Metamorphism of Himalayas in Pakistan

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2 Introduction to Metamorphism

Metamorphism is the combination of two words **Meta** mean Change and **Morph** mean Form. Earth is composed of three rocks (igneous, sedimentary and metamorphic rocks) the rocks formed due to the change in the temperature and pressure of pre-existing rocks is known as **Metamorphic Rocks. Metamorphism** is a single process or a set of processes that may change rock it may cause changes in texture, mineral composition, and chemical composition under the effect of different conditions. These different conditions may be temperature pressure or hot fluids.

Mineralogical changes occur due to effect of hot fluids on the basics of these factors we divide metamorphism into three types

- Contact Metamorphism
- Regional Metamorphism
- Dynamic Metamorphism

Contact Metamorphism is caused when magma from the mantle comes in the contact with the pre-existing rock. When this happens the temperature of country rock increases and metamorphosed a small part of the pre-existing rock body. Contact metamorphism produces non foliated rocks without any cleavage rocks such as marble, quartzite and hornfels. **Regional Metamorphism** occurs in a larger area this metamorphism produces the rocks such as gneiss and schist. Regional metamorphism is caused by mountain building processes. These rocks show unbelievable pressure that causes the rock to bent and broken by mountain building process. Foliated rocks are produces by the regional metamorphism. **Dynamic Metamorphism** also occurs in the mountain building process the huge forces of heat and pressure cause the rocks to be bent, folded, crushed, flattened and sheared.

There are different grades present in the metamorphic rocks these rocks may be low grade, medium grade, high grade metamorphic rocks formed due to change in temperature and pressure. The low grade metamorphic rocks include **Shale** and **Slate** while medium grade metamorphic rocks includes **Phyllite** and **Schist** and high grade metamorphic rocks includes **Gneines** and **Magmatites.**

3 Formation of Himalayas

About 50 million years ago Himalayas were formed due to collision plate margins the **Indian plate** cover a large distance and collided with the **Eurasian plate** and this collision is continues today. About 225 million years ago India is situated with **Australian** coast and separated from **Asia** by the **Tethys Ocean**. When the supercontinent breaks the India started to moves towards the Asia in northward direction. At the start of the northward drift the Indian plate was moving relatively fast as compared to the time when it became near to Eurasian plate about 40 to 50 Ma ago and slowed the rate of about 4 to 6 cm per year. This slowdown is the movement of India plate marks the beginning of Collision between the Indian and Eurasian plate the closing of the **Tethys Ocean** and the initiation of **Himalayan Uplift.**

Figure 1: movement of Indian Plate from super-continent breakage to collision with Eurasian Plate

The Eurasian plate wants to override the Indian plate but due to the density and high buoyancy neither continental plate is subducted this cause the continental crust to become more thickened as a result of folding and faulting due to compressional forces pushing the Himalayas and Tibetan Plateau. The continental crust at that region is twice thickened as compared to the other regions the thickening of the continental crust marks the end of the volcanic activity as the magma which tries to comes out to the surface of the earth now will consolidated under this crust and it will never reach the surface of the earth.

The Himalayas are rising 1 cm every year as the Indian plate is still moving northward in the Asia which causes the occurrence of the shallow focus earthquakes in the region today. However the forces of weathering and erosion are lowering the Himalayas with the same rate as they are rising.

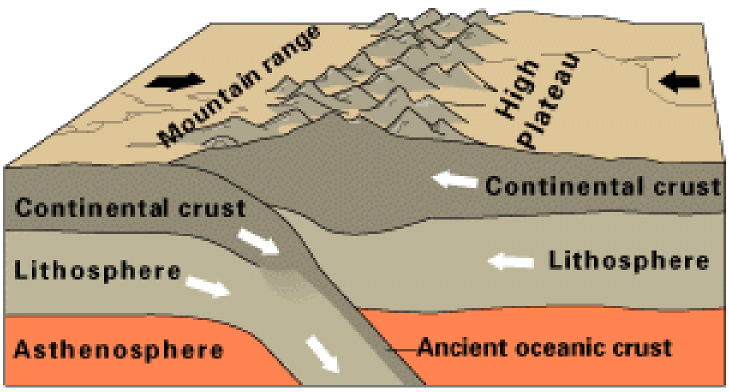

Figure 2: Continental-continental Plate Boundary forming a mountain range just like Himalayas in the collision between Indian and Eurasian Plate Boundary

3.1 Tectonic Settings of Himalayas

The Himalayas are formed as a result of the collision between the Indian and Eurasian plate where the Indian plate in subducted beneath the Eurasian plate forming a zone of subduction so as the result of this collision a mountain belt formed along the plate boundaries.
Himalayas have subdivisions in which they are divided tectonically

- Lesser Himalayas
- Sub Himalayas
- Higher Himalayas
- Tethyan Mountains

In these division of Himalayas thrust has been observed and now the details of the observed tectonically structure is given below the structural features observed in the Himalayas are as follow.

3.2 Indus-Tsangpo suture

The Indus-Tsangpo suture (e.g Ganseer 1964, 1980; LeFort 1975) marks the northern limit of Indian subcontinent following the late cretaceous-early tertiary closure of the Neo-Tethys. This suture is made up of imbricated melanges of flysch sediments, radiolarites, and pillow lavas, volcanic and basic and ultrabasic rocks that are cut by steep thrust fault.

3.3 Main Central Thrust (MCT)

The MCT at the base of crystalline zone dips 30 to 45 degree northwards, separating the higher Himalayas from the lesser Himalaya. The thrust is characterized by a zone of intense shearing; no master thrust surface is apparent. An abrupt change in the style of structures, especially folding and in the grades of metamorphism is the main manifestation of the presence of the MCT, The MCT appears to have developed since mid-tertiary time and there are some geological indications of minor recent movements along the MCT.

3.4 Main Boundary Thrust (MBT)

The MBT is a series of the thrusts that separates the predominantly pre-tertiary Lesser Himalayas sediments from the Tertiary Siwalicks sedimentary belt. The steep thrust is the planes of the MBT at the surface of gradually flatten out at depth. The MBT has developed since Pliocene time and abundant geological evidences shows that the thrust zone was active through the Pleistocene.

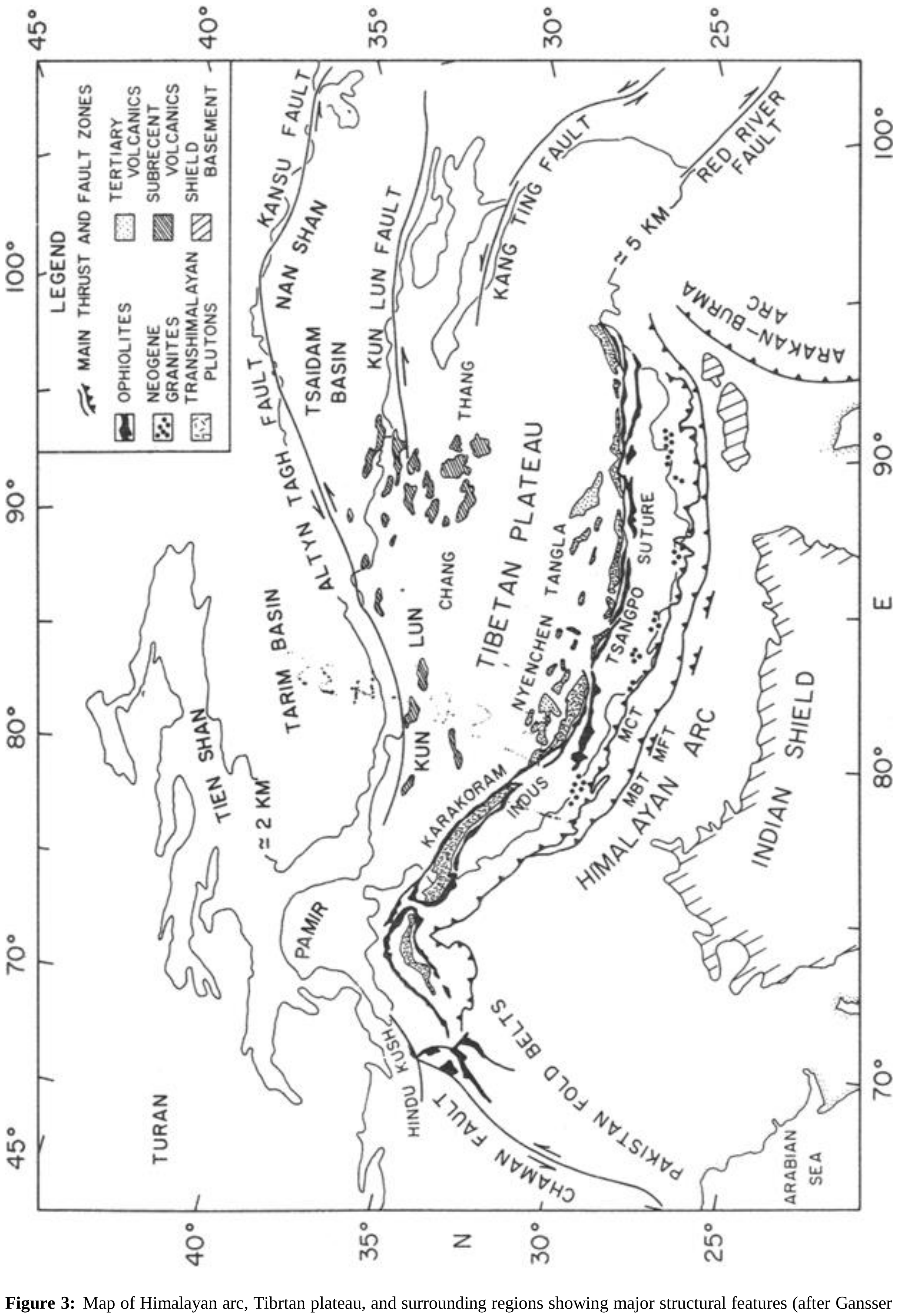

Figure 3: Map of Himalayan arc, Tibrtan plateau, and surrounding regions showing major structural features (after Gansser 1964; Molnar and tapponnier 1975). MCT, main central thrust; MBT, main boundary thrust; MFT, main fontal thrust. Neogene granites apper to related to MCT and are limited to central Himalayas.

3.5 Tethyan Slab

The region between the MCT and the Indus-Tsangpo suture is known as the Tethyan sedimentary zone in the north and the central crystalline zone in the south and is often referred to as the Tethyan slab. The richly fossiliferous, platforms-type sediments of the region are clearly of Gondwana affinities and represent the former Indian margins.

3.6 Normal faulting in the High Himalaya

Burg *et al* (19840 indicate the existence of an east-west striking, gently north-dipping normal faults of regional extent in the High Himalaya. This normal fault zone separates the highly metamorphosed crystalline rock and a transitional zone from the overlaying late Precambrian to Cambrian sedimentary sequence. A similar type of normal faulting has been observed in the Zanskar region of the western Himalayas. Movement along the shallow-dipping normal fault is believed to be about 20km and limited to the deformation of upper crust.

3.7 Strike-slip faulting

A secondary effect of the north south shortening of the Himalaya is the pervasive strile-slip faulting throughout most of the lesser Himalaya. valdiya (1976, 1981) indicated that the strike slip fault have right laterally displaced the MBT by as much as 12km. other examples of strike slip faulting in the Nepal Himalayas have been reported by Nakata (1988).

4 Pakistan Himalaya

Information about the geometry of the under thrusting Indian plate within the Pakistan Himalayan foreland and fold-and-thrust belt has been reported by Lillie *et al* (19870. Based on the interpretation of oil company reflection data they showed that beneath a salt detachment the Indian crystalline basement dips gently northward from about 1 degree beneath the salt range to about 4 degree beneath the northern Potwar Plateeau. Their results confirm earlier interpretations that detachment lies with in an Eocambrian evaporate sequence. The extent of this detachment and the geometry of the indian plate farther north beneath the Peshawar basin are not clear.

Based on an analysis of local seismicity data Seeber and Armbruster (1979) showed two northwesterly trending basement features, the Hazara Lower seismic zone (HLSZ) and the Indus-Kohistan seismic zone (IKSZ). They interpreted these features as buried extensions of the northwesrerly trending Himalayan thrust faults beyond their surface termination at the western Himalayan Syntaxis. The IKSZ the more active of the two seismic zones, is associated with under thrusting towards the northeast. The HLSZ defines as steeply dipping basement between the basement and the sedimentary rocks of the Salt Range. Proving such a relation, however, requires that one knows the deep structures beneath this region.

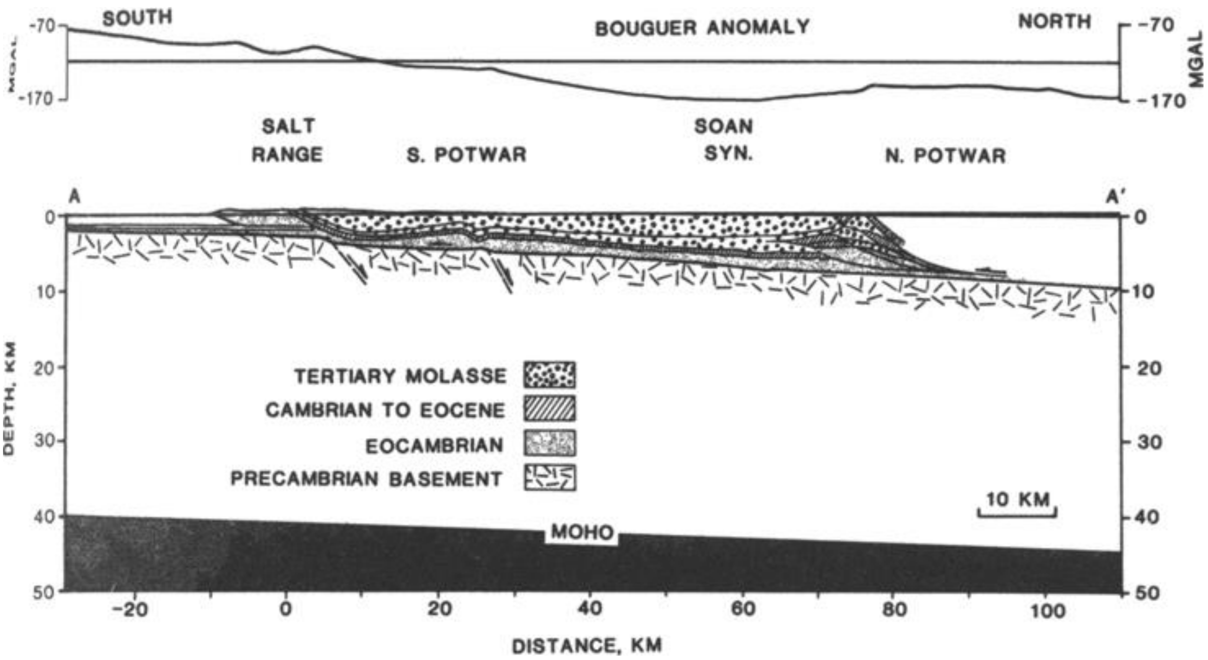

Figure 4: Structural cross-section and Bouguer gravity profile of northern jhelum Plain, Salt Range and central potwar Plateau, from Lillie *et al* (1987). the gradient in the Bouguer gravity in this region is about 1 mgal/km and is similar to that of the Indo-Gangetic Plain.

4.1 Stratigraphic Framework of Himalayas of Northern Pakistan

The Himalaya of northern Pakistan consist of three major tectonic provinces separated by the Main Boundary thrust and main mantle thrust. South of the Main Boundary thrust the Kohat and Potwar Plateaus expose un metamorphosed Mesozoic and Tertiary sedimentary rocks and Neogene Foredeep sediments deformed by folds and thrust faults. North of the main boundary thrust the main mantle thrust separates rocks of the Indian plate on the south from the Kohistan island-arc terreane, which was accreted to Asia ca. 100MA. The rocks between the main boundary and main central thrusts record a transition from the un metamorphosed fold and thrust belts to the south to high-grade metamorphic rocks in the footwall

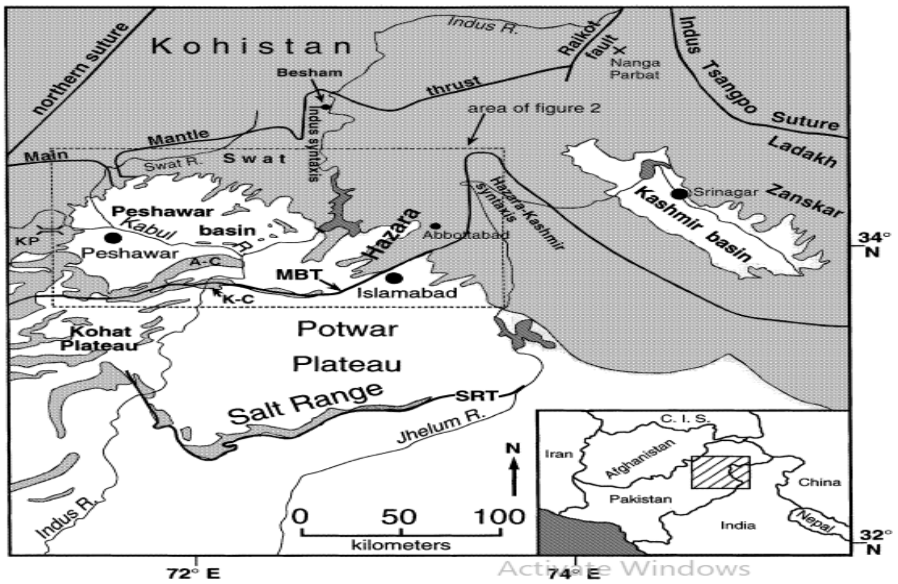

Figure 5: Location map of the Himalaya of northern Pakistan and north-western India Showing selected major faults.

Of the main mantle thrust. This region will be referred to herein as the Himalayan foothills; the topography between the main boundary and main mantle thrusts gradually rises in elevation northwards towards the high Himalayan peaks. The studied area is bounded on the east by the main boundary or Murree thrust and on the west by inadequately mapped mountains near the Afghanistan border.

The stratigraphic and structural synthrsis presented here was promoted by the publications of new geologic maps and the discovery, in the newly mapped area of stratigraphic and structural relationship that faciliatate correlations with adjacent areas mapped previously. Stratigraphic interpretations are based on generalized stratigraphic columns derived from the new maps presented here in the stratigraphic information from Latif (1974), Meissner et al. (1974), Calkins et al (1975), Hussain et al (1990), DiPietro and Lawrence (1991), and Pogue et al. (1992a).

The foothills region can be divided into three tectonic blocks, bounded by major Himalayans faults. The southern block referred to as the kala chitta-Margala block after the Kala Chitta Range and Margala Hills, which form prominent escarpments along the southern boundary of the block. The central and northern blocks are referred to as the Nathia Gali-Hissartang block and the panjal-Khairabad block, respectively, after the faults that form their southern boundaries.

4.1.1 Panjal-Khairabad block

Proerozoic Formations. Thick intervals of unfossiliferous low-grade metasedimentary rock underlie Paleozoic rocks throughout the Panjal-Khairabad block. Previously workers assigned these rocks to a variety of formations. The following stratigraphic information details a refined and regionally applicable stratigraphc nomenclature for the Proterozoic rocks of the Himalayan foothills. Correlations based on new stratigraphic information and radiometric ages also permit a further refinement of the ages of these units.

Paleozoic and Mesozoic Formations. More than 3500m of Paleozoic strata are exposed along the northeastren margin of the Peshawar basin. Unconformably overlying the Tanawal Formation, the dolomite-dominated ambar Formation forms the base of Paleozoic section. Although the Ambar is unfossiliferous, an early Cambrian age can be inferred from its stratigraphic position and lithological similarity with the Sirban Formation of Lower Cambrian Abbottabad Group. The overlying fossiliferous Ordovician through Carboniferous section is dominated by lithology's typical of shallow-water epicontinental sedimentation. Lower Paleozoic rocks correlative with the Panjal volcanics of Kashmir, the Permian is represented by the malandri Greenschist, Duma Formation and karapa Greenschist. The only confirmed Mesozoic rocks in the Panjal-Khairabad block are upper Triassic limestone of the Kashala Formation exposed in the northern Peshawar basin.

4.1.2 Nathia Gali Hissartang Block

Proterozoic Formations. The oldest rock exposed between the Panjal and Nathia Gali faults belongs to Hazara formation. Near the southern limit of expouser of the HAzara formation, sandstone and shale are the dominant lithology. The relative percentage of shale and grade of metamorphism increase northward. In the vicinity of the apmjal fault, the unit consists of weakly metamorphosed politic rock and greywacke. East of Ahripur, the upper part of the Hazara Formation contains two algal limestone and Mirjani Limestone. Latif (1969) also noted beds of gypsum in the Hazara Formation southeast of Abbottabad. The Dakhner Fornation of Attock-Cherat Range is lithologically identical to southern, shallow-water facies of the Hazara Formation. The exposed thickness of both Hazara and dakhner Formations exceeds 1,000m.

Cambrian formations. Near Abbottabad an unconformity bounded sequence dominated by dolomite and shale overlies the Hazara Formation subdivided these rocks into the Kakul Formation and Sirban Formations Compose the Abbottabad Group. The oldest unit of the Abbottabad Group is the Tanakki conglomerate, which is the basal member of the Kakul Formation. The Tanakki Conglomerates consists of angular to subangular pebble-to boulder-sized clasts, derived primarily from the underlying Hazara Formation, in a siltstone matrix. The remainder of the Kakul Formation consists of sandstone and shale interbeded with carbonate. Resistant dolomite of the overlying sirban Formation forms the most conspicuous outcrop of the Abbottabad Group. The Tarnawai Formation consists of a lower Galdanian Member Cmposed of siltstone and mudstone and an upper Hazira Member which is primarily glauconitic and phosphatic shale and siltstone. The Tarnawai Formation is Early Cambrian in age, on the basics of fossils recovered from the Hazira Member also considered the Abbpttabad Group to be Early Cambrian on the basis of its unconformable contact with underlying Proterozoic Hazara Formation and Conformable contact with the overlying Lower Cambrian Tarnawai Formation.

Paleozoic Formation. On the southern flank of the Attock-Cherat Range, an enigmatic sequence of rock is exposed in the structural block bounded by the Cherat and Hissaartang faults. The oldest of the units, the Darwaza Formation, consist of carbonate overlain by argillite. Unconformable overlying the Darwaza Formation are interbeded quartizite and argillite of the hissartang formation, that are in turn overlain by limestone of the Inzari Formation. Similarities of quartzite and argillite of hissartang Formation with the upper Misri banda Quartzite and argillite of the lower Panjpir formation Prompted Yeasts and Hussain (1987) to suggest a corealtion with these Paleaozoic rocks near Nsowshera.

Mesozoic Formations. In Hazara, Proterozoic or Lower Cambrian strata in the Nathia Gali-Hissartang block are overlain by Jurassic strata. Northeast of Abbottabad interbedded shale and sandstone of the Datta Formation form the base of the Mesozoic section. The Shinawari formation Conssists of shale with limestone interbeded. Middle Jurassic Samana Suk Formation consists of as much as 300 m of pelloidal and oolitic limestone. The Jurassic section of Abbottabad and the Datta Formation and Shinawari Formation are absent near Hassan Abdal. In the Attock-Cherat Range, the only rock that is discountineous is Samana Suk Formation in Fault-bounded block along the Cherat fault.

4.1.3 Kala Chitta-Margala block

The oldest exposed rocks in the Kala Chitta-Margala block are limestone and marl of the Lower Triassic Mianwali Formation that crop out in the northern Kala Chitta Range. Overlying the Mainwali Formation are Middle to upper Triassic limestone and dolomite of the chak jabbi and kingriali Formation. East of the kala Chitta Range, the oldest outcrops are limestone of the middle Jurassic Samana Suk Formation. The stratigraphic section of Jurassic , creteceaous and Paleocene strata of the Kala chitta-Margala block is similar but thicker than that of the Nathia Gali-Hissartang block.

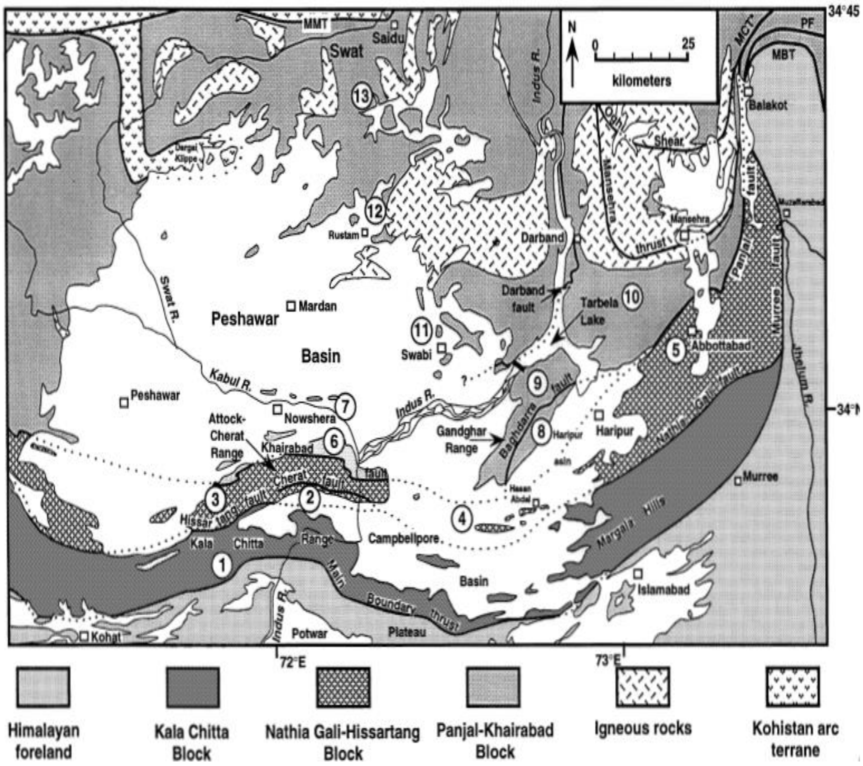

Figure 6: tectonic map of the Himalayan foothills pf Northern Pakistan MCT* is Main Central thrust; PF is Panjal Fault; MMT is the MAin Mantle thrust; MBT is the Main Boundary Thrust circled numbers refer to column locations

5 Metamorphism of Himalayas

Post-collision metamorphism in the Himalaya-Tibet region is apparently limited to the Himalaya, South of the suture. The metamorphism related to the North of the suture is the subduction and intrusion of the Trans-himalayan batholith. In the south of the suture the metamorphic sequence is better represented and has four type of zone from N to S.

The metamorphism related to the Himalayan sequence is the **Regional Metamorphism** in which there is High pressure and Low temperature zone forms the Blueschist and Eclogite facies under the action of metamorphism . Himalayas are the simple collision product between the Indian and the Eurasian Plate

5.1 High-pressure metamorphism

Blueschists in less amount occur in the areas from S to N of the suture. The most important area in the Northern Pakistan is between **Swat** and **Indus Rivers,** where Shams (1972, 1980) has reconized the glaucophane-bearing schists. The presence of glaucophane and crosstie, pseudomorphosed lawsonite, aragonite and phengite, sometimes associated with piemonite schists seems to parallel the suture in a narrow band for 60 km and may be part of discontinuous belt some 250km long, SW of nanga parbat. The second area is in **Ladakh** where the Blueschists have been found in one outcrop of Jurassic-Cretaceous Dras volcanic with ophiolitic melange and the third area lies in the E of the the basic ophiolitic melange.

In all three area the blueschists are present in the form of overthrusted formation which have a tectonic contact with the suture. In **Pakistan** the **Shangla blueschists** is likely to be associated with the high-pressure **Jijal garnet granulites** which lie on the northern or upper side of the Main Mantle Thrust or Indus Suture. The age of the blueschist is generally said to be the **Eo-Himalayan,** on the boundary between the Mesozoic and Cenozoic.

5.2 Metamorphism in the northern part of Himalaya

Due to very less metamorphism in the Tibetan Zone of the Himalaya, between the suture and the high range limited attention is given to this area. It appear from the study of Honegger *et al.* (19820 in **Ladakh,** that one regional metamorphism, increasing from zeolite facies in the N to upper amphibolite facies in the S. affected the entire pile of tectonic units. Yet this metamorphism evolves from pre- to post-kinematices in the highest units. This type of metamorphism is **Barrovian** type with prehnite-pumpellyite, chloritiod. Garnet biotite, staurolite and kyanite zone. However there may be two different belts and having two different metamorphism episodes the Tsangpo belt of melange and flysch and the Tibetan sedimentary series proper.

5.2.1 The flysch belt

From the South of the suture a discontinuous and naroow belt of low-grade metamorphism of high to medium pressure type the Yarlung zangbo river belt. The metamorphic facies ranges from prehnite pumpellyite to greenschist and affects cretaceous and lower tertiary rocks associated with the ophiolites. Towards the W, this belt coonects with the prehnite-pumpellyite zone of Northern Ladakh. Towards the E, the metamorphism increases and becomes high grade in the flysch of the Namche Barwa Region.

In the N of the Pakistan and NW India collision occurred between the Indian continent and the Kohistan island Arc, and between the latter and the Asian (Karakorum) Plate. Two different sutures were formed the Northern suture of the Karakrum Fault Zone (**KFZ)** and the southern one or Indus Suture. There is the two theories about the age of the formations of these suture one is that the southern suture is formed during the Late-Creteaceous an in comprision with that the northern suture is formed during the Late-Cretaceous-Palaeocene. However the latter may be metamorphism associated with the northern event in the Shyok Melange Zone. This is a greenschist-facies metamorphism that belongs to the high pressure type. This metamorphic belt is succeeded to the N by the regional inverted metamorphism of moderately high-pressure type with maximum conditions around 650 C and 5.5 kbar this metamorphism is probably associated with major southward overthrusting following collision with Kohistan Arc.

5.2.2 Tibetan sedimentary series

In S Tibet, the metamorphism of the Tibetan sediemtary series is described as being synchronous with the third phase of deformation. This would imply that this episode of metamorphism is different from the previous one and occurred later.

In the Southern Ladakh is as in the northern Central Nepal and in the Southern Tibet the grade of metamorphism increase togather with the intensity of the deformation with depth. In central Nepal, Lower Paleozoic rocks are generally in the amphibolite facies and greenschist-facies metamorphism may affect thhe Triassic. An unpublished study of illite cristallinity by Dunoyer de Segonzac has shown that anchizonal metamorphism may reach up to the Jurassic in Central Nepal; yet this week metamorphism is not yet well correlated with the phases of deformation and may be a remant of the first phase.

In the case of the age this metamorphism should be older than the age of the emplacement and crystallization of the Higher Himalayan leucogranities that superimpose, at the least towards their top, acontact metamorphism in the Tibetan sedimentary series, Isotopic Rb/Sr ages on minerals from the Manaslu Granite as well as a Rb/Sr whole rock isochron age from a single outcrop of the same ggranite, cluster around 18 Ma. The age of this metamorphism should also be younger than the most recent series affected it should be post-Eocene.
Towards the base of the Tibetan sedimentary series, the deep-seated amphibolite-facies rocks pass without a major break into the highly metamorphic and tectonized infrastructure the Tibetan Slab.

5.3 Inverted metamorphism of the Central Thrust Zone

Along the Himalaya from Kashmir to Arunachal, it has been possible to observe the abnormal superimposition of more metamorphic terrabes on less metamorphic ones. The zonal succession of index minerals the pressure-temprature range an dthe main of this reverse or inverted metamorphism are remarkably constant for a distance of 1600 km aor more. Recent studies have shown that the tectono metamorphic realtions of the MCT zone in the Central Nepal hey include the mapping of the distribution of metamorphic minerals along some 150 km of the MCT zone the petrography of mineral assemblages the study of fluid inclusions, the characterization of structure and texture and the petrofabrics of quartz in the quartz-rich tectonites. These studies showed that the inverted medium pressure metamorphism was synkinematics with the movement on the MCT inducing prograde assemblages in the Midland Formations due to the overthrusting of thr hot Tibetan slab. In the Tibetan Slab the inverted metamorphism is a retrograde metamorphic process of variable defree superimposed on a previous normal Barrovian Metamorphism. The degree of this retrograde metamorphism is directly related to the intial temperature and thickness of the slab which itself depends on the level of truncation of the continental crust at the initiation of the thrusting. For the highest degrees of metamorphism as seen in the Manaslu area, there is a thermal accordance at the MCT level with no metamorphic diachronism being recognizable on both sides of the MCT. There often occurs a second retrograde metamorphic phase, at lower temperature related to late movements along the thrusts however these movements are small enough to preserve in most cases evidence of the previous continuity of metamorphic events.
Indication about the age of this inverted metamorphism are given by K/Ar ages obtained on minerals from the Everest region or by Rb/Sr biotite ages and Everest gneisses all three indicates closing temperature for the analysed mineral between 15 and 20 Ma. The presence and development of this inverted metamorphism is the direct thermodynamic consequences of the large intercontinental shear zone (MCT) during which the isotherms were folded into a transitional S-Shape.

6 High-Pressure (Eclogite facies) Metamorphism in the Indian Plate NW Himalaya, Pakistan

A zone of high pressure metamorphism characterized by eclogites with an assemblage of omphactic-garnet-rulitr (+, _) phengite, has been reconized in the higher Himalaya in the Indian Plate of NE Pakistan. This Suggest that the upper Kaghan nappe is the deepest derived part of the Indoian plate to have been subducted and subsequencely uplifted along the whole length of the Himalaya. Mineral chemistry by microprobe analysis suggest that the eclogite formed at temperature of 650 +_ 50 Degree C and pressure of 13-18 kbar suggesting depth of eclogite formation at 60km. the eclogites show an incipient decompressional re-equilibration which probably occurred at decreasing temperatures.

Eclogites and eclogite facies are first recognized at the Indian plate of the Himalayan belts. The findings of this species is a special interest as it is closely associated with the subduction zone formed during the collision between the indian and the Eurasian plate. The importance of this findings is an important role in the studies of the Himalayans tectonics as a pressure derived metamorphism assemblages, such as blue schist and eclogites can be used to interpret the depth of the formation of lithology which in terms of Himalayan tectonics is the depth of subduction of the indian plate beneath the Kohistan Island arc and Asian plate.

The Himalayas are the classic example of the continent-continent collision zone yet, unlike in the Europrn Alps, high pressure assemblages are not common. The alps contain the blueschist and eclogite facies rocks affecting both the ophiloitic and continental rocks. However in contrast the recognition of high pressure assemblages has been confined to the blueschists of the Ophiolitic sutures and the garnet-granulites of the Jijal complex in Pakistan and the low- and medium-P metamorphism in the calc-alkaline magmatism in Tibet, Kohistan and Ladakh.

7 Summary

The whole summary of the topic is that due to the collision between the Indian and Eurasian plate a Mountain belt is formed about 50 million year ago which is known as Himalayan belt so as both the plates are continental plates so due to this none of them want to be subducted under the other which cause zone to develop having high pressure the resistance of the subduction is due the density and pressure as the Eursian plate has somehow stays and the indian plate started to subduct under it a zone developed which cause the regional metamorphism to take place and the rocks which are exposed due to the collision and metamorphosed in the region of the high pressure and low tempreture zone forming the facies such as eclogite and blueschist. In the northern part of the Pakistan the Himalayan belt show the metamorphosed rocks due to the sbduction which is still continues as the indian plate is continues subducting under the Eurisain plate.