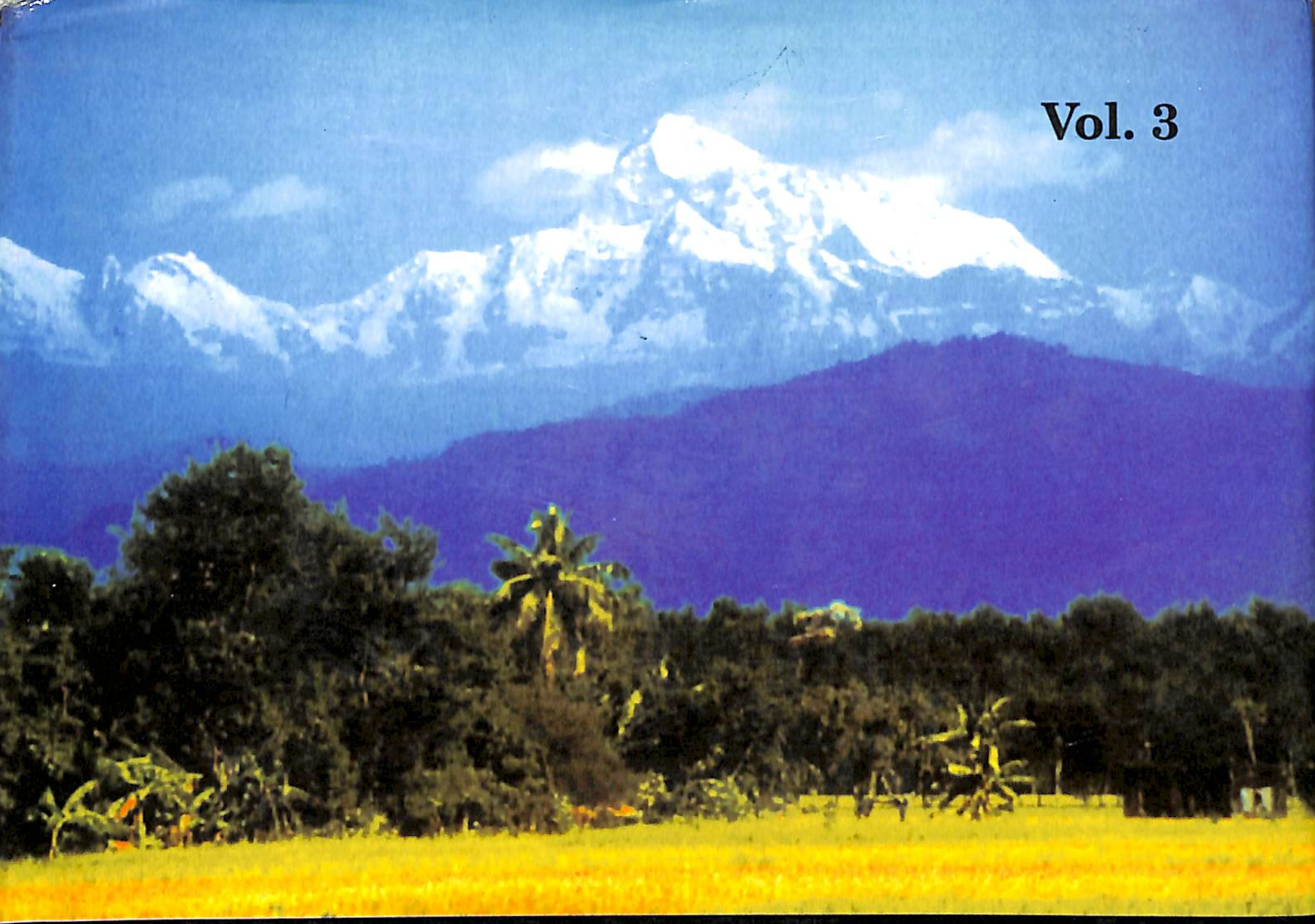
Vol. 3



HIMALAYA

(Geological Aspects)

Edited by :

Prof. P.S. Saklani

Himalaya

(Geological Aspects)

Volume - 3

Edited by :

Prof. P.S. Saklani
Department of Geology,
University of Delhi

SSPH
SATISH SERIAL PUBLISHING HOUSE
403, Express Tower, Commercial Complex, Azadpur, Delhi - 110033 (INDIA)
Phone : 011-27672469, 27672852 Fax : 91-11-27672046
E-mail : ssp@ndf.vsnl.net.in, hkjain@satishserial.com
Website : www.satishserial.com

Published by :

SATISH SERIAL PUBLISHING HOUSE
403, Express Tower, Commercial Complex, Azadpur, Delhi - 110033 (INDIA)
Phone : 011-27672469, 27672852 Fax : 91-11-27672046
E-mail : ssp@ndf.vsnl.net.in, hkjain@satishserial.com

First Published 2005

ISBN 81-89304-04-6

Printed at
SALASAR IMAGING SYSTEMS, DELHI-35

ACKNOWLEDGEMENTS

I express my sincere thanks to all contributers in this volume and to Prof. E. Appel of Tübingen University (Germany). Prof. M. Räsänen of Turku University (Finland). Prof. A. Steck of Lausanne University (Switzerland). Dr. G. Fuchs. Laimback (Austria) and very many well-wishers for their help in many ways.

P.S. SAKLANI

INTRODUCTION

The majestic Himalaya would always remain an attraction to the geoscientists, tourists, artists and a common man. I first ventured my publication activity about the Geology of the Himalaya in 1978. The combined wisdom of my fellow geoscientists is reflected in my edited volumes and due to overwhelming support and cooperation, I could publish many of them. Meanwhile, I got some academic/administrative assignments and after completing them, I noticed that still there is a need to continue with publication activity and the result is in your hands. In my opinion, Geology of the Himalaya is continuously being updated. Though the Himalaya would remain where it is, during my life time, yet interpretations would vary due to advancement of science and technology. This volume is being published under the aegis of the Geoscience Foundation, India.

In this volume, the formation of the Himalaya has been discussed by *M. Brunel et al.* They are of the view that the collision of Indian and Asian Plates took place around 53 m.y. ago (within sedimentary sequence-60 m.y.). The Tethys measured 6500 km in width. The MOHO is located at about 75 km beneath the Everest. Tomographic results indicate that Indian lithosphere went down for about 2000 km, associated with anatexis. The Precambrian Lesser Himalayan rocks occur in the form of an imbricate stack. The exhumation of the rocks to get exposed on the surface was for about 40 km. The ophiolites and associated flysch are also characterized by imbrications. The Main Central Thrust (movement for about 200 km) is a flat shear zone and the rocks were subjected to ductile deformation. Metamorphic minerals were formed around 36 m.y. ago but this formation activity was more intense between 25 to 10 m.y. and continued to be thermally active for about 2 m.y. Analogue modelling suggests that prior to collision the regime was marked by sedimentation. The neotethys was opened up in Late Permian and on the fore arc series of Tibetan margin, lavas and batholiths were emplaced.

A brief account of the history of Himalayan geology is given by *R. Sorkhabi.* The geographic explorations, geological maps and botanical catalogues of the Himalaya were made from 1175 to 1800. Colebrooke (1765-1837) was the first person to opine that the Himalaya is world's highest mountain than the Andes. W. Webb (1816-1820) determined the height of the Nada Devi (25669 feet, just 24 feet higher than today's measurement). Himalayan geology became an independent and systematic field of science between 1850-1900. The Geological Survey of India was established in Calcutta in 1851. T. Oldham (1816-1878) was the true architect of the Geological Survey of India. J.D. Hooker (1817-1911) explored Sikkim and Bengal during 1848-1852. A. Waugh (1810-1878) who succeeded G. Everest, discovered peak XV and named it as the Mount Everest (height 29002 feet which is less than 26 feet than that of the 1955 measurement). World I (1914-1918) and World War II hampered the investigations of the Himalaya. After the World War II, India became independent and since then many new advances were made in Himalayan geology. Presently native geologists of the Himalayan countries (India, Pakistan, Bangladesh, China, Nepal and Burma) and also from U.S.A., Canada, Europe, Australia, Japan etc. are actively engaged on the geological researches of the Himalayan and Tibetan regions.

Magnetotelluric techniques reveal significant information of the deep interior of earth and *G. Gupta et al.* has applied these in Mohand-Ramnagar and Phobrang regions of the

Northwestern Himalaya. Two layers of Siwalik sediments underlie the alluvium. The Upper Siwaliks are 700-1000 m in thickness while Middle and Lower Siwaliks measure 3000-4000m. The vertical conductive zone is delineated at shallow depth in Phobrang profile of the Ladakh, which is characterized by a deep-rooted fault at a depth of about 12 km.

Sedimentological studies of the Jammu region have been dealt with by *B.P. Singh et al.* The Palaeogene succession represents a regressive phase of a coastal regime. The Murrees are estuarine. The overlying sandstones belong to intertidal zone. The Palaeocene sediments were derived from the Himalayan arc and their derivation was subsequently followed from the Indus Suture Zone towards the foreland.

The biotite in granite gneiss, granites and leucogranites of Kinnaur, Himachal Pradesh have been studied by *S. Kumar and B. Singh.* The Rakcham granitoids intrude the gneiss of the Vaikrita group. The tourmaline granite is leucocratic and is a product of the Himalayan collision. The biotite from Rakcham ganitoids and granite gneiss is Fe rich while it. from the leucogranite, corresponds to siderophylite and lepidomelane field. Sheelite mineralisation is found in Rakcham granitoids.

S.C. Bhatt and R. Kumar have discussed about the mineralogical properties of the aggregates of gneiss, quartizites, schists etc. The strained quartz caused alkali-silica reaction in concrete. The rock aggregates of hard rounded quartz and feldspar produced high strength. The excess of strained quartz showed adverse effects on strength and chemical stability of aggregates of concrete.

A.K. Biyani has described the structure and tectonics of the Yamuna mylonite zone of Uttarkashi district. He is of the view that the Higher Himalayan granites were initially mylonitised in ductile conditions during the Middle Tertiary and were again later deformed under ductile-brittle conditions. Several microstructures in minerals suggest a southward displacement of the Main Central Thrust Sheet. The rocks of the hinterland experienced flattening type of strain where as in the toe region it was constrictional. The deformation continued after the thrusting and caused the formation of strike slip, reverse and normal faults. The river terraces, gorges etc. exhibit effects of Neotectonics.

A.C. Pandey et al. making use of satellite images discussed the geology and morphotectonics of a part of Tehri-Uttarkashi districts. The rocks of the area are represented by the Simla, Krol, Jaunsar and Crystalline groups delineated by thrusts. They have analysed the data of lineaments, which exhibit NE-SW, NW-SE, N-S, and E-W trends. The cross-valley and longitudinal profiles of the Bhagirathi river show breaks in the slopes, knick points etc. which were caused by dynamic rejuvenation. The river terraces were formed due to five phases of uplift.

The editor has authored the Tectonic Geology of the Main Central Thrust in Garhwal Himalayan region, which is characterised by the Vaikrita, Jutogh and Budhakedar units delineated at their base by the Main Central Thrust-I, II and III. Infact, these thrusts occur in the form of a large Duplex. The Bhagirathi Duplex was shortened for about 17 km while the shortening in the Yamunotri Duplex was about 8 km. The metamorphics, located at a depth of about 16-18 km, ramped for about 8 km during the thrusting.

The evolution of the Almora nappe along the Chhara-Someshwar Section has been contributed by *M. Joshi and A.N. Tiwari.* The structural history of this nappe is characterised by the structures of pre-, syn- and post-shear zones. The F_1, F_2 and F_3 folds are pre-shear zone while shear bands, asymmetric porphyroclasts, pressure shadows and quartz-c-axes were oriented in syn-shear zones. The post-shear zone structures are represented by steep brittle faults which were affected by Neotectonics.

Based on field and experimental studies *A.K. Dubey and R. Jayangondaperumal* have discussed the structural evolution of the Mussoorie syncline with reference to Satengal and Banali klippen. Their model explains the occurrence of older lesser Himalayan rocks over the younger ones due to combination of fault bifurcation, foreland propagation of thrust and superposed folding.

A.K. Shandilya has attempted on the sequence of thrusts (roof and floor) and imbrications. The compression caused by the northward movement of the Indian plate formed the Krol thrust. The Almora thrust was folded during the later phase of deformation. The Amri and Bijni thrusts are extensions of the North Almora Thrust.

Metamorphism and deformation of the Central Crystallines of the Alaknanda Valley have been described by *S.P. Singh et al.* The Barrovian type of metamorphism was M_1 which began at D_1 deformation and culminated at D_2 deformation. This was followed by granitisation. The M_2 metamorphism was mainly retrograde and was localized along the shear zones in the late stages of D_1 deformation. The inverted metamorphism noticed near the Main Central Thrust is the result of polyphase metamorphism.

V.K. Singh has dealt with the structural and metamorphic aspects of the Chails and the Main Central Thrusting. The structural and metamorphic studies reveal that the M_1-metamorphism took place at 600 °C to 700 °C (6-7kbar) during D_1- and D_2 deformation while the temperatures were at 350 °C-400 °C (4-5 kbar) during the M_2- metamorphism.

B.C. Joshi has contributed on the metamorphic history of Chamoli- Garhwal area which consists of repeatedly metamorphosed, folded and faulted rocks. The migmatites and gneisses were produced by load/regional metamorphism. The crystalline nappe of Chamoli-Garhwal constitutes a Duplex structure.

R. Bali has given an account of the neotectonic and morphotectonic evolution of the Dharchula - Tawaghat sector of the Kumaun Himalaya. Many microhydel schemes as well as the Dhauliganga hydroelectric project are adversely affected by the instability of hill-slopes. The area is characterized by unconsolidated and non-cohesive weak fans resting at about 45° (repose angle) and are instable. Neotectonics reactivated the debris cones.

A. Kumar and M. Sanoujam have carried out the Seismotectonic studies of Manipur region. The complex focal mechanism is due to strike-slip-movements. The NNW-SSE to NNE-SSW dragging of the Indian plate is confirmed by Harvard Centroid Moment Tensor Analysis. The focal depth in the strike slip mechanism varies from 62 to 140 km (Indian Plate) whereas this is located at 40-45 km towards the Burmese arc.

Structural patterns and geokinematics of the Mediterranean - Central Asian Orogenic belt has been contributed by *M. Kopp*, who attempted the structural analysis of the fold belt.

CONTENTS

1. **The Formation of the Himalaya** 1-17
Maurice Brunel, Stephane Dominguez, Georges Mascle

2. **Himalayan Geology: A Historical Perspective** 19-45
Rasoul B. Sorkhabi

3. **Magnetotelluric Studies in Northwestern Himalaya** 47-60
Gautam Gupta, S.G. Gokarn, C.K. Rao and C. Selvraj

4. **Sedimentology of the Palaeogene Succession in Jammu Region, Jammu and Kashmir State, NW Himalaya** 61-77
B.P. Singh, D.S. Andotra and J.S. Pawar

5. **Biotite from Neoproterozoic Granite Gneiss Cambro-Ordovician Granitoid and Neogene Leucogranite of Kinnaur District, Himachal Pradesh** 79-100
Santosh Kumar and Brijesh Singh

6. **Relation Between Mineralogical and Physical Properties of Coarse and fine Aggregates and Influence of Textural, Chemical and Dimensional Difference on Strength of Mortar and Concrete, Manali (H.P.)** 101-134
S.C. Bhatt and Rajiv Kumar

7. **Structure and Tectonics of the Yamuna Mylonite Zone, District Uttarkashi, Uttaranchal** . 135-152
A.K. Biyani

8. **Geological and Morphotectonic Studies Using Satellite Images of a Part of Tehri-Uttarkashi District, Lesser Garhwal Himalaya** 153-171
A.C. Pandey, P.S. Saklani and C.S. Dubey

9. **Tectonic Geology of the Main Central Thrust, Garhwal, Uttranchal** 173-189
P.S. Saklani

10. **Tectonic Evolution of The Almora Nappe Along the Chhara-Someshwar Transect, Kumaun Himalaya** 191-202
Mallickarjun Joshi and A.N. Tiwari

11. **Pop-up Klippen in the Mussoorie Syncline, Lesser Himalaya, Evidence from Field and Model Deformation Studies** 203-222
A.K. Dubey and R. Jayangondaperumal

12. **Development of the Thrusts in Garhwal Himalaya** 223-235
Arun K. Shandilya

13. **Metamorphic and Deformation History of the Central Crystallines of the Upper Alaknanda Valley, Garhwal Himalaya and its bearing on inverted Metamorphism** 237-255
Surya Pratap Singh, Prem Swarup Saklani, Alan Bruce Thompson

14. **Structural and Metamorphic Studies of Rocks associated with the Chail Unit and Main Central Thrust Zone of the Garhwal Himalaya** 257-278
V.K. Singh

15. **A Contribution to Metamorphic History of an Area of Chamoli Garhwal** 279-290
B.C. Joshi

16. **Neotectonic and Morphotectonic Evolution of a Part of North Eastern Kumaun Himalaya** 291-301
Rameshwar Bali

17. **Seismotectonic Studies in Manipur and Adjoining Areas** 303-316
Arun Kumar and Manichandra Sanoujam

18. **Strike-Slip Related Structural Patterns and orogenic Geokinematics of the Mediterranean-Central Asian Orogenic Belt** 317-341
M. Kopp

THE FORMATION OF THE HIMALAYA

Maurice Brunel *. Stephane Dominguez*. Georges Mascle**

Uniersite Montpellier II
UFR Science Destem & UMr. 5573 Geoph. Tecto. Sedimento.
Cc. 058 PI.E. Bataillon. 34094- Motpellier Cedex 05
** Universite Joseph Fourier Grenoble 1 LGIT. Maison Des Geoscience
1381, rue de la Piscine BP 53, 3841 Grenoble Cedex 9

ABSTRACT

The geology of the Himalaya has been described keeping in view the relief, seismic tomography, structural units, the rocks at depth and their exhumation. Attempt has also been made to suggest a possible model for the formation of the Himalaya.

INTRODUCTION

The Himalaya is considred a case study mountain belt in understanding the mechanisms of orogenesis. Switch over from the outcrop to the mountain belt and from the mountain belt to the continent is easy. The strong and variable relief allows the three dimensional understanding of its structure.

The overall kinematics can be described by the location of India-Europe rotation pole at 19° 43'N, 38° 28'E (situated in the Red sea, about 200 km SSE of La Mecue), the direction of the transform faults (Owen-Murray fault, 90° E fault) oriented N20° E, and earthquake focal mechanism. The actual convergence was thus directed between N0° and N20° E , roughly perpendicular to the belt (Patria and Achache, 1984)

The Himalaya was formed by a relatively simple assemblage: to the north, the Asian margin, built during the subduction of the large Tethys ocean, similar to the Andes being formed by the subduction of the Pacific ocean underneath the South America. To the south, the Indian margin, and old (oceanic) passive margin is characterized by a nearly continuous sedimentation during 500 Million Years ranging, from Cambrian to Eocene times (Gansser, 1964). Inherited structures are rare along the whole Indian Margin and, the tectono-metamorpic structure is essentially of the Himalayan type.

The Himalaya: The highest relief on earth is due to the thickening of the Northern edge of Indian plate during its Collision with Asia.

The Himalaya is a type example of mountain belt formed by two colliding continental plates: Indian and Asian (Le fort, 1975; Valdiya, 1984, 1988). Results form palaeontological studies, absolute dating of tectonic and metamorphic events within Himalayan rocks as well as the palaeomagneic data obtained from onshore and offshore of the Indian ocean indicate the collision of the two continents during the early Tertiary, (around-53 Million years). By this time, the large Tethys ocean, 6500 km wide existed during the Mesozoic, Between Asian and India Still sticking to Africa and Australia, (Patriat and Achache 1984). The ocean was consumed by the subduction underneath the Tibet leading to the formation of large granitic coastal masifs (of Andean type): the Lhasa or Ladakh granites. Remnants of this wide ocean are preserved only in a few locations, along the suture that was more or less followed by the large Indus and Tsang Po/Brahmaputra rivers.

The Himalaya in itself is a mountain belt resulting from the collision between the two continents; it is situated south of the disappearance line of the Tethys ocean (the Indus/ Tsang Po suture line). The highest mountain belt of the world thus resulted by the deformation on the edge of the Indian continental plate squeezed against Asia. Its relief allows the largest differences in level on the planet: 8500m from the Terai lowlands in Nepal (with the banana trees) to the top of Makalu (figure1)

Along its 2500km length the mountainous Himalayan arc is located between the Naga Parbat in the west and the Namche Bawa in the east and comprises of ten peaks higher than 8000m. The belt extends south of the Indus-Tsang Po suture to the Ganges plain with an average width of about 250 to 300 km. From the experiments of George Everest, we know that the gravitational anomaly associated with the bulk of the mountain, can only be explained by the existence of a root underneath the belt forming a bulge of light material balancing the overweighing relief(figure 2). Gravity modelling , and also seismic experiments are helpful to calculate accurately the depth of root and to locate the MOHO (boundary between the crust and the mantle) at abouth 75 km deep under the Everest. This measurement indicates that the Indian crust was deformed by doubling or even sometimes may be tripling its original thickness. This estimate is fundamental and gives us a reasonable limit to the amount of displacement of India towards the north for the formation of the Himalaya. On this basis it is generally admitted that the actual relief of the Himalaya cannot explain more than 500 km of convergence between India and Asia since 50 Ma . This means that the Himalayan relief was outlined by an average convergence speed of the order of some cm/yr.

(Frame1) Seismic tomography : new data to be taken into account.

Recently, the new techniques of seismic tomography have allowed to image the lithosphere at great depth (Van der Voo et al. 1999). The images obtained bring a revolutionary result to the understanding of the globe and, in particular, of the subduction zones. The deep tomographic section running through central Nepal presented here (figure3) shows that the Indian lithosphere went down into the mantle to more than 1500km or possibly 2000 km . Moreover, on the basis of reconstruction from oceanic magnetic anomalies maps, we can consider that the Indian continent, before the collision , was large for about a thousand kilometers(Matte et al ., 1997). In this case the Himalaya would represent the result of a convergence larger than expected between India and Asia and a large amount of continental lithosphere disappeared into the mantle . Following the hypothesis of the subduction of a large amount of Indian continental lithosphere, an important part of the crust should have disappeared either by erosion or due to the subduction.

Figure. 1: Large differences in levels on the planet: 8500m from the Terai lowlands in Nepal (having banana trees) towards the top of the Makalu.

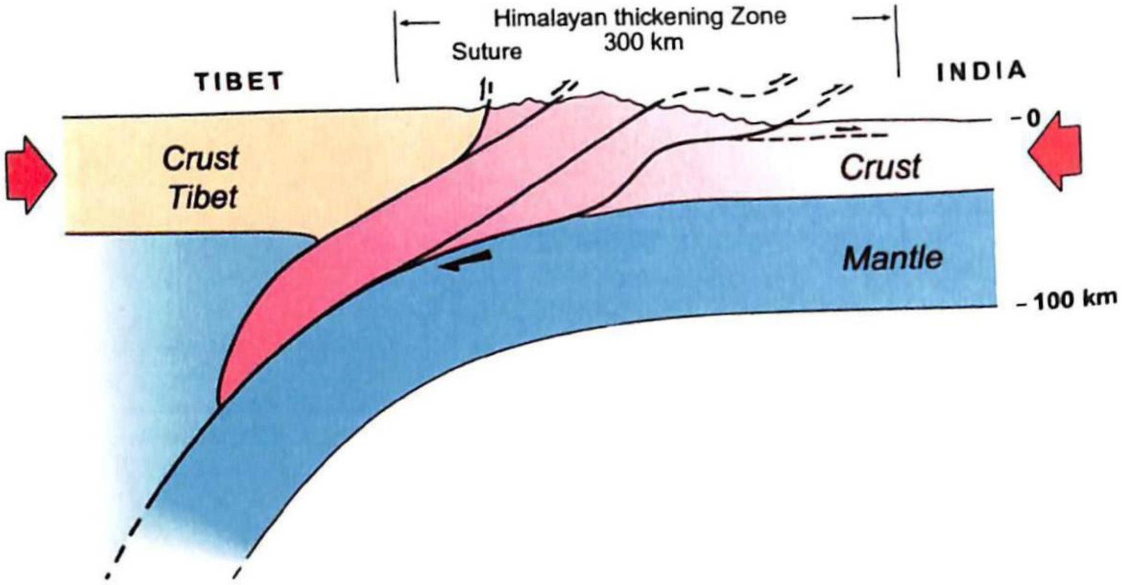


Figure. 2: Sketch section of the Himalayan accretionary thickened zone.

The Himalayan Structure: The Structural Units of the Everest Traverse (Figure 4)

Since about fifty years international teams have been working within the Himalayan belt to understand its functional processes and its construction. These works are useful to understand better the complexity of the palaeogeographic domains from which the structure and major mechanisms of crustal thickening have been reported. Though we have chosen the Everest section yet , in fact, all along the transverse sections, the structural units remain relatively constant throughout the belt. These units resulted due to the superimposition of portions of the Indian continental crust, one on top of the other along the north verging faults or thrusts , from south to north:

The Siwaliks, formed by detrital material of the molasse type were deposited on the old Indian shield and corresponded to the destruction of the Himalayan relief from Neogene to Quaternary times .These deposits are structured in a group of sheets thrusted southward along the Main Frontal Thrust or MFT on to the Quaternary sediments in the Ganga basin.

The Lesser Himalaya is thrusted on top of the Siwaliks along the Main Boundary Thrust or MBT. It is composed of series of mainly Precambrian rocks forming a nappe stack. This group of monotonous rocks is characterised by a slate like foliation or schistosity. On a regional scale,the schistosity planes tend to become parallel to the large faults and thus display a gentle northward dip. This foliation of the rocks usually displays a sub-meridian mineral lineation (Figure 6) indicating the direction of flow and transport of the rock masses towards the south , parallel to the direction of movement of India (Brunel, 1986, Pecher, 1989) . The Lesser Himalaya is buried under the High Himalaya along the Main Central Thrust or the MCT.

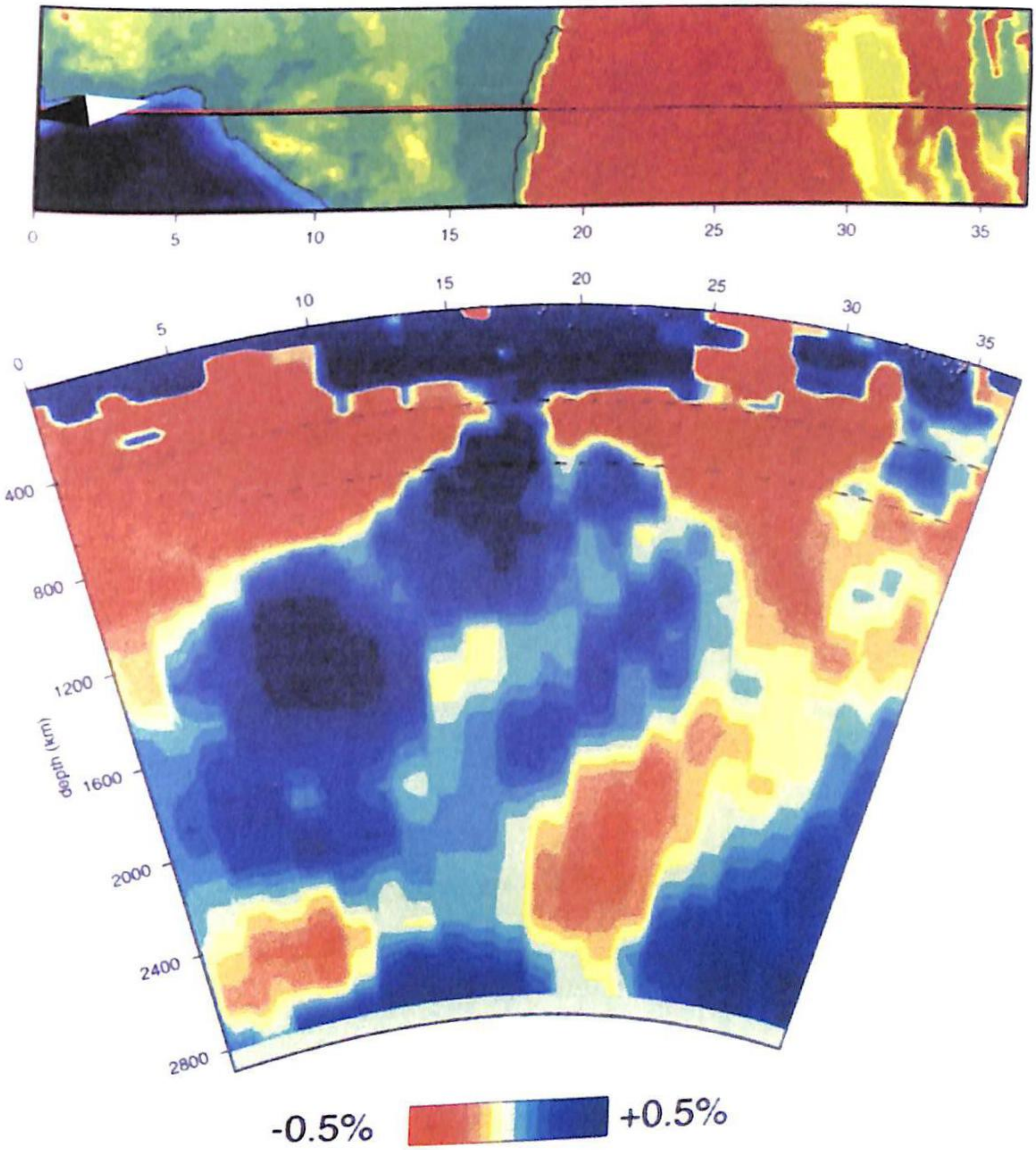


Figure. 3: Tomography across Central Nepal showing the Indian slab dipping in the mantle (after Vander Voo et al.)

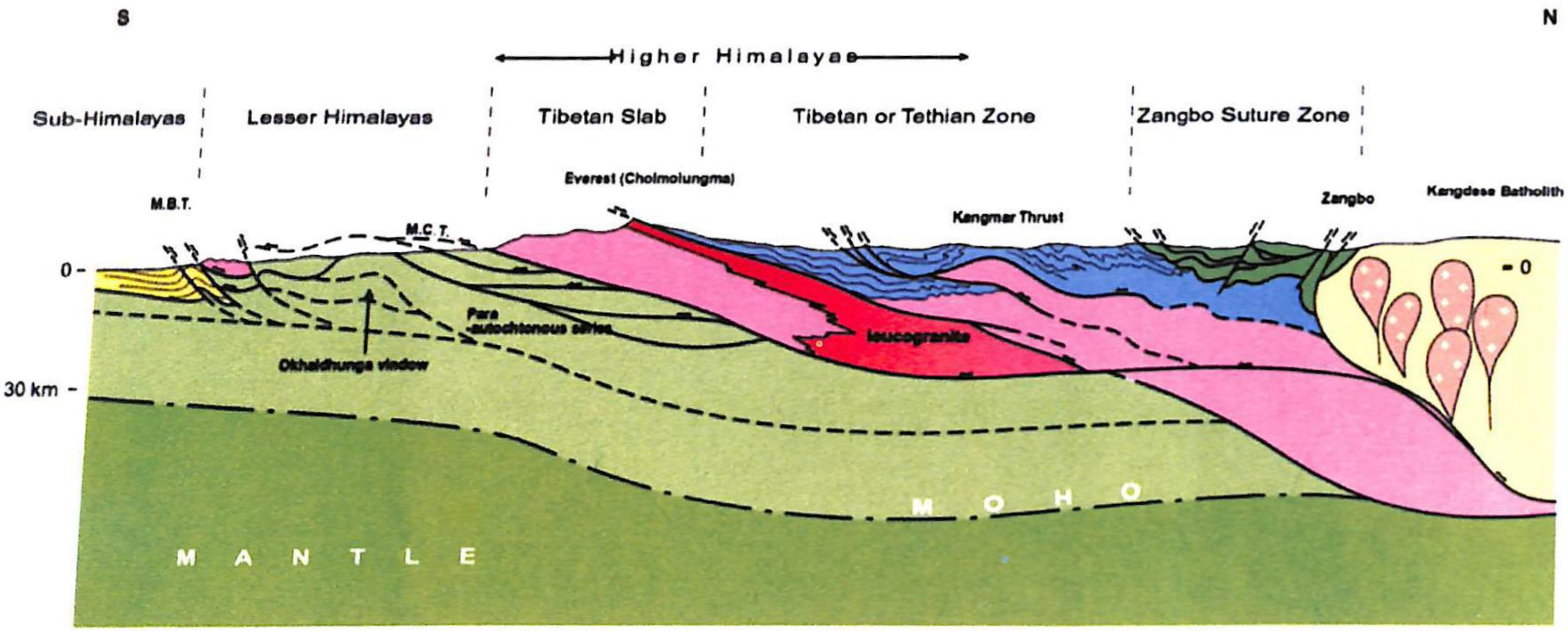


Figure. 4: Sketch section of the Everest traverse.

(Frame 2) Buying of the rocks at depth and their exhumation toward the surface.

To understand the evolution of the architecture of the belt through time and the kinematics of the continental deformation, it was necessary to describe and measure deformation at all possible scale, so that it can be linked with the physics of rock deformation from crystalline to the mountain belt scale, and finally can characterise the evolution of the physical variables such as pressure and temperature.

We know that during tectonic deformation, and evolution of the belt, the rocks at the surface are carried towards the depth where they are subjected to metamorphic modifications and even to anatectite melting to generate granitic magmas (burying process). Due to the effects of erosion and to the classical process of isostatic rebound (progressive uprising of the crustal root induced during erosion of the relief) or to more complex tectonic processes, the rocks which were at great depth, i.e., 20-30 or even 40km could be brought back towards the surface (exhumation process). The analysis of mineralogical assemblages contained within these metamorphic rocks define the pressure and temperature conditions experienced by rocks during their history. Determination of their age using absolute dating methods helps to find the path of the rock throughout the continental crust. We will thus be able to draw the PTt path (Pressure / Temperature / time path) followed by a particular rock or several rocks from the belt during its history (figure 5). This, in turn controls the burying and exhumation tectonic models.

(Frame 3) Figure 6 : picture of mineral transport lineation, Figure 7 : picture of fault zone.

At depth, the increase of temperature and pressure causes the rock to melt forming magmas that can migrate upward and infiltrate into the fault ones forming dykes (figure 7) (Pecher, 1988; Hodges et al., 1988, Guillot et al., 1994). Movement along those faults is shown by crystallization of fibrous minerals here, sillimanite fibers (figure 6).

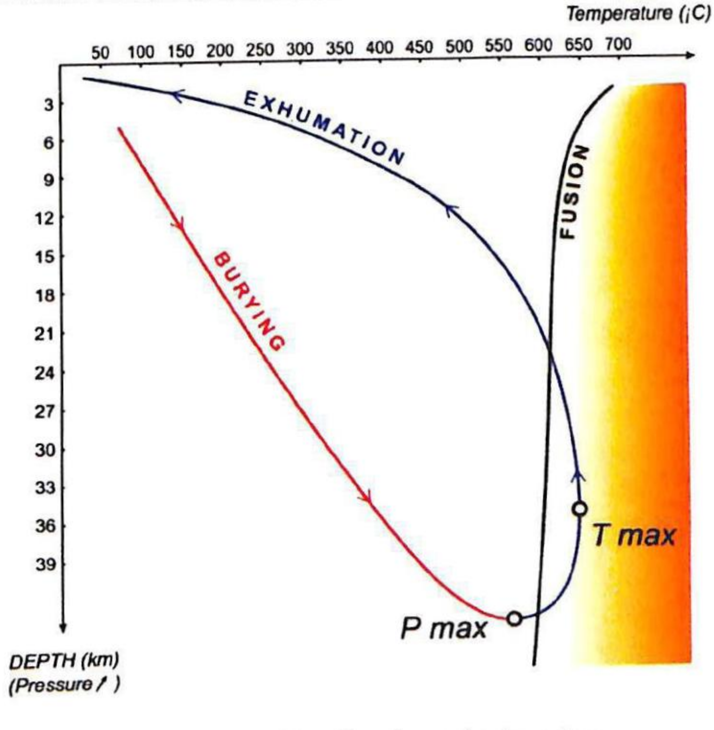


Figure.5: Models of burying and exhumation .

Within the MCT fault zone , the rocks were strongly deformed under pressure of 9 / 10 Mpa and temperature from 45°to 650° C . On the crustal scale it is possible to get the physical conditions of the deformation associated with shearing within the fault zone . Every mineral displays the characteristics which determine the direction of shearing or the direction of transportation, for example , the rotation of the so called " snow ball " garnets (figure 8) that can roll (Brunel, 1986) .

The High Himalaya overrides the Lesser Himalaya along the Main Central Thrust (MCT) (Le fort, 1975) . It is composed of a Precambrian crystalline basement, 5 to more than 10 km thick, of the Higher Himalayan Crystalline or HHC . This basement made by gneisses slides slightly dipping towards the north like the schistose structure which underneath is characterised by well - marked mineral lineation parallel to the direction of transport ("Tibet Slide") . Above the HHC a sedimentary unit (the Tibetan Series or SST) about 10 km thick, ranging in age from Cambrian to Eocene, with a subsiding continental shelf facies is exposed. The Himalayan metamorphism (45 to Ma) is observed within the gneisses (upto 700°C,1200 Mpa) which rapidly decreases in the sedimentary cover.

(Cross section of the Anapurna, Figure 9)

Within the Anapurna cross-section, the sedimentary cover is structured by slides and south-dipping folds (Bordet et al., 1972, 1975), which were reworked by the north dipping folds. The nappes were mainly formed by the sedimentary cover of the various parts of the Indian Tethys margin; two types were distinguished; some from the upper part of the margin (the shelf), some from the deeper part (slope) and, towards the West. Their basement was formed by the Inner Crystalline Massif (Tso Morari).

The Indus- Tsangpo suture zone corresponds to the old Tethyan oceanic area which disappeared due to subduction towards the north and then was deformed by the collision. It displays nappes and slides of flysch , ophiolites and radiolarites, and of blue schists covered by deformed continental conglomerates (Gansser,1964).

The Tectonic History.

The main stages are (Figure 10) :

1. *The disappearance of the oceanic domain*: the subduction of the Tethyan ocean borught the Indian block closer to north Tethyan Asian margin where the TransHimalayan belt was formed (from Middle Cretaceous times until the collision in Lower Paleocene times). The TransHimalayan magmatism (Ladakh and Kangdese belts) was typical of an active margin. To the West, the Dras-Kohistan intra-oceanic arc was docked by the Tibetan margin during the Cretaceous.
2. *Collision of the two continental margins*: collision between the active Tibetan margin to the North and the passive Indian margin to the South occurred during the Eocene (53 Ma). It was characterised by: a sharp decrease of the expanding rate of the Indian ocean (from10 to 5 cm/yr); end of the marine hiatus with

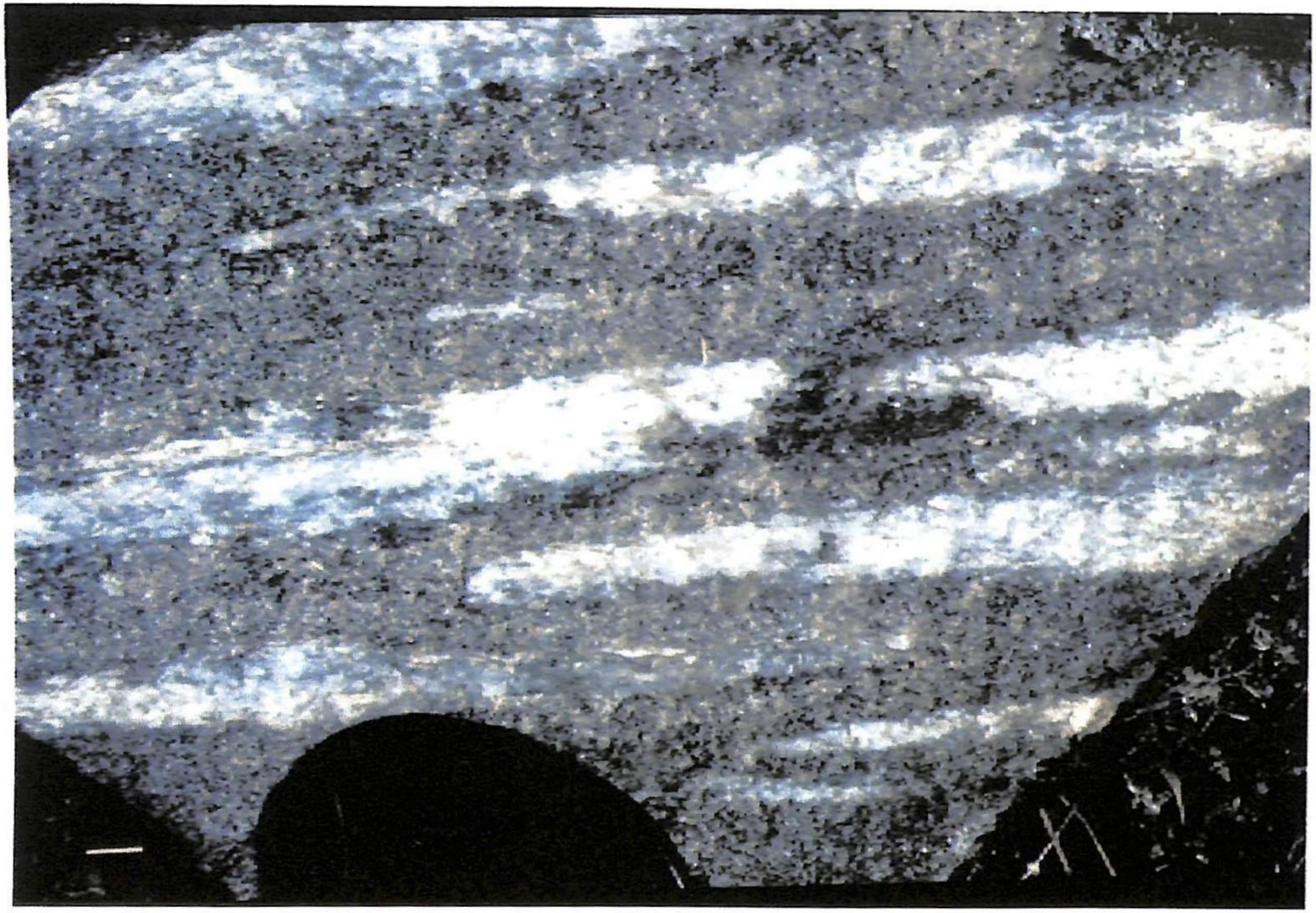


Figure 6: Sillimanite fibers in the Tibetan slab indicative of the stretching towards the transport direction.

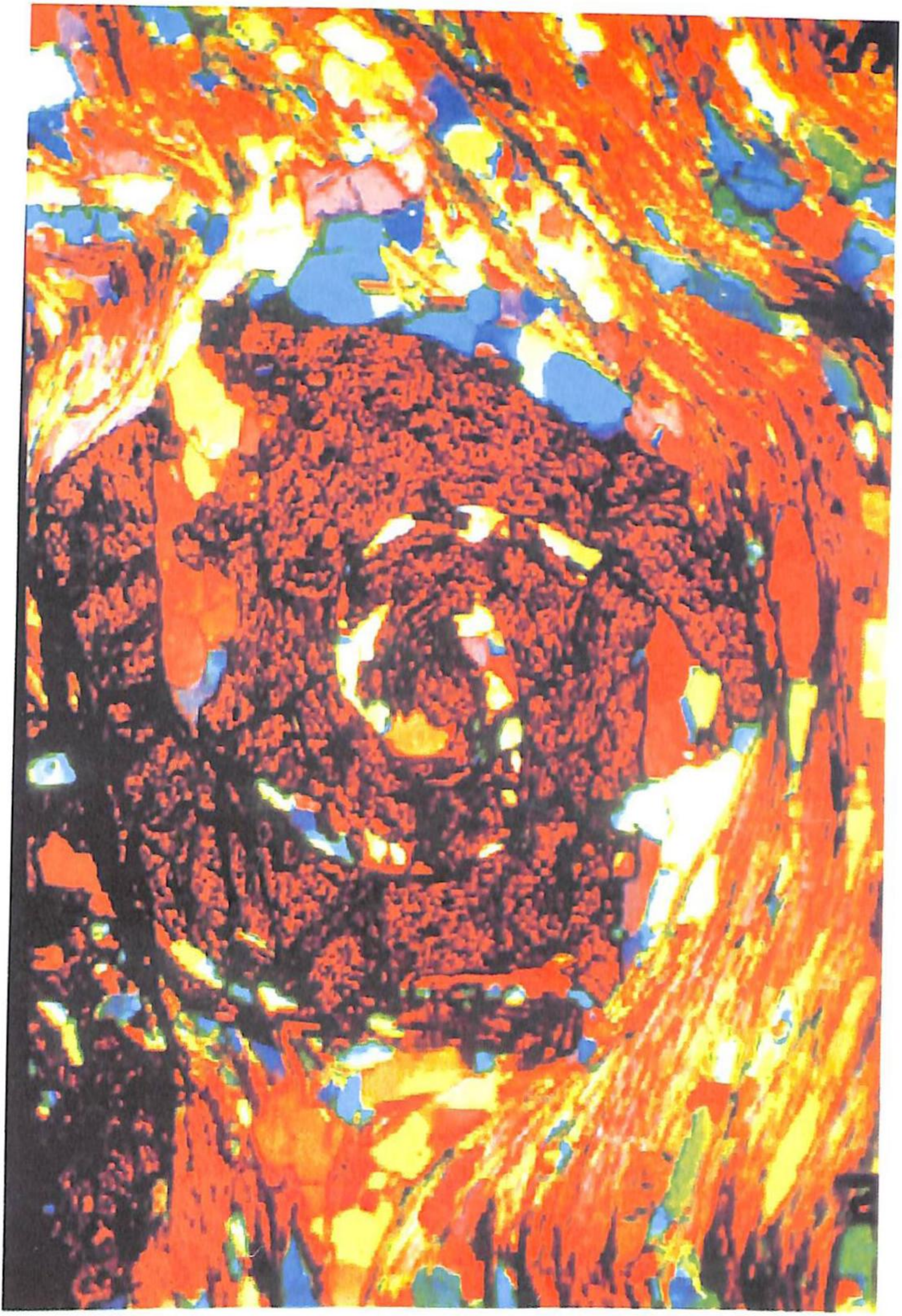


Figure 8: Typical Snow-ball garnet of the Tibetan slab showing shear sense southwards.

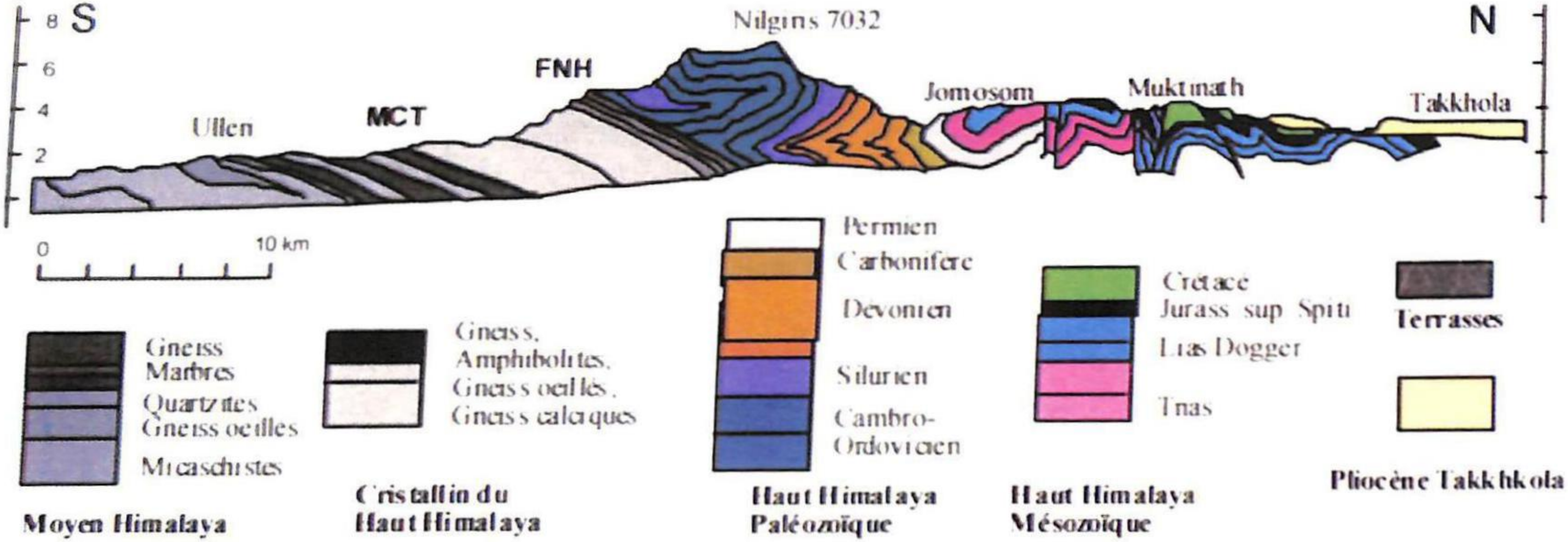


Figure 9: Geological cross-section of the Anapurna through Nilgiri: Back fold and NHF (Normal Himalayan Fault).

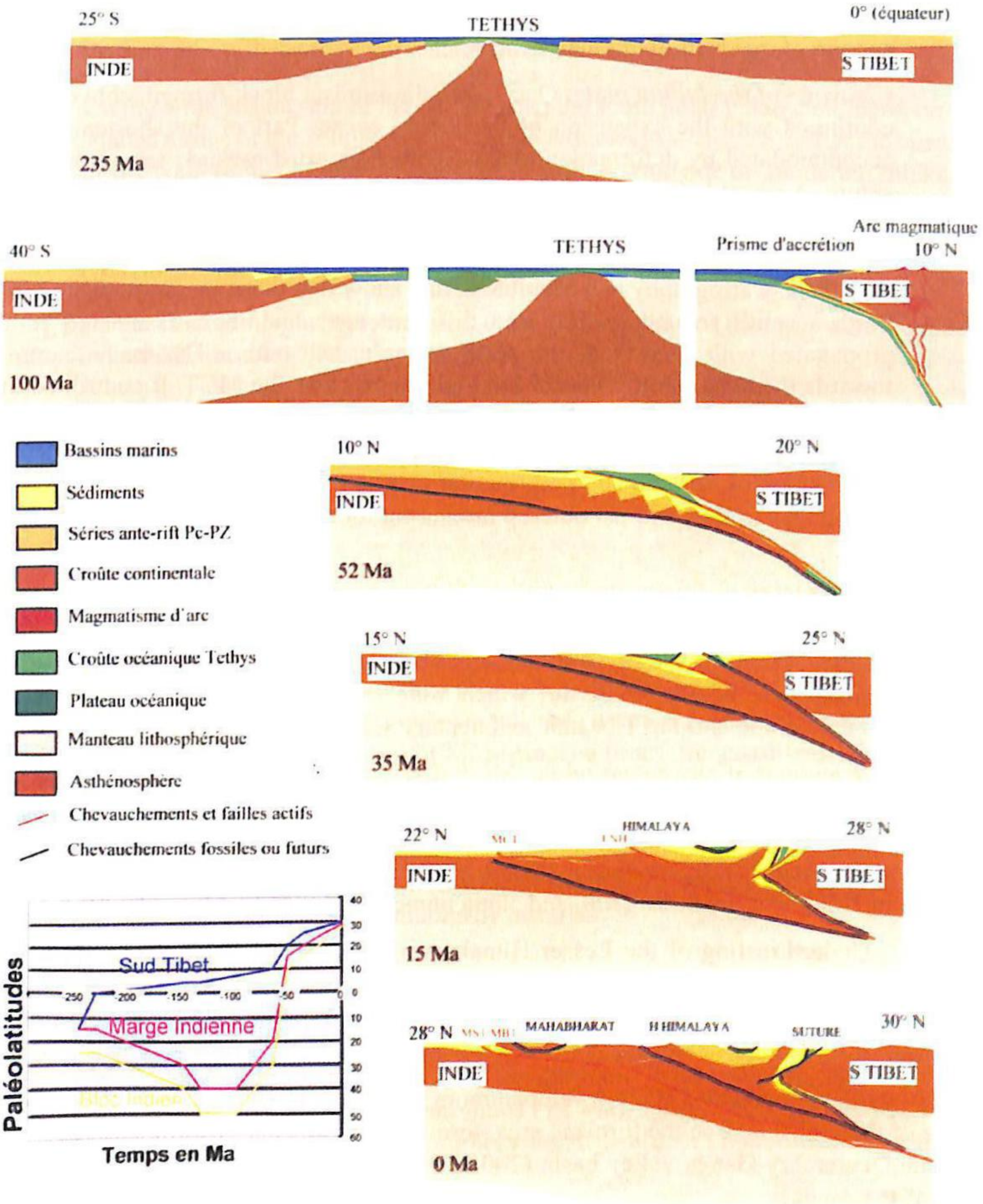
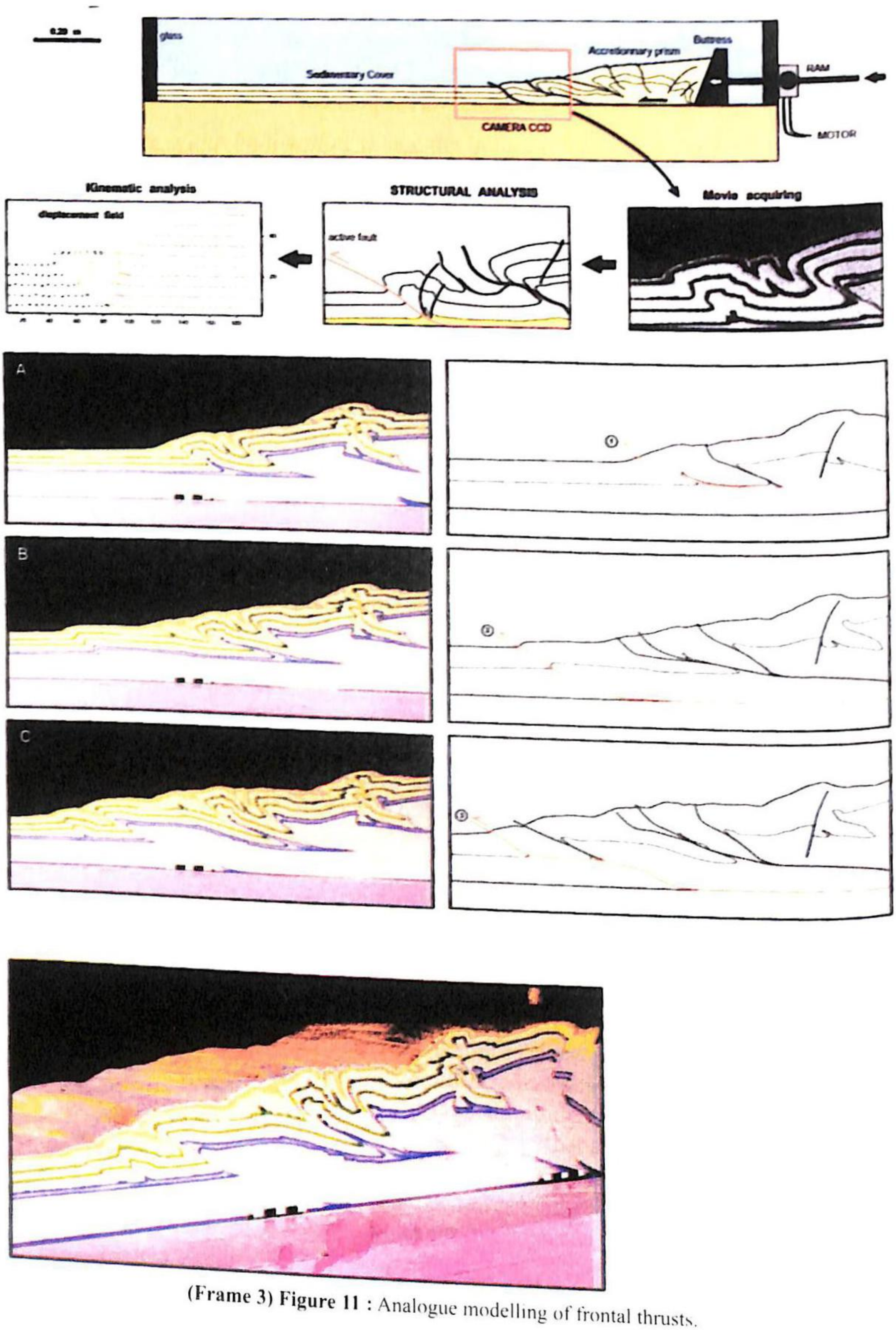


Figure 10 : Retrotectonic sketch model for the formation of the Himalaya, since 235Ma to present time.



(Frame 3) Figure 11 : Analogue modelling of frontal thrusts.

REFERENCES

Bordet, P; Colchen, M; Le Fort, P. [(Monograph) Recherches geologiques dans l ' Himalaya du Nepal du Nyi-Shang. Geological studies in the Nyi-Shang region of the Nepalese Himalayas 138pp., 1975, Edts. CNRS Paris.

Bordet, Pierre; Colchen, Michel; Le Fort, Patrick. Some feature of the geology of the Annapurna Range, Nepal Himalaya. Himalayan Geology, vol.2, pp. 537-563, 1972.

Brunel, Maurice. Ductile thrusting in the Himalayas; shear sense criteria and stretching lineations. Tectonics, vol.5, no. 2 pp. 247-265, 1986.

Gansser, August. (Monograph) The Geology of the Himalayas, 289pp., 1964, Wiley & Sons.

Guillot, Stephane; Hodges, K.V., Le Fort, Patrick; Pecher, A,. New constraints on the age of the Manaslu Leucogranite; evidence for episodic tectonic denudation in the central Himalayas. Geology, vol. 22, no pp. 559-562, Jun 1994.

Guillot, Stephane; Cosca, Michael; Allemand, Pascal; Le Fort, Patrick.. Contrasting metamorphic and geochronologic evolution along the Himalayan Belt, Special Paper -Geological Society of America, vol. 328, pp. 117-128, 1999.

Harrison, T., Mark; Ryerson, F J; Le Fort, P; Yin, An; Lovera, Oscar M; Catlos, E J. A late Miocene - Pliocene origin for the central Himalayan inverted metamorphism. Earth and Planetary Science Letters, vol. 146, no.1-2, pp. E1-E7, Jan 1997.

Hodges, K V; Hubbard, Mary S; Silverberg, D. Metamorphic constraints on the thermal evolution of the central Himalayan Orogen. Philosophical Transactions of the Royal Society of London, Series A: Mathematical and Physical Science, vol. 326, no.1589, pp. 257-280, 01 Sep 1988.

Hubbard, Mary. (Monograph) Thermobarometry, (super 40) Ar/ (super) Ar geochronology, and structure of the Main Central Thrust zone and Tibetan slab, eastern Nepal Himalaya. 169pp., 1988.

Matte, P; Mattaure, M; Olivet, J M; G riot, D A. Continental subductions beneath Tibet and the Himalayan orogeny; a review. Terra Nova, vol. 9 no. 264-270, Dec 1997.

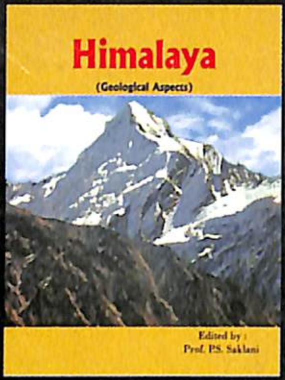
Patriat, Phillipe; Achache, Jose. India-Eurasia collision chronology has implications for crustal shortening and driving mechanism of plates., Nature (London), vol. 311, no. 5987, pp. 615-621, 18 Oct 1984.

Pecher, A. The metamorphism in the central Himalaya. Journal of Metamorphic Geology, vol .7, no. 1 pp. 31-41, Jan 1989.

Valdiya, K S. Evolution of the Himalaya. Tectonophysics, vol. 105, no. 1-4 pp. 229-248, 01 Jun 1984.

Valdiya, K S. Tectonics and evolution of the central sector of the Himalaya. Philosophical Transactions of the Royal Society of London ,Series A: Mathematical and Physical Science, vol. no. 1589, pp. 151-175, 01 Sep 1988.

Van der Voo, Rob; Spakman, Wim; Bijwaard, Harmen. Tethyan subducted slabs under India. Earth and Planetary Science Letters, vol. 171, no. 1, pp. 7-20, 15 Aug. 1999.



GEOLOGY OF THE LOWER HIMALAYA (GARHWAL)

Written by a leading geologist, this monograph presents a fascinating and incilsive, study of Himalayan Geology in one of the important regions of Lower Himalaya, It is a critical investigation and product of sound scholarship on Garhwal Geology. In the last two decades, study of stratigraphy, structure and metamorphism has constituted one of the most ground-breaking endeavours. Infact, it is difficult to understand properly the geology of the Himalaya without sufficient knowledge of these aspects. This volume of Professor P.S. Saklani specifically aims to contribute and extend this field of inquiry by dealing with several interrelated problems.

Its contents share a conviction that geology of Garhwal must be probed to resolve the mystery of its geological arena.

This volume possesses material, data and resources based principally on the author's own research, in a comparative and critical matrix of modern works and of other distinguished geoscientists, Infact, it helps to bridge the vacuum in regard to acceptance and transgression of modern thought relevant to geothemes and problems of the rock structures. Equally important is the fact that the region studied in great depth exists in the belly of the highest mountain of the world, the Himalaya; a frontier geological laboratory of the globe.

The book will be useful for geologists, academics, research scholars and also for those interested in abundant complex problems of the Himalayan geology.

255 Pages, 24 plates, 100figs., Tables and coloured Geological Map Rs. 800.00 $ 75.00

SATISH SERIAL PUBLISHING HOUSE
403, Express Tower, Commercial Complex, Azadpur, Delhi - 110033 (INDIA)
Phone : 011-27672469, 27672852 Fax : 91-11-27672046
E-mail : ssp@ndf.vsnl.net.in, hkjain1975@yahoo.com
Website : www.satishserial.com

ISBN 81-89304-04-6
9788189304041