The essential geological framework of the Pakistan Himalaya is summarized briefly below. The Kohistan-Dras island arc was initiated offshore of Asia during the late Jurassic or early Cretaceous. The arc sutured to the southern margin of the Asian Plate at between 102 Ma, the age of emplacement of the pre-suturing Matum Das pluton (Petterson & Windley 1985) and 85 Ma. The later age is derived from an c. 84 Ma U-Pb zircon age (Zeitler et al. 1981) for undeformed gabbro-norites of the Chilas complex, which contain xenoliths of Gilgit Formation gneisses that had been deformed during suturing. The age is compatible with a Rb-Sr age of 87+ 19Ma (Mikoshiba et al. 1999) assuming that their sample 92CH60 is included in the regression. After suturing the arc behaved as an Andean-style volcanic arc. Thickening of the arc accompanied suturing. Most of the deformation and metamorphism in the arc appears to have post-dated suturing, but predated collision with India. Deformation and metamorphism within the southern margin of the Asian plate appears to have been diachronous with tectonothermal events during the late Cretaceous (after suturing with Kohistan) and the Tertiary. A full review of the Cretaceous through to Tertiary history of the Asian Plate in Pakistan is given in Searle et al. (1999) and of the Kohistan arc in Treloar et al. (1996) and Searle et al. (1999). Collision between the arc and continental India followed closure of neo-Tethys. The age of collision is not precisely determined, although on the basis of the sedimentary record is likely to have been at about 55 Ma (see discussions in Garzanti et al. 1996, Pivnik & Wells 1996, Rowley 1996 and Treloar 1997). A late Cretaceous to Paleocene ophiolite emplacement event predated final closure of Neotethys (Searle 1986; Beck et al. 1995; Searle et al. 1997). Since collision the leading edge of the Indian Plate has undergone deformation, burial, metamorphism and exhumation. In contrast to the main Himalayan chain to the east, peak metamorphism in the Pakistan Himalaya was Eocene in age (Treloar & Rex 1990). Exhumation during the early Miocene was by a combination of north-vergent extension (Burg et al. 1996; Vince & Treloar 1996) and erosion with sediments deposited in the foreland basins to the south of the topographic high (Burbank et al. 1996). Deformation of these sedimentary basins continues to the present day.

The northwest Himalaya differ from the main Himalayan chain for three main reasons. Here the Asian and Indian plates are separated by the Kohistan-Dras island arc, peak metamorphism was Eocene rather than Miocene in age, and the south-vergent thrust systems are deformed by the West Himalayan syntaxes. First recognized by Wadia (1931, 1932), the syntaxes are crustal scale, north-trending antiformal structures which are essentially half windows. The Hazara syntaxis to the south deforms thrusts of the external zones. Within its core, foreland basin sediments on the footwall of the Main Boundary Thrust have been tectonically uplifted (Bossart et al. 1988). The Nanga Parbat syntaxis deforms thrusts of the internal zones. Within its core, crystalline rocks of the Indian plate have been tectonically exhumed from beneath their cover of volcanic rocks of the Kohistan-Ladakh arc sequence that had been thrust onto the Indian Plate early in collision. Present day uplift rates within the Nanga Parbat syntaxis may be as high as 6 mm a-1 (Zeitler 1985). Mechanisms of uplift and its deformational effects, timing of uplift, and the magmatic effects of rapid uplift and exhumation have been the focus of exhaustive research within the Nanga Parbat syntaxis during the last ten years. A number of British scientists funded by the Natural Environmental Research Council and the Royal Society have been working in the syntaxis. At the same time, a team from the USA under the leadership of P. K. Zeitler has been working in the area with funding from the National Science Foundation. Papers from both of these groups are included in this volume.

In setting the regional scene for the volume, Caporali describes the gravity field of the Karakoram Mountain Range and surrounding areas. He demonstrates the gravimetric low associated with the Nanga Parbat syntaxis which is a function of the rapid differential uplift within the syntaxis as well as the presence of large negative anomalies between the Karakoram Fault and the Main Karakoram Thrust. The relationship between crustal scale geological features (sutures, thrusts and syntaxes) and gravitational potential is clear when plotted on a regional scale geology map (Caporali, fig. 3).

The next seven papers deal with the Nanga Parbat syntaxis. In the first of these, Treloar et al. outline the significance of field relationships in defining long term geological histories. Mafic sheets within Indian plate gneisses within the Nanga Parbat syntaxis clearly document a polyphase deformation and metamorphic history. In stressing the importance of recognising complex histories, the authors recall the seminal work of John Sutton and Janet Watson in the Lewisian Complex.

The next papers relate to the structural and topographic evolution of the syntaxis. Butler revisits his earlier studies (Butler & Prior 1989a, b; Butler et al. 1989) on the western margin of the syntaxis to refine, in the light of recent field-work, an interpretation of the structures that accommodated bodily uplift of the syntaxis along west-vergent thrust faults. Edwards et al. describe structures exposed along the south-west of the syntaxis (i.e. to the south of those described by Butler). Uplift here was along steep, east-side up shear zones. Whereas Butler and Edwards et al. describe structures that accommodated uplift along the western margin of the syntaxis, Argles describes the structural evolution of part of the eastern margin of the syntaxis. Butler et al. describe a structural section that crosses the syntaxis and incorporate datapresented here and elsewhere to derive a model for the structural evolution of the syntaxis as a whole. This model should be viewed in connection with that published by Schneider et al. (1999). As geochronological data were first used to hint at the speed of syntaxial growth (Zeitler 1985), it is appropriate that a more profound data set should be used in an attempt to constrain uplift mechanisms. To this end, Treloar et al. use geochronological data to outline firstly, that peak metamorphism within the syntaxis is Eocene-Oligocene, rather than Miocene, in age, and also to indicate how geochronological data can be used to refine the regional scale features that accommodated uplift within the syntaxis. This set of five papers provide a benchmark on which future structural studies of the syntaxis can be built. The Nanga Parbat massif encompasses greater than 6000m of relief. This relief is a function of the rapid Neogene uplift and results in rapid erosional unroofing of the crystalline basement complex. Shroder & Bishop explore aspects of this unroofing and demonstrate that late Pleistocene processes were sufficiently rigorous to produce the present-day pronounced relief. Whereas elsewhere in the Himalaya, extensional unroofing has played an important part in exhumation, at Nanga Parbat, where exhumation is most rapid, it appears not to have done so, a point also made by Edwards et al., Bishop & Shroder argue that accelerated uplift and erosion are part of a feed-back loop with tectonic uplift. They also use remotely sensed imagery to derive a hierarchical order of topographic complexity that is a function of erosion dynamics. The use of remote sensing is probably the prime way in which the topography of the Himalaya will be mapped in future.

Large crustal-scale structures like the Nanga Parbat syntaxis should encourage debate. Two papers here do just that. In a far-reaching paper Burg & Podladchikov model the evolution of the Himalayan syntaxes numerically, (the

Nanga Parbat syntaxis and the Namche Barwhe syntaxis at the eastern end of the Himalayan chain). Their numerical modelling indicates that pure shear thickening and symmetric buckling accommodate shortening until, at a certain strain, an asymmetric thrust-like flow pattern occurs on a crustal to lithospheric scale and it is on this that the syntaxes grow. A side-effect of the model is that syntaxial growth is accompanied by the growth of marginal basins, in the case of the Nanga Parbat syntaxis these are the Kashmir and Peshawar basins. That these basins may be the result of syntaxial uplift is in contradiction to previous models which infer them to be piggyback basins developed above late-stage thrusts such as the Main Boundary Thrust. Whittington et al. use isotopic data to demonstrate that the crystalline Indian Plate rocks contained within the core of the Nanga Parbat syntaxis are typical of the Lesser Himalaya rather than of the Higher Himalaya. The implications of this are profound as they stress the differences between the Pakistan Himalaya and the Indian and Nepalese Himalaya, and indicate that models that suggest that the syntaxis is developed above the lateral tip of the Main Central Thrust may be incorrect.

The remaining papers in this volume provide a cross section across the Himalayan collision zone from the Asian plate through the Kohistan arc to the Indian plate. It has long been known that, prior to collision, the southern margin of the Asian plate was a tectonic collage formed of a series of exotic blocks sequentially accreted to the southern margin of continental Asia. The Kohistan-Dras arc was the last of these blocks to be accreted to Asia. Zanchi et al. describe one of the suture zones that encompassed the southward growth of Asia during the late Mesozoic and show how the Tirich Mir Fault Zone can be described as a suture on the basis of the presence of ophiolitic peridotites. Also on the Asian Plate, Hildebrand et al. describe the geological evolution of the Hindu Kush in the NW Frontier of Pakistan. They document a major late Mesozoic deformation probably related to suturing of Kohistan to Asia as well as an Oligocene-Miocene metamorphism-deformation event that was likely related to indentation of Kohistan into Asia following collision of Kohistan and India. This paper comes together with an important new geological map of a large part of the Hindu Kush.

Three papers deal with aspects of the Kohistan arc sequence. Yamamoto & Nakamura and Anczkiewiez & Vance date peak metamorphism within the Kamila amphibolite belt at the structural base of the arc at ¢. 95 Ma with amphibolite facies retrogression at c. 85 Ma (see Treloar et al. 1989). Arbaret et al. describe a variety of SW-vergent structures within the Kamila amphibolite belt that range from magmatic through sub-magmatic to amphibolite facies. This deformation spans the period documented geochronologically by Yamamoto & Nakamura and Anczkiewicz & Vance. What remains unclear is to what these deformation, magmatic and metamorphic events relate. Arbaret et al. interpret the magmatism and deformation as having occurred at the base of the arc during ongoing subduction of the Tethyan oceanic lithosphere beneath Kohistan. An alternative solution is that the deformation documents a change in subduction dynamics following on from suturing of Kohistan to Asia.

Three papers deal with the sutures that bound the arc. Weinburg et al. describe the suture zone between Asia and the Ladakh part of the Kohistan-Ladakh arc sequence and show that closure must have pre-dated 68_+ 1 Ma. Robertson and DiPietro et al. discuss the evolution of the suture between the Mesozoic arc and the Indian Plate. Robertson finds the Indus Suture Zone in Ladakh to be a zone of complex multi-stage processes involving deformational features which span the time interval from subduction through emplacement to post-collisional shortening. DiPietro et al. provide a detailed account of the Main Mantle Thrust (MMT) which separates the Kohistan arc from the Indian Plate and which is the true western continuation of the Indus-Tsangpo Suture Zone. They highlight the fact that the MMT is constituted of a number of strands of various ages. Although clearly a major early Tertiary tectonic feature, the MMT has been transposed many times during the Tertiary. Three papers detail the geology of the internal zones of the Indian Plate. Corfield & Searle describe the geology of the north Indian continental margin in Zanskar. They include an important new map and estimate shortening amounts across the north Indian margin. These estimates incorporate both late Cretaceous to Palaeocene ophiolite emplacement events and subsequent post-collisional shortening. Lombardo et al. describe the occurrence of glaucophaneand barroisite-bearing eclogites from the Upper Kaghan Valley. Fontan et al. also describe high-pressure rocks from Indian plate sequences in the Neelum Valley. Although eclogites have previously been described from Indian Plate sequences of north Pakistan (Pognante & Spencer 1991), it is only recently that the high pressure nature of these rocks has been recognized (O'Brien et al. 1999). The full significance of these rocks is as yet unclear. Abassi & Friend explore the significance of exotic conglomerates in the Neogene Siwalik succession and relate them in part to growth of the Nanga Parbat syntaxis. They show the Pliocene-aged Janak conglomerate to be derived from a topographic high, with erosion shedding into the Neogene foreland basin. Finally, Badshah et al. provide a detailed map of part of the Pakistan-Afghanistan border. This important map forms a link between those of Jones (1960). Wittekindt & Weippert (1973) and Bender & Raza (1995) and with these documents an important part of the collision zone between the Indian Plate and the Afghanistan Block (see Treloar & lzatt 1993).

Key words: Tectonics, Nanga Parbat syntaxis, Himalaya.

T/188. Treloar, P.J., Wheeler, J. & Potts, G.J., 1993. Metamorphism and melting within the Nanga Parbat syntaxis (Pakistan) Abstract, Volume, 8th Himalaya-Karakoram-Tibet Workshop, Vienna, 54.

Metamorphism within the Indian Plate gneisses within the Nanga Parbat syntaxis reached kyanite-bearing granulite facies in which the assemblage quartz-plagioclase-orthoclase-garnet-biotite-kyanite (or sillimanite) -rutile was stable. Calculated peak metamorphic conditions were at about 10 kbar and 8000C achieved after a period of prograde metamorphism along a P-T path with positive slope. A leucogranite melt is intimately associated with the main fabric, within the plane of which is contained a south trending lineation. This melt is considered to be an in situ anatectic melt derived by vapour absent melting during the main phase of south verging thrusting. Melt reaction topologies imply that such melting should be decompressive in nature and this may imply that late stages of the peak metamorphism were consistent with some unroofing of the metamorphic pile. Similar trends of regional metamorphism during pressure increase with some decompression at the metamorphic peak have been documented elsewhere in the Pakistan Himalaya.

That all these fabrics are folded by the large scale folds that dominate the Nanga Parbat syntaxis, and which date from syntaxial growth, as.well as being cut by large garnet-tourmaline bearing leucogranite sheets poses a problem. Do these anatectic melts date from a peak metamorphic phase that substantially predates syntaxial evolution or do they document early stages in that evolution? The lineation data within the layered anatectites is. critical here, as it indicates that the fine scale anatectic layering dates from a different tectonic environment from that of the syntaxial growth, that of southward thrusting rather than east-west shortening. Thus we infer the presence of two melt phases within the syntaxis. The first, under granulite facies conditions, dates from the main phase Himalayan metamorphic-deformation event which, elsewhere in Pakistan, reached its peak during the Eocene although reasons of structural geometry indicate that this could have been somewhat delayed within the Nanga Parbat region. The second is Neogene in age and is related to decompressive vapour-absent melting during active uplift and unroofing of the syntaxis.

Key words: Metamorphism, melting, neotectonics, Nanga Parbat, Himalaya.

T/189. Treloar, P.J., Wheeler, J. & Potts, G.J., 1994. Metamorphism and melting within the Nanga Parbat syntaxis, Pakistan Himalaya. Mineralogical Magazine 58A, 910-911.

The Nanga Parbat syntaxis, in the northwest Himalaya, is a region of increasingly rapid neotectonic uplift. Synchronous with uplift has been the emplacement into the syntaxis, within the last 10 Ma, of leucogranite sheets and bodies enriched in radiogenic Sr, the generation of which has been linked to processes of decompressive, vapour-absent melting of a continental crustal source (George et al., 1993; Zeitler et al., 1993; Smith et al., 1992). Recently published age data on monazites (Smith et al., 1992), zircons (Zeitler et al 1993) and amphiboles (Treloar et al., in prep) demonstrate that parts of the syntaxis experienced high (> 500~ temperatures during the Neogene, interpreted by Smith et al. (1992) as a regional scale high grade metamorphism associated with granite generation and emplacement. If this argument follows, there is a causal link between Neogene high temperature metamorphism, melting and, granite emplacement during regional uplift and metamorphism. Here, we question some of the assumptions implicit in this model, in particular in relation to the timing of high grade metamorphism and melting. In the northwest Himalaya, collision was between the Kohistan island arc and the Indian Plate, Kohistan being thrust southward onto the leading edge of the Indian Plate. The Nanga Parbat syntaxis is a north trending structural half window, within the core of which Indian Plate gneisses have been uplifted from beneath the structurally overlying arc rocks. The tectonics responsible for this uplift have been outlined by Treloar et al. (1991). The Indian Plate rocks exposed within the core of the syntaxis include early Proterozoic biotite-rich quartzo-feldspathic basement gneisses, and late Proterozoic cover sediments intruded by Cambrian granites. Both sequences carry intense S-, L- and S-L-tectonite fabrics, are intruded by basic sheets and Neogene Himalayan leucogranites, and are characterised by variable, often extensive, migmatisation.

Key words: Metamorphism, melting, neotectonics, Nanga Parbat, Himalaya.

T/190. Treloar, P.J., Wheeler, J. & Potts, G.J., 1995. Polycyclic Deformation, Metamorphism and Melting within the Nanga Parbat Syntaxis, Pakistan Himalaya: From whence comes the

Neogene Leucogranites. Abstract Volume, 10th Himalaya-Karakoram-Tibet Workshop, (ETH Zurich) Switzerland.

Ever since Sutton & Watson (1951) demonstrated that the early history of the Lewisian basement complex of NW Scotland was divisible into two distinct tectonothermal events separated by a phase of dyke emplacement, geologists studying basement terrains have been conscious of the need to distinguish between different cycles of deformation in crustal sections which may have passed through more than one orogenic event. In a region such as the Himalaya, where it is tempting to ascribe all deformational and metamorphic features to Tertiary-aged orogenesis, the problems of polycyclic crustal evolution are acute. That not all granites within the Himalayan chain are Tertiary in age, has been demonstrated by the recognition, all along the length of the Himalayan chain, of Cambrian aged granites, some of which have been deformed during the Tertiary. In addition, a crustal evolution event at ca. 1850Ma, which included the formation of a penetrative fabric and concluded with the emplacement of granites which crosscut that fabric, has been documented from within the most internal zones of the Indian Plate (Zeitler et al 1989; Treloar et al (1989). These basement gneisses were subsequently deformed within the Himalayan orogen.

In the NW Himalaya, collision was between the Kohistan island arc and the Indian Plate, with Kohistan thrust south onto the leading edge of the Indian Plate. The Nanga Parbat syntaxis is a N-trending structural half window, within the core of which Indian Plate gneisses have been uplifted from beneath the overlying arc rocks. The extreme youth of this increasingly rapid neotectonic uplift, which has been accommodated by a combination of NW- to W-vergent thrusting along the western margin of the syntaxis and large wavelength buckle folding within the core of the syntaxis (Butler et al 1988 1992; Madin et al 1989; Treloar et al 1991), is clearly demonstrated by extremely young mica Ar-Ar and zircon and apatite fission track ages within the core of the syntaxis (muscovite 3 Ma, zircon 2 Ma, apatite 0.4 Ma) which are significantly younger than those preserved in the rocks which flank it (e.g. some 10 km to the west of the syntaxis: muscovite 19 ma, zircon 10 Ma and apatite 6 Ma) (Zeitler 1985; Treloar et al 1989, 1991; George et al 1993; Zeitler et al 1993).

Synchronous with uplift has been the emplacement into the syntaxis, within the last 10 Ma, of leucogranite sheets and bodies enriched in radiogenic Sr. the generation of which has been linked to decompressive, vapour-absent melting of a continental crustal source (George et al 1993; Zeitler et al 1993; Smith et al 1992). The youngest of these sheets are about 2 Ma old (Zeitler & Chamberlain 1991). Pb-Pb age data on monazites (Smith et al 1992) and zircons (Zeitler et al 1993) and Ar-Ar data on amphiboles (Treloar et al, in prep) demonstrate that parts of the syntaxis were at high (>500ºC) temperatures until about 10 Ma ago. The monazite data have been interpreted as implying that the rocks exposed within the syntaxis experienced a Neogene, high grade regional metamorphism which was associated with granite generation and emplacement. If this argument follows, there is a causal link between Neogene high temperature metamorphism, melting and, granite emplacement during regional uplift and metamorphism. However, that the main metamorphic fabrics in the Indus and Astor Gorges are cut by dykes of probable pre-Tertiary age leads us to infer that models which attempt to constrain the timing of high grade metamorphism and melting within the syntaxis without considering the polycyclic nature of these rocks are over-simplifications.

Pre-Neogene deformation and metamorphism.

The pre-Tertiary metamorphic history of the Indian Plate rocks exposed within the core of the syntaxis has been described elsewhere (Wheeler et al., submitted; Treloar et a! 1994). The Indian Plate rocks include early Proterozoic biotite-rich quartz-feldspathic basement gneisses true Islcere gneisses). an a late Proterozoic cover sediments (the Shengus gneisses) intruded by Cambrian granites. Both sequences have been affected by pre-Tertiary deformation, metamorphic and magmatic events, are intruded by basic sheets and Neogene Himalayan leucogranites, and are characterised by variable, and often extensive, migmatisation. Within the Shengus para-gneisses, the main metamorphic paragenesis is quartz-plagioclase-orthoclase-garnet-biotite-kyanite and/or sillimanite-rutile. Over much of their outcrop the Shengus paragneisses are migmatitic, with a stromatic leucogranite melt segregated from the restitic pelite fabric. Field relations imply this to be an in situ anatectic melt. The presence of kyanite and garnet in equilibrium with the melt is consistent with vapour-absent melting, initially of muscovite and latterly of biotite. The common absence of muscovite implies that muscovite was completely destroyed during melting. The presence of kyanite rather than sillimanite in equilibrium with the melt is consistent with high pressures and temperatures of melting. Petrogenetic grids constrain peak metamorphic conditions to about 10 Kb and 800^0C.

That this high grade metamorphism is pre-Tertiary is demonstrated by field relationships. A series of basic dykes clearly cross-cut the layered rocks of the migmatite complex and contain xenoliths of migmatitic material. In places these sheets contain undeformed relicts of an ophitic plagioclase-clinopyroxene assemblage, with the pyroxenes rimmed by a corona-like development of fine-grained hornblende. Elsewhere, the sheets have been almost completely amphibolitized with a metamorphic assemblage of hbde-bt-qtz-pl-(grt). Thus, the sheets have undergone a post-emplacement amphibolite facies metamorphism. On the basis of their mineralogy they have not experienced the granulite facies metamorphism recorded within the migmatitic rocks. Hornblende Ar-Ar cooling ages of ca. 20 Ma (Treloar et al. in prep) document a Tertiary age for the latest cooling.

Due to post-metamorphic deformation, the peak metamorphic assemblage is rarely preserved in an undeformed state. The migmatites show evidence for ductile shearing with the development of an intense mylonitic fabric that post-dates the peak metamorphism. In outcrop, this fabric appears as a series of intense S-, L- and S-L-tectonite fabrics, within which lineations plunge gently to either N or S, consistent with a southerly transport direction of Kohistan onto India. Although the basic dykes are commonly discordant to the S-tectonite fabrics, they locally carry an internal L-S tectonite fabric sub-parallel to that of the migmatite complex. In some of the sheets this fabric is penetratively developed throughout the sheet; in others it is limited to the margins. Thus although they postdate the main phase metamorphism and migmatisation, the dykes predate the ductile shearing which pervasively deforms the metamorphic complex. We argue that this S-L fabric is Himalayan in age. The ductile shearing is itself postdated by a later thermal event, as indicated by the presence of sillimanite bundles which overprint the main tectonic fabric. Although the main metamorphism was pre-Tertiary, that sillimanite bundles overprint the main tectonite fabrics demonstrate a Tertiary-aged regional re-metamorphism during the Himalayan orogeny, after which the migmatite complex cooled back through 5000C at between 2OMa and 10 Ma (Smith et al 1992; Treloar et al, in prep).

The planar fabrics have been folded and define a series of N-trending domal structures (Madin et al 1989; Treloar et al 1991; Butler et al 1992). The simplest interpretation of the structures is that the L-S fabrics represent ductile simple shear deformation during the S-vergent thrusting of Kohistan onto the leading edge of the Indian Plate during early stages of the Himalayan collision, with folding of the S-surfaces dating from the large scale buckling that accompanied syntaxis growth (Treloar et al 1991), fold axes being sub-parallel to the earlier stretching lineation. That the fabrics which deform, and thus post-date, the formation of the migmatite complex also pre-date the initial stages of syntaxial uplift implies that the main phase migmatisation cannot be the result of late-Himalayan Neogene-aged decompressive melting. All of these fabrics are cut by the garnet-tourmaline bearing leucogranite sheets dated by Zeitler et al (1993) as <10 Ma old.

Discussion.

The prime temptation when studying rocks within the internal zones of an erogenic belt is to ascribe the metamorphism to that erogenic event. Thus, it would appear logical to ascribe the high grade metamorphism and melting within the Nanga Parbat syntaxis, which is the most internal part of the Himalayan orogen exposed anywhere, to be of Tertiary age. The Pb-Pb data presented by Zeitler et al (1993) and Smith et al (1992) have been interpreted by them as suggesting a Neogene age for high grade metamorphism and melting. However, field relationships demonstrate that, although this may be true for the leucogranite sheets which cut the migmatite complex, it is not so for the migmatite complex itself.

It is clear that two melting events have affected the Nanga Parbat region. The first, under granulite facies conditions, pre-dates dyke emplacement and is, at latest, Triassic in age. The second, which is Neogene in age, is most likely related to melting during uplift and unroofing of the syntaxis. This second melt event presents a significant problem: what is the source for the leucogranite melts. Having melted once, and thus being infertile, the migmatite terrain cannot have been the source for the Himalayan leucogranite sheets which cut it, unless Tertiary metamorphism was at higher temperatures than the pre-Tertiary metamorphism, a suggestion excluded by the amphibolite-facies mineralogy of the basic sheets. Here we consider possible source regions for the Neogene-aged melts.

In the absence of extreme temperatures, the rocks currently exposed within the core of the syntaxis, and which had undergone a dehydrative pre-Tertiary melting event, can only have melted a second time if their fertility had been recharged. There are two possible mechanisms by which this may have been achieved. The first is related to the late stages of the main metamorphism and migmatisation. The preservation of centimeter-scale leucosomes within the metapelites demonstrates that melt extraction was inefficient. Crystallization of the retained pockets and layers of melt caused some back reaction within the restites. Textural relationships within the Shengus gneisses are consistent with a back reaction such as: grt + kfs + melt = bt + kya + qtz.

Similarly, the growth of small muscovite flakes within feldspar and crosscutting biotite may indicate an analogous muscovite generating back reaction. Muscovite is though rarely present in large quantities within the Shengus gneisses. Within the Iskere gneisses, mica content varies. Some are biotite -rich with no muscovite, whereas others contain both biotite and muscovite. Assuming that these migmtitic gneisses have been to the same elevated temperatures as the Shengus gneisses, we infer that the fabric forming muscovite present is the result of a migmatitic back reaction of the type: bt + als + kfs + melt = ms + pla + qtz.

The muscovites then recystallised during early Tertiary simple shear. If high enough temperatures were attained during the Neogene, then some melt could be produced by vapour-absent melting of muscovite produced through melt related back reactions. However, few of the rocks within the Indus and Astor Gorges contain significant muscovite contents and this process does not appear capable of generating significant melt quantities.

A second mechanism of re-fertilizing the Nanga Parbat gneisses would be by rehydrating them through a process of focussed fluid flow. Some samples contain mats of muscovite, which overprint the peak metamorphic assemblages. These mats reflect the growth of muscovite during the influx of water at temperatures sufficient to destabilise the orthoclase-kyanite present in the peak metamorphic assemblage. It is worth noting that Neogene aged monazites dated by Smith et al (1992) are often contained within fabric parallel (?) muscovites. As the major tectonic fabrics are probably early Tertiary in age, it is difficult to see how they can contain Neogene-aged monazites. However, if the muscovite mats within which the monazites are contained reflect new mineral growth in zones of fluid flow channelised through the dry granulites of the Nanga Parbat massif, rather than a regional scale Neogene-aged prograde metamorphism, this dichotomy can be resolved.

That there are localised pockets of Neogene-aged metamorphism (Smith et al. 1992; Zeitler et al. 1993) is indisputable. Cordierite-bearing low pressure granulites, intruded by cordierite-bearing leucogranites dated by Neogene-aged monazites have been described from the Fairy Meadows area (Zeitler et al 1993; Smith et al 1992). These rocks are not readily explicable in terms of the structure of the whole massif. Similar rocks are not widespread across the syntaxis. They must represent either a suite of the low-pressure rocks imbricated within the main granulite suite, or a localised re-metamorphism of an older higher-pressure granulite terrain. If the latter is correct, the cordierite gneisses may represent a Neogene re-metamorphism associated with locally pervasive fluid flow on the hanging wall of the thrusts developed along the W margin of the syntaxis, along which the syntaxis has been uplifted.

What is the source of the channelised fluids? Due to the continuing northward movement of India, previously unmetamorphosed and thus wet Indian Plate sediments are currently being underthrust beneath the Nanga Parbat syntaxis. Metamorphism of these sediments through dehydration reactions will lead to fluid release and it is likely that at least some of this fluid will pass up through the overlying dry granulites of the Nanga Parbat syntaxis. Thus, at least some of the leucogranite generation may be due to hydration rather than decompression. If metamorphism of these underthrust Indian Plate shelf sediments was at sufficiently high temperatures, then they also provide an alternative source for the leucogranite melts which intrude the Nanga Parbat massif.

It is commonly assumed that leucogranite generation within the Nanga Parbat syntaxis is through decompressive melting. Treloar et al (1991) argued that the uplift recorded within the syntaxis could be explained solely in terms of the folding and thrusting mapped by them and others. This would be consistent with decompressive melting within the upper crustal layers. However, melting in the presence of channelised fluid flow derived from underthrust units does not need decompression. In addition, if the underthrust fertile sediments are the source of the Neogene leucogranite melts, and if these granites are truly decompressive, they provide a constraint on uplift mechanisms for the syntaxis. Thrusting and folding effectively thicken units observed at surface and thus would increase the pressure on the underthrust fertile sediments where melting is inferred to be taking place. If this melting is decompressive, and that needs still to be demonstrated, it follows that syntaxial uplift cannot be accommodated solely in terms of thin skinned thrusting and folding of the upper crust, but needs to be modelled in terms of deep crustal processes, such as delamination, with the upward velocity more than compensating for the extra loading on the melting zone caused by compressional tectonics across the syntaxial arc.

Key words: Deformation, metamorphism, leucogranites, Nanga Parbat, Himalaya.

T/191. Treloar, P.J., Wheeler, J., Potts, G.J. & Rex, D.C. 1991. Structural evolution and asymmetric uplift of the Nanga Parbat syntaxis, Pakistan Himalaya. Geologisches Rundschau. 80. 411-428.

Key words: Deformation, structure, metamorphism, Nanga Parbat, Himalaya.

T/192. Treloar, P.J., Wheeler, J., Potts, G.J., Rex, D.C. & Hurford, A.J., 1993. Geochronology of the Indus Gorge and Astor valley sections through the Nanga Parbat syntaxis: Constraints on uplift history. Abstract, Volume, 8th Himalaya-Karakoram-Tibet Workshop, Vienna, 79-80.

The Indus Gorge provides a constant altitude east-west section across the north-trending Nanga Parbat syntaxis. The Astor Valley, to the south, provides a second section, this one NW-SE trending, through the syntaxis, although not a constant altitude one. The syntaxis is a structural half window, within the core of which Indian Plate gneisses are updomed from beneath a cover of overthrust volcanics of the Kohistan-Ladakh island arc complex. These sections

provide an opportunity for detailed, structurally constrained, sampling for both P-T-t path analysis and geochronology. Here we present data from these traverses that enable us to constrain the uplift history of the syntaxis. 120 samples were collected for analysis by hornblende and mica Ar-Ar and K-Ar techniques, and by zircon and apatite fission track techniques. When those data of Zeitler (1985), Zeitler and Chamberlain (1989), Smith et al (1992) and George et al (1993) are included we have a copious, closely spaced data set.
A marked break in cooling ages occurs across the western margin of the syntaxis. This margin is marked by the Raikot-Sassi Fault Zone, a complex fault system with an overall oblique sense of displacement that includes both right lateral and thrust type displacements. The data imply that significant displacements have occurred along this zone within the last 1 to 2 Ma.
The eastern margin is marked by neither a significant fault zone nor a marked step in cooling ages. Instead cooling ages gradually decrease westward across the margin into the syntaxis, a decrease explained by exhumation during the growth of a large scale antiformal fold located within the syntaxis.
Within the Indus Gorge section, hornblende and mica Ar-Ar ages are both younger within the western half of the syntaxis than in the eastern half. This is consistent with the recognition of a series of domal structures within the syntaxis not all of which grew synchronously. Within the Indus Gorge section, the data are consistent with the growth of an antiform within the eastern part of the section before 5 Ma ago, and the subsequent growth of a similar structure, at Ca. 3 Ma ago, in the western part of the section. Neither zircon nor apatite ages show this age difference from east to west, indicating that folding may have become of secondary importance to uplift controlled by faulting along the eastern margin after about 2 Ma ago. Locally hornblende and monazite ages indicate $T>500^0C$ as recently as 9-10 Ma and in the case of muscovite Rb-Sr ages as recently as 5 Ma. Some of these very young ages may be due to localized thermal perturbations due to melt emplacement.
Within the Astor Valley section, a different cooling profile is recorded with mica ages increasing towards the west, a pattern shown less well by the fission track ages. The tectonic significance of this variation is, as yet, uncertain.
Although a combination of early folding followed by later oblique slip thrusting along the western margin may explain the uplift and cooling history of the Indus Gorge section, it may be unwise to extrapolate this model without qualification to the rest of the syntaxis, as shown by the data from the Astor Valley. The internal structure of the syntaxis is best modeled as a series of nested domes. Folds within the Indus Gorge plunge south, whereas those within the Astor Valley plunge north. More detailed geochronology is required to demonstrate the extent to which these developed diachronously as well as their temporal relationships to thrusting along the western margin.
Total exhumation and overall uplift rates are difficult to quantify given the vertical telescoping of isotherms due to rapid uplift and unroofing, and the emplacement, as recently as 2 Ma ago, of leucogranite dykes and bodies to high structural levels. However, due to the constant altitude of the Indus Gorge section, the antecedent nature of the river and the magnitude of the unroofing indicated by the cooling history data, we feel confident that exhumation amounts approximately equal bulk uplift amounts. As such, it is hard to escape the conclusion that fold amplification was exponential, or that recent uplift rates have been as high as $6mmyr^{-1}$, as suggested by Zeitler (1985).
Key words: Geochronology, structure, Nanga Parbat, Astore, Himalaya.

T/193. Treloar, P.J., Wheeler, J., Potts, G.J., Rex, D.C. & Hurford, A.J., 1995. Geochronology of the Indus Gorge and Astor Valley Sections through the Nanga Parbat Syntaxis: Constraints of Uplift History. Abstract Volume, 10th Himalaya-Karakoram-Tibet Workshop, (ETH Zurich) Switzerland.

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Key words: Geochronology, Indus Gorge, Astor Valley, Nanga Parbat Syntaxis,

T/194. Treloar, P.J., Williams, M.P. & Coward, M.P., 1989. Metamorphism and crustal stacking in the north Indian Plate, north Pakistan. Tectonophysics 165, 167-184.

The northern part of the Indian Plate in North Pakistan is composed of a number of large-scale crustal nappes, each of which are stratigraphically distinct, and which were stacked late in the main phase of southeasterly directed thrusting associated with the Himalayan event. The major nappes recognised in the Swat to Kaghan area of North Pakistan are the Besham, Swat, Hazara, Banna, Lower Kaghan and Upper Kaghan nappes. Metamorphism was synchronous with early stages of deformation. Within each nappe the metamorphic grade increases upwards, an overall inversion that represents post-metamorphic imbrication within individual nappes, synchronous with the main phase of nappe stacking, rather than a “hot iron” type inversion as described under the MCT in Nepal and India. As a result of this “within-nappe” imbrication each thrust slice within any particular nappe contains rocks of a higher metamorphic grade than those in the slice below, with sharp metamorphic breaks across the imbricating thrusts as well as across the major shears that bound the crustal-scale nappes. Uplift along these imbricating thrusts initiated cooling of the stack. K-Ar mica and hornblende cooling ages imply that much of this uplift was completed by 30 Ma, or within 20 Ma of the collision.
Key words: Metamorphism, tectonics, nappes, Indian Plate.

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Key words: Nanga Parbat, Himalaya.

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Key words: Hydrology, groundwater, Bannu.