GEOCHRONOLOGICAL STUDIES OF HIMALAYAN GRANITOIDS

By

Jayshanker R. Trivedi

A THESIS

SUBMITTED FOR THE DEGREE OF

DOCTOR OF PHILOSOPHY

OF THE

GUJARAT UNIVERSITY

July 1990

PHYSICAL RESEARCH LABORATORY

AHMEDABAD

INDIA

To

My Guruji

Gopalan

C E R T I F I C A T E

I hereby declare that the work presented in this thesis is original and has not formed the basis for the award of any degree or diploma by any University or Institution.

J.R.Trivedi

(Author)

Certified by:

B.L.K.Somayajulu

Professor-in-charge

CONTENTS

BRIEF OUTLINE OF THE THESIS

The Himalayan mountain range is one of the most prominent geological features on the surface of the Earth. This mountain range is a result of collision between the Indian and Eurasian continental plates and offers an excellent setup to examine the physical causes and mechanisms of mountain building. Studies of igneous rocks which are the principal units of the Himalaya play an important role in revealing these mechanisms.

Granitoids of large dimensions occur in all the structural zones of the Himalaya except in the Sub Himalaya. These granitoids are exposed in linear belts parallel to the Himalayan trend. They are widely distributed in space and time from Trans Himalaya to Lesser Himalaya and from Early-Precambrian to as young as Late-Tertiary, revealing atleast 2000 Ma old history of plutonism and granitization. The present geochronological studies are confined to granitoids exposed in four of the five longitudinal zones.

This thesis describes an attempt to gain insight into afew of the problems related with the correlation of Lesser Himalayan metamorphic nappes and the tectonic significance of granitoids of the Himalaya using the Rb-Sr (isochron) dating method. Specifically, two problems have been addressed :

1. Chronology and significance of the granitoids from different zones of the Himalaya.

2. The correlation of the Kumaun Lesser Himalayan nappes and their associated klippen.

About 100 analyses on whole rocks and about 25 analyses on their constituent minerals have been carried out. A detailed discussion of the present work along with that available in literature is presented. The implications are discussed in the context of the evolution of the Himalaya.

The thesis is divided into seven chapters, a brief summary of each is given below:

Chapter 1 : The geology of the Himalaya with emphasis on the clssification of the rock sequences provided by Gansser (1964), Valdiya (1980a, 1983) and others, is described.

Geologically, the Himalaya are divided into five longitudinal structural zones which are delineated from one another by boundary thrusts. In a north to south traverse these zones are : (1) Trans Himalaya (2) Tethys Himalaya (3) Great Himalaya (4) Lesser Himalaya and (5) Sub Himalaya.

Chapter 2 : A critical and detailed survey of the existing geochronological data on the Himalaya, obtained bydifferent isotopic techniques, is presented to provide the background for the present investigation.

Chapter 3 : The outcrops of granites or granitic rocks associated with different tectonic zones that were sampled in the present investigation are described in relation to their appropriate field settings.

Chapter 4 : The experimental methods used for sample crushing, mineral separation, sample dissolution, isotope dilution and isotopic measurements by mass spectrometry are described in this chapter. Mass spectrometric analysis based on manual peak jumping and recording with chart recorder have a precision of about 2% for $^{87}Rb/^{86}Sr$ and 0.1% for $^{87}Sr/^{86}Sr$. Blank analysis run in parallel with samples show negligible contamination at the levels of Rb and Sr normally handled. An automated data acquisition system using an IBM-PC/XT developed by the author during the course of this work has enhanced the precision of analysis.

The data have been plotted on Sr evolution diagrams to calculate the age of isotopic equilibration of a given set of related samples and the Sr isotopic composition at equilibration using a two-error least-squares regression method. Criteria have been developed to distinguished departure from perfect isochronism - other than due to experimental errors. The whole rock ages fall into three age groups at 1800-2000 Ma, 450-550 Ma and 30 Ma, whereas, mineral ages vary from 16-470 Ma.

Chapter 6 : The implications of the age data to the geological sequence, emphasizing the agreement or otherwise between the traditional belief and the new findings regarding the Himalayan tectogenesis are presented in this chapter. The data are discussed in terms of a general framework for the chronology of the Himalayan rock units.

The principal findings of this research are :

1 Three prominent phases of magmatism/metamorphism in the Himalaya have been found, one of them related to the Himalayan Orogeny (Tertiary) and the other two being Pre Himalayan dated at 470-560 Ma and 1800-2000 Ma.

2 Definitive evidence for the wide spread occurrence of 1800 Ma old components in much of the Kumaun Lesser Himalayan material and their possible equivalents in the Peninsular region of India is obtained.

3 The results enable identification of more than half a dozen acidic igneous plutons intruded during Early Palaeozoic time (~500 Ma) in different tectonic settings all along the Himalayan range. It is likely that these granitic activities represent a Pre Himalayan Orogeny.

4 At least some components of the Ladakh batholith are of Permo-Triassic age i.e. older than Himalayan Orogeny. These are considered to be the probable remnants of older continental material in the area north of the Suture Zone.

Anolog recording of mass spectrometer data followed by manual reading of peak heights have limited the precision of isotopic ratio measurements to not better than 0·1% . The initial Sr ratios therefore, could not be determined to the accuracy required for petrogenetic interpretations. However, the following broad generalizations can be made.

1. Early Precambrian granites and gneisses with $(^{87}Sr/^{86}Sr)_i$ = 0.7090-0.7230 and Early Palaeozoic granite with $(^{87}Sr/^{86}Sr)_i$ = 0.7088-0.7181 originated in the upper crust either due to fusion of the pre-existing sedimentary material or regional metamorphism of their igneous precursors.
2. The Tertiary Sela granite with $(^{87}Sr/^{86}Sr)_i$ = 0.7950 was formed from anatectic magmas generated by partial melting of the crustal material during the Himalayan Orogeny and
3. A Permo-Triassic granite with $(^{87}Sr/^{86}Sr)_i$ = 0.7081 (Gaik granite which crystallized 230 Ma ago) which is a part of Ladakh batholith in the Trans Himalaya was derived probably from a Rb-poor source. Evolution of the Lesser Himalayan nappes/ tectonostratigraphic units have been a major subject of debate and many models have been proposed. A comprehensive correlation between different tectonic units of Kumaun Lesser Himalaya and a chronological framework for the evolution of the Himalayan region, especially in the respect of processes and time scales for magmatic/metamorphic events, are provided by the studies in this thesis.

The main conclusions of this study along with the suggested lines for future work in the region are presented in the concluding **Chapter 7**.

ACKNOWLEDGEMENTS

Professor K.Gopalan suggested this project and introduced me to the field of geochronology and I am indebted to him. I sincerely thank Professor B.L.K.Somayajulu for guiding me throughout the course of this investigation.

I thank Professor S.Krishnaswami for valuable suggestions and criticisms. I also thank Professor D.Lal and Professor R.K.Varma for their encouragement.

Professor K.S.Valdiya of the Kumaun University, Nainital and Professor K.K.Sharma of the Wadia Institute of Himalayan Geology, Dehradun have very kindly enlightened me on the subtle and controversial aspects of Himalayan geology. I am grateful to them.

I am thankful to Dr.D.K.Paul (Director) and Mr.J.K.Bhalla (Sr.Geologist) of the Geological Survey of India, Calcutta and Dr.K.R.Gupta of the Department of Science and Technology, New Delhi for advice and support during the field work/sample collection.

My special thanks are due to Dr.Kanchan Pande for his numerous suggestions/helps which considerably improved the thesis.

I have benefitted from occasional discussions I had with Drs.T.R.Venkatesan, J.N.Goswami, Ashok Singhvi, S.V.S.Murty, R.Ramesh, M.M.Sarin, S.K.Bhattacharya, P.N.Shukla and R.K.Pant.

Mr.V.G.Shah very kindly introduced me to the mysteries of computer hardware.

Sarvasri H.D.Nagewadia, J.M.Panchal, K.K.Sivasankaran, M.P.K.Kurup and A.R.S.Pandian offered innumerable help during the course of this investigation and I sincerely thank them all.

Cheerful company given by Padia, Rashmi, Mathew, Rengarajan, Pauline and Anjan and Rathore made this work more enjoyable.

Dedicated help given by Vaghela, Bhavsar and Gangacharan is thankfully acknowledged.

Valuable help was rendered by Mr.D.R.Ranpura, Mr.J.G.Vora and Mr.S.K.Bhavsar during the preparation of this thesis. The Library staff members, especially Mrs.Urmilaben Ghiya and Mrs.Kokilaben Bhatt, have extended their full cooperation and I am thankful to all of them.

I appreciate the neat typing of this thesis by Mr.K.R.Nambiar.

This work would never have been possible but for the constant push, love and affection given by my wife, Jayshree and my daughters Prutha and Dhara.

Finally I wish to thank my parents and other family members for their encouragement all these years.

J.R.Trivedi

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

The Himalayan mountain range, extending over 2400 km from Indus river in the west-northwest (elevation at Nanga Parabat = 8125 m) to the Brahmputra river in the east (elevation at Namche Barwa = 7755 m) has an average width of about 200-250 km. This very young and the highest mountain range in the world is considered to have arisen as a result of subduction of the oceanic lithosphere of the Indian plate under the Tibetan plate followed by a collision between the two continental blocks of India and Tibet, respectively (Dewey and Bird, 1970; Powell and Conaghan, 1973; Le Fort, 1975). This hypothesis of continent-continent collision for Himalayan Orogeny is supported by the majority of workers.

The geology and structure of the Himalaya have been

CHAPTER 1

INTRODUCTION

The Himalayan mountain range, extending over 2400 km from Indus river in the west-northwest (elevation at Nanga Parabat = 8125 m) to the Brahmputra river in the east (elevation at Namche Barwa = 7755 m) has an average width of about 200-250 km. This very young and the highest mountain range in the world is considered to have arisen as a result of subduction of the oceanic lithosphere of the Indian plate under the Tibetan plate followed by a collision between the two continental blocks of India and Tibet, respectively (Dewey and Bird, 1970; Powell and Conaghan, 1973; Le Fort, 1975). This hypothesis of continent-continent collision for Himalayan Orogeny is supported by the majority of workers.

The geology and structure of the Himalaya have been explored for more than a century dating back to the work of Stoliczka (1865) and Lydekker (1883). Subsequent workers have generally carried out numerous but isolated and localized studies. An excellent regional synthesis on Himalayan studies has been provided by Gansser (1964).

The geologic structure of the Himalaya can be conveniently divided into a series of terrains separated from each other by boundary thrusts approximately parallel to each other (Fig 1.1). From north to south these zones are : (1) Trans Himalaya, (2) Tethys Himalaya, (3) Great Himalaya, (4) Lesser Himalaya and (5) Sub Himalaya. Despite variations along the strike, these terrains can be traced for most of the length of the range. Therefore, cross sections at different parts of the range are quite similar to one another. The gross features of the geology of the Himalaya, therefore, can be illustrated by one such cross-section (Fig.1.2).

It is also customary and useful, for the purpose of description, to divide this range into seven geographic transverse sections viz. Kashmir, Himachal, Kumaun, Nepal, Sikkim, Bhutan and Arunachal (Fig.1.3).

The Kumaun Himalaya, lying between the Kali and Tons rivers, has been the most intensely studied section. It exhibits the full development of all the lithotectonic and physiographic zones. The Kumaun Himalayan section therefore serves to illustrate the Himalayan geology and tectonic structure (Gansser, 1964; Valdiya, 1980a).

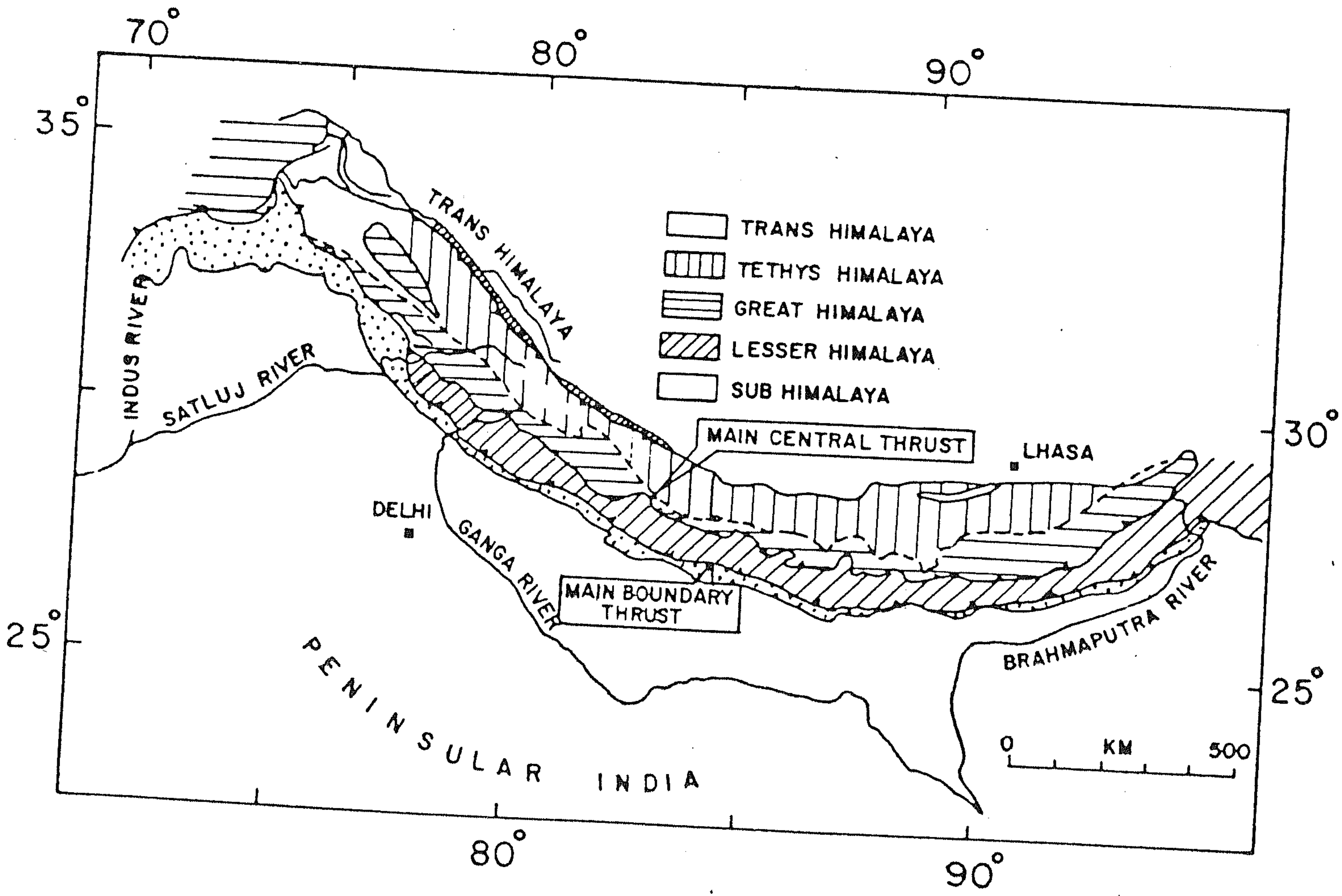


Fig.1.1 The Litho tectonic zones of the Himalaya

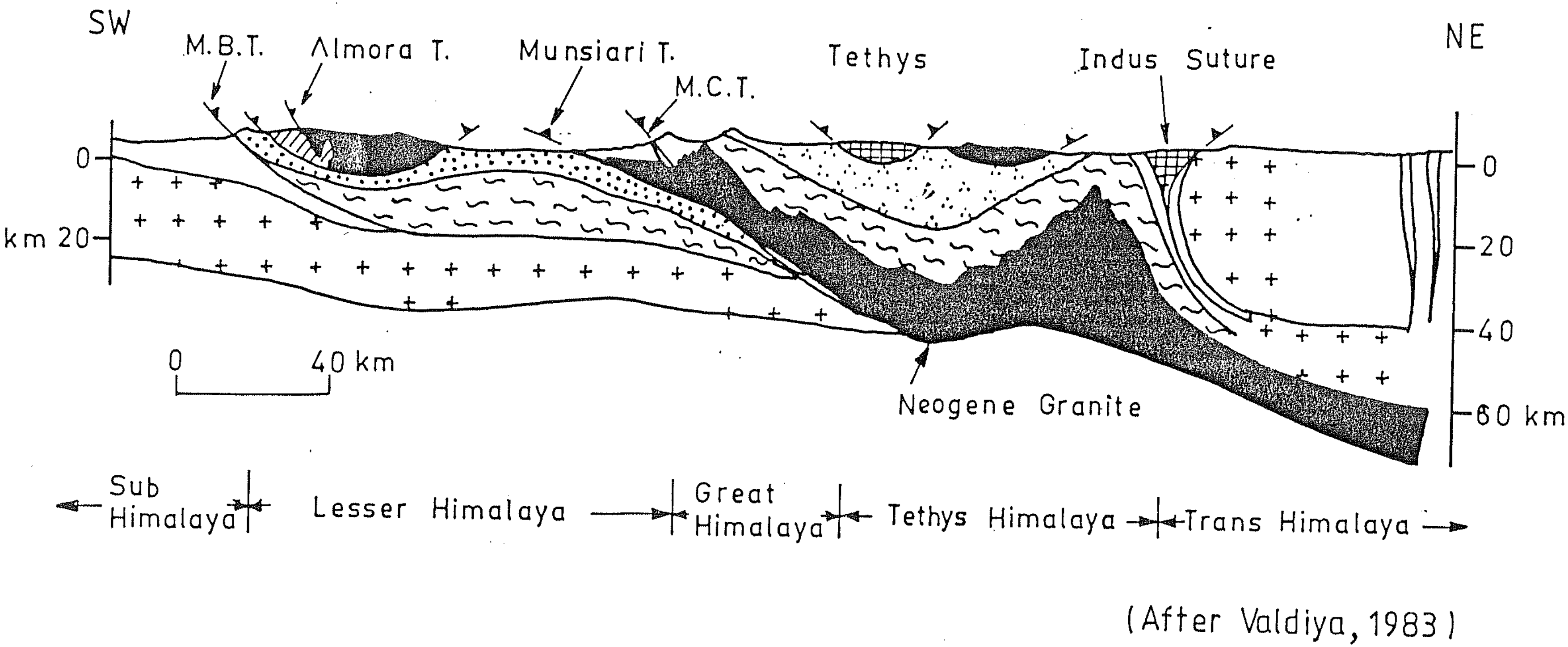


Fig.1.2 Generalized cross section of the Himalaya (After Valdiya,1983)

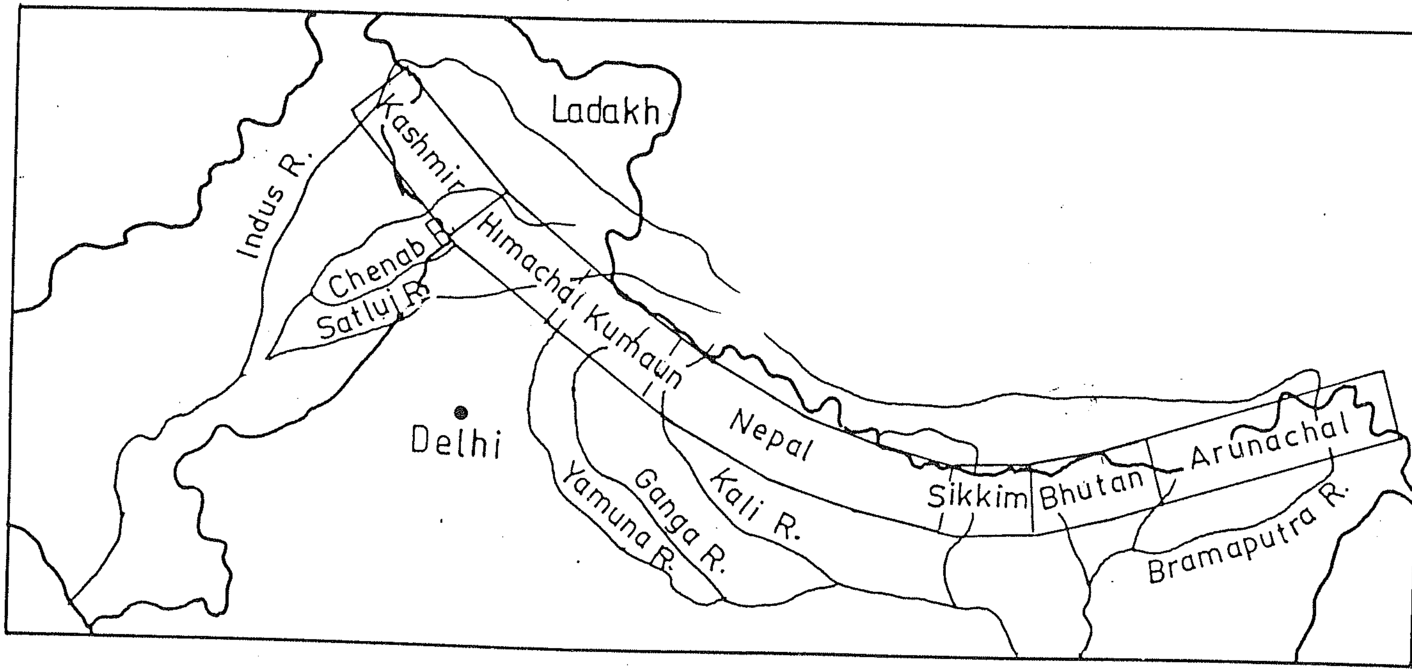


Fig.1.3 Geographic sub-divisions of the Himalaya

(1) Trans Himalaya :

The Trans Himalaya lies to the north of the Indus Tsangpo Suture Zone (ITSZ). A chain of granodioritic batholiths which intrude into Palaeozoic-Mesozoic sediments and volcanics is known as the Ladakh-Kangdese (or Gangdese) granites. This belt of granites is bifurcated at Karakorum and Ladakh in the west and extends through Kailas to Lhasa in the east. It has a width of about 50 km.

(2) Tethys Himalaya :

The Tethys Himalaya is sandwiched between ITSZ and the Trans-Himadri thrust (Valdiya, 1987). This zone comprises of a predominantly fossiliferous sedimentary sequence of the Tethyan basin ranging in age from late Precambrian to Eocene. The sedimentary rocks are intruded by granites at several places and are well exposed in Kashmir, Zanskar, Spiti and Nepal.

(3) Great Himalaya :

The Great Himalayan zone marks the region of the tallest peaks of the Himalaya viz. Nun-Kun, Leoparagil, Kedarnath, Badrinath, Nandadevi, Nampa, Dhaulagiri, Api, Everest and Kanchanjanga. This zone is delimited by Trans-Himadri thrust in the north and the Main Central Thrust (MCT) in the south. There are various views about the location of the MCT (Valdiya, 1980a and b, 1981). One of the most characteristic geologic features in the Great Himalaya is the presence of tourmaline bearing granites, besides older biotite granites, intruding high grade katazonal metamorphics commonly termed as the "Central Crystallines". These central crystallines form the basement for the Tethyan sediments.

(4) Lesser Himalaya :

Bounded by MCT in the north and MBT in the south, the geomorphologically mature Lesser Himalayan zone is largely made up of Rippean sediments and allochthonous crystalline nappes and Klippen. Several granitic plutons are exposed in all the lithotectonic units.

(5) Sub Himalaya :

The Sub Himalayan zone, also known as the Siwaliks, is separated from the Ganga basin in the south by the Himalayan Frontal Fault (HFF). The MBT separates it from the Lesser Himalaya in the north. This zone is made up of Early to late Tertiary and Quaternary sediments. These sediments are deposited in a basin formed in the foredeep of the rising Himalaya. These mollasic sediments are derived from the erosion of the Himalayan ranges.

The fine structure and correlation of the various sections have remained problematic, especially in the Lesser Himalaya, mainly because of the unfossiliferous nature of sediments and the lack of geochronological data on the metamorphic nappes. Radiometric dating of the Himalayan granites and metamorphics has been underway since the pioneering work of Krummenacher (1961) to resolve these problems. However, the data, even today, are of a reconnaissance nature primarily because of the inaccessibility of the terrain. Also, the available geochronological data are based on different isotopic chronometers applied to a variety of rock types rendering direct correlation and comparison of the data difficult or ambiguous.

This thesis describes an attempt to gain some insight into a few of the problems related with the correlation and the tectonic significance of granitoids* of the Himalaya using the Rb-Sr isochron method. Specifically, two problems have been addressed:

1. The correlation of the Kumaun Lesser Himalayan nappes and
2. Chronology and significance of the granitoids from other parts of the Himalaya.

Since Kumaun Himalaya, as stated earlier, is an epitome of the entire Himalayan range, correlation of the tectonic units could be extended to the other parts of the range. For this purpose, granites and gneisses from different lithotectonic units of the Kumaun Lesser Himalayan region were systematically sampled and analysed.

---

* In this thesis, the term granitoid and granite are used in their wider sense to include gneisses, granites, adamallites, granodiorites, quartzodiorites.

As shown in Fig 1.4 granitoid bodies of varying dimensions occur in most of the Himalayan regions. Significantly, these occur in long linear belts along the entire length of the range. Available geochronological data indicate the presence of pre-Himalayan events in addition to Tertiary magmatism. In this thesis, I have attempted to evaluate the significance of some of the granitoid bodies exposed in all the four structural zones of Himalaya.

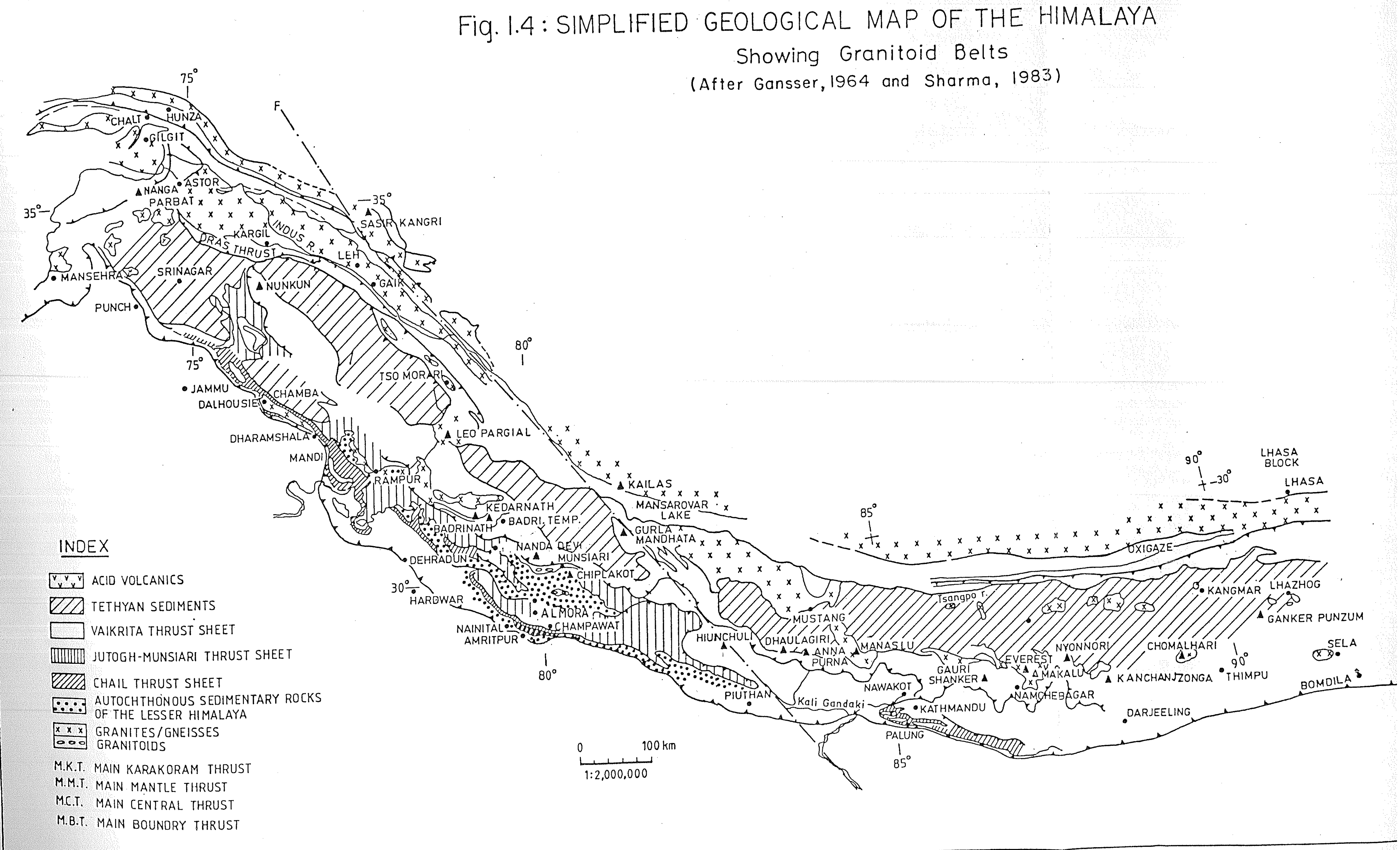


Fig. 1.4 : SIMPLIFIED GEOLOGICAL MAP OF THE HIMALAYA
Showing Granitoid Belts
(After Gansser, 1964 and Sharma, 1983)
INDEX
ACID VOLCANICS
TETHYAN SEDIMENTS
VAIKRITA THRUST SHEET
JUTOGH-MUNSIARI THRUST SHEET
CHAIL THRUST SHEET
AUTOCHTHONOUS SEDIMENTARY ROCKS OF THE LESSER HIMALAYA
GRANITES/GNEISSES
GRANITOIDS
M.K.T. MAIN KARAKORAM THRUST
M.M.T. MAIN MANTLE THRUST
M.C.T. MAIN CENTRAL THRUST
M.B.T. MAIN BOUNDRY THRUST
0 100 km
1:2,000,000
75°
35°
80°
85°
90°
30°
F
CHALT
HUNZA
GILGIT
ASTOR
NANGA PARBAT
SASIR KANGRI
KARGIL
INDUS R.
DRAS THRUST
LEH
GAIK
MANSEHRA
SRINAGAR
NUNKUN
PUNCH
TSO MORARI
JAMMU
CHAMBA
DALHOUSIE
DHARAMSHALA
LEO PARGIAL
MANDI
RAMPUR
KAILAS
KEDARNATH
BADRINATH
BADRI TEMP.
MANSAROVAR LAKE
GURLA MANDHATA
NANDA DEVI
MUNSIARI
DEHRADUN
CHIPLAKOT
HARDWAR
ALMORA
NAINITAL
AMRITPUR
CHAMPAWAT
MUSTANG
HIUNCHULI
DHAULAGIRI
ANNA PURNA
MANASLU
PIUTHAN
Kali Gandaki
NAWAKOT
KATHMANDU
PALUNG
GAURI SHANKER
EVEREST
MAKALU
NAMCHEBAGAR
NYONNORI
KANCHANJZONGA
CHOMALHARI
THIMPU
SELA
BOMDILA
DARJEELING
Tsangpo r.
OXIGAZE
KANGMAR
LHAZHOG
GANKER PUNZUM
LHASA BLOCK
LHASA

CHAPTER 2

CRITICAL REVIEW OF THE PREVIOUS GEOCHRONOLOGICAL DATA

The Himalayan region has been the focus of geochronological studies over the last thirty years beginning with the pioneering work of Krummenacher (1961). However, the data, even today, are of a reconnaissance type except for some parts of Ladakh, Himachal, Nepal and the Lhasa block. Age data have been reported on a variety of rock types by all principal radioactive decay schemes viz. Rb/Sr, U/Pb, K/Ar, Sm/Nd and U/fission tracks, but analyses with reliable field controls, especially in the Lesser and Great Himalaya for any definitive interpretations, have been very few in number.

A comprehensive compilation of the available geochronological data up to 1983 from the Himalaya has been presented by Crawford (1981). A useful summary of the data for the granitoids belts is provided by Sharma (1983). Both these works, however, have not evaluated the data critically in the light of fact that data based on different isotopic chronometers applied to a variety of rock types render direct correlation and comparison difficult and/or ambiguous.

In the polyphasedly deformed and metamorphosed Himalayan terrain, the K/Ar and fission track ages can be easily reset by secondary events. In such cases the Rb/Sr and Sm/Nd data based on the multi sample isochron method are more reliable than the Rb/Sr and Sm/Nd model ages based on single samples. The bulk of the ages reported for Himalaya are K/Ar and Rb/Sr model ages and therefore need critical evaluation. The U/Pb studies on zircons which could yield original ages despite gain or loss of parent/daughter elements are very rare. With strict criteria of data selection, only a small fraction of the ages from Himalaya can be considered as definitive. However, the more recent data on the Trans Himalayan granites and the Himalayan leucogranites are of high quality.

The present discussion will be confined to the data on only granites and gneisses from the different tectonic zones.

2.1 Trans Himalaya :

The chain of granitic batholiths, in the southern Tibet and Ladakh known as the Trans Himalayan granites are generally ascribed to the subduction of oceanic lithosphere beneath the southern margin of Eurasia around 100 Ma ago. Most reported ages for these granites have been obtained by the K-Ar method (Bally et al. 1980; Zhang et al. 1981; Sharma et al. 1978; Zhou et al. 1981) a few by $^{39}Ar/^{40}Ar$ (Brookfield and Reynolds, 1981, Maluski et al. 1982) and Rb-Sr (Honegger et al 1982, Tu et al 1981) and U-Pb (Honegger et al. 1982) techniques. These ages are consistent with the intrusions of granites from 110 to 40 Ma ago, although some of the ages are as old as 120 Ma. A few younger ages in the range of 40 to even 10 Ma (Sharma et al. 1978a and Tu et al. 1981) are also reported but the significance of these dates is not clear.

2.2 Tethys Himalaya :

The biotite-muscovite granites, south of the suture zone known as Laghoi Kangri belt are distinct from the tourmaline granites, Makalu type of the Great Himalaya and the Hornblende bearing Trans Himalayan granites in the north. Not much geochronological data exist for this long belt of granites. Frank et al (1977) reported a six point whole rock (WR) Rb-Sr isochron age of 512±16 Ma for Jaspa granite from Himachal.

The Kangmar granite in the Lhasa block has been dated at 485±6 Ma (Wang et al 1981) and 484±7 Ma (Debon et al 1981) by the Rb-Sr whole rock isochron method. However, a U-Pb age of 562±4 Ma for this pluton has been reported by Schärer et al (1986). The age difference of about 80 Ma between U-Pb and Rb-Sr ages (562 vs 485 Ma) has been attributed either to a much later closure of Rb-Sr whole rock system or a subsequent re-equilibration at whole rock scale. Le Fort et al (1982) reported an age of 517±62 Ma for the augen gneisses from Nepal. From this limited information it can inferred that the Tethyan granites and gneisses represent a magmatic/metamorphic event around 500 Ma.

2.3 Great Himalaya :

The granites and gneisses of the Great Himalaya belong to two distinct generations - the tourmaline bearing leucogranites which appear frequently at high elevations and the biotite granites similar to those of Lesser and Tethys Himalaya.

The significant isotopic variations in the Himalayan leucogranites have rendered the whole rock (WR) Rb-Sr isochron age determination difficult. The ages of intrusions of different leucogranitic bodies have been roughly estimated by Dietrich and Gansser (1981) between 30 Ma and 12 Ma. The 29±1 WR Rb-Sr isochron age of the Manaslu granite by Hamet and Allègre (1976, 1978) was questioned by Vidal (1978) on the basis of isotopic heterogeneity of the samples. However, a reliable Rb-Sr WR isochron age of 18.1±0.5 Ma has been obtained by Deniel et al (1983). Deniel et al (1987) reported U-Pb age of 25 Ma for this granite. The difference of 7 Ma in the Rb-Sr and U-Pb ages led them to suggest that this magmatic activity lasted at least 7 Ma.

Kai (1981a,b) reported Rb-Sr WR isochron age of 92.7±9.4 Ma for the Makalu leucogranite including some two mica granites. This age seems to be unrealistic and probably is an artifact of partial homogenization of the older granitic rocks. The Rb-Sr ages on muscovites and biotites from the leucogranites and pegmatites have yielded younger ages ranging 17-11 Ma similar to the K-Ar ages (Hamet and Allègre, 1978; Kai, 1981a,b).

The U-Pb ages on zircons and monazite have yielded ages of 16.8±0.6 Ma for the Nialam migmatite granite, 15.1±0.5 Ma for the Lhagoi Kangari granite, 14.3±0.6 Ma for the granite from Mt. Everest and 9.8±0.7 Ma and 9.2±0.9 Ma for two varieties of the Maja granite (Schärer et al. 1986).

The available geochronological data for the leucogranites indicate a period from 24 Ma to 9 Ma for these plutonic activities. This is consistent with the view that all these leucogranites are anatectic in origin and result from intracrustal collision between India and Eurasia.

The Great Himalayan rocks are also intruded by huge bodies of biotite granites of older ages. The Kinnar Kailas granite and the Karcham Sangla gneiss have been dated at 675±70, 495±50 respectively by Bhanot et al (quoted in Sharma, 1983) but not much information is available to assess these numbers.

A four point WR Rb-Sr isochron age of 467±46 for Manikaran has been given by Bhanot et al (1979). Mehta (1977) reported 581±9 Ma for central gneisses from Rohtang pass and 500±8 Ma for Kulu migmitite gneiss (using Rb of 1.47×10^{-11}yr). These ages become 600±9 Ma and 518±8 Ma granites. This age seems to be unrealistic and probably is an artifact of partial homogenization of the older granitic rocks. The Rb-Sr ages on muscovites and biotites from the leucogranites and pegmatites have yielded younger ages ranging 17-11 Ma similar to the K-Ar ages (Hamet and Allègre, 1978; Kai, 1981a,b).

The U-Pb ages on zircons and monazite have yielded ages of 16.8±0.6 Ma for the Nialam migmatite granite, 15.1±0.5 Ma for the Lhagoi Kangari granite, 14.3±0.6 Ma for the granite from Mt. Everest and 9.8±0.7 Ma and 9.2±0.9 Ma for two varieties of the Maja granite (Schärer et al. 1986).

The available geochronological data for the leucogranites indicate a period from 24 Ma to 9 Ma for these plutonic activities. This is consistent with the view that all these leucogranites are anatectic in origin and result from intracrustal collision between India and Eurasia.

The Great Himalayan rocks are also intruded by huge bodies of biotite granites of older ages. The Kinnar Kailas granite and the Karcham Sangla gneiss have been dated at 675±70, 495±50 respectively by Bhanot et al (quoted in Sharma, 1983) but not much information is available to assess these numbers.

A four point WR Rb-Sr isochron age of 467±46 for Manikaran has been given by Bhanot et al (1979). Mehta (1977) reported 581±9 Ma for central gneisses from Rohtang pass and 500±8 Ma for Kulu migmitite gneiss (using Rb of $1.47X10^{-11}$yr). These ages become 600±9 Ma and 518±8 Ma respectively when renormalized for $\lambda = 1.42 \times 10^{-11}$ yr^{-1}. These Early Palaeozoic granites and gneisses have been interpreted as due to synkinematic high grade metamorphism and migmitization during a last Precambrian-Cambrian event probably the Assyntian (Cadomian) orogenic cycle by Mehta (1977).

2.4 **Lesser Himalaya** :

Granites and gneisses are exposed in nappes and autochthonous sediments of the Lesser Himalaya. The available geochronological data for this area are of variable quality. Bulk of the Rb-Sr ages reported so far are either model ages or isochrons based only on two or three points or isochrons having very large scatter in the data points or high analytical errors.

The reliable Early Palaeozoic Rb-Sr age data are: 500±100 Ma and 545±12 for Mandi granite (Jäger et al. 1971 and Mehta, 1977), 516±16 Ma for Manserah granite, Pakistan (Le Fort et al. 1980), 486±10 Ma for Palung granite (Mitchell et al. 1981) and 511±55 Ma for Simchar pluton (Le Fort et al 1983). Schärer et al (1986) confirmed the age of Palung granite (470±4 Ma) by the U-Pb method. Mehta (1977) and Frank et al (1977) relate these Early Palaeozoic ages to Pre Himalayan Orogeny whereas Le Fort et al(1980, 1983) attribute these magmatic activities to some epi-orogenic events.

Besides the Early Palaeozoic event, indications based on the Rb-Sr WR isochron method, are also given for the presence of Precambrian basement by Frank et al (1977) and Raju et al (1982) in Himachal and Garhwal.

The data by Bhanot et al. (1981), Pande et al(1981a,b) and Singh et al (1985, 1986) also fall within this age range. However, these data are of variable quality due to large analytical errors (1% errors on $^{87}Sr/^{86}Sr$ and 5% errors on $^{87}Rb/^{86}Sr$). The Rb-Sr WR isochron age of 1620±90 Ma by Powell (979) is not acceptable because the regression of isochron is performed on samples from different thrust sheets. Similarly, Rb-Sr WR isochrons ages of 1275±12 Ma and 1139±46 Ma by Bhattacharya et al (1982), 1090±28 Ma by Paul et al. (1982) and 1020±29 Ma by Sinha Roy and Sen Gupta (1986) are of questionable quality because the recalculation of the data does not reproduce the reported values.

The Rb-Sr WR isochrons age of 311±16 Ma for the Mandi leucogranite reported by Mehta (1977) is the only reliable age falling within the Hercynian cycle. Though 322±10 Ma and 360±8.5 Ma Rb-Sr model ages for Mandi muscovites and several K-Ar ages in the range of 290-360 reported by Krummenacher (1966, 1971) and Saxena and Miller (1972) have been used to support his contention for a Hercynian cycle in the Himalaya, reliable ages within this time bracket from other parts of the Himalaya have not been reported so far.

The foregoing discussions indicate that the vast Himalayan region , the Tethys and the Lesser Himalaya in particular, need better quality data in more focused areas in order to have meaningful geological significance.

However, the published age data indicate three major geological events in the Himalayan region as shown in the form of two histograms (Fig.2.1). The sources of data are given in the figure caption. Fig 2.1a shows the histogram of ages obtained by K-Ar and fission track (FT) methods whereas Fig 2.1b shows these obtained by Rb-Sr and U-Pb methods. The histograms reveal the strong imprint of the Himalayan Orogeny showing prominent peaks at Tertiary. The wide range of ages in Fig 2.1a as against Fig 2.1b can be attributed to loss/gain of argon by rocks/minerals. Fig 2.1b shows peaks at 450-600 Ma and 1800-2000 Ma period in addition to the Tertiary indicating Precambrian magmatic/metamorphic events. Majority of the data in the age group 1400-1000 Ma are not reliable as discussed earlier. Considerable debate exists about the meaning of the Early Paleozoic event in the region and also on its correlation with global tectonics. This needs to be looked into from various angles.

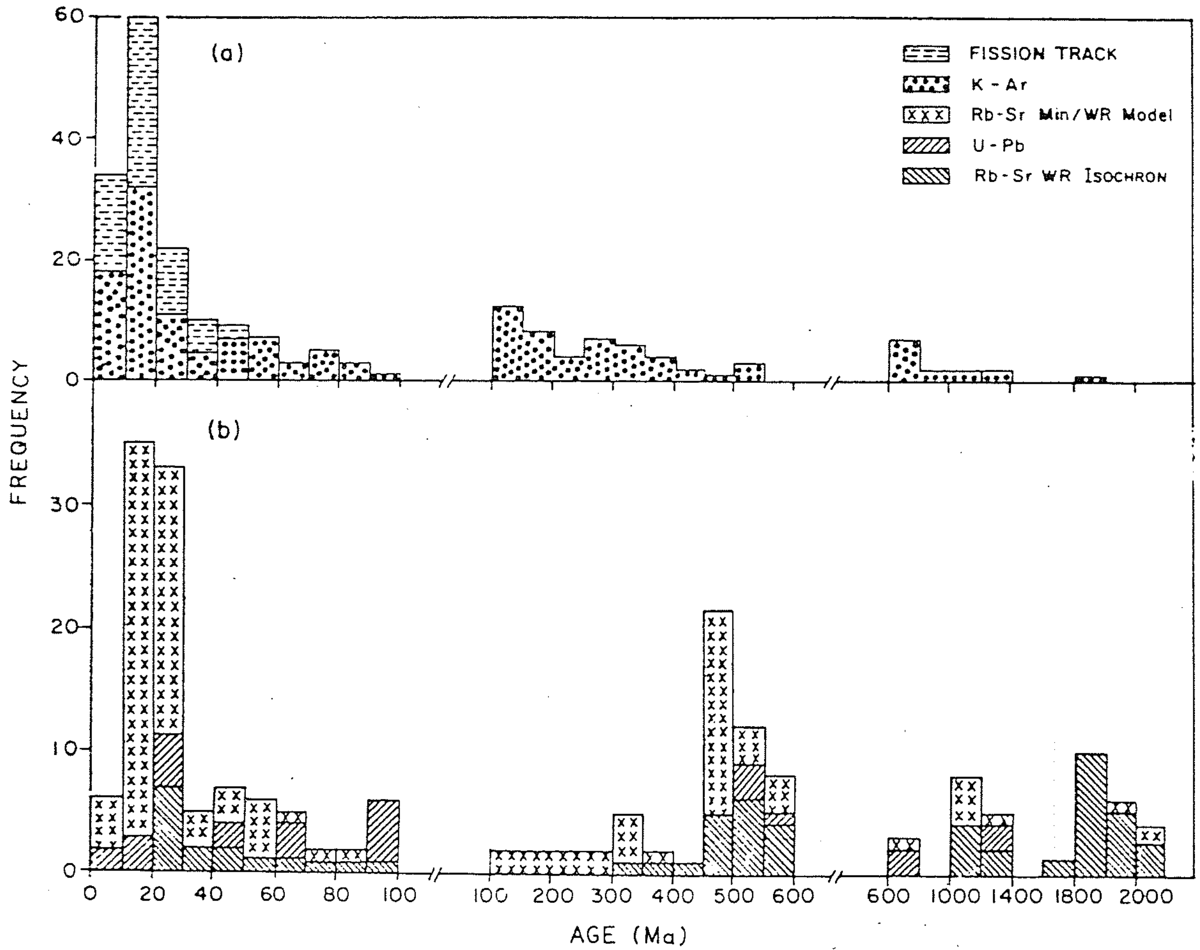


Fig.2.1 Histogram showing radiometric ages from the Himalaya

Fig 2.1 Histogram showing radiometric ages from the Himalaya. Data compiled from following sources.

Acharya (1973),
Andrieux et al (1977),
Ashgierei et al (1975, 1977),
Bhalla and Gupta (1979),
Bhanot et al (1974, 1975, 1976a,b ,1977, 1978, 1979),
Bhattacharya et al (1982)
Brookfield and Reynolds (1981),
Desio et al. (1964)
Dietrich and Gansser (1981),
Dixit (1977),
Frank (1973, 1977),
Gariepy et al (1985)
Hamet and Allegre (1976, 1978)
Honegger et al (1982)
Jäger et al (1971)
Kai (1981a,b,c)
Khan and Tater (1970)
Krummenacher (1961, 1966, 1971, 1978)
Le Fort et al (1980)
Mehta (1977),
Mehta and Rex (1977),
Mitchell (1981)
Nagpal et al (1973)
Pande and Kumar (1974)
Paul et al (1982)
Powell et al (1979)
Raju et al (1982)
Sarkar et al. (1964),
Saxena and Miller (1972),
Schärer et al (1984a,b,c, 1986)
Seitz et al (1976)
Sharma et al (1978)
Singh et al (1985, 1986)
Singh R P et al (1986)
Sinha (1975),
Sinha and Bagdasarian (1977),
Sinha Roy and Sen Gupta (1986).
Talalov (1972)
Varadarajan (1977, 1978)
Vidal (1978)
Xu et al (1985)

CHAPTER 3

DESCRIPTION OF THE GRANITIC BODIES

Granites and gneisses occur in all the tectonically distinct zones, except the Sub Himalaya, with diverse lithostratigraphic settings. In the Lesser Himalaya, the porphyritic granites of Precambrian age are highly sheared and mylonitized, but occur paradoxically in the epi-metamorphic thrust sheet. These granites seems to represent the granitic basement on which the Lesser Himalayan sediments were deposited. The tonalite-granodiorite bodies with marginal augen gneisses of granitic composition, that occur in the meso-metamorphic thrust sheet emplaced upon the epi-metamorphic nappes, are compositionally different and younger in age. Both the porphyritic granites within the epi-metamorphics and the trondhjemitic suite of the meso-metamorphics have been intruded concordantly by leucocratic adamellites which are comparatively less deformed.

The Kata-metamorphic assemblages of the Great Himalaya are characterized by batholiths, stocks, dykes and veins of granites and aplites of Tertiary age. These undeformed granites are post tectonic. The pre-Himalayan granites, which are biotite rich and quite distinct from the post tectonic two-mica granites, are also present in the region.

Granitic plutons of different characteristics compared to those of Trans Himalayan granites are exposed in Tethyan sedimentary sequence which are well exposed and easily accessible in the Kashmir region. In Zanskar region just south of ITSZ, this granite represents one of the northern most parts of the Indian platform. Their probable equivalents in the eastern part are exposed in Kangmar region.

The granodiorite-quartzdiorite bodies associated with calc-alkaline volcanics occupy the Indus-Tsangpo Suture Zone. This granitic association represents an Andean-type magmatic arc that evolved as a consequence of collision and under thrusting of the Indian plate into the Eurasian plate at the beginning of the Tertiary period.

Granitoid Samples have been collected from all these four zones representing different sectors of the range. The Ladakh batholith is known to be a complex of granitic rocks of different composition. The Gaik granite exposed to the south of Leh is much different in composition and situated in different tectonic environment than most of granites in the Ladakh batholith. This granite is dated in order to decipher its origin and correlate it with the rest of the batholith.

Correlation of different tectonic units of the Kumaun Lesser Himalaya using geochronological studies have been attempted. Therefore, granitic rocks were sampled from all the nappes and their representative Klippen of the region. The Tethys and the Great Himalayan region were also sampled to find granitic components in addition to that related to the Himalayan orogeny.

3.1 The Trans Himalaya :

A chain of granitic batholiths extend from one end of the range to the other known as the Ladakh-Kangdese belt. In the western part, this belt is bifurcated into the Ladakh and Karakorum batholiths. The northern belt, called the Karakorum axial batholith, lies to the North of the ITSZ and intrudes the Upper Paleozoic metamorphics. The southern belt, called the Ladakh-Deosai batholith, intrudes the Upper Cretaceous-Eocene rocks of the Indus suture zone.

The Ladakh batholith which occurs as a linear body measuring about 600 km in length, 25-75 km in width with an exposed thickness of 3 km, occupies a major part of the Ladakh range in the Trans Himalayan region. It is best exposed in the north-western Himalaya but continues westward into Astor-Deosai-Skardu area as reported by Auden (1935) and

Wadia (1937), and eastward into the Tibetan region as shown by Gansser (1977) and Tapponnier et al (1981). The Ladakh batholith has an intrusive relationship with the Dras volcanics near Burzil (Wadia, 1937) and Kargil Batalik area (Sharma, 1983) and a tectonic relationship with the rocks of the Indus-flysch between Kiari and Chumathang. At other places the southern contact of Ladakh batholith is covered by a linear belt of the Indus Molasses. The northern margin of Ladakh batholith is covered by the Shyok volcanics of the early Cenozoic period, which are acidic to intermediate (calc-alkaline) in composition (Sharma and Gupta, 1978).

The Ladakh batholith is composed mainly of quartz bearing rocks that vary widely in composition from quartz diorite, granodiorite, quartz-monzodiorite, quartz monzonite to granite. Occasionally, bodies of diorite, gabbro, pyroxenite and anorthosite are seen associated with the batholith. Also present are dykes of aplite, pegmatite, granophyre and lamprophyre. Though the bulk composition of the Ladakh granitoid is calc-alkaline, the batholith is a complex body composed of a large number of plutons of different compositions and character which can be readily distinguished from one another in the field by differences in texture and mineral composition as is evident in the Gaik-Kiari and Hanuthang sections.

3.1.1 Gaik Granite :

The Gaik granite is exposed 150 km south east of Leh and is a part of the Ladakh batholith (Fig 3.1). The Gaik granite is a pink porphyritic granite. This has been exposed because of the uplifted section between Upshi and Kiari. The pink porphyritic granite and the leucogranite exposed in this section are either free from hornblende or very poor in it and thus differ from the hornblende granites which are extensively developed in other parts of the Ladakh batholith. Samples were collected at the river bank near Gaik.

3.2 The Tethys Himalaya :

On the structural map of the Himalaya and southern Tibet, Gansser (1977), for the first time, delineated a granitoid belt in the Tethys Himalaya. This region consists of granitoid rocks intruded over a distance of 600 km, within the Tethyan sedimentary cover. A few segments of these granitoid rocks comprise of stocks and plutons of two mica granites and leucogranites while at places some segments expose windows of gneissified granites and gneisses. Tapponnier et al (1981) called Tethys Himalayan granitoid belt as Lhagoi Kangari granitoids. Heron (1922) mentioned the intrusions of massive, light gray and fine grained biotite-muscovite-granites which are different from tourmaline granite (Makalu type) and hornblende bearing Kyi-chi granite. Wadia (1935) recognized that igneous intrusions of granitic composition encircle the Paleozoic

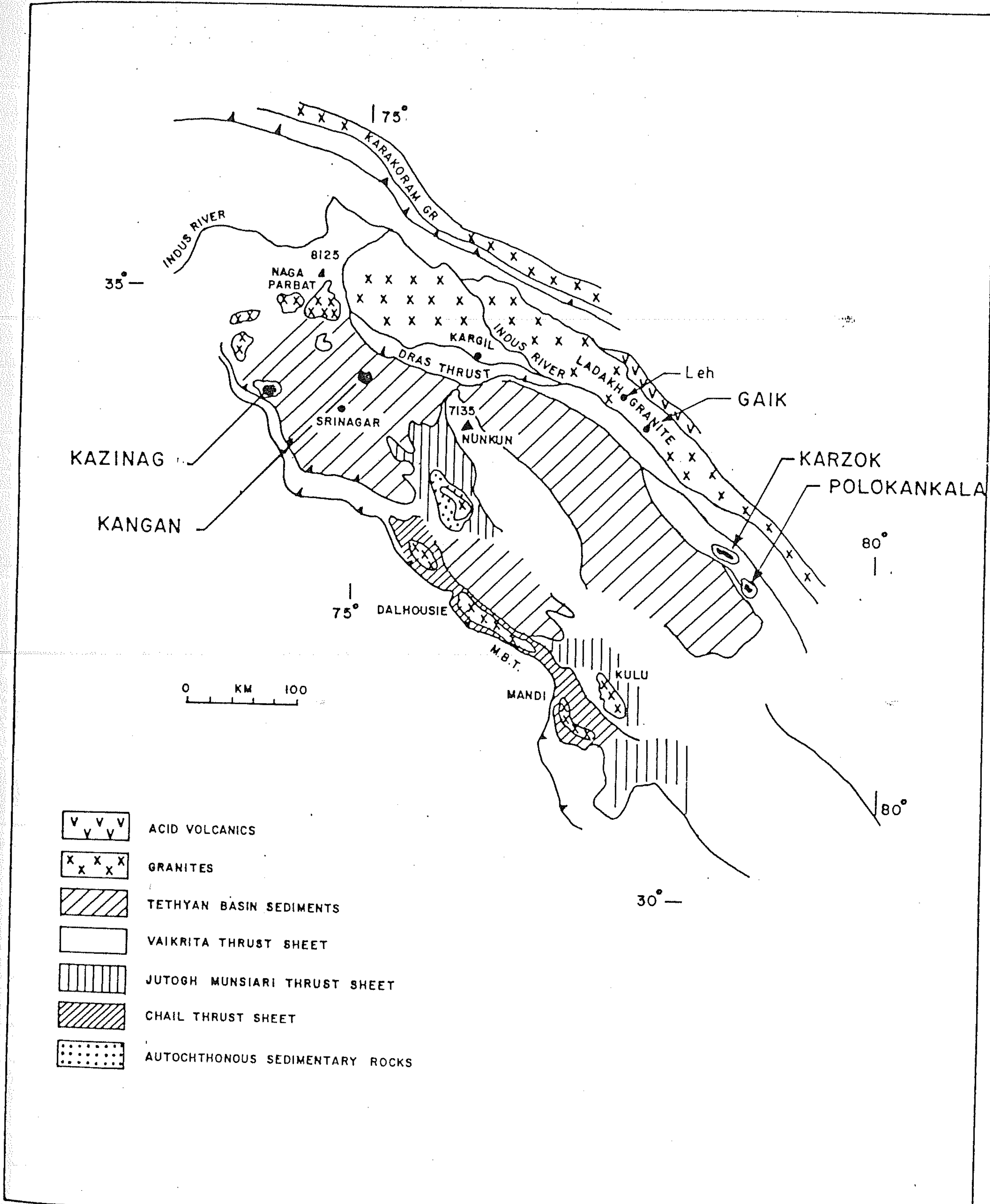


Fig.3.1 Simplified geological map of NW oHimalaya (After Sharma, 1983)

basin of Kashmir. Middlemiss (1911), and De Terra (1935) also referred to biotite and hornblende granites in Kashmir. Kangan and Kazing granites in the Kashmir valley and Polokanka-La and Karzok granites in Zanskar valley have been sampled for the present investigation. These are described in following section.

3.2.1. Kangan Granite and Kazinag Granite :

The Kangan and Kazinag granites intrude into the Cambrian sequence of the Kashmir valley. The Kashmir valley lies in the tectonic depression between the Pir Panjal and the Great Himalayan ranges and preserves almost a complete sequence of rock formation.

The Kangan granite is a plutonic body which lies in the eastern-most part of the Kashmir basin. It is exposed on either side of the Sind river around Kangan village situated on the Srinagar - Leh road. The largest outcrop measures about 50 sq.km. and is exposed north of Kangan. Another outcrop measuring about 15 sq.km. is exposed on a ridge south of Kangan.

The Kazinag granite (Fig 3.1) is one of the largest granite exposures in the Kashmir basin. This lenticular body, measuring about 200 sq. km. is exposed 15 km. west of Baramula and intrudes along the contact between Salkhalas and Dogra slates. Samples representing different composition and textural variations have been collected from both the suites.

3.2.2 Polokanka-La Granite and Karzok (Rupshu) Granite :

The Polokanka-La granite and the Karzok granites (Fig 3.1) are intruding into Tso-Morrari crystalline rocks in the Zanskar Range just south of the ITSZ. The Tso-Morrari crystallines constitute an important lithological entity in the Ladakh Himalaya because of their location in the wedge between the Indus Suture zone in north and the Tethyan rocks of the Zanskar basin in the south. The geological setting in the Zanskar basin is different from the Kashmir basin. The Precambrian and possibly the Lower Palaeozoic rocks are exposed in two basement highs which lie on either side of the Zanskar sedimentary zone. The Polokanka-La and Karzok granites are coarse grained, prophyritic and foliated. They contain quartz, feldspar, muscovite, biotite, hornblende and tourmaline. A later phase of aplite is also present that intrudes the coarse grained granite.

3.3 **The Great Himalaya :**

The Great Himalayan belt comprises leucogranites intruded during Himalayan Orogeny into the Precambrian basement gneisses, migmatites and metasediments which are known as crystalline rocks. These crystallines rocks constitute the main range of the Great Himalaya (Dietrich and Gansser, 1981; Vidal et al. 1982, Schärer, 1984, Le Fort, 1981, 1988). The leucogranites occur as sill, stock or batholithic bodies and are irregularly distributed along 2000 km of the Great Himalayan chain. These granites commonly contain accessory tourmaline or garnet and show S-type characteristics (Chappel and White, 1974). Thimpu migmitite gneiss exposed in Bhutan and tourmaline being Sela granite, Arunachal Pradesh have also been sampled for the present study . Geology of this region is not well known.

3.3.1 Sela Granite :

In Arunachal Pradesh some of the lithostratigraphic units namely the Tenga formation, the Bomdila Group and the Sela Group consist of granitic and gneissic rocks (Das et al. 1977; Tripathi et al. 1980). The Sela granite occurs within the Sela group of rocks (Fig.3.2). This group comprises the crystalline garnetiferrous augen gneiss, muscovite-biotite and tourmaline granite, migmatites and pegmatites correlatable with the Great Himalayan crystallines. The Sela granite is unfoliated two mica tourmaline bearing leucogranite which is well exposed in Dirang-Doimara area. This granitic body is intruding into high grade metamorphics (migmitite gneiss).of the Sela group. Samples were collected between Jang and Sela.

3.3.2 Thimpu Gneiss :

The Thimpu gneiss of Thimpu formation (Fig.3.3) is juxtaposed with Buxa Formation along thrust Fault (Jangpangi (1978). Thimpu formation is overlying the Buxa formation and only difference between these two structurally alike formations is the sharp rise in grade of metamorphism. The

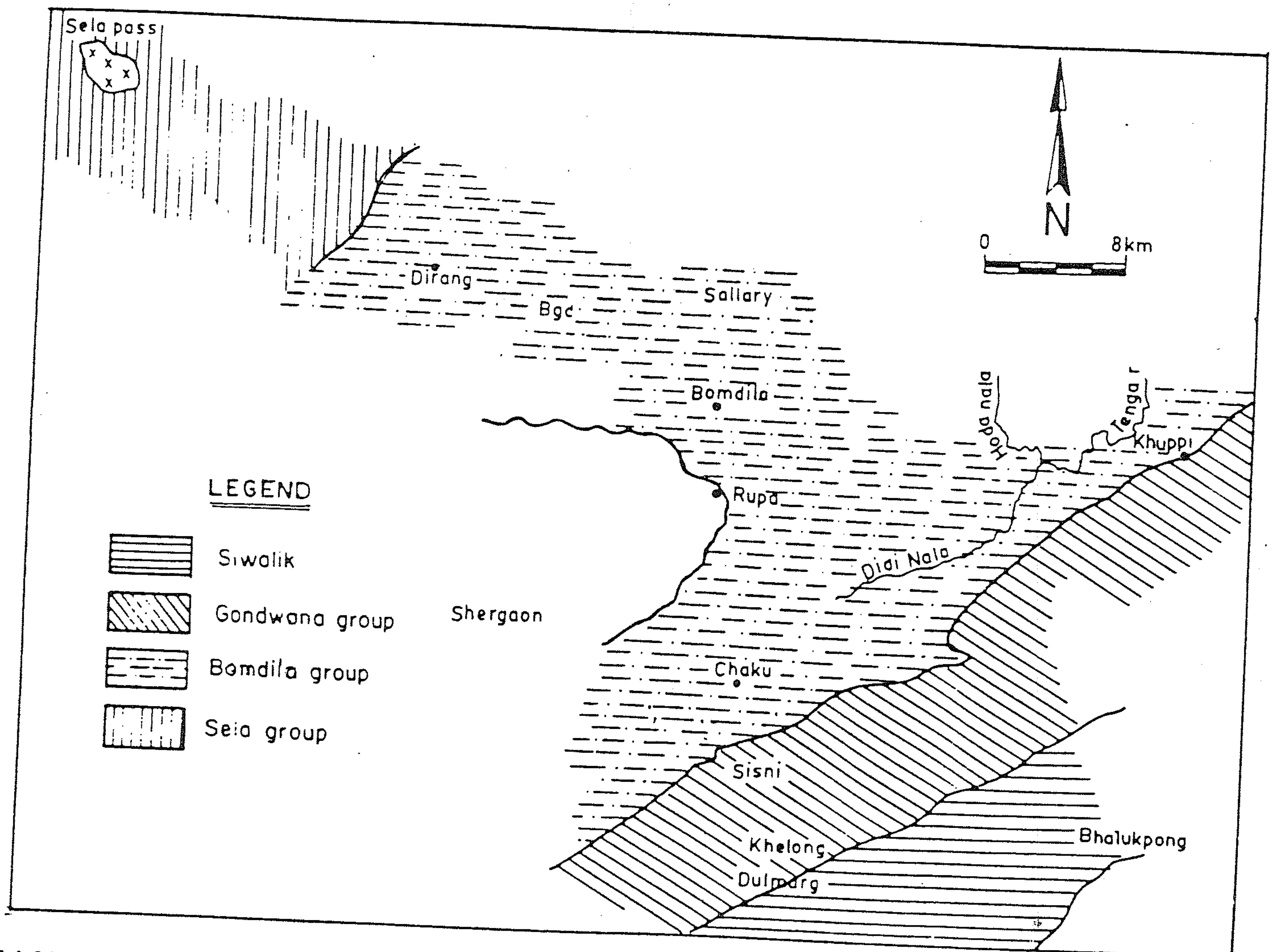


Fig.3.2 Simplified geological map of Kameng district, Arunachal Pradesh (After Verma and Tandon,1976)

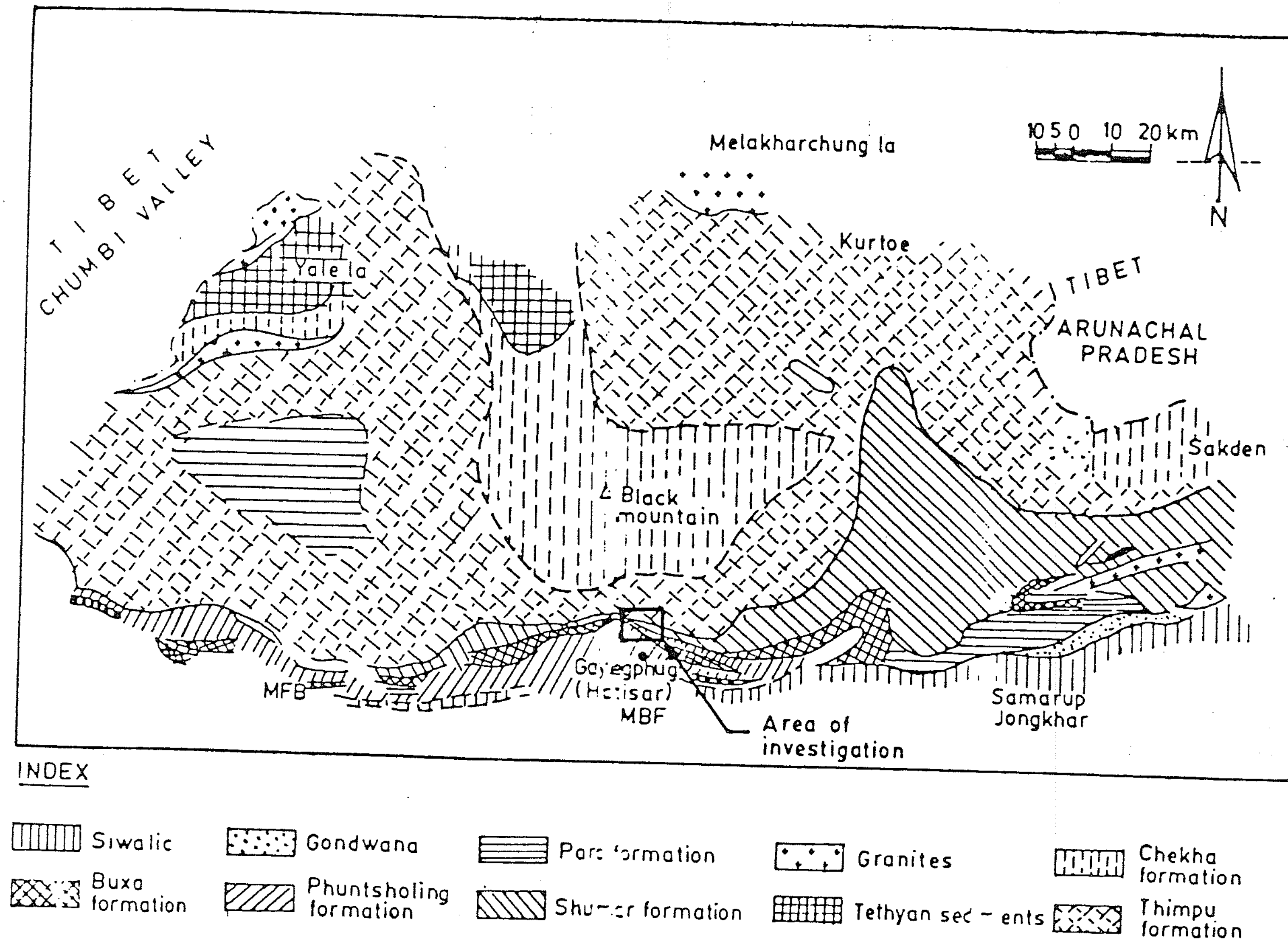


Fig.3.3 Simplified geological map of Bhutan (After Jangpangi, 1978)

Thimpu formation comprises of garnetiferrous quartz-biotite-muscovite schists, calcareous quartzite, calc gneiss, granite , gneiss and tourmaline granite. The Thimpu migmatite gneiss is regarded as a product of anatexis of metasedimentry group by Jangpangi (1978). Tungsten mineralization occur in the skarn rocks near the contact of Thimpu gneiss and Buxa Formation metasediments. Borehole samples were obtained by the Geological Survey of India to study occurrence of tungsten mineralization. Since the expouser of the Thimpu gneiss is very small samples for Rb-Sr study were collected from two such bore holes.

3.4 The Lesser Himalaya :

The Lesser Himalaya is composed of three nappes overriding the autochthonous Precambrian sediments. The crystalline rocks of these nappes are similar to those of the Great Himalaya but the low metasediments of the Lesser Himalaya do not correlate with the sedimentary sequence of the Tethys Himalaya. The rarity of fossils in the Lesser Himalayan sediments has created confusion regarding its age and stratigraphic positions of its different units.

The central sector these nappes are known as Krol (=Berinag), Ramgarh (=Chail) and Almora (=Jutogh). The lowermost sheet is madeup of mainly Palaeozoic sedimentaries. It occurs in the southern belt and has been thrust over by a thick pile of low grade metamorphics of greenschist facies, constituting the Ramgarh Nappe. In the northern part, these epi-metamorphics are tectonically overlain by medium grade metamorphics of lower amphibolite facies constituting the Almora Nappe.

Granitic rocks are exposed in three lithotectonic settings which are shown in simplified geological map of the Kumaun Lesser Himalaya (Fig 3.4). They occur as rare and minor intrusives showing almost no metamorphism in the autochthonous sedimentary zone whereas in the Ramgarh nappe they occur as cataclastically deformed porphyritic granite and quartz-porphyry. They are also exposed in the Almora nappe, its klippen and root zone as lenses of granodiorite-granite complex grading marginally in to augen gneisses. Tourmaline rich leucocratic granites are intruding into granites of the Almora (Middlemiss, 1887; Valdiya, 1962a,b and Gansser, 1964).

3.4.1 Ramgarh Granitic Gneiss :

The Ramgarh quartz porphyry, a part of Ramgarh nappe, is a relatively thin plate sandwiched between the Krol and Almora nappe. Heim and Gansser (1939) and Gansser (1964) regard it as a part of the Almora Nappe while Valdiya (1976) and Fuchs and Sinha (1978) distinguish it from the Almora Nappe. This unit having thick quartz porphyry interbeded with schists and micaceous quartzites has suffered strong metamorphism, rendering it to gneissose or schistose. The fine grained massive variety of quartz porphyry grades to augen gneiss and is intruded locally by comagmatic

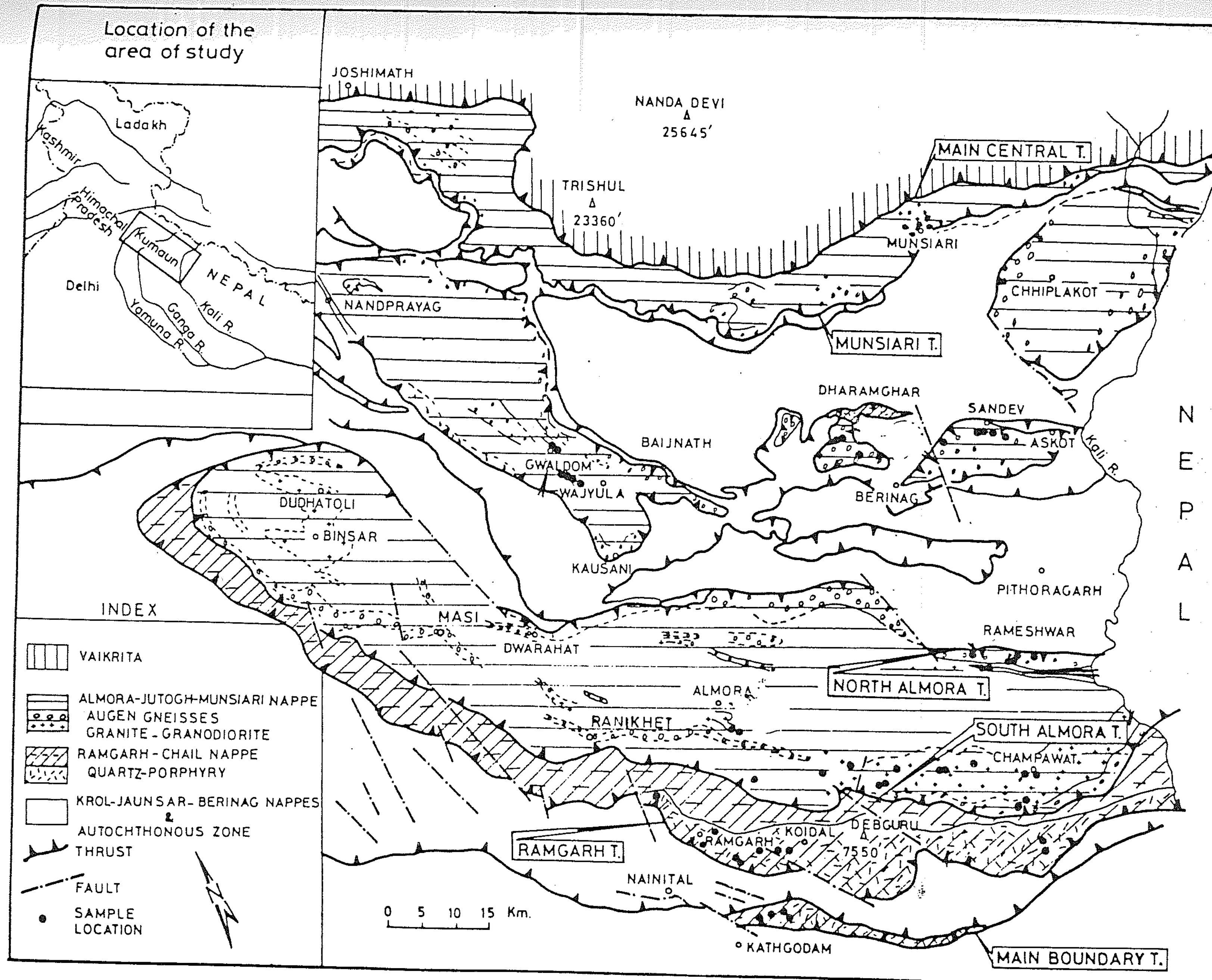


Fig. 3.4: Simplified geological map of Kumaun Lesser Himalaya (After Valdiya, 1980)

porphyritic gneissose granite. Merh (1968) called it as sheared granite while Pande (1956-57) recognized it as migmatites. Valdiya (1980a) noticed that this mylonitized quartz porphyry having granitoid bands, occur as porphyritic granite and gneissose granite porphyry near Debguru mountain where vary coarse grained biotite granite occurs within gneissose quartz porphyry. The coarse grained granite is nearly adamellitic in composition. According to Misra and Sharma (1967), the granite of Debguru mountain represents several phases of intrusions of acidic and basic magmas. Valdiya (1962a) observed the extension of Debguru porphyroid in Kali Valley (South of Champawat).

3.4.2 Amritpur Granite :

The Amritpur granite which is a part of the Ramgarh nappe, occurs as a lensoid body measuring about 3 km long and about 1 km wide. It has a unique occurrence of being located along the MBT. It is closely associated with quartzite - metabasite sequence of the Bhimtal-Bowali area. Xenoliths of quartzite and metabasites have been reported by Varadarajan and Rawat (1976). Nautiyal (1955) considered Amritpur granite to be tectonically transported to its present position while Chatterjee (1976) believed it to be a synkinematic emplacement along the MBT. Raina and Dungrakoti (1975) related it with Ramgarh Porphyry and according to Desai et al (1976), Amritpur granite and Ramgarh Porphyry are Keratophyric in nature and are related to spilites of the Bhimtal-Bowali area. This granite is having phenocrysts of feldspar and it contains quartz, biotite, orthoclase and oligoclase. At least two phases of granites are present in the area.

3.4.3 Almora Granite-Granodiorite and Almora Augen Gneiss :

The Almora group of medium grade metamorphics intruded by a massive granite granodiorite suite is exposed along the belt extending from Dudatoli, Almora to Champawat. This batholithic body is bordered by augen gneisses formed presumably as a result of metasomatic granitization during the late tectonic phase of this magmatism. The Almora granite grades into quartzdiorite to quartzmonzodiorite and is adamellitic in composition near Almora. It is coarse to medium grained in texture and is converted into augen gneisses.

Almora nappe contains biotite quartz rich granodiorite-granite rocks which are intruded by late tourmaline rich leucocratic granite. The granite-granodiorite of Almora, its Klippen and root grade marginally into augen gneisses. While the Champawat granodiorite occurs as a batholithic-sized-body near Champawat (Valdiya, 1962b) it thins down considerably near Almora. Valdiya (1962a), Merh and Vashi (1965),Desai (1973) and Das(1979) observed two different types of augen gneisses, one which are gneissose variety of Champawat granodiorite and the other which was formed due to metasomatism of the metasediments. The augen gneisses of the basal part exposed in northern flank of Almora synform are comparable in texture to that of augen gneisses exposed in Ramgarh nappe.

3.4.4 Askot Gneiss :

The coarse grained gneisses and crystalline schists of Askot overlie the sericite quartzite of Berinag. The exact boundary between Askot gneisses and Berinag quartzite is difficult to distinguish due to the highly metamorphosed nature of the quartzite. Large masses of uniform gneiss having biotite, muscovite and alkali feldspar similar to those of Almora have been observed.

3.4.5 Baijnath-Dharamghar Gneisses and Gwaldom Granite :

Tectonically this zone is similar to that of Askot. The granite-gneisses and augen gneisses exposed south of Gwaldom resemble those of Askot. The rocks are mainly dioretic and the massive zone of diorites are rich in tourmaline. The granite gneisses, mica schists and quartzites are interbeded with basic sills. The schistose carbonaceous layer occurs north of Baijnath. The basic sills consist of diorite amphibolites with a zone of uncommon tourmaline - epidote amphibolites. The granite gneiss and granite are bordered by basic sills and overlain by more gneisses and schists.

3.4.6 Munsiari Gneiss :

This zone is a tectonic boundary between sedimentary rocks of para-autochthon and the crystalline rocks of the Munsiari Formation at the base of the Great Himalaya. Sandwiched between the MC(V)T (Valdiya, 1980b) above and the Munsiari thrust below, the crystalline rocks of amphibolite facies are intruded by the porphyritic granite. Cataclastic deformation has converted these Munsiari rocks into mylonitized rocks including augen gneisses. Possibly, these crystallines of Munsiari and of Askot, Baijnath, Almora constitute the basement on which the sedimentary rocks of the Lesser Himalaya were deposited.

CHAPTER 4

ANALYTICAL TECHNIQUES

The analytical procedures for the determination of Rb-Sr isotopic abundances and composition in rocks and minerals are presented in three parts: (i) sample crushing and mineral separation, (ii) chemical processing and (iii) isotopic measurements on a home made solid source mass spectrometer. The development of an automated data acquisition system using an IBM-PC/XT in the later part of the study, is also described.

4.1 Rock crushing and Mineral separation :

Well documented samples, each weighing about 15-20 kg were cleaned using wire brush and distilled water to remove any surface contamination. They were broken into smaller pieces using a hammer. These pieces were checked for any inclusions and then crushed to <3-5 mm size using a jaw crusher (Fritz pulverizer). The crushing surfaces of the pulverizer were cleaned using a high pressure air blast and preconditioned using a small amount of the sample being processed. Crushed samples were collected in a plastic container and thoroughly homogenized. The samples were poured into a conical mound on a clean paper and quartered with a stainless steel spatula, and opposite quarters were collected. They were further quartered to draw about 5-7 kg of the representative coarse fragments. These were further reduced to less than 1 mm size powder, using the jaw crusher again. The procedure was repeated until a representative sample quantity of about 300 gm was obtained.

About 1 kg of the coarse fraction from the remaining part was saved in a polythene bag for mineral separation. The 300 gm of representative coarse fraction was ground to very fine powder (<200 mesh) using a TEMA swing mill for 20 minutes and stored in pre-cleaned and pre-conditioned polythene bottle/vial. This fraction is a homogeneous representative of the whole rock sample. Maximum care was taken to prevent any cross-contamination and to prevent loss of fines during these operations.

Special care was taken in mineral separations which were carried out in a separate room. A fraction of the sample powder, kept separately for mineral separation, was sieved using stainless steel sieves to obtain a size fraction between 120 to 150 mesh. All the sieves were pre-cleaned with AR grade acetone and dry nitrogen gas. A nylon brush was used to remove any grains of the previous sample stuck in the sieve. About 20 gm of the sieved sample powder was spread on a glossy butter paper to remove strongly magnetic particles with a hand magnet covered with polythene. The sample was rinsed three to four times with AR grade acetone to remove fine dust and finally dried in an oven at 110^{o}C. Usually only biotite and feldspar fractions were separated for analyses using a Frantz isodynamic separator and heavy liquids. All parts of the magnetic separator which come in contact with sample were pre-cleaned with acetone and/or dry nitrogen gas and they were pre-conditioned with a small amount of sample. The strongly magnetic particles were removed first by running the sample in a low magnetic field. Usually a forward tilt of 20^{o} and side tilt of 15^{o} were used for biotite separation, and the magnetic field strength was decided each time by trial. Each sample was run through two-three times to achieve a pure biotite fraction. The non-magnetic fraction meant for feldspar separation was run through the magnetic separator at high magnetic field to remove the remaining magnetic minerals present as well as to remove any composite grains. This non-magnetic fraction was used to separate K-feldspar and plagioclase using bromoform with appropriate acetone dilutions. At every stage precaution were taken to prevent contamination.

4.2 Chemical Procedures :

Analytical procedures like dissolution, spiking, ion exchange separation and mass spectrometric analysis are identical for whole rocks and mineral separates.

All chemical operations were carried in a clean laboratory equipped with a fume-hood flushed with filtered air. All labware were either of teflon or quartz. The procedure for sample dissolution, spike addition and ion exchange separation is as follows.

About 100 mg of representative sample powder or 30-50 mg of mineral separate were weighed in a Mettler balance (H51 AR) on a weighing paper and then transferred to a 15ml teflon vial (Savellex) for dissolution. About 1 ml of HNO_3 and 5 ml of HF were added and allowed to stand at a low temperature (~50°C) for 3-4 hours with the vial covered with the lid. Subsequently the lid was removed and the temperature increased to evaporate the sample to dryness. About 2 ml of HCl was added and dried before adding about 5 ml of 2.5N HCl to get a clear solution.

4.2.1 Isotope dilution :

The ^{87}Rb and ^{84}Sr spikes of high isotopic purity were used for isotopic dilution analysis. The isotopic abundances of the Rb and Sr spikes are given in Table 4.1. Concentrations of the spikes were calibrated against standard solutions of normal Rb and Sr (NBS 984 and 987). Dilute Rb and Sr spike solutions (concentrations about 17.59 ppm and

TABLE 4.1

ISOTOPIC ABUNDANCES IN SPIKE

^{84}Sr Spike

$^{88}Sr/^{84}Sr$ = 0.0009

$^{86}Sr/^{84}Sr$ - 0.0011

$^{87}Sr/^{84}Sr$ = 0.0002

^{87}Rb Spike

$^{85}Rb/^{87}Rb$ = 0.008

1.59 ppm respectively) were prepared from concentrate spike solutions for use with rock and mineral samples. Though the concentrations of the dilute spikes were exactly known from the dilution factor, they were calibrated and periodically checked to guard against evaporation losses. All the spikes and standard solutions were stored in teflon bottles inside a glass bell jar to minimize evaporation loss. Spikes were added by weight to sample solution and evaporated to dryness after ensuring complete mixing. For optimal spiking, the Rb and Sr concentrations in samples were measured with an Atomic Absorption Spectrophotometer.

4.2.2 Ion Exchange :

Ion exchange chromatography was used to separate Rb and Sr not only from each other but also from other matrix elements. The ion exchange columns were made from quartz tubes (ID=0.8 cm) and filled with Dowex 50W X8 (200 to 400 mesh) cation exchange resin to a height of 19 cm. Elution was done using 2.5N HCl. The columns were frequently calibrated to ensure optimum collection of Rb and Sr fractions. Sample solutions were centrifuged for about 5 minutes in clean 3 ml quartz centrifuge tubes covered with parafilm and then loaded gently onto the resin bed using a pipette. The Rb and Sr fractions were collected in separate teflon beakers, evaporated to dryness and then stored for mass spectrometric analysis. The columns were cleaned between samples with at least 200 ml of 6N HCl and 10 ml of distilled water and conditioned using 25 ml of 2.5 N HCl.

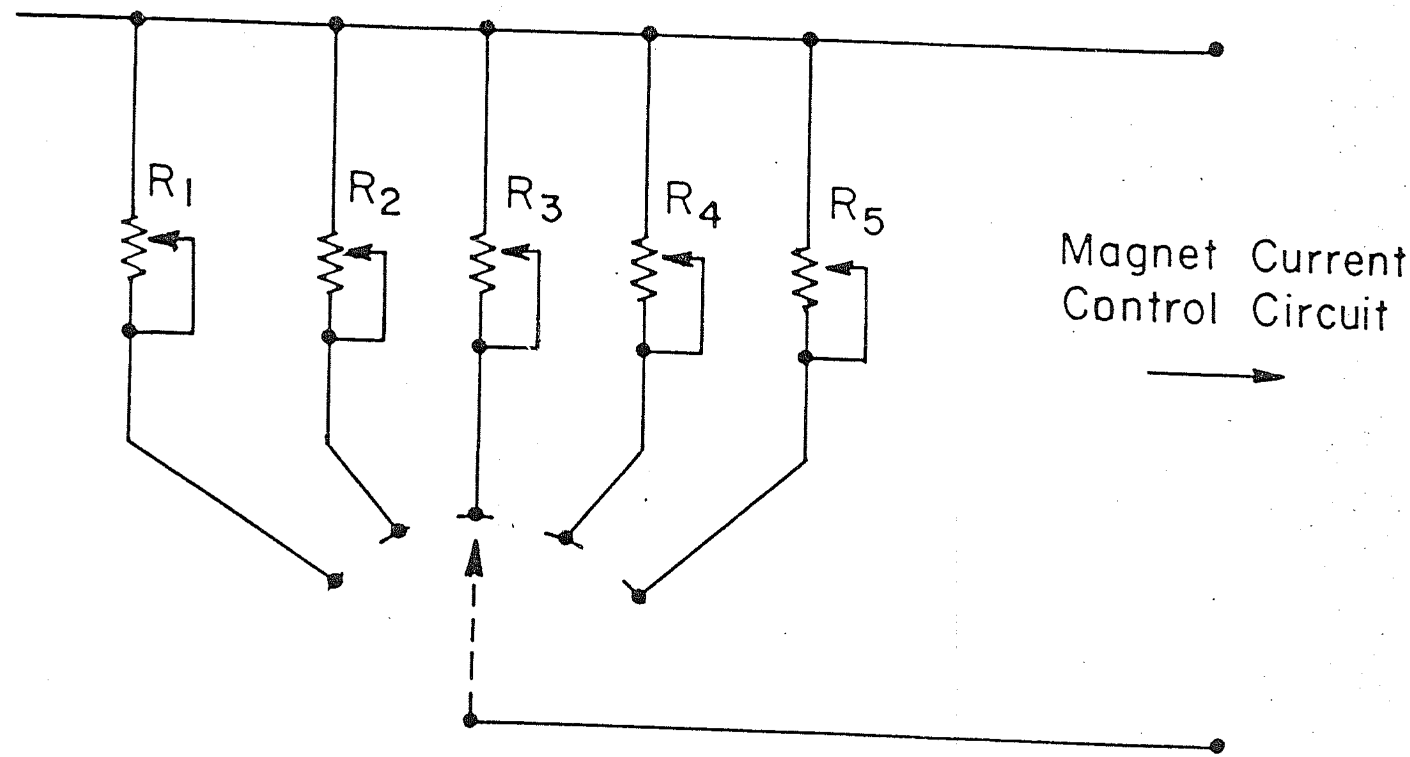
4.3 Mass Spectrometry :

The mass spectrometer used for isotope analysis is a 23 cm radius, 60^{0} sector magnetic field single focusing instrument fabricated in our laboratory. A picture of the mass spectrometer is shown in Fig 4.1. It is fitted with a thin lens ion source and a Faraday cup for collection of ions. The filament holder with first source slit is removable so that a new filament could be spot welded, degassed and loaded with sample. Tantalum filaments (0.030"X0.001") of more than 99.99% purity (obtained from H. Cross) were outgassed in a separate vacuum system at a temperature higher than that required for efficient ionization of Sr. Samples were taken up in a precleaned teflon pipette and evaporated directly on the center of a precleaned filament. Pipettes were used only once. The mass spectrometer is pumped by two vac-ion pumps - 30 lit/sec. pump for the analyzer tube and 80 lit/sec. pump for the source region. The source was initially pumped down to a pressure of 10^{-3} torr with a rotary and a sorption pump. It was then isolated from these pumps and gradually opened to the 80 lit/sec ion pump. A working pressure of $1X10^{-7}$ torr in the source chamber was obtained in about one hour after introducing a new sample. The ion acceleration potential used was usually 4500V. The filament was heated with a highly stable DC current supply. The magnet current supply

Fig.4.1 Home made Solid Source Mass Spectrometer

is of hybrid design using power tubes and solid state error amplifiers. The electromagnet has high resistance coils which require about 400 mA for a field of about 4000 gauss. Ion currents were measured using a vibrating reed electrometer, Cary Model 31, with an input resistance of 10^{11} ohm and recorded in the analog mode with a strip chart recorder. Rb data were taken at 100-300 mv signal level whereas Sr data usually at 1000 to 3000 mv level for ^{88}Sr. By the time the Sr beam reached the measuring range, any small residual Rb was completely burnt out.

The magnet current can be switched cyclically through discrete values using 4 preset potentiometers and a rotary switch as shown in Fig.4.2. Each potentiometer was initially tuned to a specific isotope. After a few cycles and returning, the effect of hysteresis is reduced. Typical analog recording of a few cycles of peak switching through a Sr mass spectrum is shown in Fig.4.3. Baselines and Rb interference checks were made before and after each set of 10-15 cycles. Usually two good sets were recorded. The peak heights were read from the chart using a high precision scale and ratios calculated using linear interpolation of the signal of the index isotope. Standard deviation of $^{87}Sr/^{86}Sr$ ratio measurements was usually between 0.1 to 0.15% . Based on replicate analyses of calibration mixtures and a few rock samples, the errors in the mass spectrometric determination of ^{87}Rb and ^{86}Sr are estimated to be ±1.5% and ±1%, respectively, leading to a random error of not more than ±2%



All potentiometers are 1 KΩ (10 turn)

Fig.4.2 Potentiometers arrangement for manual peak switching

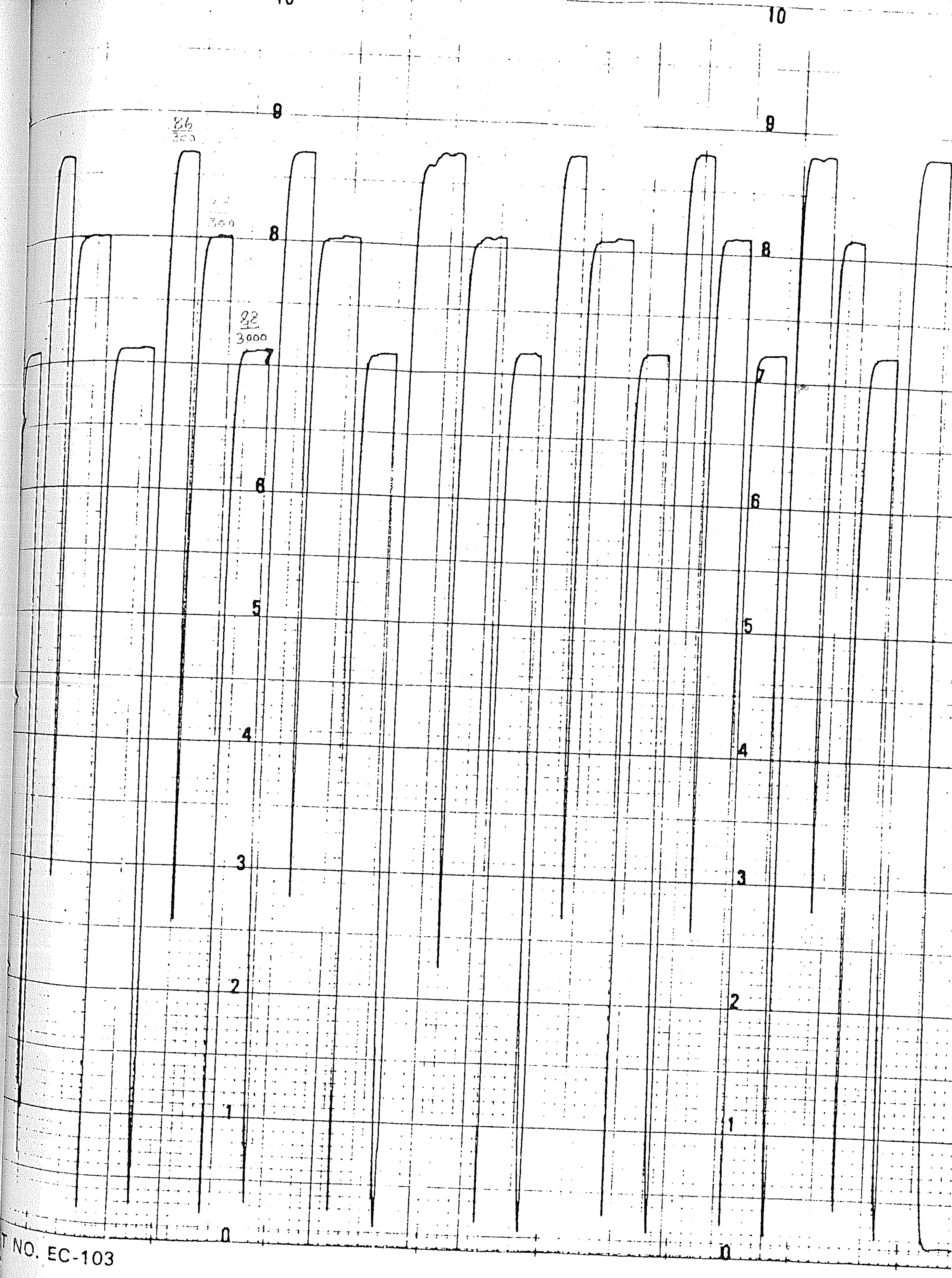


Fig.4.3 Typical Sr spectrum showing peaks (manual peaks jumping)

for their ratio.

Since the Sr spike is highly enriched in ^{84}Sr (>99.5%), it is possible to calculate both $^{87}Sr/^{86}Sr$ ratio and ^{86}Sr concentration in a rock or mineral sample from the isotopic composition of the mixture of spike and the sample Sr. The method used, involves a simple iteration procedure which could be most conveniently done with a hand calculator. The $^{87}Sr/^{86}Sr$ ratios were corrected for mass fractionation assuming 0.1194 for the value of $^{86}Sr/^{88}Sr$ in sample Sr.

During the course of the present work, the total Rb and Sr contaminations from the reagents and chemical procedures were measured by running a series of blanks in parallel with samples. About 25 blank determinations during the course of this work are given in Table 4.2. Typical blanks were in the range 0.1 to 0.3 nanogram for ^{87}Rb and 1 to 5 nanogram for ^{88}Sr. The contamination correction was negligible for bulk of the analyses reported.

The long-time-reproducibility of the mass spectrometric measurements was checked by analyzing the NBS-987 standard. The $^{87}Sr/^{86}Sr$ ratios obtained during the period of study are shown in Table 4.3A. The bulk of the ratios varied from 0.710 to 0.711. Though the ion beams were steady, this precision is poor by modern standards due to the limited number of ratios collected and measured manually. The intrinsic precision the machine should be much better.

TABLE 4.2

TOTAL BLANK CONTRIBUTION FROM REAGENTS AND OTHER PROCEDURES

Date	^{87}Rb $X10^{-9}g$	^{88}Sr $X10^{-9}g$
17 March 1981	0.3	6.1
26 March 1981	0.9	13.0
24 August 1981	0.7	3.1
13 January 1982	0.35	4.1
18 April 1982	0.7	5.1
22 May 1982	0.8	5.4
2 July 1982	0.3	5.6
23 September 1982	0.6	5.7
18 December 1982	0.6	4.1
9 February 1983	0.3	2.5
9 July 1983	0.7	2.6
6 September 1983	0.3	3.4
7 January 1984	0.6	7.2
22 April 1984	0.2	1.2
10 October 1984	0.1	1.8
16 January 1985	0.16	2.3
20 April 1985	0.3	0.9
30 November 1985	0.11	4.0
16 April 1986	0.13	0.9
8 December 1986	0.1	1.0
10 February 1987	0.09	0.8
30 November 1987	0.11	1.6
16 April 1988	0.18	2.2
22 September 1988	0.16	1.7
12 January 1989	0.13	1.2
18 July 1989	0.11	1.2

TABLE 4.3

$^{87}Sr/^{86}Sr$ VALUES OF NBS-987 MEASURED DURING THE COURSE OF THIS STUDY

Date	$^{87}Sr/^{86}Sr$
A. Prior to automation :	
22 April 1980	0.7120±36
24 May 1980	0.7120±48
8 July 1980	0.7123±18
27 November 1980	0.7117±11
1 April 1981	0.7088±06
24 September 1981	0.7112±10
16 April 1982	0.7112±07
29 October 1982	0.7098±20
25 November 1982	0.7105±06
25 December 1982	0.7095±07
11 February 1983	0.7105±15
2 July 1983	0.7124±08
16 September 1983	0.7122±10
3 September 1983	0.7095±10
19 April 1984	0.7117±12
28 July 1984	0.7124±10
7 December 1984	0.7118±09
15 February 1985	0.7113±10
8 April 1985	0.7110±18
13 September 1985	0.7121±12
1 December 1985	0.7117±20
7 February 1986	0.7116±19
23 August 1986	0.7108±19
27 November 1986	0.7114±12
20 January 1987	0.7105±09
11 February 1987	0.7109±06
17 April 1987	0.7108±04
B. After automation :	
3 September 1988	0.7109±05
11 April 1989	0.7101±09
15 May 1989	0.7106±02
13 July 1989	0.7107±06
31 August 1989	0.7109±06
1 September 1989	0.7110±04
4 September 1989	0.7105±02

All measurements are normalized to $(^{86}Sr/^{88}Sr) = 0.1194$.

Reference NBS value is 0.71014 ± 0.0002.

Errors (1σ) quoted are on last two digits.

4.3.1 Semi-automatic peak switching and digital data acquisition system :

To overcome the inherent limitation of analog recording of peak heights, a semi-automatic data collection system using an IBM-PC/XT has been developed and used for some of the more recent measurements. This system controls the mass spectrometer in the peak switching mode (as described by Stacey and Hope, 1975), measures the ion currents digitally and computes isotopic ratios. A schematic diagram of the system is shown in Fig.4.4.

The basic parts of the system are: (1) a programmable magnetic field control, (2) digital voltmeter for ion beam integration and (3) data storage and calculation of isotopic ratios.

4.3.2 Magnet current control :

Automatic peak switching requires that the magnetic field settings are stable and reproducible well within the flatness of the peak tops. Since the magnet supply is not field-controlled, current switching was used using 7 preset potentiometers (Fig 4.5)to select different field positions corresponding to peak tops or baselines.Initially, potentiometers were adjusted manually for each isotope and baseline. The potentiometers are switched cyclically to minimize hysteresis offsets. Automatic switching of the potentiometers was then carried out through a number of

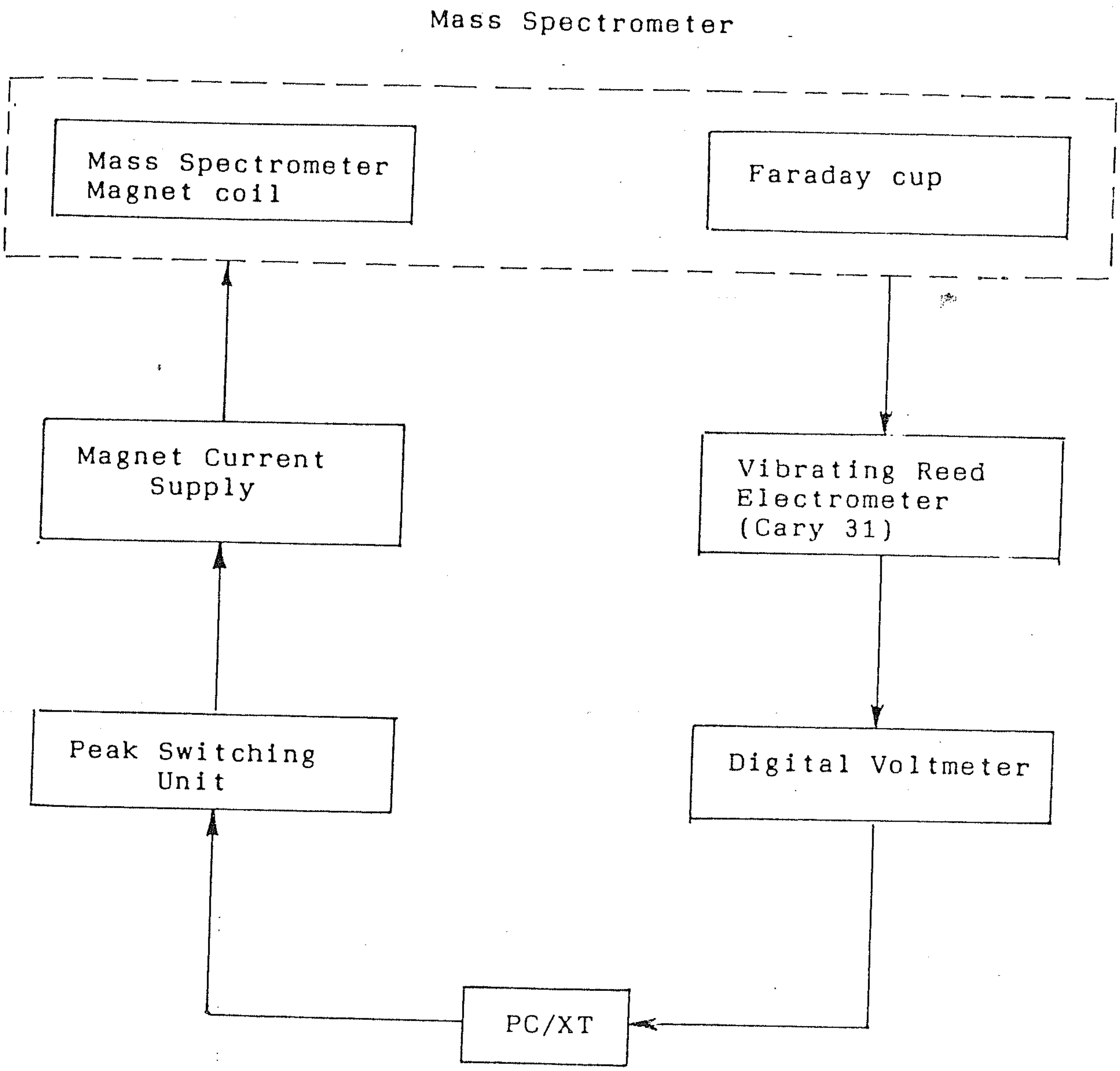
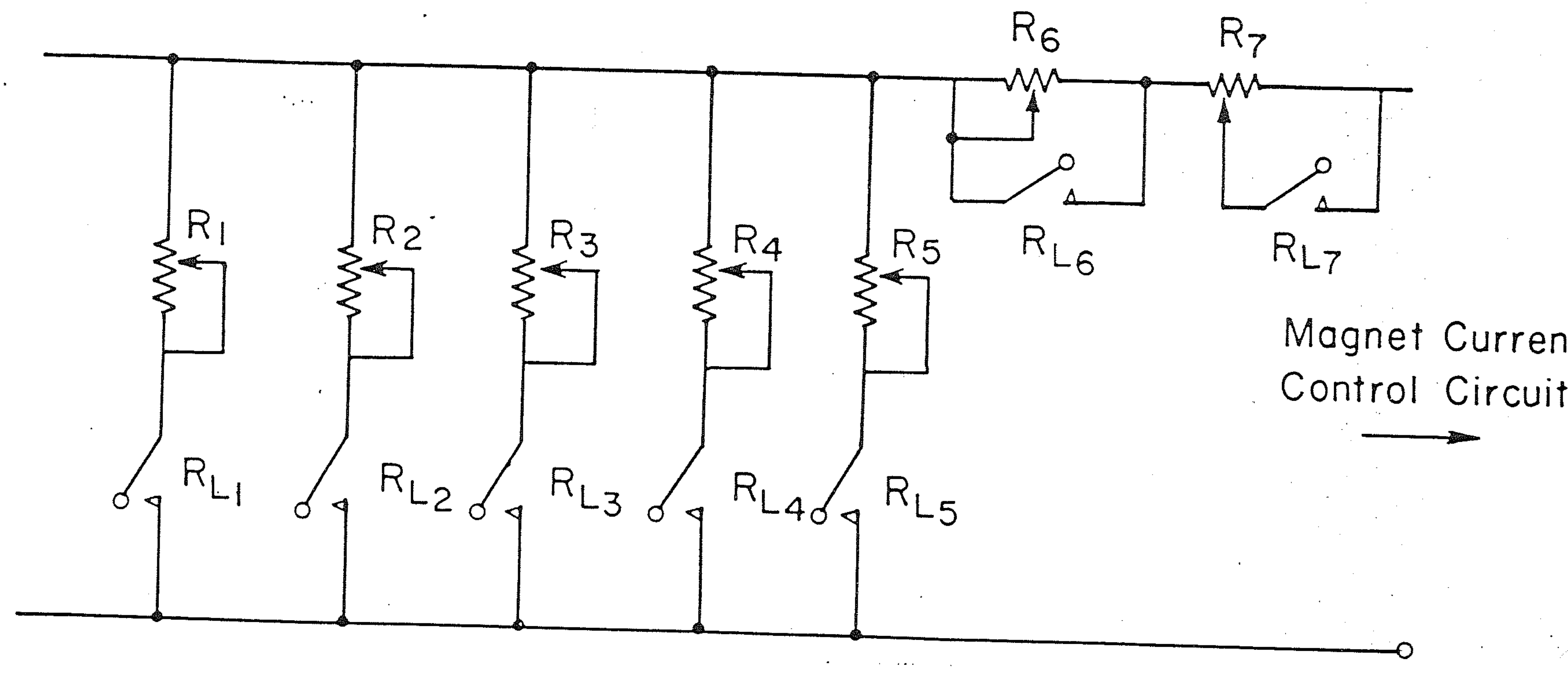


Fig.4.4 Semi-automatic peak switching and data acquisition system



Potentiometers R_1 to R_5 are 1KΩ 10 turn
R_6 and R_7 are 500Ω 10 turn
R_{L1} to R_{L7} are relays controlled by IBM-PC,

Fig.4.5 Potentiometers arrangements for relay controlled peak switching relays controlled via the general purpose interface board in an IBM-PC/XT computer. Two potentiometers were added for peak offsetting. The dwell time on each current position was selected to allow at least 5 seconds so that the switching transients die out before ion current integration is initiated.

4.3.3 Digital measurement of ion currents :

The analog output voltage of the Cary Model 31 vibrating reed electrometer (VRE) is fed into a $6\frac{1}{2}$ digit voltmeter (Solartron Model 7060). The digital output of the voltmeter is read by the computer via an IEE-488 interface. The computer's internal clock is used to record the time of each measurement. Since the VRE and DVM are highly linear, all peaks were measured on one appropriate scale range only.

The BASIC language programme (flow chart- Fig 4.6) developed for control and data acquisition and processing consists of four subroutines, for peak switching, reading the DVM and corresponding time, calculation of isotope ratios and abundances.

Chart recordings are now made only for the initial focusing of the ion beam and to check for Rb interference. The Sr isotope ratios of NBS-987 measured with this improved system are listed in Table 4.3B. Both the internal and external precisions are much better than those from analog recording and manual data processing.

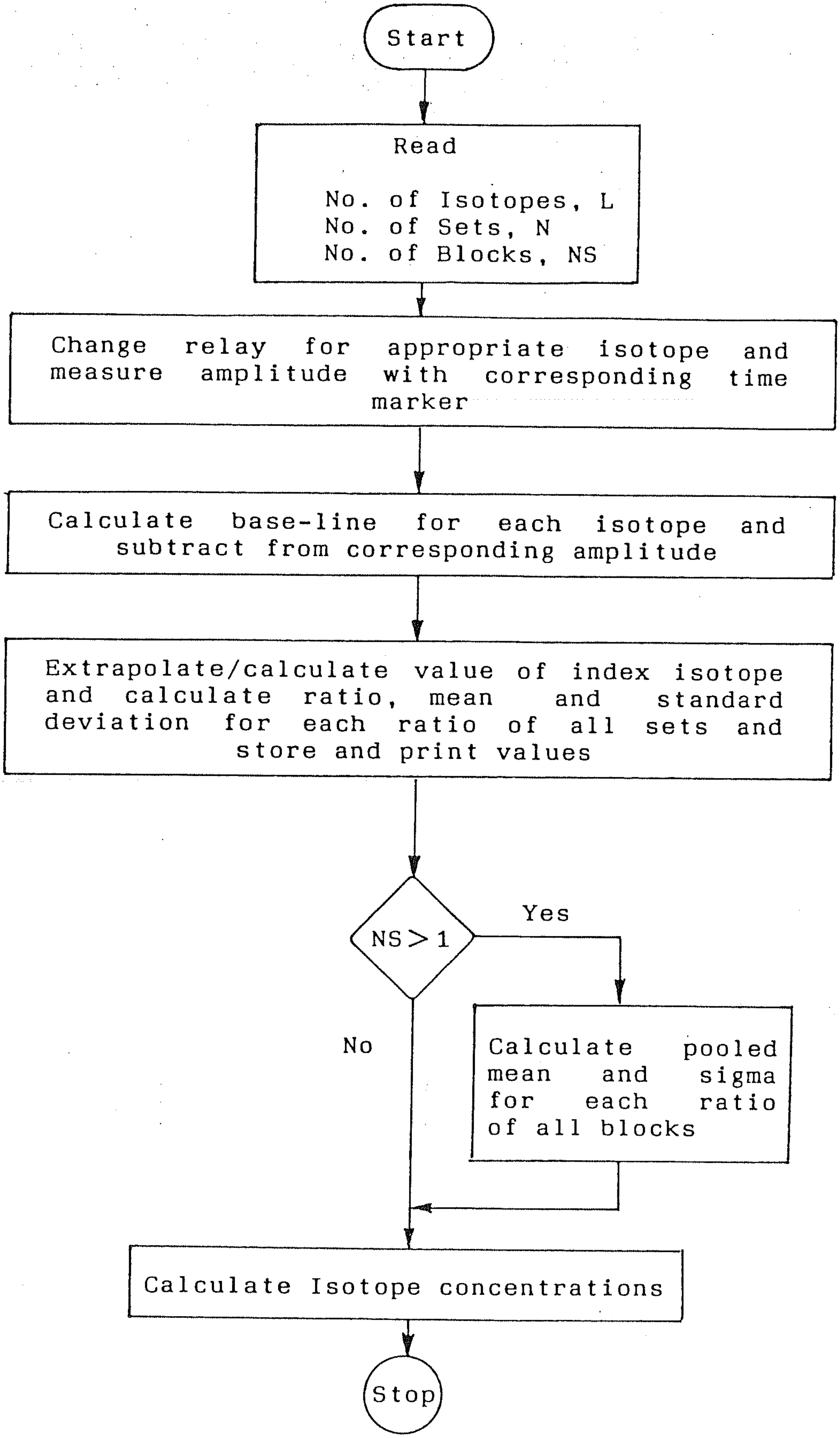


Fig.4.6 Flow chart for Computer programme

Since current switching requires frequent returning of potentiometer, field control of the magnet is to be preferred. This improvement is in progress.

CHAPTER 5

ANALYTICAL RESULTS

The Rb-Sr isotopic data for more than hundred whole rock samples and about twenty five minerals separated from whole rock samples are presented in this chapter. The whole rock samples represent some of the granitoids associated with all the four lithotectonic zones of the Himalaya described in Chapter 1. The whole rock Rb-Sr data have been used to obtain the time of primary crystallization or metamorphism and information on the source from which a particular suite of rocks were derived. The mineral data on the other hand have been used to infer the effects of secondary thermal events, if any.

The $^{87}Rb/^{86}Sr$ and $^{87}Sr/^{86}Sr$ ratios measured for a set of whole rock samples conform to a straight line on a Sr evolution diagram provided all samples had identical initial $^{87}Sr/^{86}Sr$ ratios and $^{87}Sr/^{86}Sr$ remained chemically closed to Rb and Sr, since time 't' (Nicolaysen 1961, Lanphere et al, 1964). Such a straight line, called an isochron, is defined by the equation.

$$\left[\frac{^{87}Sr}{^{86}Sr}\right] = \left[\frac{^{87}Sr}{^{86}Sr}\right]_i + \left[\frac{^{87}Rb}{^{86}Sr}\right] \times (e^{\lambda t}-1) \qquad \ldots(1)$$

where λ is the decay constant of ^{87}Rb.

The slope of this isochron gives the time since the samples remained closed and the intercept on the ordinate gives their common initial $^{87}Sr/^{86}Sr$ composition. In cases where there is independent geological evidence that the samples are cogenetic, t can be interpreted as a geologically meaningful event in the history of the samples. It can be seen from the equation (1) that samples with poor radiogenic Sr enrichment closely constrain the intercept, while those with large radiogenic enrichment define the slope very precisely. Hence a good dispersion in the Rb/Sr ratio of samples relative to the precision of measurement is desirable.

The data points do not strictly conform to a straight line if they are subject to analytical errors. This leads to the problem of determination of the best slope and intercept for a given set of experimental points. The best-fit-line obtained by simple regression techniques in which one of the co-ordinates is assumed to be free of errors is not satisfactorily valid. Murthy and Compston (1965) and York (1966) developed a procedure in which allowance is made for errors in both the co-ordinates. The procedure assumes that the errors are uncorrelated and normally distributed. Individual weighting factors are assigned to each point. These are commonly the inverse square of fractional experimental errors. In this model the regression line

$$y = a\,x + b \qquad \ldots(2)$$

is found by minimizing the expression

$$S = \sum_{i=1}^{N} \left[w(X_i)\,(x_i - X_i)^2 + W(Y_i)\,(y_i - Y_i)^2 \right] \qquad \ldots(3)$$

where (Xi, Yi) is the observed point

(xi, yi) is the adjusted point, and

W(Xi) and W(Yi) are the weights of (Xi, Yi)

To minimize expression (3), S is differentiated with respect to a and b. The differential coefficients are equated to zero. The equations obtained are combined to yield a cubic equation in b.

$$C_1 b^3 + C_2 b^2 + C_3 b + C_4 = 0 \qquad \ldots(4)$$

After substituting an approximate value of b in expression (4), C´s are obtained and one of the roots of b gives a meaningful value of b. The newly obtained value of b can be used to recalculate the C´s and hence a better value of b.

This iteration is continued until a desired degree of accuracy for b is obtained. However, they did not give any criterion to test the goodness of fit of the straight line to the data. McIntyre et al (1966) gave a slightly different method and arrived at a least squares cubic equation similar to equation 4. They also gave exact expressions for the variance of slope and intercept and specify that the goodness of fit can be judged by computing a quantity called the mean square of weighted deviates (MSWD), given by

$$MSWD = \frac{1}{N-2} \left[\sum_{i=1}^{N} W_i \, (a + bX_i - Y_i)^2 \right] \qquad \ldots(5)$$

where Wi is a function of W(Xi), W(Yi) and b.

The quantity in the bracket has an expectation of (N-2) MSWD, therefore must be close to unity. If MSWD significantly exceeds unity, it implies that either the measurements are less accurate than assumed in the calculation of weights or the various assumptions underlying the expectation of a linear array have not been satisfied. In other words, (a) some of the samples may have behaved as open systems with respect to Rb and/or Sr, (b) the samples may not have commenced with the same initial Sr composition, and (c) the samples may not be of the same age. In such cases, i.e. where MSWD >1, the authors call the straight line fit an 'errorchron' and suggest various models for weighting the data in such a way as to make MSWD close to unity. The slope is recalculated with new weights. The scatter of data in such cases is attributed to geological processes over and above the analytical errors. Brooks et al (1968) recommended yet another weighting procedure. York (1969) gave a method for correlated errors. The relative merits of all these methods have been reviewed by Brooks et al (1972). Williamson (1968), adopting a similar weighting technique as York (1966), showed that the least squares cubic is redundant and can be reduced to a linear equation. He also gave an exact expression for variance in the slope and intercept and criteria for testing the goodness of fit by performing χ^2 test on the expression within the parenthesis in equation (5). Williamson's method has been followed for regression of the data presented in this study.

In the present study, samples were collected from out-crops for which the field relationships are fairly known (described in Chapter 3). Attempts were made to collect samples with varying mineral composition in order to get reasonable spread in their Rb/Sr ratios. The analytical uncertainty for weighting individual points is ± 2% for $^{87}Rb/^{86}Sr$ and the standard deviation of 15 to 20 ratio measurements for $^{87}Sr/^{86}Sr$. Allowing for some inhomogeneity in the initial Sr composition possibly due to wide sampling, the cut off value for MSWD has been fixed at 3.5 The uncertainty in the slope and intercept has been quoted at 2σ level. The ages have been calculated using the decay constant of ^{87}Rb as $1.42X10^{-11}$ yr^{-1} recommended by IUGC

Subcommission on Geochronology (Steiger and Jäger, 1977).

Mineral phases separated from whole rock samples have also been analysed to infer the thermal history (Faure, 1986) of a region from which rock samples have been collected. The $^{87}Rb/^{86}Sr$ and $^{87}Sr/^{86}Sr$ ratios for mineral phases separated from a whole rock sample will plot on the whole rock isochron if the minerals have also remained closed systems since their crystallization from the parent magma. A later thermal event of sufficient intensity can redistribute Sr isotopes among the mineral phases without significantly disturbing the closed system evolution of the whole rock samples (Compston and Jeffrey, 1959). Then the minerals of each whole rock in the suite will define a series of parallel isochrons whose slopes represent the time elapsed since closure after the internal strontium isotopic homogenization among the mineral phases. This will lead to mineral ages younger than the whole rock ages. These mineral ages can be related to the time of secondary thermal event. Partial exchange of Sr isotopes between minerals will lead to a scatter of the data points (Gast et al 1964; Lanphere et al. 1964; Long, 1964), and no meaningful time information can be obtained in such cases. Summary of all the whole rock and mineral isochron data are given in Table 5.1 to 5.10. The FORTRAN program for the regression treatment and the computation for one (Sela whole rock) isochron is given in Appendix-1. In the following sections individual isochrons are described in detail.

TABLE 5.1

ANALYTICAL RESULTS

Sample Number	^{87}Rb (ppm)	^{86}Sr (ppm)	$(^{87}Rb/^{86}Sr)$ (atomic)	$(^{87}Sr/^{86}Sr)$ (atomic)
		GAIK GRANITE, LADAKH		
LKG-750	60.24	89.38	0.67	0.7107±09
LKG-752	70.76	50.98	1.37	0.7122±09
LKG-752 B-I	376.77	2.31	161.23	0.7791±10
LKG-752 B-II	331.32	7.12	46.00	0.7318±20
LKG-752 KF	113.09	59.46	1.88	0.7153±08
LKG-752 PL	8.6	49.28	0.17	0.7094±15
LKG-753	108.28 110.22	15.70 16.03	6.82 6.80	0.7307±14 0.7324±12
LKG-753 B-I	518.8	1.264	405.72	0.8774±11
LKG-753 B-II	513.71	0.638	795.9	1.0563±20
LKG-753 KF	173.77	19.79	8.7	0.7315±16
LKG-753 PL	8.54	9.22	0.92	0.7275±12
LKG-756	58.67	96.41	0.60	0.7102±10
LKG-757	57.98	87.12	0.66	0.7104±09
LKG-758	72.80	46.33	1.55	0.7128±11

B - Biotite KF - K Feldspar

PL - Plagioclase

TABLE 5.2

ANALYTICAL RESULTS

Sample Number	^{87}Rb (ppm)	^{86}Sr (ppm)	($^{87}Rb/^{86}Sr$) (atomic)	($^{87}Sr/^{86}Sr$) (atomic)
		KANGAN GRANITE, KASHMIR		
KG-107	156.88	1.32	117.48	1.4364±18
KG-108	83.44 82.03	4.147 4.11	19.89 19.72	0.8759±16 0.8747±16
KG-108 MU	374.60	0.587	630.83	4.3360±13
KG-108 KF	118.20	12.998	8.989	0.8366±19
KG-108 BI	166.83	1.461	112.88	0.9970±05
KG-108 PL	16.43	2.179	7.454	0.8410±13
KG-109	82.93	9.020	9.088	0.7731±14
KG-110	96.07	6.388	14.870	0.8246±10
KG-110 BI-I	325.33	3.380	95.140	0.9586±30
KG-110 BI-II	241.11	1.318	180.83	1.2395±25
KG-110 KF	145.50	11.240	12.800	0.8141±18
KG-110 MU	253.27	1.822	137.41	1.6491±30
KG-111	83.20 79.88	8.636 8.17	9.523 9.66	0.7869±10 0.7865±09
KG-114	207.83	0.102	2024.0	13.2700±40
DG-8	68.94	12.400	5.500	0.7528±16
DG-10	74.38	9.903	7.425	0.7665±10

B - Biotite KF - K Feldspar

PL - Plagioclase Mu - Muscovite

TABLE 5.3

ANALYTICAL RESULTS

Sample Number	^{87}Rb (ppm)	^{86}Sr (ppm)	($^{87}Rb/^{86}Sr$) (atomic)	($^{87}Sr/^{86}Sr$) (atomic)
		KAZINAG GRANITE, KASHMIR		
KG-25	100.55	7.23	13.75	0.8085±10
KG-39	70.48	11.82	5.89	0.7528±05
KG-42	85.05	9.25	9.19	0.7772±03
KG-43	57.45	17.99	3.16	0.7362±06
		KARZOK (RUPSHU), KASHMIR		
LKG-680	113.84	2.93	38.40	0.9799±07
LKG-681	111.69	0.82	134.60	1.6340±08
LKG-685	66.25	8.07	8.12	0.7675±08
LKG-686	87.83	2.07	41.90	1.0038±09
		POLOKANKALA GRANITE, KASHMIR		
LKG-688	89.56	3.08	28.70	0.9133±09
LKG-691	60.60	5.46	10.97	0.7916±08
LKG-692	88.93	3.414	25.75	0.8974±07
LKG-693	78.96	3.198	24.4	0.8830±09

TABLE 5.4

ANALYTICAL RESULTS

Sample Number	^{87}Rb (ppm)	^{86}Sr (ppm)	$(^{87}Rb/^{86}Sr)$ (atomic)	$(^{87}Sr/^{86}Sr)$ (atomic)
SELA GRANITE, ARUNACHAL				
AR-104	68.24	8.355	8.07	0.7988±02
AR-105	41.23	7.876	5.17	0.7975±03
AR-106	67.94	3.7	18.15	0.8027±02
AR-109	76.62	7.2	10.52	0.7993±02
AR-110	81.76	4.97	16.27	0.8022±03
THIMPU GNEISS, BHUTAN				
JK/BH/23	169.44	0.7099	235.94	2.1516±28 *
JK/BH/27	121.99	3.93	30.68	0.9273±09
JK/BH/29	130.44	7.17	17.98	0.8358±07
JK/BH/33	97.79	15.86	6.1	0.7537±11
JK/BH/34	123.06	2.71	44.93	1.0455±24
JK/BH/35	121.01	2.698	44.33	1.0293±16

* Not included in age calculation.

TABLE 5.5

ANALYTICAL RESULTS

Sample Number	^{87}Rb (ppm)	^{86}Sr (ppm)	($^{87}Rb/^{86}Sr$) (atomic)	($^{87}Sr/^{86}Sr$) (atomic)
		RAMGARH GRANITIC GNEISS, KUMAUN		
R-1	88.23	0.71	122.8	1.9128±10 *
R-2	60.40	4.42	13.51	1.1129±14
R-3	58.75	3.73	15.57	1.5973±17 *
R-4	67.91	15.84	4.24	0.8382±13
R-5	66.32	15.70	4.18	0.8305±12
R-6	73.79	14.36	5.04	0.8469±10
R-8	67.93	0.59	113.8	3.4554±70
AU/B-4	67.13	15.02	4.42	0.8401±12
AU/B-5	70.00	15.03	4.60	0.8400±18
K83-1	72.69 73.65	7.38 7.34	9.74 9.92	0.9528±28 0.9546±21
K83-6	78.52 79.13	12.04 12.14	6.45 6.44	0.8647±12 0.8639±18

* Not included in age calculation.

TABLE 5.6

ANALYTICAL RESULTS

Sample Number	^{87}Rb (ppm)	^{86}Sr (ppm)	$(^{87}Rb/^{86}Sr)$ (atomic)	$(^{87}Sr/^{86}Sr)$ (atomic)
		AMRITPUR GRANITE, KUMAUN		
AG-6	63.19	14.19	4.4	0.8367±05
AG-14	88.01	0.94	92.55	3.1347±42
AG-35	68.11	13.01	5.175	0.8532±06
AG-40	67.89	14.98	4.48	0.8378±09
AG-46	77.62	1.83	41.93	1.9239±24
AM-1	84.97	14.16	5.93	0.8622±13
AM-3	101.76	1.24	81.12	2.0289±20 *
AM-4	78.40	0.741	104.58	2.1779±24 *
AM-5	87.12	0.698	123.08	3.9914±36
AM-7	86.07	1.25	68.06	2.2450±24 *

* Not included in age calculation.

TABLE 5.7

ANALYTICAL RESULTS

Sample Number	^{87}Rb (ppm)	^{86}Sr (ppm)	($^{87}Rb/^{86}Sr$) (atomic)	($^{87}Sr/^{86}Sr$) (atomic)
ALMORA GRANODIORITE AND GRANITE, KUMAUN				
AL-2	53.56	14.99	3.53	0.7363±13
AL-3	55.81	14.29	3.86	0.7402±11
AL-7	111.8	3.31	33.38	0.9697±13
AL-8	7.78	2.29	3.36	0.7396±12
AL-11	53.02	16.30	3.22	0.7358±08
AL-12	8.60	3.82	2.22	0.7312±13
AL-13	51.93	16.26	3.16	0.7359±08
AL-14	53.48	14.96	3.53	0.7391±13
AL-16	54.49	15.95	3.38	0.7386±20
AL-18	70.79	10.19	6.87	0.7618±13
AL-23	88.71	7.75	11.33	0.8080±11
AL-24	97.25	6.46	14.88	0.8265±11
AL-24BI	407.4	0.74	544.21	0.9497±40
AL-24MU	236.5	1.11	210.61	1.7712±30
AL-24KF	46.37	9.94	4.61	0.7678±15
AU/B-2	81.56	9.2	8.76	0.7804±30
AU/S-2	81.46	9.64	8.35	0.7808±15
AU/S-3	61.37	11.29	5.37	0.7544±13
K83-7	77.74	13.35	5.76	0.7558±13
K83-18	75.53	9.27	8.05	0.7809±20
K83-21	76.86	8.33	9.12	0.7879±15
K83-22	69.70	10.03	6.87	0.7642±19

TABLE 5.8

ANALYTICAL RESULTS

Sample Number	^{87}Rb (ppm)	^{86}Sr (ppm)	$(^{87}Rb/^{86}Sr)$ (atomic)	$(^{87}Sr/^{86}Sr)$ (atomic)
ALMORA AUGEN GNEISS, KUMAUN				
AU/B-1	62.11	15.16	4.05	0.8235±30
AU/S-4	82.40	8.23	9.90	0.9740±14
AU/S-5	69.44	7.74	8.87	0.9490±16
AU/S-6	76.90	13.91	5.46	0.8555±11
AU/S-9	64.35	12.01	5.30	0.8753±12
AU/S-10	83.19	12.18	6.75	0.8762±11
AU/S-11	83.03	14.07	5.83	0.8671±20

TABLE 5.9

ANALYTICAL RESULTS

Sample Number	^{87}Rb (ppm)	^{86}Sr (ppm)	($^{87}Rb/^{86}Sr$) (atomic)	($^{87}Sr/^{86}Sr$) (atomic)
ASKOT DHARAMGHAR KLIPPEN ZONE, KUMAUN				
AS-3	177.6	1.32	133.00	4.3345±170
AS-4	189.4	1.11	168.70	4.9937±90
AS-6	191.1	1.70	111.1	3.8305±65
AS-7	197.3	1.04	187.5	5.3118±120
AS-9	36.58	32.89	1.10	0.7371±07
AS-10	40.37	36.34	1.10	0.7380±14
AS-11	99.55	3.29	29.91	1.4441±18
AS-12	96.22	3.50	27.17	1.3651±17
AS-13	46.48	26.28	1.75	0.7550±11
GWALDOM GRANITE, KUMAUN				
AS-14	73.94	4.17	17.53	1.1706±15
AS-15	87.67	3.48	24.90	1.3479±13
AS-16	79.71	3.91	20.15	1.2084±16
AS-17	85.27	3.89	21.67	1.2618±20
AS-18	66.80	7.15	9.24	0.9638±14
AS-19	67.43	8.22	8.11	0.9324±14

TABLE 5.10

ANALYTICAL RESULTS

Sample Number	^{87}Rb (ppm)	^{86}Sr (ppm)	($^{87}Rb/^{86}Sr$) (atomic)	($^{87}Sr/^{86}Sr$) (atomic)
		MUNSIARI GNEISS, KUMAUN		
K83-42	29.136	52.03	0.55	0.7176±10
K83-51	73.64	32.39	2.247	0.7607±10
MS-1	41.35	31.73	1.29	0.7397±07
MS-2	77.72	122.29	0.63	0.7147±10 *
MS-3	59.17	28.99	2.02	0.7561±10
MS-4	45.29	18.69	2.39	0.7831±07
	44.97	18.63	2.39	0.7823±05
MS-5	58.40	39.60	1.46	0.7422±08

* Not included in age calculation.

5.1 Gaik Granite :

The Rb-Sr isotopic data for six whole rock samples from the Gaik granite (Fig 3.1), a part of Ladakh granite in the Trans Himalayan region, are given in Table 5.1. The data are plotted on a Rb-Sr evolution diagram as shown in Fig. 5.1, with the straight line shown being the least squares fit of the data based on the two error weighted regression of Williamson (1968). The dispersion in the $^{87}Rb/^{86}Sr$ ratio among the samples ranges from 0.6 to 1.5 with one sample at about 7. As can be seen, all the samples conform to a linear array within experimental error. The samples are poorly radiogenic and are not evenly distributed along the linear array, the slope being controlled mainly by the lone radiogenic point. This line corresponds to an age of 230±35 Ma and initial $^{87}Sr/^{86}Sr$ ratio of 0.7081±0.0011. The MSWD at 0.14 indicates that the samples have evolved as closed systems after their crystallization. Replicate analysis of LKG-753 shows that though the Rb and Sr concentrations differ more than precision of measurements, their ratios are within 2% of each other. Biotite, plagioclase and K-feldspar fractions were separated from two of the whole rock samples (LKG-752 and LKG-753) and analysed in the same way as whole rocks. Biotite-I and Biotite-II are two separate fractions. If these individual mineral phases of the whole rock samples had also remained closed chemical systems since 230 Ma ago, they should plot on the 230 Ma isochron of the whole rock samples. Fig. 5.2 and Fig. 5.3 show the isochron diagram for

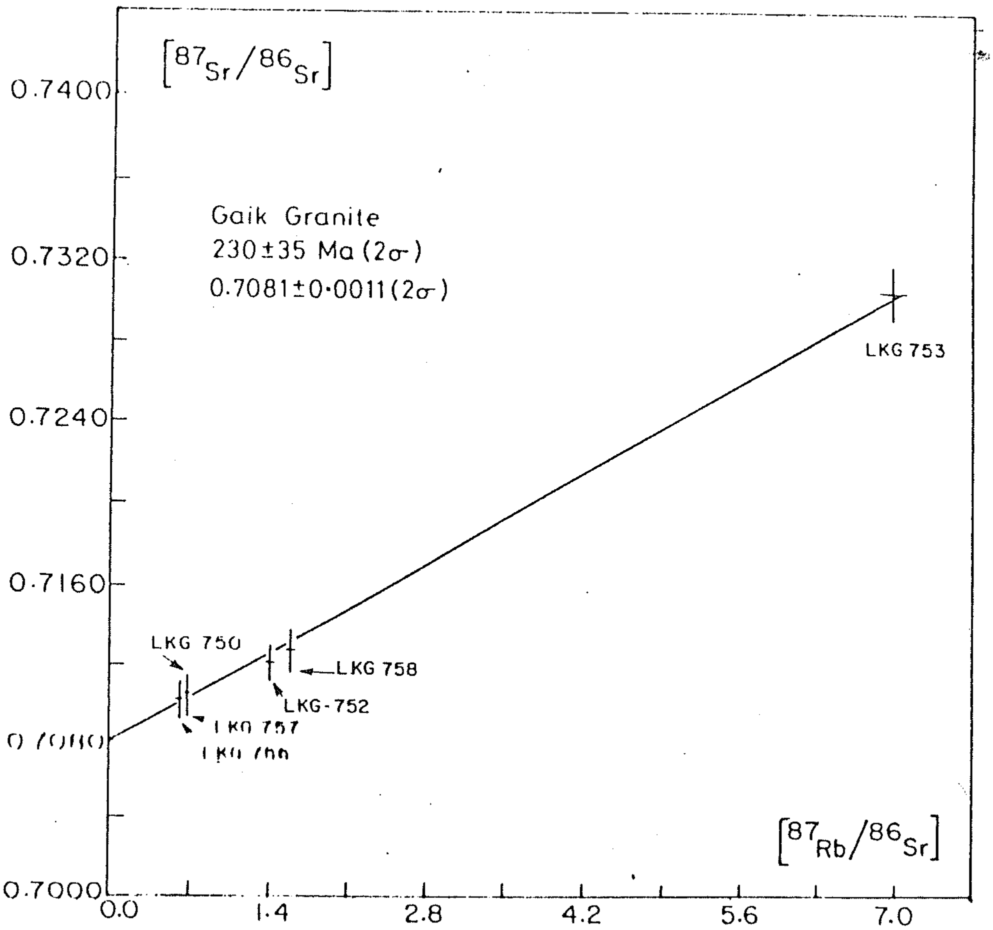


Fig.5.1 Whole Rock isochron for the Gaik Granite

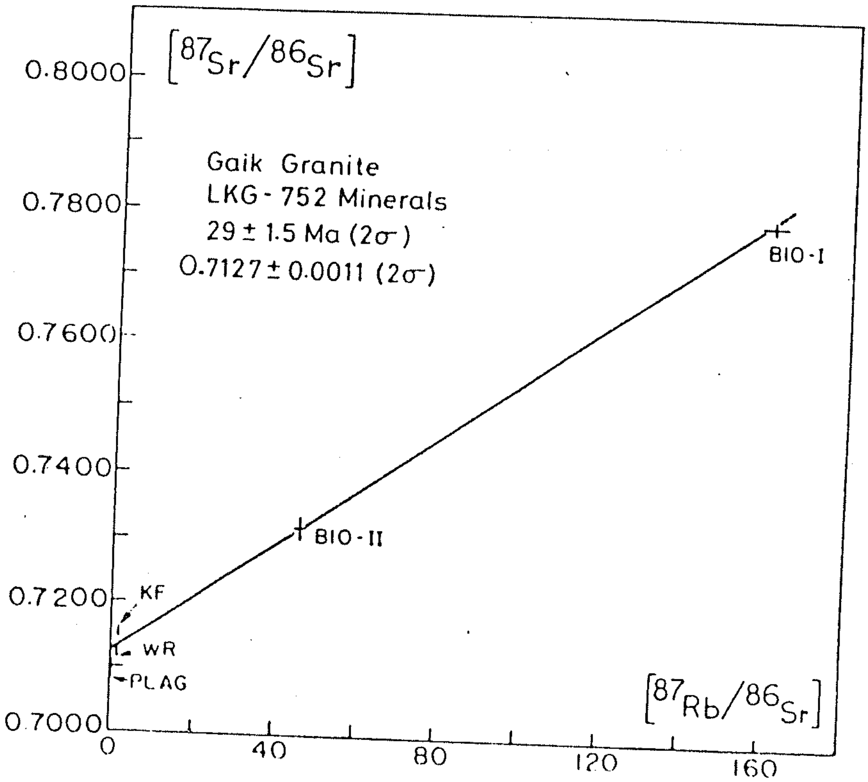


Fig.5.2 Mineral isochron for the Gaik Granite

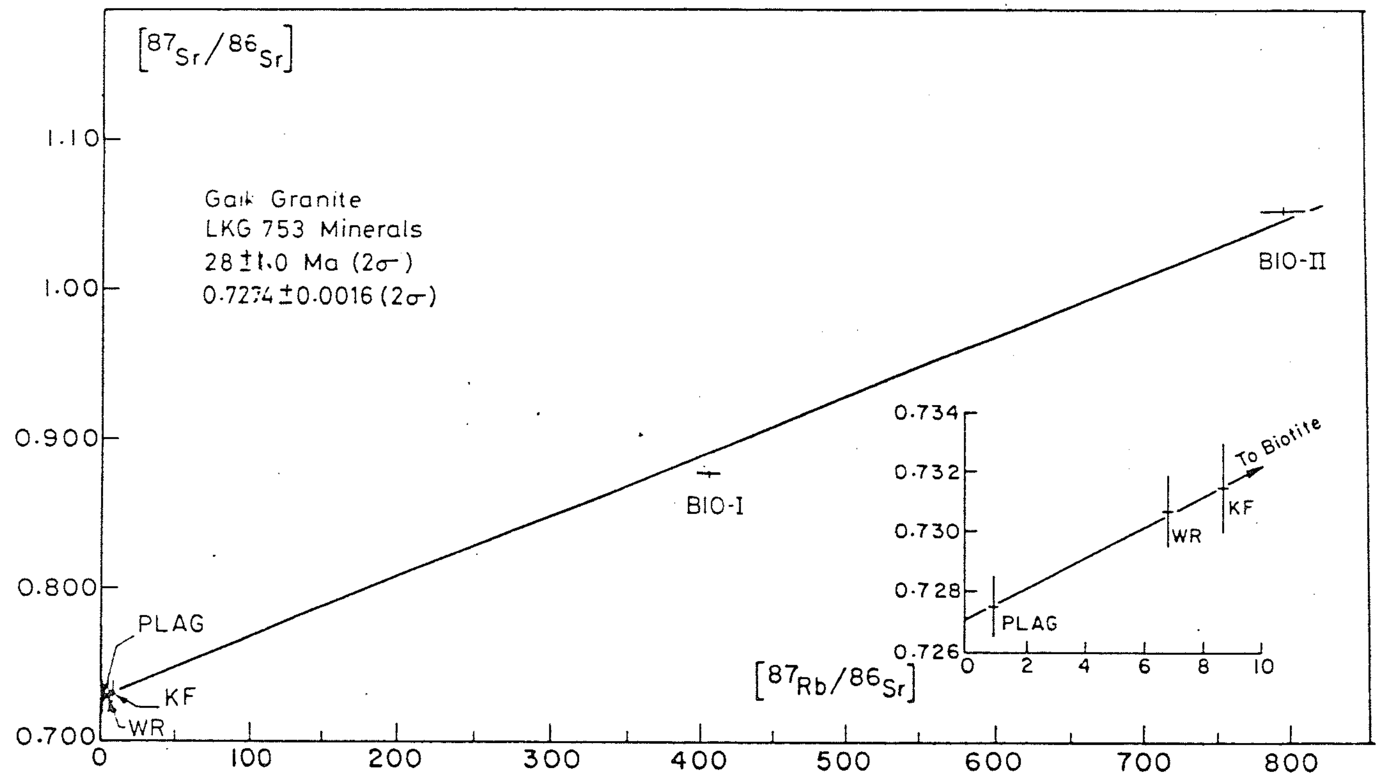


Fig.5.3 Mineral isochron for the Gaik Granite

the mineral fractions separated from LKG-752 and LKG-753, respectively. These points do not lie on a 230 Ma isochron but rather define 29±1.5 Ma and 28±1.0 Ma isochrons with intercepts at 0.7127 and 0.7274. From Figs. 5.2 and 5.3 it is evident that minerals of the rock LKG-753 underwent more complete isotopic equilibration at about 30 Ma ago as compared to LKG-752, but have remained closed systems ever since. The growth of radiogenic Sr in these whole rocks from 230 Ma until 30 Ma ago is reflected in the higher intercepts, a change from 0.7081 to 0.7127 for LKG-752 and from 0.7081 to 0.7274 for LKG-753.

The two distinct isochrons for minerals and whole rocks respectively show that although complete or nearly complete isotopic equilibration or exchange occurred between mineral phases in each of the rock samples, the whole rock samples themselves are evidently large enough that negligible net gain or loss of Rb and Sr occurred in them since their emplacement.

5.2 Kangan Granite :

The Kangan granite shown in Fig.3.4 occurs within Tethys Himalaya, near Srinagar in the Kashmir region. The Rb-Sr isotopic analyses for eight whole rocks and mineral separates are given in Table 5.2. In addition to biotite (Bi), K-feldspar (KF) and plagioclase (Pl), a fourth mineral muscovite (Mu) have also been separated from two rocks KG-108 and 110. Fig.5.4 shows the isochron diagram for whole rocks. The $^{87}Rb/^{86}Sr$ ratio varies from 5.5 (DG-8) to 117.48 (KG-107). Though the whole rock sample KG-114 is highly radiogenic ($^{87}Sr/^{86}Sr$ = 13.27), it is only marginally away from the least squares line. It is evident from the inset of the Fig.5.4, that the samples are evenly distributed along the linear array. This line corresponds to an age of 480±15 Ma and an initial $^{87}Sr/^{86}Sr$ ratio of 0.7181±0.0027.

The mineral isochron (Mu, KF and WR) of KG-110, shown in Fig.5.5 also defines an age of 470±21 Ma and initial ratio of 0.7264±0.0055 which agree with those of the whole rock isochron within experimental errors. But the biotite of KG-110 does not fall on the isochron and shows an open system behaviour. The WR-biotite pair gives an age of 118 Ma whose geological meaning is not clear. The minerals of KG-108 show open system behaviour. In the case of KG-108 muscovite is less disturbed as compared to biotite. The WR-muscovite pair of KG-108 yields ~400 Ma while WR-biotite, 92 Ma. Thus it is evident that mineral phases of KG-108 appear to have been disturbed more than those of KG-110. Since both KG-108 and KG-110 were collected within a distance of about 1.5 - 2 kilometers, this difference is difficult to explain. However, it has been reported earlier that different whole rock samples from the same outcrop may show a differential response to thermal disturbance (Wetherill and Bickford, 1964). The MSWD for the regression of eight whole rock

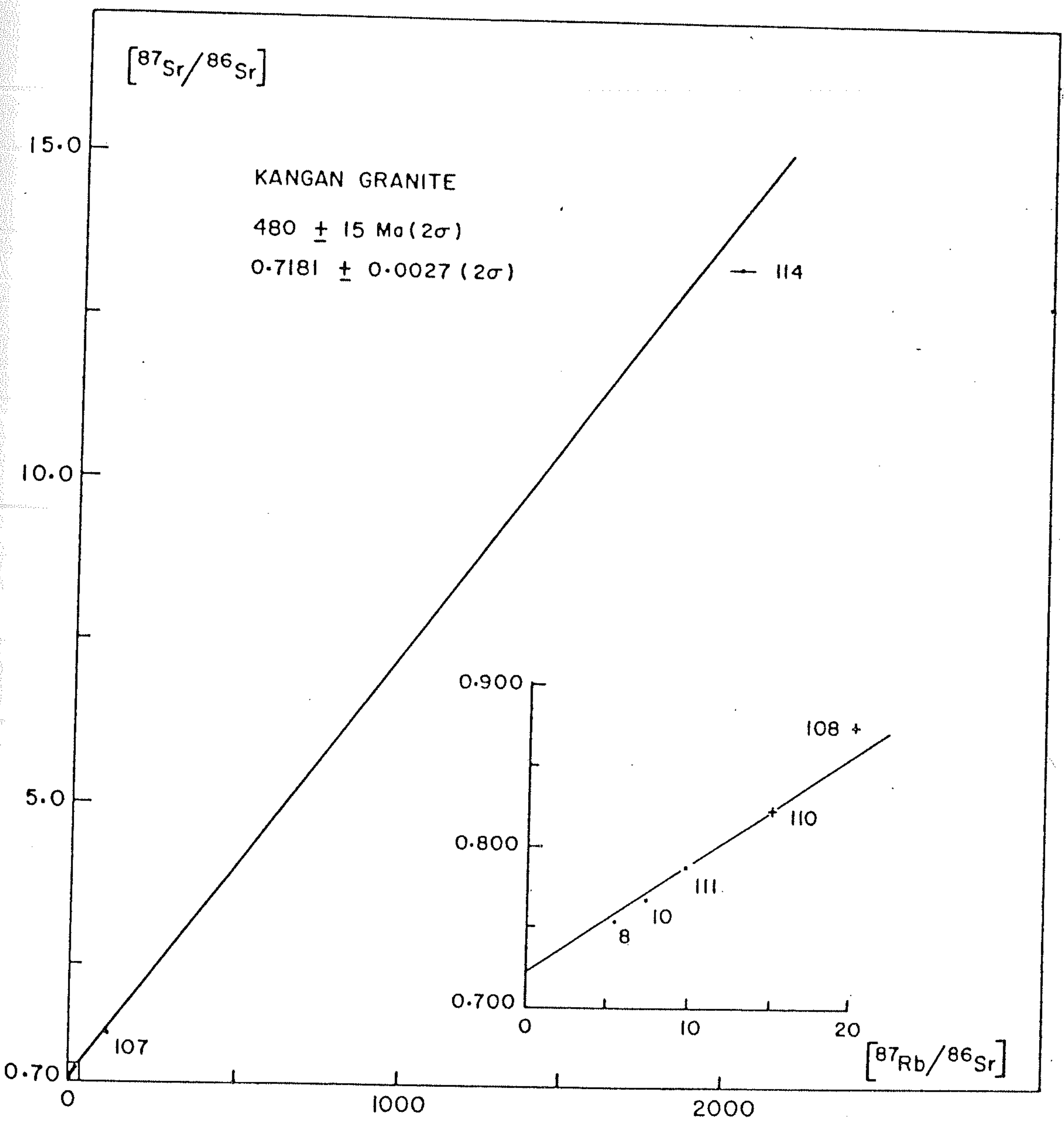


Fig. 5.4. Whole Rock isochron for the Kangan Granite

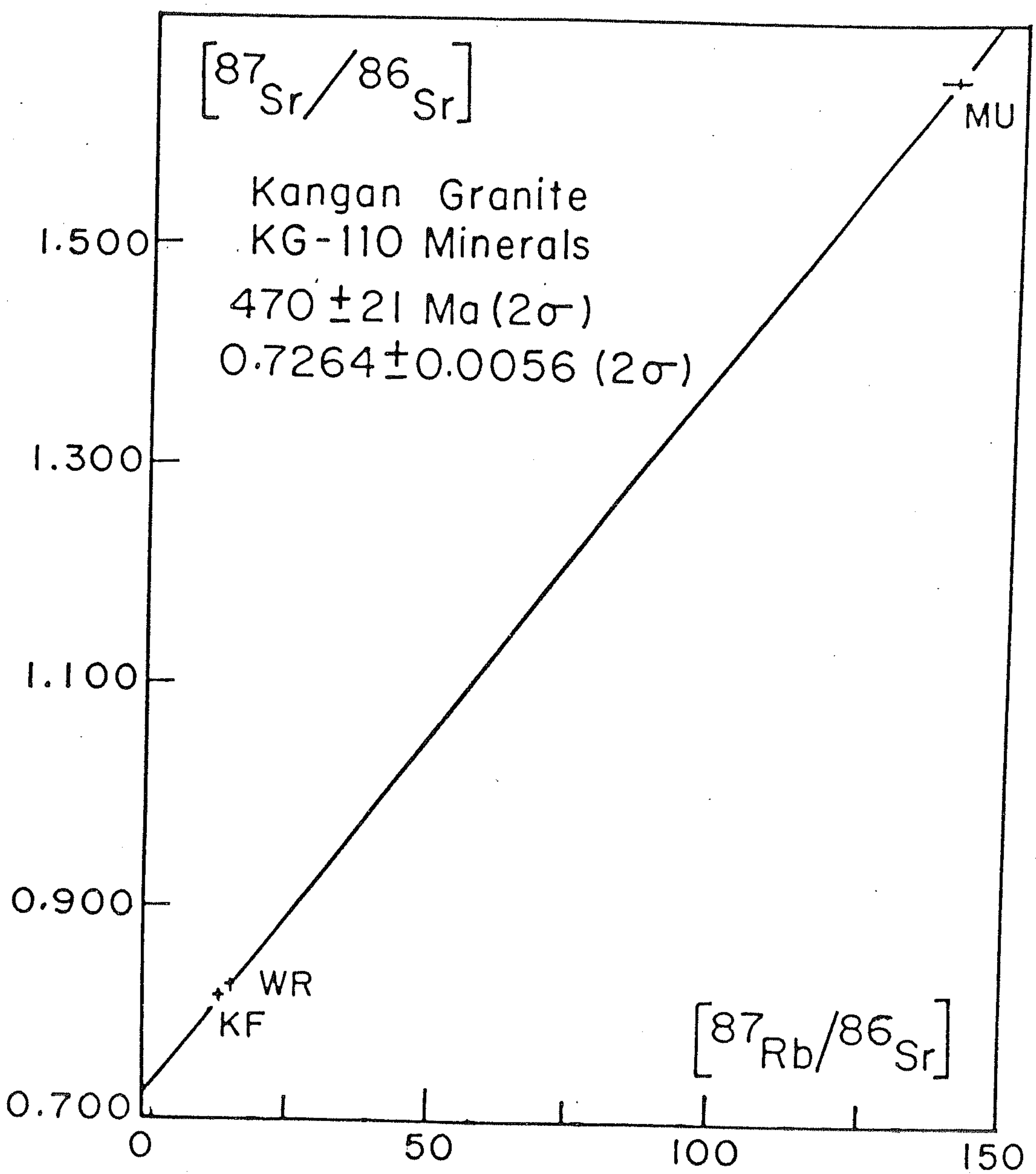


Fig. 5.5. Mineral isochron for the Kangan Granite

samples is quite high at 18 indicating that the scatter is mainly due to intrinsic geological factors. However, the true age of the Kangan granite is very probably close to 480 Ma. The examination of the mineral behaviour shows that biotite has been much more open than muscovite and K-feldspar due to the subsequent thermal episode. Biotite is known to be most responsive to secondary equilibration. The discordance in the two biotite ages indicates that they did not equilibrate completely precluding any geological significance to these apparently young ages.

5.3 Kazinag Granite :

Very fresh and large samples were collected from an active quarry from this granite body is shown in Fig.3.1. The four samples analysed show good radiogenic enrichment and mutual spread in their Rb/Sr ratios. The line fitted (Fig 5.6) to these data points (Table 5.3) corresponds to an age of 477±24 Ma and initial Sr ratio of 0.7141±0.0021. The MSWD is 1.57 which indicates that the fit of the straight line is good. No mineral analysis was attempted for these rocks.

5.4 Karzok and PolokankaLa Granite :

These two granite bodies shown in Fig.3.4 represent two major intrusions within a relatively small area in the Tethyan rocks in Zanskar range just south of ITSZ i.e. they represent the northern most exposed part of the Indian plate.

The Rb-Sr data (Table 5.3) for four whole rock samples

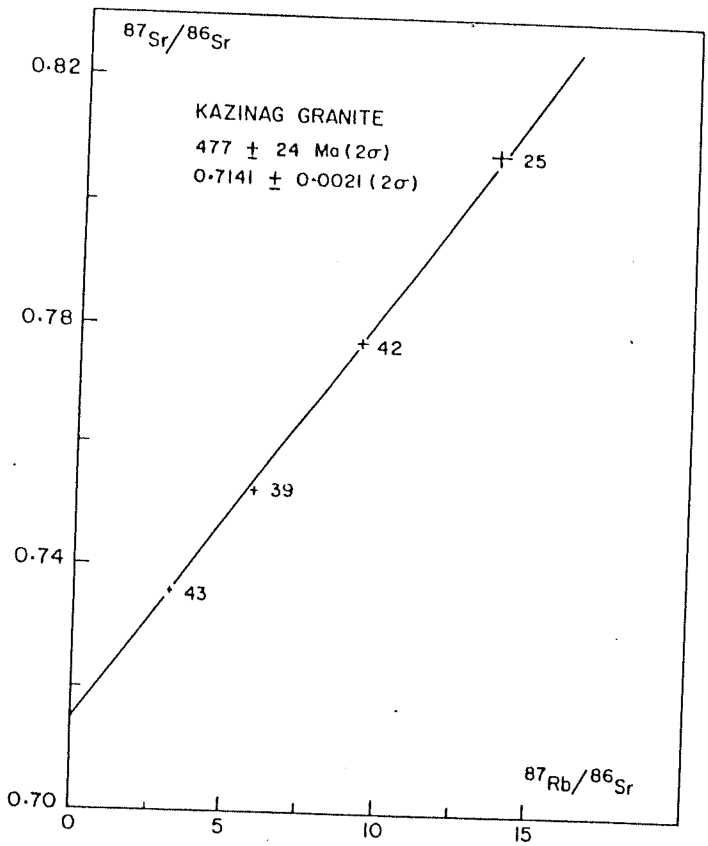


Fig.5.6 Whole Rock isochron for the Kazinag Granite

of Karzok granite is plotted in Fig.5.7. All the samples were collected within a small area of 5-6 km^2 which yield a well defined isochron corresponding to an age of 487±14 Ma and initial Sr ratio of 0.7113±0.0036. The excellent alignment of all the four samples is reflected in a low MSWD of 0.31, which shows that the Karzok granite body formed 490 Ma ago with its initial Sr composition at 0.7113.

Data given in Table 5.3 for four samples from the Polokanka-La granite exposed ~100 km west of Karzok body lying within the same Tethyan sediments, are plotted on an isochron diagram shown in Fig.5.8. Regression of the four points gives an age of 487±25 and an initial Sr composition of 0.7154±0.0067. The MSWD at 0.58 indicates good fit of the data.

The pooled isochron for Karzok and Polokanka-La granites gives an age of 490±12 Ma with initial Sr ratio of 0.7127±0.0031. MSWD = 1.08 indicates good fit of the data. The Karzok and Polokanka-La granites can, therefore, be assigned a common age close to 490 Ma. It appears that the Karzok granite may be the eastern extension of the Polokanka-La granite. The ages of these two intrusions in the Zanskar valley are similar to those of the granites in Kashmir valley viz. the Kangan granite and the Kazinag granite near Srinagar.

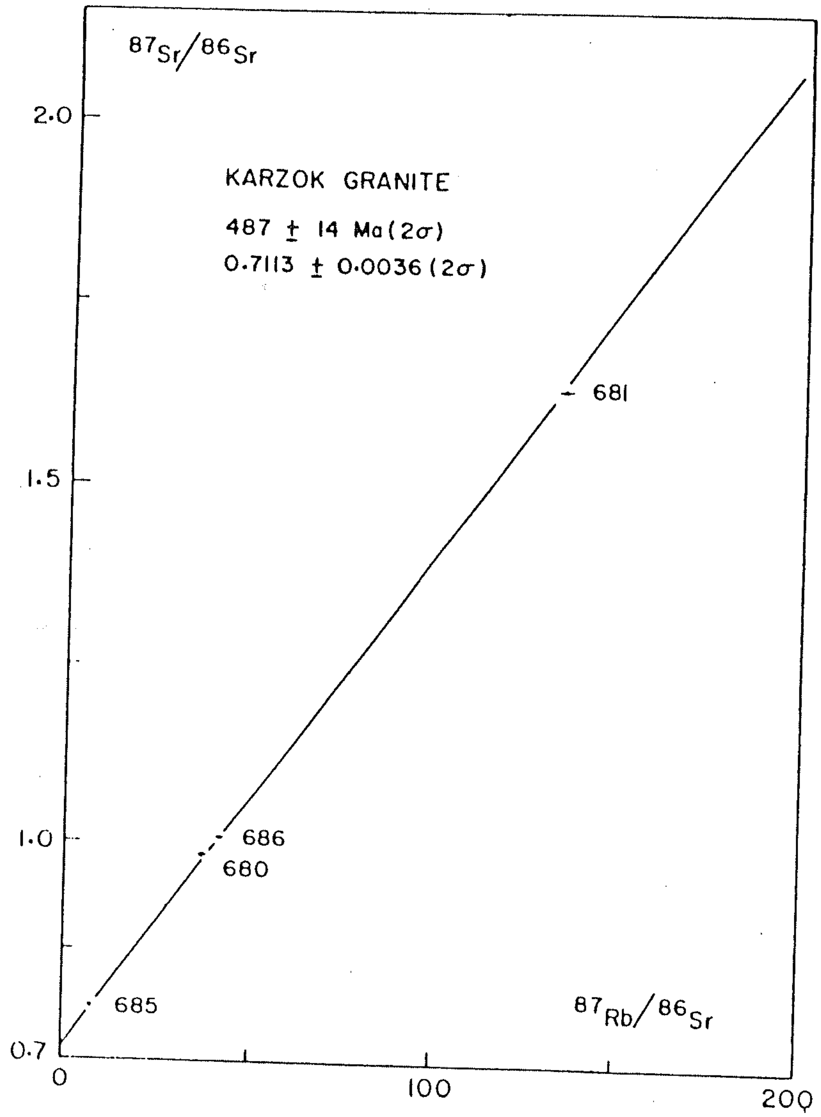


Fig.5.7 Whole Rock isochron for the Karzok Granite

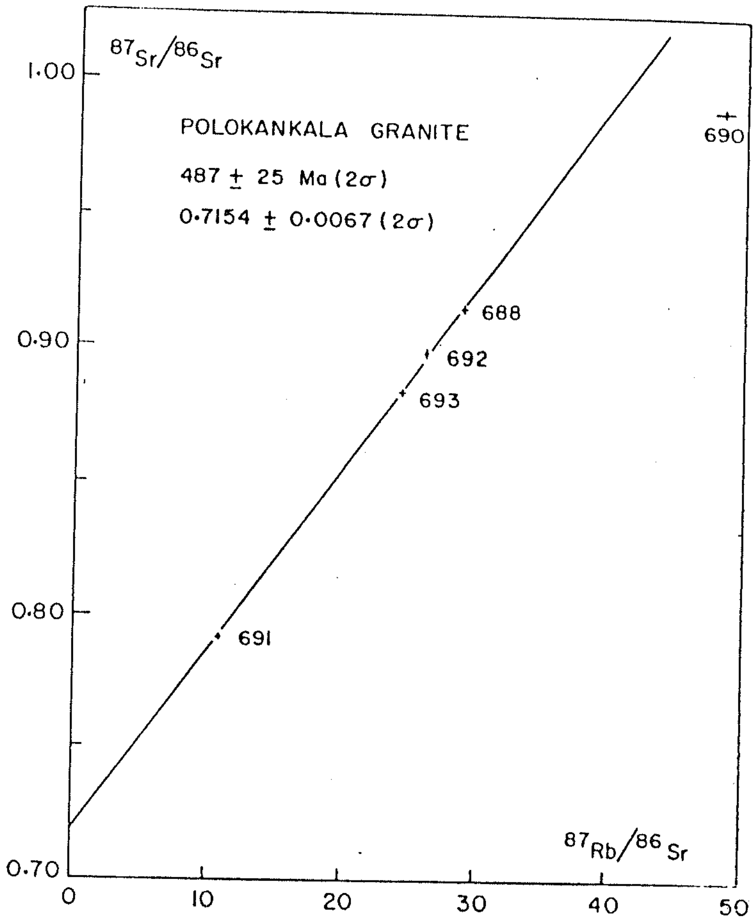


Fig.5.8 Whole Rock isochron for the Polokanka-La Granite

5.5 Sela Granite :

Rb-Sr analyses have been made on five whole rock samples of the Sela granite (Fig.3.5) a part of the Great Himalaya in Arunachal Pradesh. The data (Table 5.4) for all the five samples are plotted on a Sr evolution diagram (Fig.5.9). Regression of the data points give an age of 28.6±3.5 Ma and an initial Sr composition of 0.7954±0.0006. The MSWD at 1.15 indicates that the fit of the points to a straight line is very good. Granites of similar ages are found to occur in most of the Great Himalayan ranges.

5.6 Thimpu Gneiss :

The Thimpu gneiss exposed in the Great Himalaya of Bhutan is a part of Thimpu Formation (Fig.3.6). Six samples were collected and analysed and the data is given in Table 5.4. One sample, JK-BH-23 which is highly radiogenic ($^{87}Sr/^{86}Sr$=2.1516 and $^{87}Rb/^{86}Sr$=235.94) does not fit the other data. The isochron defined by the other five samples is shown in Fig.5.10. As can be seen, these five samples align along a linear array and are evenly distributed. This isochron corresponds to an age of 508±15 Ma and an initial Sr ratio of 0.7088±0.0035. The fit of the data to a straight line is very good with the MSWD = 1.67. Regression of all the six samples reduces the isochron age to 483±12 Ma and increases the initial Sr ratio to 0.7130±0.0032. But the later regression yields MSWD = 12.4 which is significantly

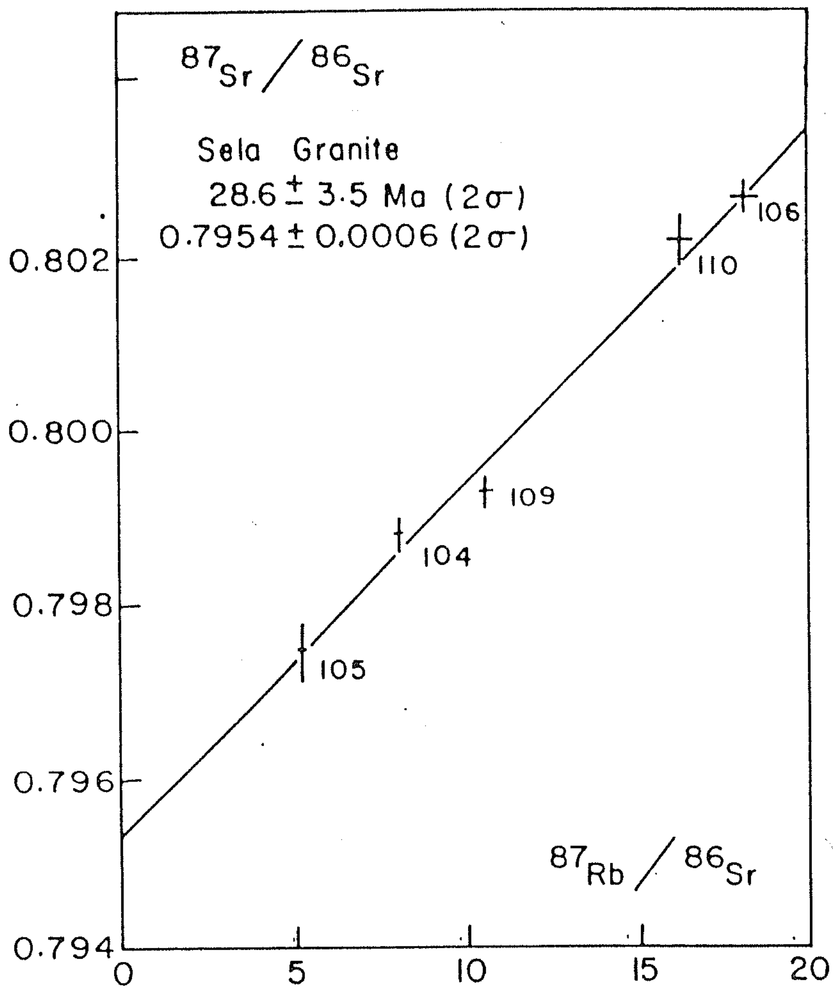


Fig.5.9 Whole Rock isochron for the Sela Granite

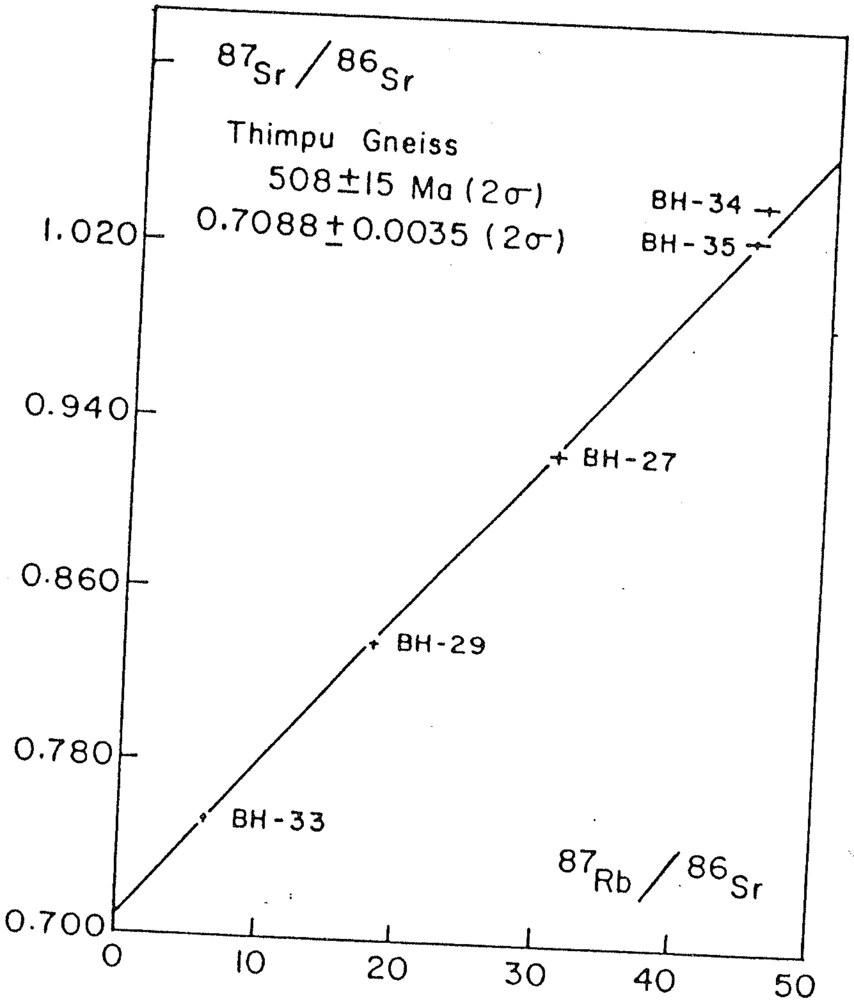


Fig.5.10 Whole Rock isochron for the Thimpu Gneiss

higher. The reason for the deviation of JK-BH-23 may be due to the open system behaviour of this highly radiogenic sample. No mineral analysis was attempted for any of these rocks.

5.7 Ramgarh Granitic Gneiss :

The Rb-Sr data for 11 samples of the porphyritic and mylonitized granite gneiss of the Ramgarh Group (Fig.3.7) are given in Table 5.5. and plotted in Fig.5.11. The points scatter considerably. However, except for R-1 and R-3, other points fall close to a linear array corresponding to an age of 1770±56 Ma and an initial Sr ratio of 0.7230±0.0046. These results have to be taken with considerable caution, as the MSWD is high at 16.67. The scatter of the data points to a significant departure from closed system evolution, presumably due to post emplacement and thermo-tectonic disturbances. The mylonitization of the rocks may have also contributed to the isotopic disturbances. If the single highly radiogenic point R-8 is omitted from the regression, the age becomes 1875±90 Ma.

5.8 Amritpur Granite :

The Amritpur granite (Fig.3.7) is the only large granitic body occurring in the vicinity of MBT. It is truncated in the south by the MBT. The body represents a complex assemblage of granites probably of different generations cross cutting one another and making it difficult

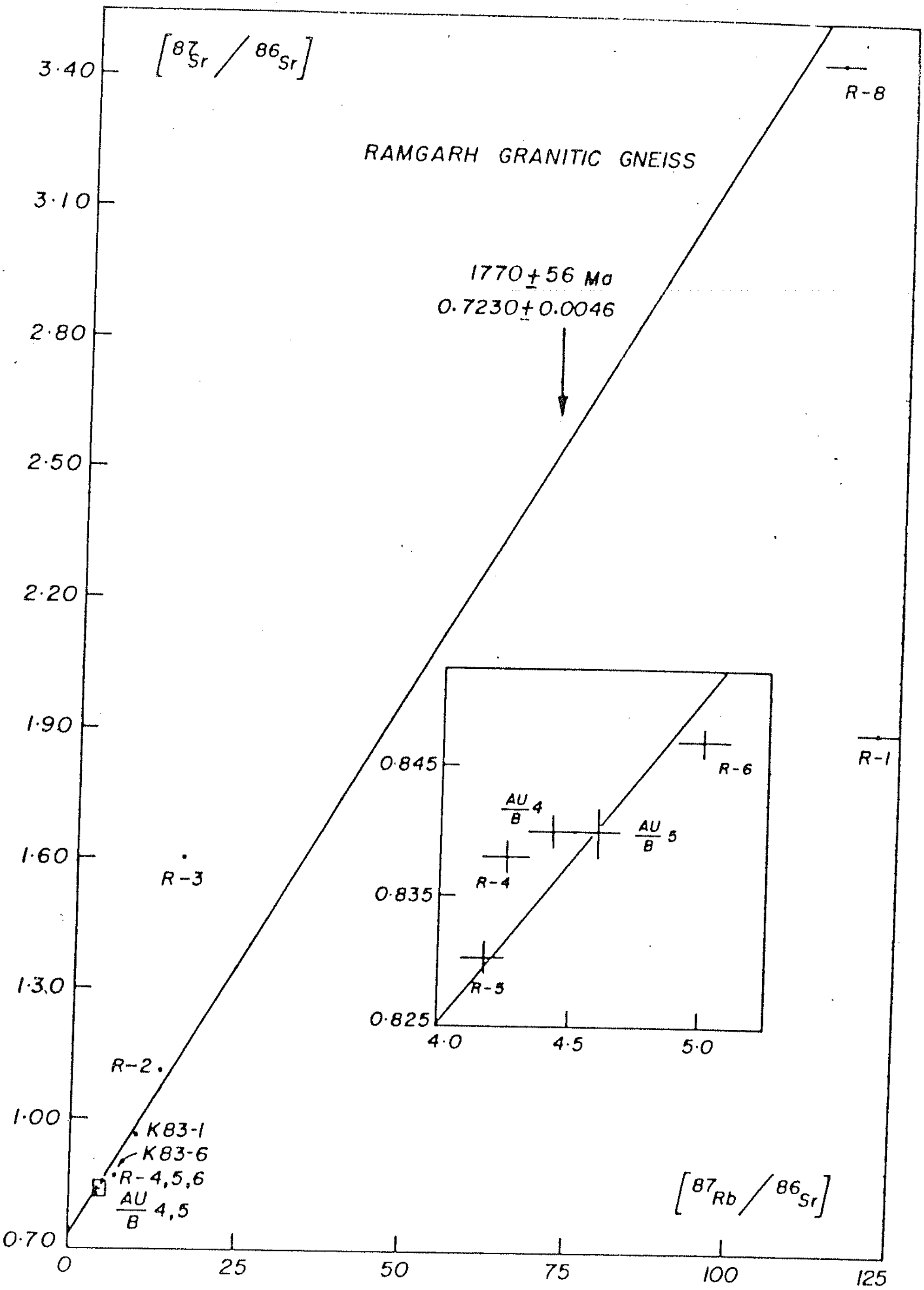


Fig.5.11 Whole Rock isochron for the Ramgarh Granitic Gneiss

to collect samples belonging to one genetic suite. As many as nine samples have been analysed and data are given in Table 5.6. These samples show good radiogenic enrichment and mutual spread in their Rb/Sr ratios. A well defined isochron (Fig.5.12) can be constructed from six of these points. Samples for AM-3, AM-4, and AM-7 are excluded. Regression of the six points gives an age of 1888±46 with an initial Sr ratio of 0.7117±0.0044. The MSWD is 6.88, which is somewhat high and attributed to intrinsic geological factors. However, it can be concluded that the Amritpur granite formed about 1880 Ma ago. The out-crop shows abundant intrusions of leucocratic/aplitic granites at a number of places. AM-3, AM-4, and AM-7 are samples from such coarse grained massive leucogranites. Model ages for these four samples range from 1200 to 1600 Ma assuming an initial Sr ratio of 0.7118. Since these samples are highly radiogenic, their model ages are not sensitive to small differences in the value of initial Sr ratio assumed.

5.9 Almora-Champawat Granodiorite :

The Almora group of medium grade metamorphics is intruded by a massive granite granodiorite suite known as Almora-Champawat granodiorite. This batholithic body is now exposed along a belt extending from Dudhatoli, Almora to Champawat (Fig.3.7) and is bordered by augen gneisses formed presumably as a result of metasomatic granitization during the late tectonic phase of this magmatism. In all, eleven

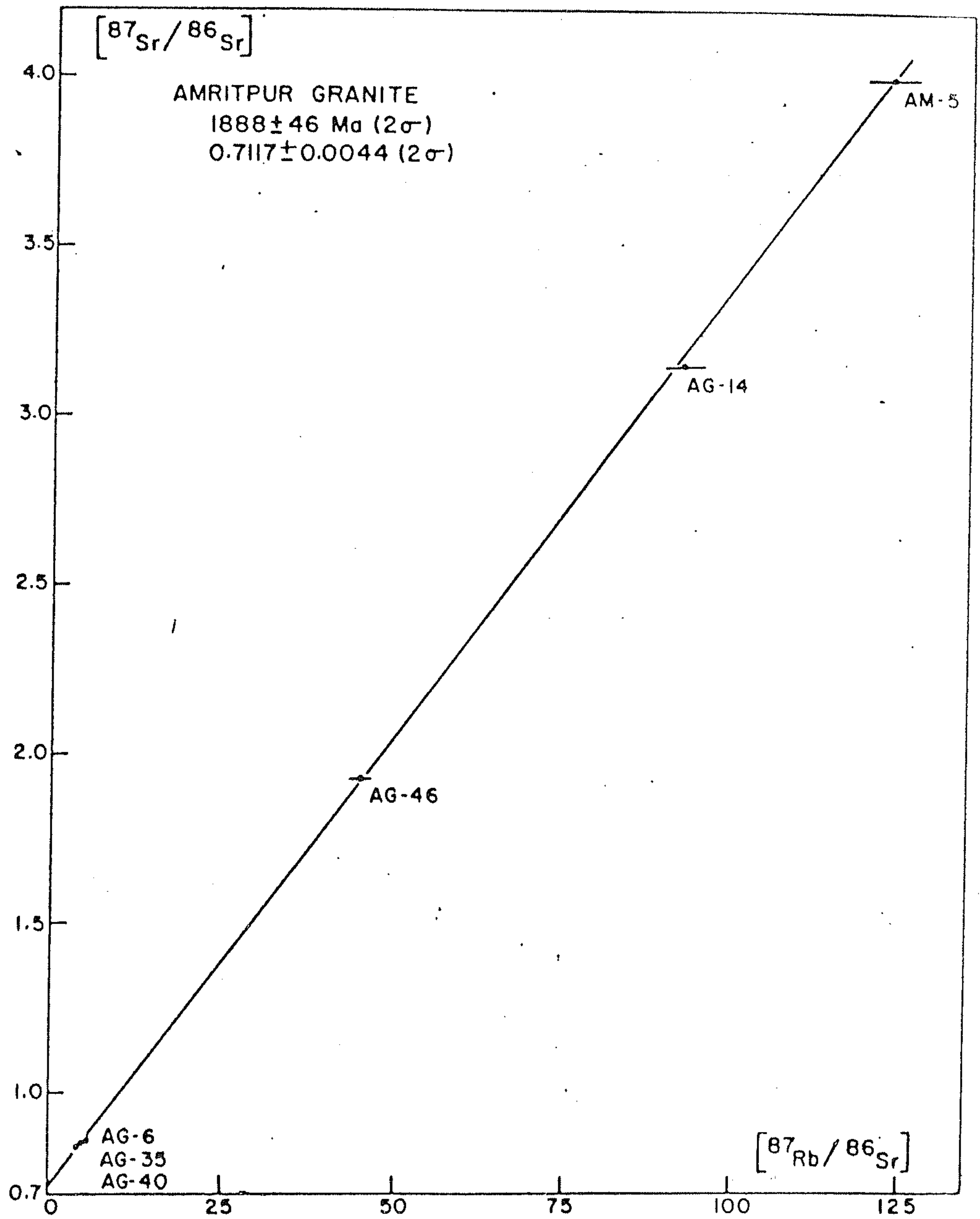


Fig.5.12 Whole Rock isochron for the Amritpur Granite

samples from the Champawat granodiorite were analysed. The data for all these samples are given in Table 5.7. The best fit line (Fig 5.13) to the eleven samples gives an age of 565±22 Ma and initial Sr ratio of 0.7102±0.0016. The MSWD at 2.83 indicates that the fit of the data points is satisfactory. AL-7 and AL-8 are leucogranites cross-cutting the Champawat granite. AU/S-2 and AU/S-3 are samples from a narrow zone near the North Almora Thrust. Since all these four samples also fall on the 565 Ma isochron within experimental errors, they are not significantly different in the age from the Champawat granodiorite. K83-7, K83-8, K83-21 and K83-22 are samples of augen gneiss at the border of the Champawat granodiorite. These samples were not large and fresh. Their model ages range from 550 to 700 Ma, which show that they also formed or were isotopically equilibrated at the same time as the Champawat granodiorite.

The Rb-Sr data of minerals separated from the Almora granite AL-24 is shown in Fig.5.14. While the whole rock-biotite pair gives an age of 16.4 Ma, whole rock-muscovite and potash feldspar form a three point isochron at 352 Ma. Powell et al (1979) also reported similar ages (16 and 19 Ma) for the whole rock-biotite pair but much older ages of 345 and 287 Ma, respectively for whole rock-muscovite pairs.

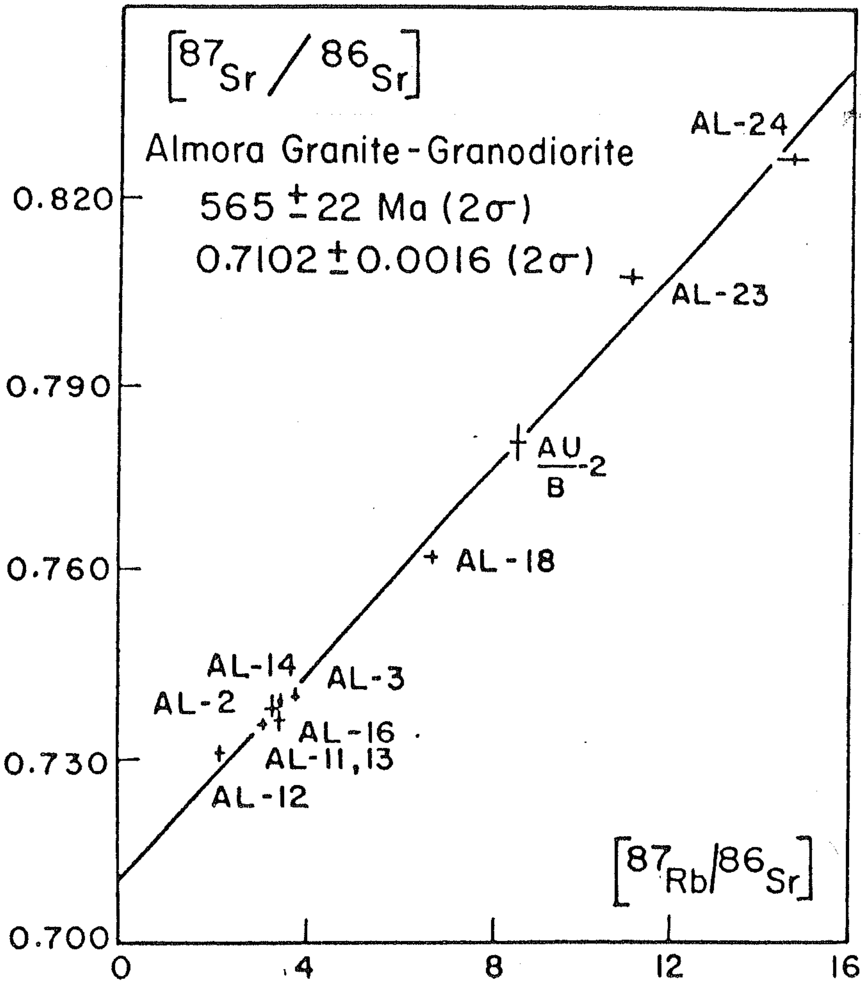


Fig.5.13 Whole Rock isochron for the Almora Granite-Granodiorite

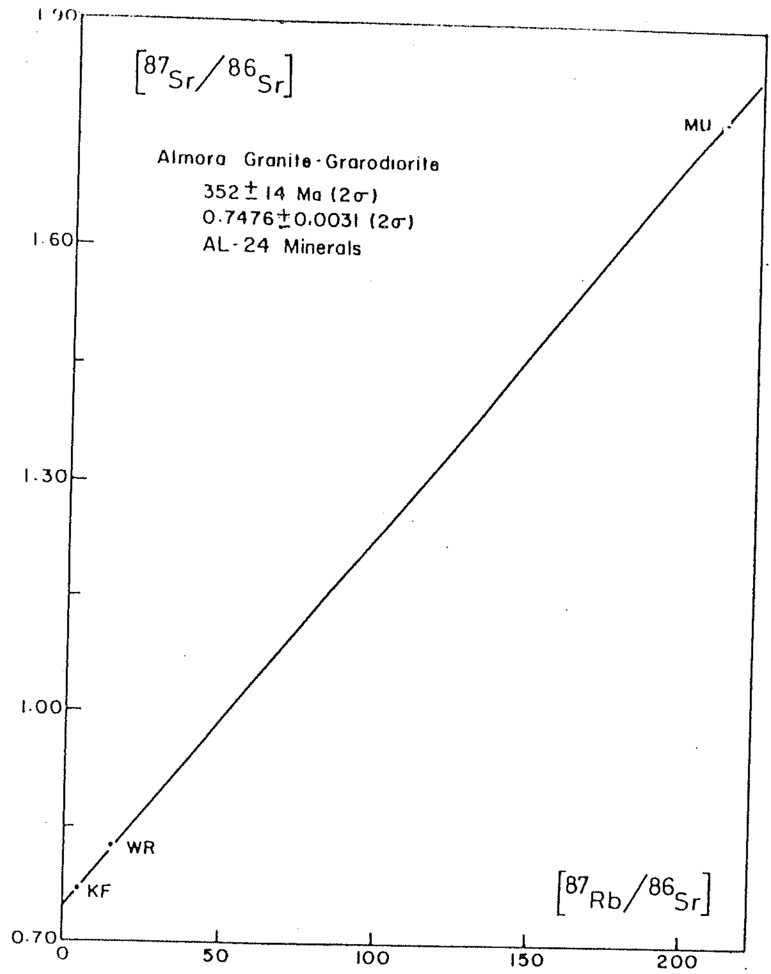


Fig.5.14 Mineral isochron for the Almora Granite

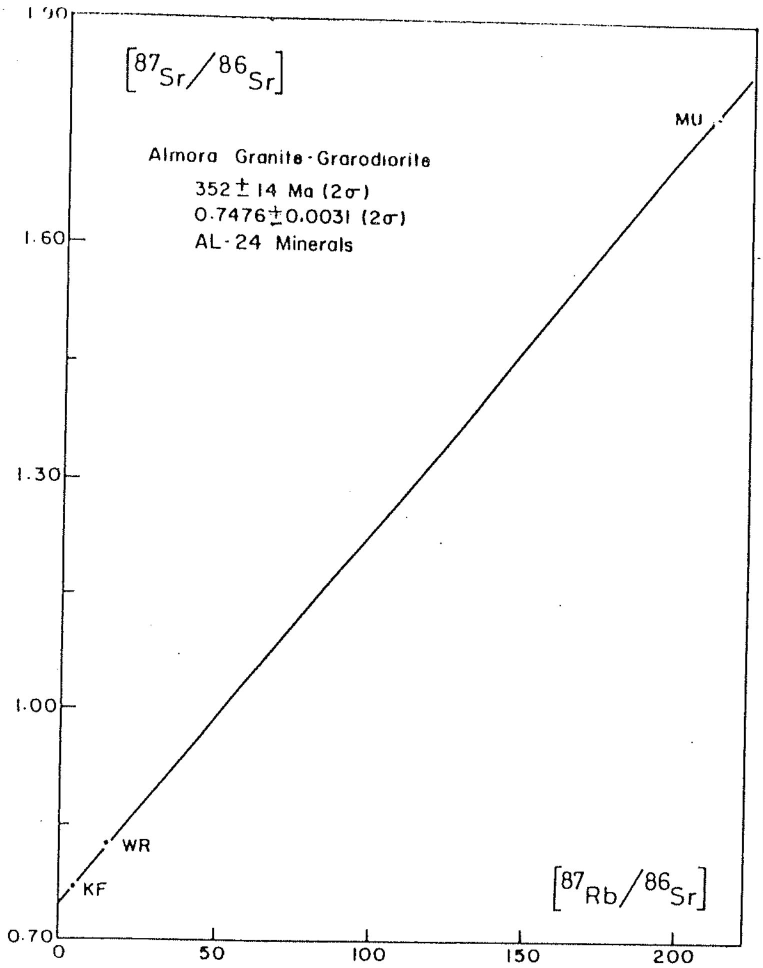


Fig.5.14 Mineral isochron for the Almora Granite

5.10 Almora augen Gneiss :

Unlike the above samples from the upper part of the Almora Nappe, data in Table 5.8 for six samples of augen gneiss from the narrow wedge of outcrops bordering the synclinal Almora crystallines in the north and corresponding to the basal part of the Almora Nappe define an isochron (Fig.5.15) corresponding to an age of 1820±127 Ma and initial Sr ratio of 0.7148±0.0115. The relatively large error in the initial ratio has resulted from the large extrapolation of the data to the ordinate. The MSWD at 0.41 suggest good fit of the data points. The two points AU/S-9 and AU/S-10 are not included in the regression as they scatter considerably away from the best-fit-line. These samples were collected very near to the contact zone of the north Almora thrust. The lone sample, AU/B-1 of augen gneiss collected from the southern margin of the Almora synform conforms to this isochron. We could not collect more fresh samples from the southern border because of its occurrence as a very thin band. This suggests the presence of a thin wedge of the older augen gneisses in the southern border of the Almora group which was attenuated presumably due to movement along the south Almora Thrust.

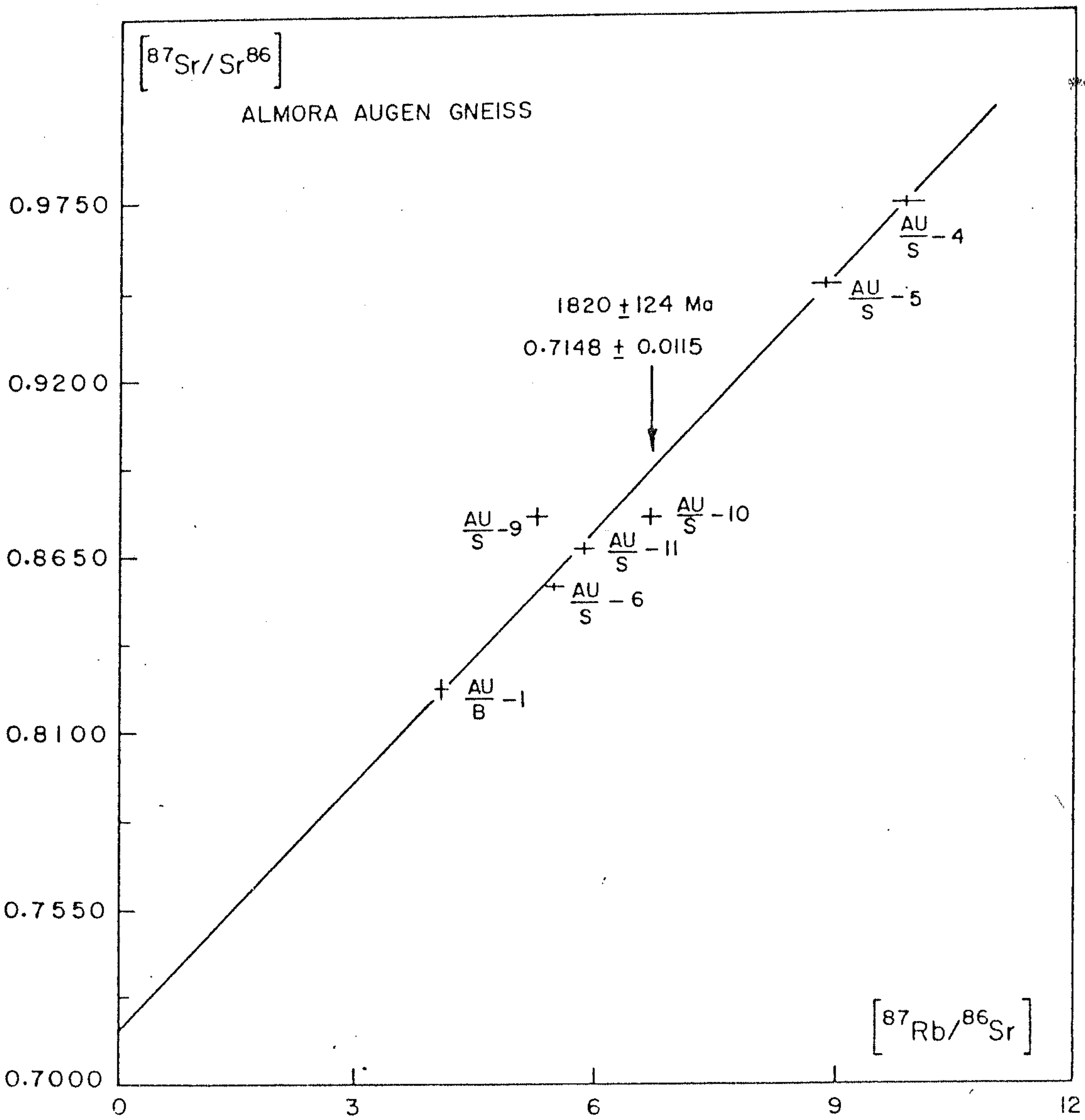


Fig.5.15 Whole Rock isochron for the Almora Augen Gneiss

5.11 Askot-Dharamghar Gneiss :

The Rb-Sr data for nine samples of augen gneiss from Askot and Dharamghar Klippen (six from Askot and 3 from Dharamghar) are given in Table 5.9. The best fit line yields an age of 1795±30 Ma and an initial Sr ratio of 0.7090±0.0015. Some of the samples are highly radiogenic. A slight departure of data points from a strictly linear array is indicated by the high MSWD at 7.10. Rocks dated at 1620 Ma by Powell et al (1979) are also from the Askot Klippen.

5.12 The Gwaldom Granite :

The Gwaldom granite occurs within the adjacent Baijnath Klippe to the west of Askot Dharamghar Klippe. Table 5.9 gives the Rb-Sr data for six whole rock samples of the granite. The isochron is shown in Fig. 5.16. These samples give a slightly younger age of 1690±65 Ma and a more evolved initial Sr ratio of 0.7375±0.0127 and MSWD = 1.19. With the present data, it is not possible to distinguish between the ages of the three physically separate granitoids (Askot, Dharamghar and Baijnath) in the Klippen zone. Therefore, a pooled isochron for all the three bodies (Askot, Dharamghar and Gwaldom) is plotted on isochron (Fig.5.17) giving an age of 1810±20 Ma and initial Sr ratio of 0.7090±0015.

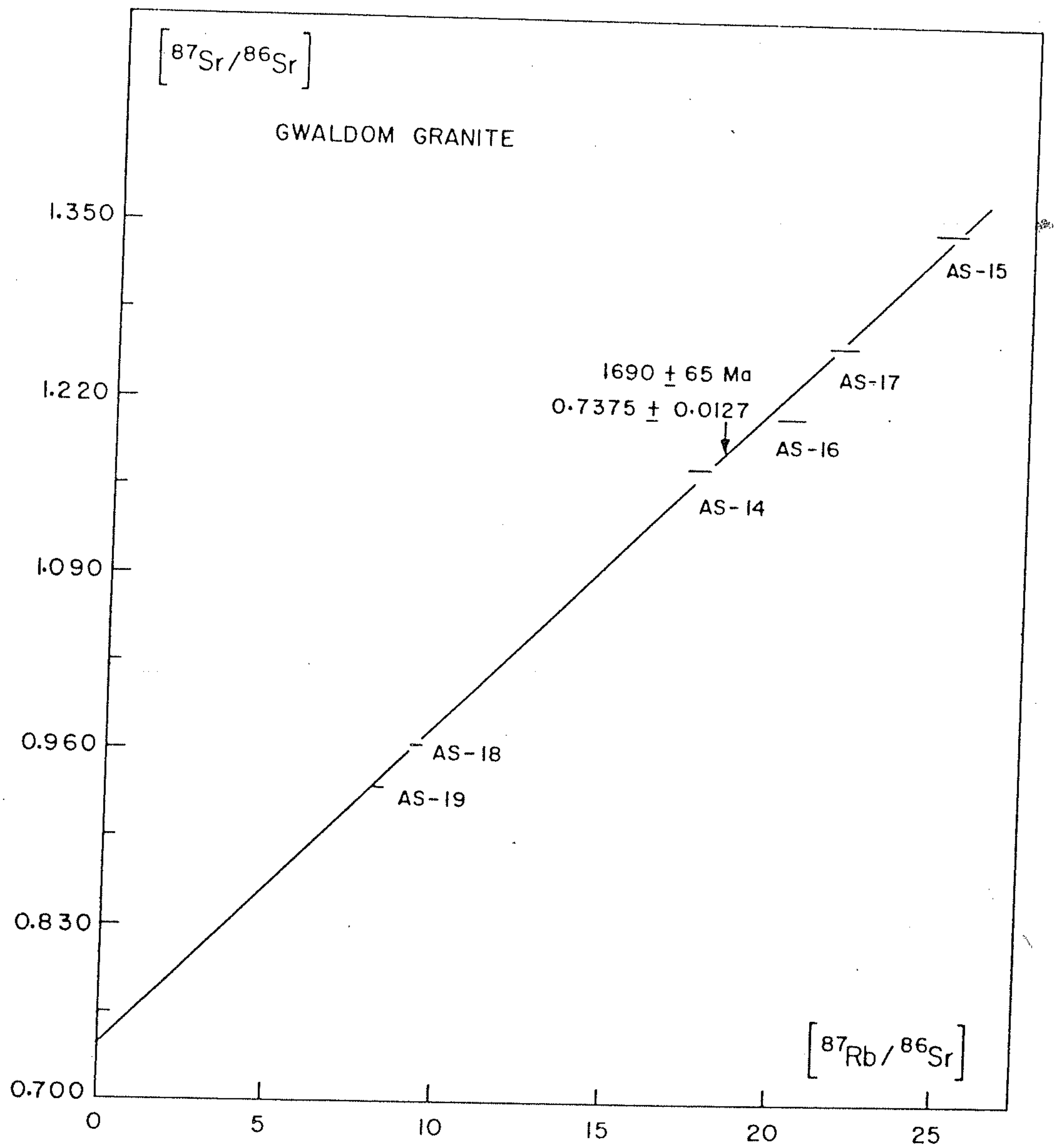


Fig.5.16 Whole Rock isochron for the Gwaldom Granite

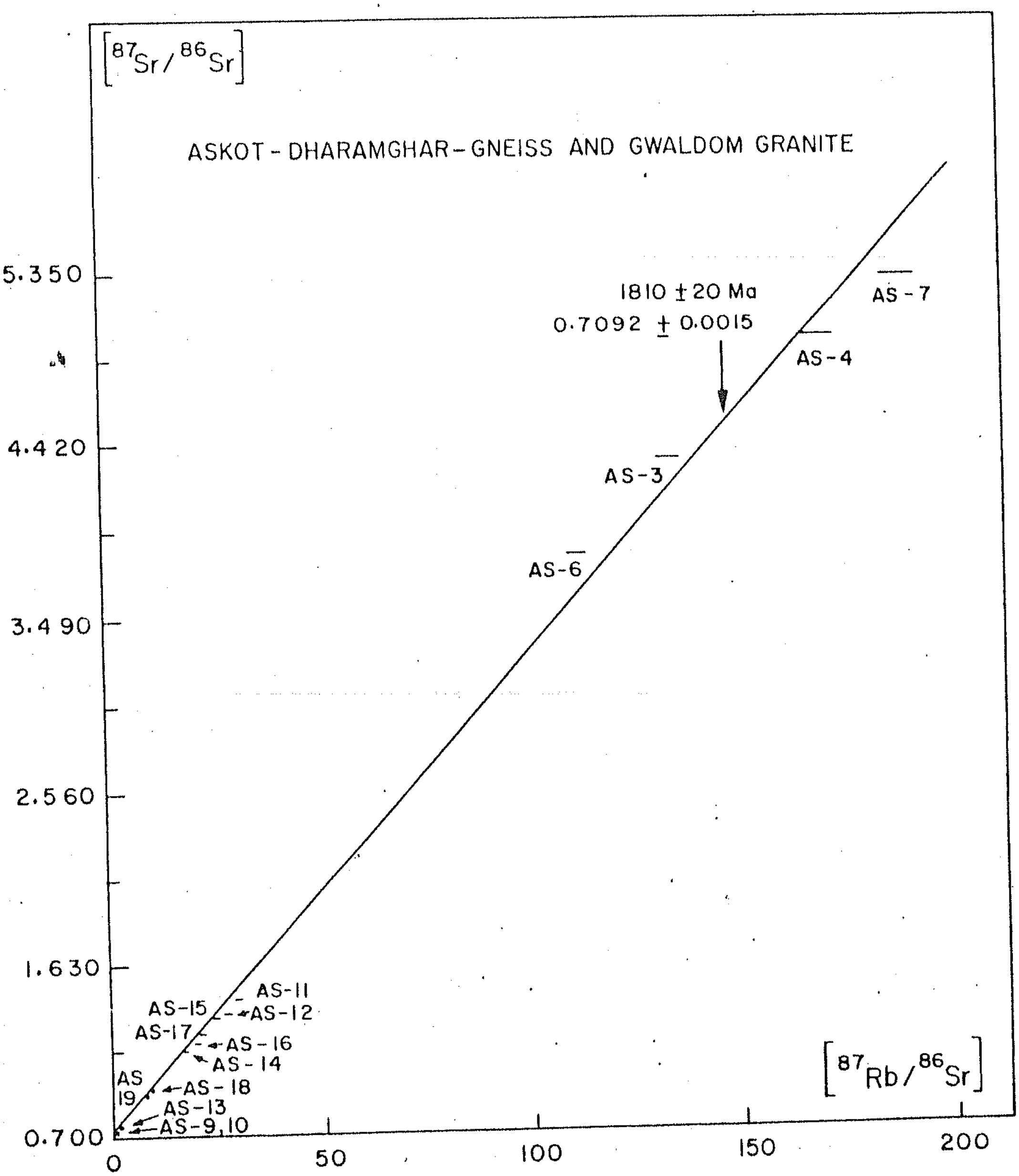


Fig.5.17 Whole Rock isochron for the Askot-Dharamghar Gneiss and Gwaldom Granite

5.13 Munsiari Gneiss (Root zone) :

The Klippen zone discussed in the previous section are almost connected with the Munsiari Formation at the base of the Great Himalaya known as the root zone of the Almora thrust sheet. This Munsiari Formation is sandwiched between the MCT and the Munsiari Thrust below. Porphyritic granite intrudes the crystalline rocks of the Munsiari Formation.

Six samples of the Munsiari gneiss (Table 5.10) have been analysed with the results shown in Fig.5.18. The samples are evenly distributed but are not as highly radiogenic as those in Amritpur, Ramgarh, Almora basal part and Klippen of Almora. Excluding one sample (MS-2), others conform to a linear array corresponding to an age of 1815±128 Ma with an initial Sr ratio of 0.7032±0.0028. The fit of the data points is very good as evident from the low MSWD of 0.47. This age is similar to that of granitoids of Amritpur, Ramgarh, Almora basal part and Almora Klippen. The initial ratio is significantly less evolved than in the previous rock bodies. The discrepancy of MS-2 may be due to the small size of the sample and slight alteration.

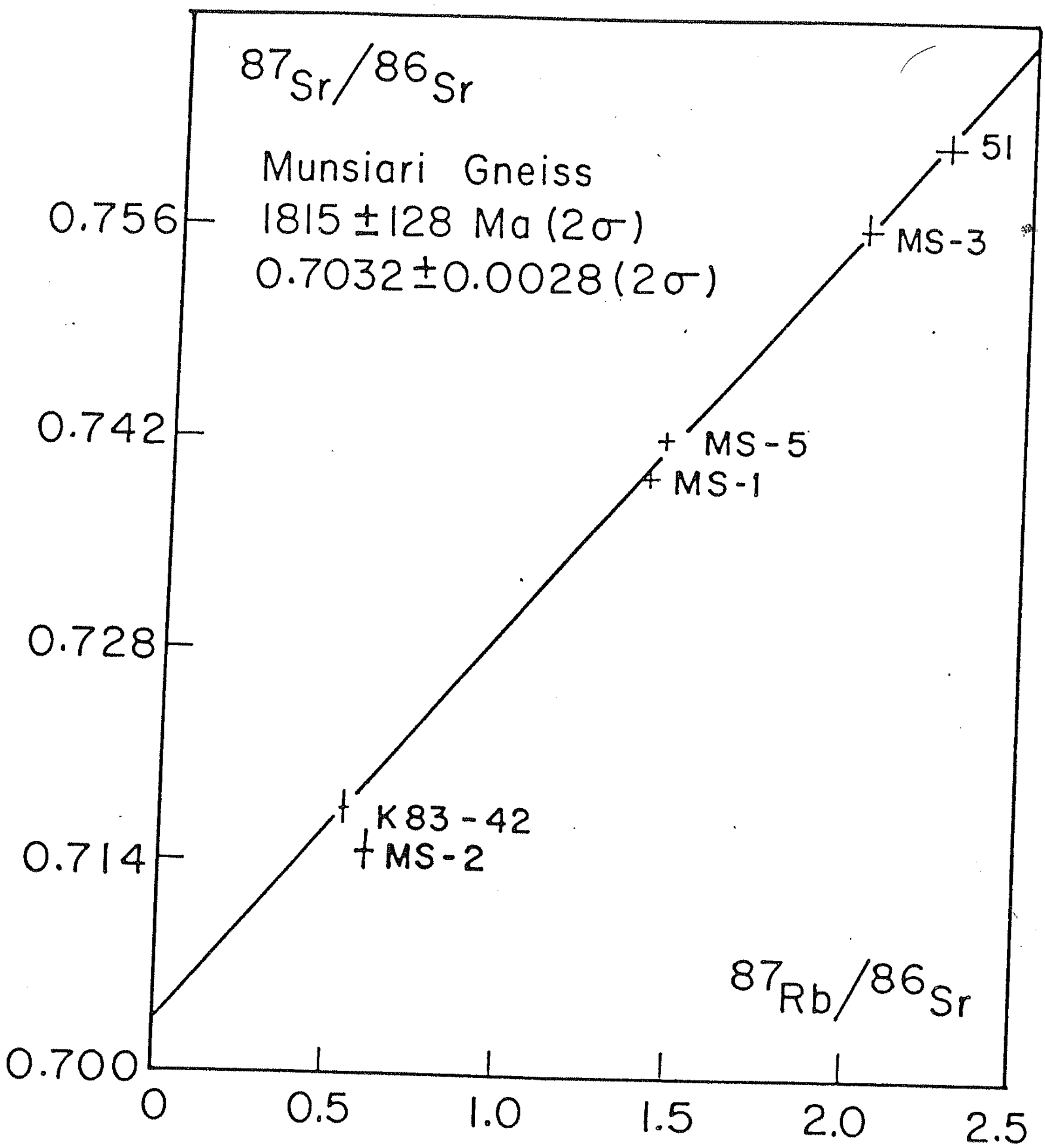


Fig.5.18 Whole Rock isochron for the Munsiari Gneiss

CHAPTER 6

DISCUSSION

Based on the data presented in the previous chapter a summary of Rb-Sr whole rock isochron ages for fifteen granitoid suites along with two mineral isochrons of Ladakh granite, one mineral isochron for Kangan granite and one mineral isochron for Almora granite are given in Table 6.1 and 6.2. This chapter brings out the main findings and discusses the data. The data from Lesser Himalaya are discussed in terms of the possible correlation of different tectonic units of the Kumaun Lesser Himalaya and a possible scenario for pre-thrust provenances of these tectonic units in the Peninsular platform of northern India and interprets the results in terms of evolution of rock units studied in the different structural zones.

TABLE 6.1

Rb-Sr WHOLE ROCK ISOCHRON RESULTS

SAMPLE LOCALITY	NO. OF SAMPLES	AGE Ma	$^{87}Sr/^{86}Sr$ Initial	MSWD
		A. Trans Himalaya		
Gaik	6	230±35	0.7081±0.0011	0.14
		B. Tethys Himalaya		
Kangan	8	480±15	0.7181±0.0027	18.7
Kazinag	4	477±24	0.7141±0.0021	1.57
Polokanka-La	4	487±25	0.7154±0.0067	0.58
Karzok	4	487±14	0.7113±0.0036	0.31
		C. Great Himalaya		
Sela	5	28.6±3.5	0.7954±0.0006	1.15
Thimpu	5	508±15	0.7088±0.0035	1.67
		D. Lesser Himalaya		
1. Ramgarh (= Chail) Nappe				
Ramgarh	9	1770±56	0.7230±0.0046	16.67
Amritpur	7	1888±46	0.7117±0.0044	6.88
2. Almora (= Jutogh Nappe)				
Almora-Granite -Granodiorite	11	565±22	0.7102±0.0016	2.83
Almora Augen Gn.	5	1820±127	0.7148±0.0115	0.41
Askot+Dharamghar	9	1791±30	0.7090±0.0015	7.10
Gwaldom	6	1690±65	0.7375±0.0127	1.19
Munsiari	6	1815±128	0.7032±0.0028	0.32

TABLE 6.2

Rb-Sr Mineral ages

SAMPLE NUMBER		AGE Ma	$^{87}Sr/^{86}Sr$ Initial
Gaik Granite, Ladakh			
LKG-752	Mineral isochron (WR, B, Mu, KF, Pl)	29±1.5	0.7127±0.0011
LKG-753	Mineral isochron (WR, B, Mu, KF, Pl)	28±1.0	0.7274±0.0016
Kangan Granite, Kashmir			
KG-110	Mineral isochron (WR, Mu, KF)	470±21	0.7264±0.0056
KG-110	WR-B-I pair	117	---
KG-110	WR-B-II pair	176	
KG-108	WR-B pair	92	---
KG-108	WR-KF pair	253	---
KG-108	WR-Mu pair	398	---
KG-108	WR-Pl pair	197	---
Almora Granite-Granodiorite, Kumaun			
AL-24	Mineral isochron (WR, MU, KF)	352±14	0.7476±0.0031
AL-24	WR-B pair	16.4	---

B - Biotite

KF - K Feldspar

Mu - Muscovite

Pl - Plagioclase

6.1 Trans Himalaya of Kashmir :

The granites of the Ladakh Range are considered to be the product of magma generated due to consumption of oceanic lithosphere (Frank et al. 1977; Gansser, 1980; Allègre and Othman, 1980 and Honegger et al. 1982) of the Indian plate under the Tibetan plate.

A granite body exposed between Gaik and Kiari (Sharma and Choubey, 1983) which is mineralogically quite different from the main granitoids of the Ladakh batholith is defining a Rb-Sr isochron age at 230 ± 35 Ma with a Sr composition of 0.7081 ± 0.0011. In contrast to the main batholith, this pink granite is biotite rich and is more or less devoid of hornblende.

Though, at present, this suite appears as a part of the Ladakh batholith, it is bounded by faults and does not seem to be genetically related to the Ladakh granitoids of Palaeogene age.

The presence of NE-SW cross faults in addition to its similarity with the two-mica porphyritic granites from Pangong Range (Sharma, 1983), suggests that a part of Karakorum batholith was probably shifted southwards along these cross faults. It became a part of the main Ladakh batholith due to later intrusion of granitic magma generated as result of subduction of the Indian plate during Early Cenozoic. This is indicated by the mineral isochrons for the two whole rock samples LKG-752 and LKG-753 yielding an age of 29 ± 1.5 Ma. Moreover, large scale plutonic activity during Late Cretaceous to early Tertiary period played an important role in the evolution of the Ladakh batholith. The present data are not adequate to resolve the controversy about the age of the Ladakh batholith as a whole. However, the data do suggest that the Ladakh batholith is a complex body (Honegger et al. 1982; Raz and Honegger, 1989) and some component of this is a remnant of a continental crust as old as Permo-Triassic in age which got shifted southward along cross faults. Schärer et al (1984a) also obtained a model age of 579 Ma for a diorite sample collected from the eastern part of the belt near Leh. They considered it either due to heterogeneities in the initial strontium or chemical fractionation during metamorphism. They also obtained Sm-Nd model age of 713 Ma attributing it to recycled crust and favoured the presence of old crustal components even in the basic member of the belt.

The initial Sr ratio 0.7081 ± 0.0004 of the Gaik granite indicates a Rb-poor precursor for the granite magma. This implies a deep crustal origin of the granite. Detailed isotopic and chemical studies would lead to a better understanding of the temporal evolution of the complex Ladakh batholith.

6.2 Tethys Himalaya of Kashmir :

Granites and gneisses of the Tethys Himalaya are clearly distinct from the Trans Himalayan plutons and unlike in Trans Himalaya these are exposed as smaller caps. These are located between the ITSZ and the high mountain chain of the Great Himalaya and are distributed all along the Himalayan Range (Fig 1.1). These granites/gneisses are relatively well documented in the western and central region in particular (Hayden, 1904; Middlemiss, 1911; De Terra, 1935; Wadia, 1935; Gansser, 1964, 1977; Stocklin, 1977 and Le Fort, 1981). Among them, the Kangan granite, the Kazinag granite and the Hunt granite are exposed in the Kashmir valley whereas the Polokanka-La granite, the Karzok granite (also known as Rupshu granite) and Tso Morrari gneiss are exposed in the Zanskar region.

The Kangan and Kazinag granites intrude the Lower Cambrian shales of the Kashmir basin. The whole rock isochron ages of these suits are 480±16 and 477±24 Ma, respectively and hence indistinguishable. Although their initial Sr ratios are marginally different, the poor precision of measurement does not warrant a serious assessment of this difference. The muscovite and K-feldspar fractions from one of the whole rock samples (KG-110) yield an internal isochron age of 470 Ma which is concordant with the whole rock age. The biotite fractions of this sample have, however, been partially re-equilibrated yielding an apparent age of 120 Ma. In the case of another whole rock, KG-108, even the K-feldspar shows evidence of open system behaviour subsequent to 470 Ma. The muscovite-whole rock pair yields an apparent age of 400 Ma, K-feldspar whole rock pair gives 250 Ma and the biotite-whole rock pair yields 92 Ma. It is clear that the granitic body experienced a mild thermal episode long after its emplacement which led to the partial re-equilibration of Sr isotopes between the constituent mineral phases. But the lack of concordance among the apparent mineral ages precludes even an approximate estimation of the time of this secondary event.

The Polokanka-La granite which intrudes the crystalline rocks (schists and gneisses) west of Puga and occupies the core portion of the Tso Morrari dome gives a whole rock isochron age of 487±25 Ma with an initial Sr ratio of 0.7154±0.0067.

The Karzok granite which intrudes the low grade metasedimentaries of Tso Morrari crystallines along its southern limb is dated at 487±14 Ma (initial Sr ratio at 0.7113±0.0036).

Thus the Polokanka-La granite and the Karzok granite which form the base of Tethyan sequence of the Zanskar were emplaced 480 Ma ago. Thakur and Virdi (1979) and Thakur (1983) assigned post-Permian age to these granites based on stratigraphic considerations. This is not valid in the light of the present result.

So all the four suites Kangan, Kazinag, Polokanka-La and Karzok were emplaced at about the same time, 475-485 Ma ago. Their initial Sr ratios (0.7113 to 0.7181) indicate a crustal origin for their magma.

6.3 <u>**Great Himalaya of Arunachal**</u> :

In the Great Himalaya, several suites of leucogranite are exposed along the main range. The Sela granite is located in Arunachal Pradesh. This granite is believed to have formed by large scale anatexis during the Himalayan Orogeny. This granite postdates the collision of India with Eurasia which occurred in Cretaceous or early Tertiary. Tripathi et al (1980) assigned a Precambrian age to this granite whereas Das et al (1977) expected it to be Tertiary in origin.

The Rb-Sr whole rock isochron age of this suite is 28.6±3.5 Ma with a very high initial Sr ratio of 0.7954±0.0006. The age corresponds to the time of Himalayan Orogeny. The high initial ratio indicates that the granite originated from the anatexis of Rb rich crustal material, most probably Palaeozoic and Precambrian rocks. A number of tourmaline bearing Tertiary granites are reported from other parts of the Himalaya (Dietrich and Gansser, 1982; Gansser, 1964 and others).

Le Fort (1973, 1975, 1981), Vidal et al (1982) and Deniel et al (1987) confirmed the anatectic nature of Manaslu leucogranite (in Nepal) of Tertiary age and considered Tibetan slab as its parent material.

Extensive study by Dietrich and Gansser (1981) in Bhutan, the experimental work by Ghosh and Singh (1977) and the Sm-Nd and strontium isotopic studies by Allègre and Othman (1980) have shown that the leucogranites of the Great

Himalaya were derived from an anatectic melt from the 1100-2300 Ma old Precambrian basement.

Based on ^{18}O studies, Blattner et al (1983) have shown a clear distinction between leucogranites of the Great Himalaya and the Trans Himalaya and compared the granites of Great Himalaya with those of Upper Palaeozoic S-type batholiths elsewhere (for example, in England).

Gariepy et al. (1985) also reported that the granitoid magma in the Great Himalayan belt was produced by partial melting of its basement rocks. Their inferences have been based on Pb isotopic studies.

The characteristics of the Tertiary granites of the Great Himalaya are quite different from those of the Trans Himalaya as noted by Le Fort (1975), Allègre and Othman (1980), Dietrich and Gansser (1981), Deniel et al. (1987 andreferences therein). The heat sources for anatectic melting in the Himalaya have been identified by Bird (1978), Molnar et al (1983), Jaupart and Provost (1985) based on seismic studies. They have shown (for Lhasa block) that the heat source is located in the crust rather than in the mantle. In-situ radioactive decay is considered to be a more likely heat source than frictional heating along thrust planes for large scale melting.

The present data show that the Sela granite is also anatectic in origin and crystallized from the magma produced by melting of pre-existing Precambrian crustal material during the Himalayan Orogeny.

6.4 Great Himalaya of Bhutan :

In the Great Himalayan granites another variety i.e.. biotite granites are also present. One of them is the Thimpu granitic gneiss, a part of Thimpu Formation near Bhurkhola which is considered to be syntectonic/post tectonic (Jangpangi, 1978). Surface exposures of this gneiss are too small to yield samples of reasonable size. Consequently, the samples were collected from two bore holes (34 meter and 84 meter long) from the region. The Rb-Sr whole rock isochron age for this rock is 508±15 Ma with a initial Sr ratio of 0.7088±0.0035. The other reported ages for Lower Paleozoic granites of the Great Himalaya are 581±9 Ma for the Manali-Rohtang gneiss (Mehta, 1977), 500±8 Ma for Kulu migmitite (Mehta, 1977), 545±45 Ma for Jaspa granite (Frank et al. 1977) and 467±46 for the Manikaran granite (Bhanot et al. 1979). These Lower Palaeozoic granites are coeval with many other intrusions in different tectonic regimes in other parts of the Himalaya. In the light of the present and published data, a large scale magmatic activity on both sides of the present day axial zone at ~500 Ma ago is evident.

6.5 Lesser Himalaya of Himalaya :

As mentioned earlier, according to plate tectonic interpretation of the Himalayan Orogeny (Dewey and Bird, 1970, Powell and Conaghan, 1973; Le Fort, 1975), the Lesser Himalayan rocks and much of the material in the basal part of the Great Himalaya are modified parts of the peninsular platform. According to Heim and Gansser (1939), Gansser (1964), Valdiya (1962a, 1980b) and several others, the Kumaun Lesser Himalaya contains different tectonic units (viz. Krol, Ramgarh and Almora nappes overriding the autochthonous Precambrian sediments). The correlation of the different tectonic units has been very difficult due to the almost complete absence of fossils in most of the crucial formations of the Lesser Himalayan region, repeated thrusting and the problem of reversed metamorphism across the thrust plane. The whole rock isotopic age data for a set of granitic components within the Ramgarh and Almora units and associated Klippen and root zone are discussed and interpreted in the following.

6.5.1 <u>Ramgarh Granitic Gneiss</u> :

A whole rock isochron age of 1770 ± 56 Ma and initial Sr composition of 0.7230 ± 0.0046 are obtained for the porphyritic and mylonitized granite gneiss of the Ramgarh Group. Due to the excessive scatter of the data points, the validity of this age can be questioned. For example, the age becomes 1875 ± 90 Ma, if the lone highly radiogenic sample R-8 is excluded. Bhanot et al (1980) reported a model age of 1170±120 Ma from a single foliated granite sample collected from Koidal and correlated it with the Ramgarh gneiss. In view of the considerable scatter of individual analyses in our study, a model age from a single analysis is not reliable. Through the definition of the isochron is poor in the present instance, it suggests that the most probable age of the Ramgarh granite gneiss is close to 1800 Ma.

6.5.2 Amritpur Granite :

A whole rock isochron age of 1888 ± 46 Ma and an initial Sr ratio of 0.7117 ± 0.0044 are obtained for the Amritpur granite. Pande (1966, 1975) and Saxena (1974) assigned an age between Upper Cretaceous and Lower Tertiary. Raina and Dungrakoti (1975) considered this granite as intrusive and related it with the Ramgarh quartz porphyry. While Desai et al.(1976) considered Amritpur granite and Ramgarh quartz porphyry as keratophyre and related them with spilites of the Bhimtal Bowali area, Varadarajan (1977) reported a K-Ar age of 228 ± 10 Ma for metabasites from Bhimtal Bowali area. According to him these metabasites are intruded by the Amritpur granite. Later Varadarajan (1978) reported K-Ar ages for muscovite and biotite from this granitic body as 1880 ± 40 Ma and 1330 ± 40 Ma respectively. He attributed such discrepancy, viz. host dating younger than the intrusive granite, to the complex nature of the Amritpur granite. It is well documented that K-Ar age is susceptible to gain or loss of argon even during low grade metamorphism subsequent to extrusion of the volcanics. Therefore the reliability of K-Ar dates becomes questionable. Based on Rb-Sr studies Singh et al (1986) reported an age of 1584 ± 192 Ma with a very high initial Sr composition of 0.946 for a white granite from the region. Since his isochron is based on only four highly radiogenic points with no point near origin, the validity of such an unusually high initial Sr ratio is ambiguous. Since there are three phases of granites in the region, and only four samples analysed, even the age reported by them cannot be directly compared with the present study.

From the present result based on careful sampling from a well studied region and one particular intrusive phase, it is concluded that at least a major component of the Amritpur granite intruded as early as 1880 Ma ago. Its initial Sr composition is much better constrained than in the earlier work and suggests a crustal origin for the granite magma. Whether the other components of the Amritpur Granite are distinctly younger than 1880 Ma remains to be investigated.

6.5.3 Almora Granite-Granodiorite :

The principal granitoid suites exposed in the Almora Nappe and its associated Klippen are Almora - Dùdhatoli granite, Champawat granite, Gwaldom granite, augen gneisses of Askot, Dharamghar, Nandprayag, Chiplakot and Baijnath.

Four whole rock isochrons have been obtained for granites/gneisses from this thrust sheet. Even allowing for some bias in sampling, the present data show a distinct pattern of ages. Our results show two distinct groups around 1800 Ma and 550 Ma respectively, which are discussed below.

The Rb-Sr isochron age of Almora granite and granodiorite is 565±22 Ma and its initial ratio is 0.7102±0.0016. Pande et al (1981a) also reported a Rb-Sr age (485±55 Ma) and initial ratio (0.735) for gneisses from Ranikhet (~100 km SW of Almora) and a younger age (370±115 Ma, initial ratio 0.756) for gneisses near Masi (~50 km SW of Almora). Sinha and Bagdasarian (1977) reported K-Ar ages between 300 and 400 Ma for a variety of rocks in this region. In Himachal Pradesh and Nepal, granitoids of this Early Palaeozoic age are also known. They are Mandi granite (500±100 Ma - Jäger et al. 1971), Dalhousie granite (456±50 Ma - Bhanot et al. 1975) and Palung granite (486±10 Ma - Mitchell, 1981). All these ages are based on the Rb-Sr method.

A mineral isochron age 352±14 Ma for the Almora granite has been obtained. The significance of this age is not clear at present because we do not have enough database. However, it is significant to note that a Rb-Sr WR isochron age of 311±6 Ma for Mandi leucogranite and 322-360 Ma for muscovites from Mandi granite reported by Mehta (1977). These ages be attributed to the Hercynian cycle in the Himalaya. These aspects need further investigation.

6.5.4 Almora augen Gneiss

This granite-granodiorite suite of Almora is bordered by augen gneisses. The isochron age of augen gneiss, exposed in the northern boundary is 1820±127 Ma with an initial Sr ratio of 0.7148±0.0115. One radiogenic sample of augen gneiss collected from southern boundary also falls on this isochron. Powell et al (1979) regressed one sample from the northern boundary with the Rb-Sr data of augen gneiss from Askot giving an age of 1620±90 Ma. The southern boundary of Almora syncline is very small and the presence of highly sheared gneisses makes it difficult to get good samples from the region. But the definite presence of granitic intrusions of two ages (550 Ma and 1800 Ma) are now established within this Almora syncline. Since the two physically separate granite suites apparently occupy the same stratigraphic horizon given by Gansser (1964), the question arises if the younger granite of Almora syncline has been reconstituted from the pre-existing older granites/gneisses. In the absence of precisely known initial Sr composition for the older granites/gneisses, a definitive assessment of this suggestion is difficult. However Schärer and Allègre (1983) attributed anatexis of Precambrian continental crust for the magma of the Palung granite in Nepal and related the genesis of the Palung granite to a regional high temperature/high pressure metamorphism which affected the Indian shield in lower Palaeozoic times.

6.5.5 Askot-Dharamghar-Munsiari Gneisses and Gwaldom Granite

Both the individual and pooled isochrons for three Klippen (Askot, Dharamghar and Gwaldom-Baijnath) of the Almora thrust sheet give the age of the augen gneiss/granite to be very close to 1800 Ma. Though Pandey et al (1981b) and Bhanot et al (1981) gave the Rb-Sr isochron age as 1800-2000 Ma for Askot and Nandprayag, they gave a younger age of 1310±80 Ma with a high initial Sr ratio of 0.793 for the Gwaldom granite. The Munsiari Formation is considered to be the root zone for the Almora thrust sheet. The Munsiari Formation predominantly contains augen gneisses of granitic to granodioritic composition. The Rb-Sr isochron age of these augen gneisses is determined as 1815±128 Ma with an initial Sr composition of 0.7032±0.0028. Bhanot et al (1980) obtained a Rb-Sr isochron age of 1890±155 Ma for the Munsiari augen gneiss

Thus in Kumaun Lesser Himalaya, granitoids of two distinct generations, around 1800 Ma and 550 Ma, are identified. This is in contrast to the wide range of ages reported by earlier workers (Bhanot et al. 1980 and references therein). The presence of rocks of other ages cannot yet be ruled out. Despite much evidence on isotopic disturbances due to thrusting and metamorphism, fairly reliable Rb-Sr ages have been obtained. The degree of coherence in the present data which is based on extensive sampling and careful analyses does not appear to be fortuitous.

Comparison of the data presented here with published data for the region is difficult, because the published data is based on model ages (Bhanot et al. 1976a) or isochron ages on samples collected from different tectonic regimes (Powell et al. 1979). For example, the reported ages vary widely, viz. 1620±90 Ma by Powell et al.1979, 1983±80 Ma by Bhanot et al (1980) and 1810±20 Ma (this work) even for apparently the same Almora-Askot crystallines. In the case of Ramgarh quartz porphyry the difference is even wider, as the ages are 1170±20 Ma (Bhanot et al. 1976a) and 1765±60 Ma in the present study.

It is clear from the foregoing discussion that the present results indicate that the ages of the granitic gneisses in the Lesser Himalaya including the Munsiari root zone at the base of the Great Himalaya are broadly the same at about 1800 Ma. The concordance of the ages of many granitic gneisses (Amritpur, Ramgarh, Almora basal part, Askot, Dharamghar, Gwaldom and Munsiari) in the Lesser Himalaya constitutes the first definitive evidence for extensive magmatism or metamorphism in this region as far back as 1800 Ma ago. Only the Almora system contains granites-granodiorite of Early Palaeozoic age at about 500 Ma (Table 6.1). In adjacent Himachal Pradesh and Nepal Himalaya, intrusives of early Palaeozoic age are also known in the root zone which are equivalent to the Almora Nappe in these sectors (Jäger et al. 1971; Frank et al. 1977; Mehta, 1977; and Powell et al. 1979).

Like the ages, the reported initial Sr ratios also vary widely even for apparently the same rock unit., viz. 0.749±0.007 (Powell et al. 1979), 0.727 (Bhanot et al 1977) and 0.709±0.002 (present work). In the absence of precise initial Sr ratios, a definitive assessment of the parent sources is difficult. Nevertheless, they indicate an upper crustal origin due to fusion of pre-existing sedimentary material or regional metamorphism of their igneous precursors in the pre-Himalayan provenances of these rocks.

If the Precambrian rocks of Kumaun Lesser Himalaya are largely a part of the Peninsular India, their nearest age equivalents have to be found about 500 km to the southwest in the Alwar basin just east of the Aravalli Range, (Choudhary et al. 1984). It is possible that the basement rocks near Alwar are concealed under the intervening alluvium of the Indo-Gangetic plain. A drill core through the alluvium will greatly help in clarifying this Peninsular connection (Crawford, 1981). The conceivable Peninsular equivalents of early Palaeozoic granites of Kumaun Lesser Himalaya are likely to occur on a southwestern prolongation into the Peninsula, west of the Aravalli Range. Auden (1935) also reported pre-Himalayan deformation, parallel to the Aravalli trend, in the rocks of the Kumaun Lesser Himalaya. But the Malani igneous suite of acid volcanics and peralkaline granites including the Tusham igneous complex close to the Himalayan foot hills are definitely older, at about 750 Ma (Kochar et al. 1985; Crawford and Compston, 1970). It is likely that the early Palaeozoic granites/gneisses of Himalaya represent the later intruded part in the Trans Aravalli terrain which is indicated by secondary thermal imprint at about 550 Ma in granitic rocks exposed west of

Aravalli Range (Choudhary et al. 1984). This implies that the thermal field caused by the intrusion of granites during Early Palaeozoic period in the Trans-Aravalli region penetrated as far as the Mt. Abu granite (~ 750 km SW of Delhi) at the south-western extreme of the Aravalli Range. The thermal field which affected such widely separated granites, should be regional in character. Fuchs (1967), and Schärer and Allègre (1983) correlated this Lower Palaeozoic event with the Caledonian Orogeny. Mehta (1977) related this period to the formation of the protoform of the Great Himalayan "Central Crystalline axis", while Le Fort et al (1981, 1983) considered this event to be epi-orogenic in nature. The regional geology and the tectonic frame work of the Kumaun Lesser Himalaya have been a subject of controversy. The paucity of fossiliferrous sediments, the complex nature of the structural belt and repeated deformation/thrusting have led scientists to interpret the structure and geology of this zone differently.

Heim and Gansser (1939) and Gansser (1964) proposed a model based on the assumption that the various crystalline masses overlying the sediment sequence of the Lesser Himalaya were allochthonous and transported southward from their root zone along thrust planes. Subsequent folding and erosion led to synformal nappes and Klippen. They named this crystalline synform as Almora nappe and proposed that it is bounded by the North Almora Thrust (NAT) and the South Almora Thrust (SAT). The NAT is very prominent whereas it is difficult to observe SAT in the field, a fact which other workers have also noted. Similarly, the position of NAT is unanimously agreed upon while the location and even the presence of SAT have always been questioned (Pande, 1956-57; Valdiya, 1962b; Merh and Vashi, 1965, 1966; Merh, 1966; Kumar et al. 1974; Saxena, 1974; Raina and Dungrakoti, 1975; Shah and Merh, 1976). Based on this interpretation of the position of SAT, Pande (1956-57) gave Ramgarh porphyry the separate status of a small synformal thrust sheet and named it as Ramgarh Nappe. Valdiya (1978, 1979 and 1980b) proposed a comprehensive tectonic set up for the Kumaun Lesser Himalaya. He suggested that, similar to the adjacent Himachal Pradesh, there are three nappes namely the Krol, Ramgarh and Almora in the region. He subdivided the single crystalline nappe of Heim and Gansser into two constituents - the Ramgarh and Almora Nappes.

The present geochronological data on the spatial distribution of the two distinct age components within the Ramgarh Group, the Almora Nappe and their associated Klippen provide new clues on the mutual relation between the top two tectono-stratigraphic units of the Kumaun Lesser Himalaya. Three possibilities (Fig.6.1) can be put forward.

(a) The more or less similar age at about 1800 Ma for the Ramgarh porphyritic granite gneiss, narrow belt of augen gneisses at the northern flank of the Almora synform, the crystalline rocks of the Askot - Dharamghar Klippen and the augen gneisses of the Munsiari root zone suggest

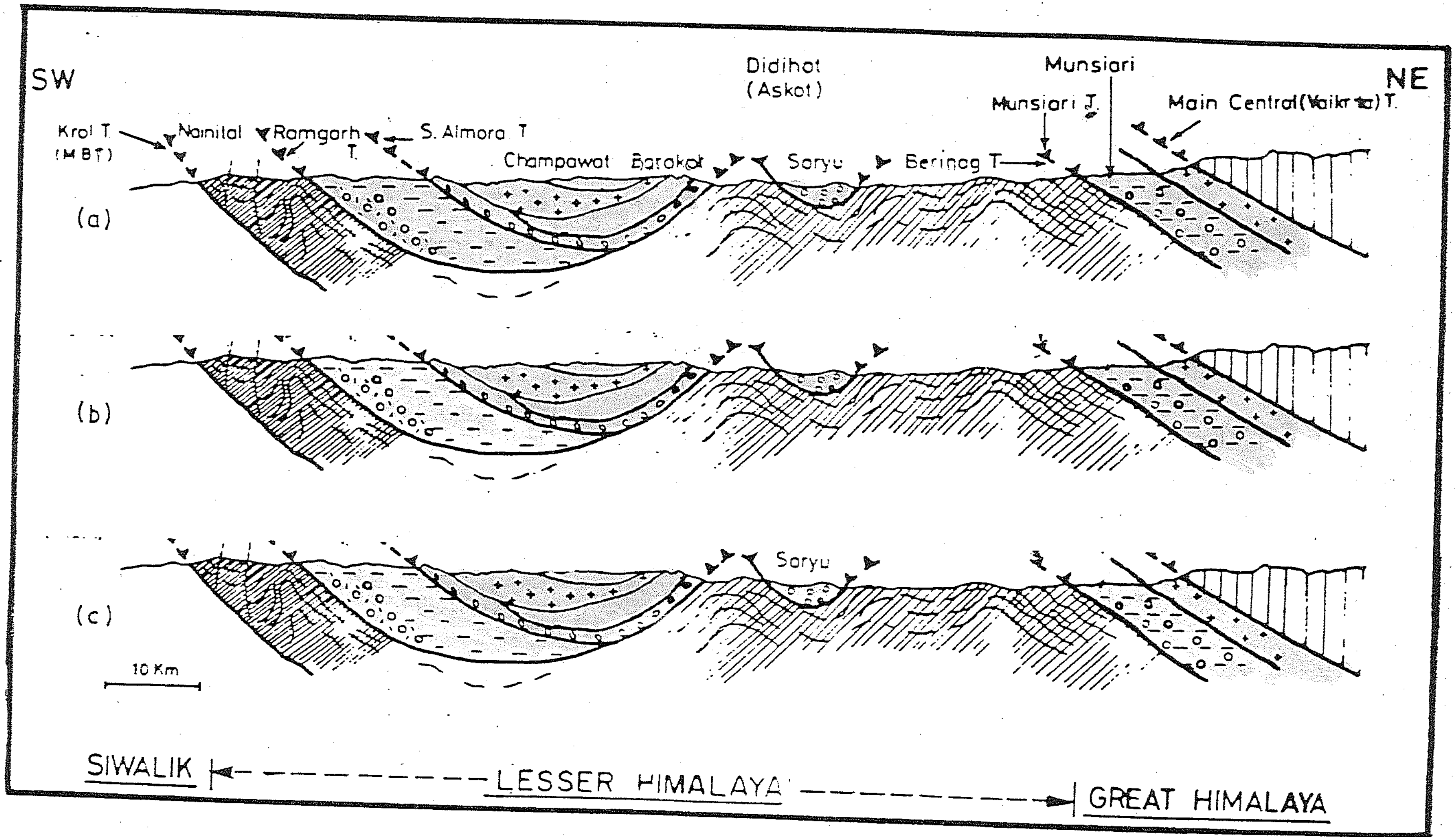


Fig.6.1 The generalized section of the Kumaun Lesser Himalaya showing the possible configuration of the different units consistent with the age data.

that all these are parts of a once continuous sheet of metasediments. If this interpretation is valid then the NAT *senso stricto* must be the northern flank of the Ramgarh thrust. The 550 Ma old Almora granodiorite granite suite may be a younger intrusive at the upper levels of the Ramgarh sequence, as originally proposed by Gansser (1964). Equivalents of the 550 Ma must have been removed by erosion in the Klippen zones. In this scheme, the Almora unit will lose its status as a separate nappe and the observed discontinuities at its base may be merely intraformational dislocations.

(b) The second alternative is based on the earlier proposal of Valdiya (1980b). In this case, the Almora Nappe rests imbricately over the Ramgarh Nappe. Both these thrust sheets contain 1800 Ma old porphyritic gneiss and gneissose quartz - porphyry at their base. But only the Almora contains the additional 550 Ma old granodiorite - granite suite at its upper part. It is not clear whether this difference between the Almora and the Ramgarh sequence is an original feature before thrusting, or due to tectonic truncation of the younger sequence from the Ramgarh during thrusting. The absence of the 550 Ma old component in both the Klippen zone and root zone can also be attributed to pronounced erosion or tectonic slicing of this component from these lithounits.

(c) The third alternative is to assign the two magmatic events to two distinct units thereby retaining the separate identities of the Almora and Ramgarh sequences. In this case the younger component (550 Ma) is assigned only to Almora sequence while the older component (1800 Ma) to the Ramgarh. Here it is assumed that the older component does not exist at the southern border of the Almora thrust plane, while the 1800 Ma old Saryu augen gneisses at the northern border of the Almora crystallines will represent the northern counter part of the 1800 Ma old Ramgarh porphyry of the Ramgarh Nappe. It also implies that the existing North Almora Thrust is really the North Ramgarh Thrust, thereby shifting the genuine North Almora Thrust further south to the southern margin of the Saryu Formation. In this region the epi-metamorphic Ramgarh thrust sheet having two phases of deformation is overlain by meso-metamorphic Almora thrust sheet having three phases of deformation (Valdiya, 1980b). This problem of reversed metamorphism and the different deformational histories of these nappes can also be understood under this interpretation. In this scheme the 1800 Ma gneisses of the Klippen and root zone will now represent the remnants of the Ramgarh Thrust sheet and the Almora sequence with the younger intrusive has perhaps been eroded away everywhere except in the Champawat-Almora-Ranikhet syncline of the Almora sheet. More focused sampling at critical sectors and search for 550 Ma old granites at the upper levels of the Munsiari Formation (root zone) at the base of Great Himalaya would help narrow down the above possibilities.

6.6 Significance of the Lower Palaeozoic granites/ granodiorites :

The seven principal granitic and gneissic suites viz. Kangan granite (480±16 Ma), Kazinag granite (477±24 Ma), Polokanka-La granite (487±25 Ma), Karzok granite (487±14 Ma), Almora granite and Champawat granodiorite (565±22 Ma) and Thimpu gneiss (508±15 Ma) dated in the present study come from the Tethys Himalaya, the Great Himalaya and the Lesser Himalaya. The ages of these granitic/gneissic massifs span a fairly narrow range of 80 Ma between 480-560 Ma. Besides these, many more Lower Palaeozoic granites/gneisses of comparable age have been reported from the Tethys and Great Himalaya. The present ages together with that reported earlier for Lower Palaeozoic granites/gneisses dated by Rb-Sr and U-Pb methods are given in Table 6.3. The significance of this wide spread magmatic activity is discussed below.

It appears that the Lower Palaeozoic granites exposed in the lesser Himalayan region have moved southward along with nappe and at places acquired foliation and lineation of feldspar (augen gneiss of Almora, Jaspa migmatites etc.) as a result of deformation during the Himalayan Orogeny.

TABLE 6.3

Rb-Sr AGES OF EARLY PALEOZOIC GRANITOIDS IN THE HIMALAYA

Sr No.	Location	Age Ma	$^{87}Sr/^{86}Sr$ Initial	No. of samples	Ref.
1.	Kangan Granite *Tethys Himalaya*	480±15	0.7181±0.0027	8	1
2.	Kazinag Granite *Tethys Himalaya*	477±24	0.7141±0.0021	4	1
3.	Polokanka-La Granite *Tethys Himalaya*	487±25	0.7154±0.0067	4	1
4.	Karzok (Rupshu) Gn. *Tethys Himalaya*	487±14	0.7113±0.0036	4	1
5.	Jaspa Granite *Tethys Himalaya*	512±16 *	0.720±0.002	6	2
6.	Manali-Rohtang *Great Himalaya*	600±9 *	0.7113±0.0007	5	3
7.	Mandi Granite *Lesser Himalaya*	517±100 *	0.7189	4	4
8.	Dalhousie Granite *Lesser Himalaya*	472±50 *	---	-	5
9.	Manikaran Granite *Great Himalaya*	467±46	0.719	4	6
10.	Kulu Migmitite Gn. *Great Himalaya*	518±8	0.7190±0.0007	4	3
11.	Ranikhet Gneiss *Lesser Himalaya*	485±55	0.735±0.009	5	7
12. 13.	Almora Granite and Champawat Granodi-diorite *Lesser Himalaya*	562±22	0.7102±0.0016	17	8

Table 6.3 Contd......

14. Kangmar Granite *Tethys Himalaya*	485±6 484±7 562±4 **	0.7186±0.0018 0.7140±0.001	6 5	9 10 11
15. Simchar Granite *Lesser Himalaya*	511±55	0.7085±0.0048	7	12
16. Palung Granite *Lesser Himalaya*	486±10 470±4 **	0.720	-	13 14
17. Augen Gneiss (Nepal) *Tethys Himalaya*	517±62 +	0.7097±0.0120	8	15
18. Thimpu Gneiss *Tethys Himalaya*	508±15	0.7088±0.0035	5	1
19. Manserah Granite *Lesser Himalaya* (Pakistan)	516±16	0.7189±0.0006	7	16
20. Behsud Pluton (Afghanistan)	496±11	0.7106	15	17

* Recalculated using $\lambda = 1.42 \times 10^{-11}$ yr^{-1}

** Uranium lead age

\+ Pseudo Isochron

References : 1 Present work
2. Frank et al (1977)
3. Mehta (1977)
4. Jäger et al (1971)
5. Bhanot et al (1974)
6. Bhanot et al (1979)
7. Pandey et al (1981a,b)
8. Trivedi et al (1984)
9. Wang et al (1981)
10. Debon et al (1981)
11. Schärer et al (1986)
12. Le Fort et al (1983)
13. Mitchell (1981)
14. Schärer and Allegre (1983)
15. Le Fort et al (1980)
16. Le Fort et al (1982)
17. Montenat et al (1981)

Fuchs (1968, 1977), Mehta (1977, 1979) and Montenat et al (1981) considered this large scale activity as a strong evidence for a Late Cambrian Orogeny in the Himalaya. Schärer and Allègre (1983) also indicated the possibility of this magmatic activity being related to an orogeny. Mitchell et al (1983) related the generation of these Lower Palaeozoic granites to an orogeny and suggested their emplacement either in a back-arc magmatic belt or a zone of crustal thickening due to thrusting. A Lower Palaeozoic orogenic cycle is also known as the Indian Ocean Cycle (Balasubramanyan, 1978, and Sarkar, 1980) and a corresponding orogeny referred to as the Pan African Orogeny (Kennedy, 1964) has been identified in the African continent. Le Fort (1983) considered this wide spread magmatic activity observed in the Himalayan region as epi-orogenic in nature and attributed its origin either to crustal thinning with simultaneous arcing or to thermal corridor due to crustal strike-slip movements.

Associated with the granite magmatism the following geological phenomena have also been observed in the Lesser Himalaya and the Spiti basin of the Great Himalaya (Gansser, 1964; Valdiya, 1970; Jain and Thakur, 1978; Shah et al. 1978; Shah, 1980).

1. The turbidite sequence of Late Precambrian - Early Cambrian age and contemporaneous volcanic activity (Bafliaz volcanics of Ordovician age) in the upper part.
2. Uplift marked by depositional breaks and unconformity in

the Lesser Himalayan and the Tethyan basin.

3. Occurrence of serpetinite mafic and ultramafic bodies at least in the western Pir Panjal region, where telescoping of the thrust sheet is less intense.

The forgoing discussion on isotopic data and geological observations points to the presence of atleast two dozen granitoid plutons which were formed 450-500 Ma ago in a long linear belt parallel to the Himalayan strike. This large scale activity must be related to some large scale tectonic episode. One possibility is an episode of convergence of continental masses about 500 Ma before the more recent continent-continent collision leading to the Himalayan uplift.

CHAPTER 7

SUMMARY AND RECOMMENDATIONS

This work represents the first systematic geochronological effort on Himalaya rocks from an Indian laboratory. The sampling, sample processing and chemistry have been carried out according to modern standard procedures. But, the analog recording of mass spectral data followed by manual reading of peak heights have limited the precision of isotope ratio measurements to not better than 0.1% . The choice of fairly radiogenic acidic rocks has, however, permitted determination of reliable ages. But the initial Sr ratios could not be determined to the modern standards. In view of this, interpretation of the data has been confined mainly to the ages of rocks rather than to their initial Sr isotopic compositions.

The data indicate three major geological events in the Himalayan region : an imprint of the Tertiary Himalayan orogeny and two Precambrian magmatic/metamorphic events at 450-600Ma and 1800-2000 Ma.

The seven principal granitic and gneissic suites viz. Kangan granite (480±16 Ma), Kazinag granite (477±24 Ma), Polakanka-La granite (487±25 Ma), Karzok granite (487±14 Ma), Almora granite and Champawat granodiorite (565±22 Ma) and Thimpu gneiss (508±15 Ma) dated in the present study come from the Tethys, the Great and the Lesser Himalaya. The presence of atleast two dozen granitoid plutons which were formed 450-500 Ma ago in a long linear belt parallel to the Himalayan strike including these seven plutons suggest that this large scale magmatic activity must be related to some large scale tectonic episode. One possibility is an episode of convergence of continental masses about 500 Ma before the more recent continent-continent collision leading to the Himalayan uplift took place. This aspect needs further investigation.

The presence of the Hercynian cycle in the Himalaya as suggested by Mehta (1977) based on only one reliable Rb-Sr whole rock isochron age of 311±6 Ma is very speculative. It is significant to note that except for a mineral isochron age of 352±14 Ma for Almora granite reported in the present work, no other reliable age falls within this time period. Whether such an event is wide spread in Himalaya or very local (confined to small pockets) can be assessed only after detailed investigations.

The present geochronological data on the spatial distribution of the two distinct age components 1800 and 500 Ma within the Ramgarh Group, the Almora Nappe and their associated Klippen provide new clues on the mutual relation between the top two tectono-stratigraphic units of the Kumaun Lesser Himalaya. Three possibilities are suggested. More focussed sampling at critical sectors and search for 550 Ma old granites at the upper lvels of the Munsiari Formation (root zone) at the base of Great Himalaya would help narrow down these possibilities. Extension of geochronologic work in the adjoining Himachal and Nepal Lesser Himalaya would also help in tracing the areal extent of these tectonic units.

The present results indicate that the ages of the granitic gneisses in the Lesser Himalaya including the Munsiari root zone at the base of the Great Himalaya are broadly the same at about 1800 Ma. The concordance of the ages of many granitic gneisses in the Lesser Himalaya at 1800 Ma constitutes the first definitive evidence for extensive magmatism or metamorphism in this region as far back as 1800 Ma ago. If the Precambrian rocks of Kumaun Lesser Himalaya are a part of the Peninsular India, their nearest age equivalents are to be found about 500 km to the southwest in the Alwar basin just east of the Aravalli Range. It is possible that the basement rocks near Alwar are concealed under the intervening alluvium of the Indo-Gangetic plain. A drill core through the alluvium will greatly help in clarifying this Penisnular connection. It is conceivable the Peninsular equivalents of early Palaeozoic granites of Kumaun Lesser Himalaya are likely to occur on a southwestern prolongation into the Peninsula, west of the Aravalli Range. Significantly, the 1800 Ma old rocks have been identified only in Kumaun and Himachal Himalaya, the direct extention of the Aravalli. Their Presence in other parts of the Himalaya need further investigation.

The present data show that the 29±1.5 Ma old Sela granite is anatectic in origin similar to the many Tertiary leucogranites of the Great Himalaya. It adds to the growing number of magmatic bodies formed during Himalayan Orogeny.

The Ladakh batholith which is a granitoid complex varying in composition from quartz diorite, quartzdiorite, granodiorite, quartz monzodiorite to granite has some components which are remnants of continental crust as old as Permo-Triassic. A granitic component of this batholith has been dated at 230±35 Ma in contrast to the Tertiary ages reported from different parts of this complex. Detailed isotopic and chemical studies would lead to a better understanding of the temporal evolution of the Ladakh batholith.

Geochronological studies to understand the crustal evolution of the Indian sub-continent is the long term programme of our laboratory and the data presented in this thesis form an initial part. Improvement of the precision and accuracy of the Sr isotope measurements as well as setting up of a facility for rapid and accurate measurement of elemental (both major and trace) concentrations are the two requirements the development of which are being taken up with the fervent hope that some of the above mentioned problems associated with the Himalayan Orogeny can be addressed soon in the near future.

APPENDIX I

```
C TWO ERROR REGRESSION TO FIT AN ISOCHRON
C USING WILLIAMSON (1968) METHOD AND
C COMPUTATION OF AGE AND INITIAL RATIO.
C
C  *** NOTATIONS : (ARRAYS)
C
C GRANIT     : NAME OF THE ROCK BODY.
C X,Y        : EXPERIMENTAL DATA POINTS.
C            : X = Rb/Sr , Y = Sr/Sr.
C P          : ERROR IN X (TAKEN AS 2% OF X VALUE).
C Q          : ERROR IN Y.
C
C      --- SCALARS ---
C
C NP         : NO. OF SAMPLES.
C ACC        : DESIRED ACCURACY IN SLOPE.
C A,B        : INTERCEPT AND SLOPE OF THE FITTED LINE.
C SIGMAA     : STANDARD DEVIATION IN A.
C SIGMAB     : STANDARD DEVIATION IN B.
C ALAMDA     : DECAY CONSTANT OF RUBIDIUM.
C
C-----------------------------------------------------------------
      IMPLICIT REAL*8(A-H,O-Z)
      CHARACTER TIT *10(25)
      DIMENSION X(25),Y(25),XE(25),YE(25),Q(25),
     1GRANIT(10),P(25)
      DIMENSION U(25),V(25),XP(25),YP(25),W(25),Z(25),ZP(25)
C
C     IPT1: DEVICE NUMBER FOR INPUT DATA
C
      ACCEPT * , IPT1
 1000 CONTINUE
C
C     DATA INPUT
```

```
C
      READ (IPT1,3,END=500)(GRANIT(I),I=1,10)
      READ (IPT1,*) NP
    2 FORMAT (2I2)
    3 FORMAT(10A8)
      DO 9 I=1,NP
      READ (IPT1,*) X(I),Y(I),Q(I),TIT(I)
    9 CONTINUE
      ACC=1.D-06
C
C     VARIANCES OF X AND Y.
C
      DO 1 I=1,NP
      P(I)=2.0*X(I)/100.0
      U(I)=P(I)*P(I)
    1 V(I)=Q(I)*Q(I)
      IFLAG=0
      B1=0.
   12 CONTINUE
      XN=0.
      YN=0.
      ZN=0.
      D=0.
C
C     WEIGHTS OF INDIVIDUAL DATA POINTS.
C
      DO 21 I=1,NP
      W(I)=1./(V(I)+B1**2*U(I))
      D=D+W(I)
      XN=XN+W(I)*X(I)
   21 YN=YN+W(I)*Y(I)
C
      XB=XN/D
      YB=YN/D
      B2N=0.
```

```
      B2D=0.
C
C     SLOPE CALCULATION.
C
      DO 31 J=1,NP
      XP(J)=X(J)-XB
      YP(J)=Y(J)-YB
      Z(J)=W(J)*(V(J)*XP(J)+B1*U(J)*YP(J))
      B2N=B2N+W(J)*Z(J)*YP(J)
   31 B2D=B2D+W(J)*Z(J)*XP(J)
C
      B2=B2N/B2D
      ERR=DABS(B2-B1)
      IF(IFLAG.EQ.20)STOP'  NO CONVERGENCE'
      IF(ERR.LT.ACC)GO TO 41
      B1=B2
      IFLAG=IFLAG+1
      GO TO 12
C
C     INTERCEPT AND VARIANCES IN SLOPE AND INTERCEPT
C     COMPUTATION.
C
   41 B=B2
      DO 51 I =1,NP
   51 ZN=ZN+W(I)*Z(I)
      ZB=ZN/D
      O=0
      DO 61 I=1,NP
      ZP(I)=Z(I)-ZB
   61 O=O+W(I)*(XP(I)*YP(I)/B+4.*ZP(I)*(Z(I)-XP(I)))
      O=1./O
      VARB=0.
C
      DO 71 I=1,NP
   71 VARB =VARB+W(I)**2*(XP(I)**2*V(I)+YP(I)**2*U(I))
```

```
      VARB=O**2*VARB
      VARA=1./D+2.*(XB+2.*ZB)*ZB*O+(XB+2.*ZB)**2*VARB
      A=YB-B*XB
      SIGMAB=DSQRT(VARB)
      SIGMAA=DSQRT(VARA)
      SIGMAA=2*SIGMAA
C
C     AGE CALCULATION.
C
      ALAMDA=1.42D-11
      T1=DLOG(B+1.0)/ALAMDA
      T=T1*1.0D-06
      ERRT1=2.0*SIGMAB/(ALAMDA*(1.0+B))
      ERRT=ERRT1*1.0D-06
      IT=T
      IERRT=ERRT
C
C     COMPUTATION OF MEAN SQUARE OF WEIGHTED DEVIATES.
C
      S1=0.
      DO 75 I=1,NP
   75 S1=S1+W(I)*(A+B*X(I)-Y(I))**2
      S=S1/(NP-2.0)
C
C     PRINT RESULTS.
C
      PRINT 72
   72 FORMAT(1H2,2(/1H0),20X,'*** R E S U L T S ***'
     1/24X,'(WILLIAMSON-1968)'///)
      PRINT 4,(GRANIT(I),I=1,N1)
    4 FORMAT(15X,10A8,////)
      PRINT 76
   76 FORMAT(' '21X,'Xi',8X,'Yi',6X,'Exi',6X,'Eyi'//)
      DO 77 I=1,NP
   77 PRINT 78, TIT(I),X(I),Y(I),P(I),Q(I)
   78 FORMAT (6X,A,2X,4F9.4/)
```

```
      PRINT 79 ,B ,SIGMAB
   79 FORMAT (/15X,'SLOPE = ',F9.5,1X,'+/-',1X,F12.4)
      PRINT 80 ,(T,ERRT)
   80 FORMAT (/1H0,/6X,'ISOCHRON  AGE IN MYR =',F9.4,' +/-',F9.4,
     1' (TWO SIGMA)'/6X,'(DECAY CONST-1.42D-11/YR.)'/1H0)
      PRINT 82 ,(A,SIGMAA)
   82 FORMAT (/6X,'INITIAL SR RATIO =',F9.5,' +/-',F9.5,'  (TWO
     1 SIGMA)'/1H0)
      PRINT 73 ,S
   73 FORMAT (26X,'MSWD = ',F6.2)
      PRINT 74
   74 FORMAT (4(/1H0))
      GO TO 1000
  500 STOP
      END
```

RESULTS

(WILLIAMSON, 1968)

SELA GRANITE

	X_i	Y_i	Ex_i	Ey_i
AR-104A	8.0700	0.7988	0.1614	0.0002
AR-105A	5.1700	0.7975	0.1034	0.0003
AR-109A	10.5200	0.7993	0.2104	0.0002
AR-110A	16.2700	0.8022	0.3254	0.0003
AR-106A	18.1500	0.8027	0.3630	0.0002

SLOPE = 0.00041 ± 0.000025

ISOCHRON AGE IN Ma = 28.5710 ± 3.4602 (2σ)

(Decay Const. 1.42D -11/yr.)

IINITIAL SR RATIO = 0.79535 ± 0.00060 (2σ)

MSWD = 1.15

REFERENCES

Acharya, S.K., 1973. Late Paleozoic glacification vs volcanic activity along the Himalayan chain, with special reference to eastern Himalaya. Him. Geol. 3, 209-230

Allegre, C.J. and Othman, D.B., 1980. Nd-Sr isotopic relationship in granitoid rocks and continental crust development: a technical approach to orogenesis. Nature, 286, July, pp.335-346.

Andrieux, J., Brunel, M. and Hamet, J., 1977. Metamorphism and relations with the Main Central Thrust in Central Nepal. $^{87}Sr/^{86}Sr$ age determinations and discussion. Colloqn. int. CNRS No.268, Ecologie at Geologie de L' Himalaya, p. 31-40, Paris.

Ashgirei, G.D., Sinha, A.K., Pande, I.C. and Mallik, B.C. 1975. A Contribution to the Geology, Geochronology and History of Regional Metamorphism of Himachal Himalaya. Chayanica Geologica, 1, 143-151.

Ashgirei, G.D., Sinha Anshu, K., Pande, I.C. and Mallik, B.C., 1977. A contribution to the Geology, Geochronology and history of regional metamorphism of Himachal Pradesh. Him. Geol. 7, 107-117.

Auden, J.B., 1935. Traverses in the Himalaya. Rec. Geol. Surv. India, 69 (2), 123-167.

Balasubramanyan, M.N., 1978. Geochronology and geochemistry of Archaen tonalitic gneisses and granites of South Kanara district, Karnataka State, India. In: Archean Geochemistry, (eds) Windley, B.F. and Naqvi, S.M., Elsvier, pp.59-77.

Bally, A.W., Allen, C.R., Geyer, R.E., Hamilton, W.B., Hopson, C.A., et al. 1980. Notes on the geology of Tibet and adjacent areas - report of the American Plate Tectonics delegation to the People's Republic of China. US Geol. Surv. Open File Rep., 80-501, 100 pp.

Bhalla, N.S. and Gupta, J.N., 1979. U-Pb isotopic ages of Uraninites from Kulu, Himachal Pradesh, J. Geol. Soc. Ind. **20**, 481-488.

Bhanot, V.B., Gill, J.S., Arora, R.P. and Bhalla, J.K., 1974. Radiometric dating of the Dalhousie granite, Curr. Sci. **43**, 208.

Bhanot, V.B., Goel, A.K. Singh, V.P. and Kwatra,S.K., 1975. Radiometric studies for Dalhousie and Rohtang Pass area, Himachal Pradesh. Curr. Sci. **44**, 219-220.

Bhanot, V.H., Bhandari, A.K., Singh, V.P. and Kansal, A.K., 1976a. Precambrian Rb-Sr whole rock isochron age for Bandal granite, Kalu-Himalaya, H.P. (Abs.). Himalayan Geology Seminar, Sept. 13-17, New Delhi.

Bhanot, V.B., Bhandari, A.K., Singh, V.P. and Goel, A.K., 1976b. The petrographic studies and the age determination of Koidal gneiss, Kumaun Himalaya, Curr. Sci. **45**, 18.

Bhanot, V.B., Singh, V.P., Kansal, A.K. and Thakur, V.C., 1977a. Early proterozoic Rb-Sr whole rock age for central crystalline gneiss of Higher Himalaya, Kumaun. Geol. Soc. Ind **18**, 90-91.

Bhanot, V.B., Pandey, B.K., Singh, V.P. and Thakur, V.C., 1977b. Rb-Sr whole rock age of the granitic gneisses from Askot area, eastern Kumaun and its implication on tectonic interpretation of the area. Him. Geol. 7, 118-122.

Bhanot, V.B., Bhandari, A.K., Singh, V.P. and Kansal, A.K., 1979. Geochronological and Geological studies on a granite of Higher Himalaya, NE of Manikaran. H.P. Geol. Soc. India, 20, 90-94.

Bhanot, V.B., Pandey, B.K., Singh, V.P. and Kansal, A.K., 1980. Rb-Sr ages for some granite and gneissic rocks of Kumaun and Himachal Himalaya. In: stratigraphy and correlation of Lesser Himalayan Formations. (ed) K.S.Valdiya and S.B.Bhatiya. Hindustan Publ. Corp. N. Delhi, p. 139-142.

Bhanot, V.B., Singh, V.P., Pandey, S.B. and Singh Rampal, 1981. Rb-Sr isochron age for the gneissic rocks of Askot Crystallines, Kumaun Himala (U.P.). In: Contemporary Geoscientific Researches in Himalaya, (ed) A.K.Sinha) Dehradun,Vol. 1, pp 117-119.

Bhattacharya, A.K., Bhatnagar, G.S., Narayan Das, G.R., Gupta, J.N., Chabria, T. and Bhalla, N.S., 1982. Rb-Sr dating and geological interpretation of sheared granite-gneisses of Brijranigad-Ingedinala, Bhillangana valley, Tehri district, U P. Him. Geol.12, pp 212-224.

Bird, P., 1978. Initiation of intracontinental subduction in the Himalaya. J. Geophys. Res. 883, 4975-4987.

Blattner, P., Dietrich, V. and Gansser, A., 1983. Contrasting ^{18}O enrichment and origins of High Himalayan and Trans-Himalayan intrusives. Earth Planet. Sci. Lett., 65, 276-286.

Brookfield, M.E., Reynolds, P.H., 1981. Late Cretaceous emplacement of the Indus Suture Zone ophiolite melanges and an Eocene-Oligocene magmatic arc on the northern edge of the Indian plate. Earth Planet. Sci. Lett., 55, 157-62.

Brooks, C., Wendt, I. and Herre, W., 1968. A two-error regression treatment and its application to Rb-Sr and initial $^{87}Sr/^{86}Sr$ ratios of younger variscan granitic rocks from the Schwarzwald Massif, South-west Germany. J. Geophys. Res., 73, 6071.

Brooks, C., Hart, S.R. and Wendt, I., 1972. Realistic use of two error regression treatments as applied to rubidium-strontium data. Rev. Geophys. and Space Physics, 10(2), p. 551-577.

Chappell, B.W. and White, A.J.R., 1974. Two contrasting granite types. Pacif. Geol. 8, pp. 173-174.

Chatterjee, B., 1976. A note on the occurrence of Microgranite along the Main Boundary Fault in Amritpur area, Nainital District, U.P. Him. Geol. Seminar, Delhi, PP 241-250.

Choudhary, A.K., Gopalan, K and Anjaya Sastry, 1984. Present status of the geochronology of the Precambrian rocks of

Rajasthan. Tectonophysics, **105** 131-40.

Compston, W. and Jeffery, P.M., 1959. Anomalous 'Common Strontium' in Granite. Nature, **184**, 1792.

Crawford, A.R., 1981. Isotopic age data for the Eastern half of the Alpine-Himalayan Belt. In: Zagros-Hindu Kush-Himalaya Geodynamic Evolution, Geodynamics Series, (eds.) H.K.Gupta and F.M.Delany, American Geophysical Union,Vol.3, p.189-203.

Crawford, A.R. and Compston, W., 1970. The age of the Vindhyan system of Peninsular India. Quart. Jour. Geol. Soc. London. V. 125, PP. 351-371.

Das, A.K., Bakliwal, P.C. and Dhoundial, D.P., 1977. A brief outline of the geology of parts of Kameng District. Misc. Publ. Geol. Surv. India, **24**, 115-127.

Das, B.K., 1979. Petrology and structure of the granitic gneisses and the associated mesograde metamorphites of the Dwarahat area, Lower Kumaun Himalaya. In: Structural Geology of the Himalaya. (Ed) Saklani, P.S. p. 41-58.

Debon, F., Le Fort, P. and Sonet, J., 1981. Granitoid belts west and south of Tibet about their geochemical trends and Rb-Sr isotopic studies Symp. Geol. Ecol. Stud. of Qinghai Xizang Plateau 1, Beijing, May 1980. Beijing Science press. P. 395-405.

Deniel, C., Vidal, P. and Le Fort, P., 1983. The Manaslu granite (Himalaya, Nepal) : New Sr and Nd isotopic data. Terra Cognita, **3**, 266.

Deniel, C., Vidal, P., Fernandez A., Le Fort, P and Peucat J.J., 1987. Isotopic study of the Manaslu granite (Himalaya, Nepal): inferences on the age and source of the Himalayan leucogranites. Contrib. Mineral Petrol, 96 pp 78-92.

Desai, S.J., 1973. Mode of origin and tectonic setting of gneissic rocks of Siahi Devi area. Dist. Almora, U.P. Him. Geol. 3, 345-356.

Desai, S.J., Patel, S.G. and Merh, S.S., 1976. Spilite-Keratophyre - Soda Granite association of Ranibagh Amritpur in Nainital Dist. Kumaun. Him. Geol. 6, 449-466.

Desio, A.,Tongiorgi, E. and Ferrrara, G., 1964. On the geological age of some Granites of the Karakorum, Hindu Kush and Badakhshan (Central Asia). Rep. 22nd Sess. Intern. Geol. Congress, Pt. XI, 479-496, New Delhi.

De Terra, 1935. Geological studies in the Northwest Himalaya between the Kashmir and Indus valley. Mem. Connecticut Acad. Arts Sci. 8, 18-76.

Dewey, J.F. and Bird, J.M., 1970. Mountain belts and the new global tectonics. Jour. Geophs. Research, V.75, p. 2625-2647.

Dietrich, V., Gansser, A., 1981. The leucogranites of the Bhutan Himalaya (crustal anatexis versus mantle melting). Schweiz Mineral Petrogr Mitt., 61, 177-202.

Dixit, A.C., 1977. K-Ar ages of the Granitoids of the Chor area, Himachal Pradesh. 8th Him. Geol. Sem. Chandigarh.

Faure, G., 1986. Principles of Isotope Geology, John. Wiley, New York. P 589.

Frank, W., Hoinkes, G., Purtseheller, F., Richter, W. and Thoni, M., 1973. Relations between metamorphism and orogeny in a typical section of the Himalaya. Tscher. Min. Petr. Milt., **20**, 303-332.

Frank, W., Thoni, M. and Purtscheller, F., 1977. Geology and Petrography of Kulu-south Lahaul area. Colloqu. Intern. C.N.R.5, No.268, Ecologie et Geologie de L Himalaya, p. 147-172, Paris.

Fuchs, G., 1967. Zun Bau des Himalaya Ost. Akad. Wiss. Mat. Nat. Klasse Denkschr. **113**, 1-211, Wien.

Fuchs, G., 1968. The geological history of Himalayas. XXII Inter. Geol. Cong. Prague, **3**, 161-174.

Fuchs, G., 1977. The geology of the Himalayas in synoptic view, in Himalaya Science de la terre. Collo. intern. du. C.N.R.S. No. 268, 173-180.

Fuchs, G. and Sinha, A.K., 1978. The tectonics of the Garhwal-Kumaun Lesser Himalaya, Jahrb. Geol. B.A. **121(2)**, 219-241.

Gansser, A., 1964. Geology of the Himalayas. Interscience publishers, Wiley, London, p. 1-289.

Gansser, A., 1977. The great suture zone between Himalaya and Tibet, In Himalaya: Science de la Terre, pp. 181-191, Paris : Ed. Cent. Natl. Rech. Sci.

Gansser, A., 1980. The significance of the Himalayan suture zone. Tectonophysics, **62**, 37-52.

Gansser, A., 1981. The geodynamic history of the Himalaya. In Zagros, Hindukush, Himalaya geodynamic evolution. Geodynamic series Vol.3. 111-121.

Gariepy, C., Allegre, C.J. and Xu, R.H., 1985. The Pb-isotope geochemistry of granitoids from the Himalaya-Tibet collision zone: implications for crustal evolution, Earth Planet Sci. Lett., **74**, 220-234.

Gast, P.W., Tilton, G.R. and Hedge, C.E., 1964. Isotopic composition of lead and strontium from Ascension and Gough Islands. Sci. 145, 1181-1185.

Ghose, N.C. and Singh, N.K., 1977. Experimental study of granitic rocks of Darjeeling (West Bengal, India) and its application to the origin of Himalayan granites. Tectonophysics, **43**, pp. 23-40.

Hamet, J. and Allegre, C.J., 1976. Rb-Sr systematics in granite from central Nepal (Manaslu): significance of the Oligocene age and high $^{87}Sr/^{86}Sr$ ratio in Himalayan orogeny. Geology, **4**, PP. 470-472.

Hamet, J. and Allegre, C.J., 1978. Rb-Sr systematics in granite from central Nepal (Manaslu): Significance of the Oligocene age and high $^{87}Sr/^{86}Sr$ ratio in Himalayan orogeny: Reply to Vidal (1978), Geology **6**, p.197.

Hayden, H.H., 1904. The geology of Spiti with parts of Bushar and Rupshu. Mem. Surv. India, **36**, 1-129.

Heim, A. and Gansser, A., 1939. Central Himalaya, Geological observations of the Swiss expedition 1936. Mem. Soc. Helv. Sci. Nat. 73(1), 1-245.

Heron, A.M., 1922. Geological results of the Mt. Everest reconnaissance Expedition, Rec. Geol. Surv. India, **54** (2),215-234.

Honegger, K., Dietrich, V., Frank, W., Gansser, A., Thoni, M., Trommsdorff, V., 1982. Magmatism and metamorphism in the Ladakh Himalayas (the Indus-Tsangpo suture zone). Earth Planet. Sci. Lett., **60**, 253-292.

Jager, E., Bhandari, A.K. and Bhanot, V.B., 1971. Rb-Sr age determination on biotites and W.R samples from the Mandi and Chor granite, Himachal Pradesh, India. Eclogae Geol. Helv. 64(3), 521-527.

Jain, A.K., Thakur, V.C. and Tandon, S.K., 1974. Stratigraphy an structure of the Siang district, Arunachal (NEFA) Himalaya. Him. Geol. Vol. **4**, p. 28-60.

Jain, A.K., and Thakur, V.C., 1978. Abor Volcanics of the Arunachal Himalaya. Jour. Geol. Soc. India; **19**, P. 335-349.

Jangpangi, B.S., 1978. Stratigraphy and structure of Bhutan Himalaya. In: Tectonic Geology of Himalaya (ed) P.S.Saklani, Today and tomorroow's, New Delhi, pp 221-242.

Jaupart, C. and Provost, A., 1985. Heat focussing granite gneiss and inverted metamorphic gradients in continental collision zones, Earth Planet. Sci. Lett., **73**, 385-397.

Kai, K., 1981a. Rb-Sr Geochronology of the Rocks of the Himalayas, Eastern Nepal, Part I. The Metamorphic Age of the Himalayan Gneiss. Mem. Fac. Sci. Kyoto Univ., Ser. Geol. and Mineral. **47/2**, pp. 135-148.

Kai, K., 1981b. Rb-Sr Geochronology of the Rocks of the Himalayas, Eastern Nepal, Part II. The Age and the Origin of the Granite of the Higher Himalayas. Mem. Fac. Sci. Kyoto Univ., Ser. Geol. and Mineral, **47/2**, pp.149-157.

Kai, K., 1981c. Rb-Sr ages of the biotite and muscovite of the Himalayas, eastern Nepal: its implication in the uplift history. Geochim. J. **15**, pp.63-68.

Kennedy, W.Q., 1964. The structural differentiation of Africa in the Pan-African (± 500 m.y.) tectonic episode. 8th Ann. Rep. Res. Inst. African Geol. Univ. Leeds, 48.

Khan, R.H. and Tater, J.M., 1970. Radiometric dates of some Nepalese rocks. Nepal Geol. Surv. Spec. Publ., 1-6.

Kochar, N., Pande, K., and Gopalan, K., 1985. Rb-Sr age of the Tusham ring complex, Bhivani, India. Jour. Geol. Soc. India. **26**, P 216-218.

Krummenacher, D., 1961. Determinations d age isotopique des roches de l´ Himalaya du Nepal par la methode potassium argon. Bull. Swisse Min. Petrogr. Mitt. **41**, 273-283.

Krummenacher, D., 1966. Nepal central: geochronometrie des series de l´Himalaya. Schweiz. Mineral. Petrogr. Mitt., **46**, 43-54.

Krummenacher, D., 1971. Geochronometric des roches de l´ Himalaya in Recherches geologiques dans l´ Himalaya du

Nepal, Region de la Thakhola. Paris. C.N.R.S. p. 187-202.

Krummenacher, D., Basett, A.M., Kinger, F.A., Layne, H.F., 1978. Petrology, metamorphism and K-Ar age determinations in Eastern Nepal, (ed) P.S. Saklani, Tectonic geol of the Himalaya, pp 151-166.

Kumar, G., Prakash, G. and Singh, K.N., 1974. Geology of the Deoprayag-Dwarhat area, Garhwal Chamoli and Almora dists. Kumaun Himalaya, U.P. Him. Geol. **4**, 323-347.

Lanphere, M.A., Wasserburg, G.J., Albee, A.L. and Tilton, G.R., 1964. Redistribution of Sr and Rb isotopes during metamorphism, World Beater Complex, Panamint Range, California. Isotopic and Cosmic Chemistry, North Holland Publishing Company, Amesterdam.

Le Fort, P., 1973. Les Leucogranites a tourmaline de l'Himalaya, sur I'example du granite du Manaslu (Nepal central), Soc. Geol. France Bull. **7**, pp.555-561.

Le Fort, P., 1975. Himalaya : The collided range. Present Knowledge of the continental arc. Am. J. Sci. **275a**, 1-44.

Le Fort, P., 1981. Manaslu leucogranite : A collission signature of the Himalaya - a model for its genesis and explacement. Jour. Geophys. Research, **86**, 10545-10568.

Le Fort, P., 1988. Granites in the tectonic evolution of the Himalaya, Karakoram and southren Tibet. Phil. Trans. R. Soc. Lond. **A 326** pp 281-299

Le Fort, P., Debon, F. and Sonet, J., 1980. The lesser Himalayan Cordierite granite belt. Typology and age of the Pluton Manserah, Pakistan. Proc. Int. Commit.

Geodynamics. Crp.6, Mfg. Pethawar Nov. 23-29, 1979. Spec. Issue Geol. Bull. Univ. Peshwar, Vol.

Le Fort, P., Debon, F., and Sonet J., 1981. Lower Palaeozoic emplacement for granites and granitic gneisses of the Kathamandu Nappe (Central Nepal) Terra Congnita, special issue, 30, P. 72.

Le Fort, P., Pecher, A. and Vidal Ph. 1982 - Les gneiss oeilles de la Dalle du Tibet: un episode magmatique au Paleozoique inferieur en Himalaya du Nepal. 9 eme Reun. Annu. Sci. de la Terre, Paris, Soc. geol. Fr. ed., 369.

Le Fort, P., Debon, F., and Sonet, J., 1983. The lower Palaeozoic "Lesser Himalayan" granitic belt: emphasis on the Simchar Pluton of central Nepal Granites of Himalayas karakorum and Hindu Kush, (ed) Sham, F.A, Institute of Geology, Punjab Univ., Lahore, Pakistan, pp 235-255.

Long, L.E., 1964. Rb-Sr Chronology of the Carn Chuinneag intrusion, Ross-Shire, Scotland Jour. Geophy. Res., 69, p.1589.

Lydekkar, R., 1983. The Geology of the Kashmir and Chamba territories and the British district of Khagan. Mem. Geol. Surv. Ind. 22, 1-334.

Maluski, M., Proust, F., Xiao, X.C., 1982. First results of $^{39}Ar/^{40}Ar$ dating of the Transhimalaya, calc-alkaline magnetism of southern Tibet. Nature, 298, 152-154.

Mc Intyre, G.A., Brooks, C., Compston, W. and Turek, A., (1966). The statistical assessment of Rb-Sr isochrons.

Jour. Geophys. Res., 71, 5459.

Mehta P.K., 1977. Rb-Sr geochronology of the Kulu Mandi Belt - its implications for the Himalayan tectogenesis. Geol. Rundschan, 66, 156-175.

Mehta P.K., 1979. Rb-Sr geochronology of the Kulu-Mandi belt: Its implications for the Himalayan Tectogenesis - reply. Geol. Rundschau 68, P. 383-392.

Mehta, P.K. and Rex, D.C., 1977. K-Ar geochronology of the Kulu-Mandi Belt. NW Himalaya, India. Neyes Jahrb fur Mineral, Monastsuefle 8, 343-355.

Merh, S.S., 1966. On the tectonic pattern of the Central Kumaun Himalayas. Pub. Centr. Adv. Stnd. Geol. Punjab Univ., 1, p.15.

Merh, S,S., 1968. A preliminary note on the structural histotry of the Central Kumaun Himalayas . Bull.Geol. Soc. India. 5(1)

Merh, S.S. and Vashi N.M., 1965. Structure and metamorphism of the Ranikhet area, Almora Dist., U.P., India. Indian Meneralogy, 6, 58-66.

Merh, S.S. and Vashi, N.M., 1966. On the nature of the SAT near Uparari, Souh of Ranikhet, Dist. Almora, Pub. Centr. Adv. Stud. Geol. Punjab Univ., 1, p.18.

Middlemiss, C.S., 1887. Crystalline and metamorphic rocks of the Lower Himalaya. Garhwal and Kumaun. Rec. Geol. Surv. India, 20(3), 134-143.

Middlemiss, C.S., 1911. Sections in the Pir Panjal Range and Sind valley, Kashmir, Mem. Geol. Surv. Ind., **41**, 86-115.

Misra, R.C. and Sharma, 1967. Geology of the Devidhura area, Almora , U. P. Jour. Geol. Soc. India. 8 110-118.

Mitchell, A.H.G., 1981. Himalayan and Transhimalayan granitic rocks in and adjacent to Nepal and their mineral potential. Jour. Geol. Soc. Nepal. 1. P 41-52.

Mitchell, A.H.G., Bhandary, A.N. and Amatya, K.M., 1983. Granitic rocks of the Central Himalayas: Their tectonic setting and mineral potential. In: Granites of Himalaya, (ed) Sham, F.A., Karakorum and Hindu-Kush. Punjab Univ., Lahore, Pakistan, P. 287-297.

Molnar, P., Chen, W.P. and Padovani, A., 1983. Calculated temperatures in overthrust terranes and possible combinations of heat sources responsable for the Tertiary granites in the Greater Himalaya. J. Geophs. Res. 88, 6415-6429.

Montenat, C., Blaise, J., Bordet, P., Debon, F., Deutsch, S., Le Fort, P. and Sonet, J., 1981. Metamorphisme et pluttonisme au Paleozoique ancien en domaine gondwan sur la marge nord-ouest des Montagnes Centrales d Afghanistan. Bull. Soc. geol. Fr., 7, t. XXIII , n 1 , pp 101-`110

Murthy, V.R. and Compston, W., (1965). Rb-Sr ages of chondrules and carbonaceous chondrites. Jour. Geophys. Res. 70, 5297.

Nagpal, K.K., Gupta, M.L. and Mehta, P.P., 1973. Fission track ages of some Himalayan granites. Him. Geol. 3, 249-261.

Nautiyal, S.P., 1955. Director generals's report for 1944 on Nainital Dist. Rec. Geol. Surv. India, 79, 590-598.

Nicolaysen, L.O., 1961. Graphic interpretation of discordant age measurements of metamorphic rocks. N.Y. Acad. Sci. 91, 198-206.

Pande, I.C., 1956-57. Migmatites of Ramgarh, Dist. Nainital, Jour. Sci. Res. B.H.U. 7 (10), 1-52.

Pande, I.C., 1966. A contribution to the Geology of Kathgodam Ranibagh area, Dist. Nainital (India), Publ. Cent. Adv. Stud. Geol., Punjab Univ., 1, p.8

Pande, I.C., 1975. Recent advances in Himalayan Geology. Presidential Address, 62nd Ind. Sci. Congr., p.1-52.

Pande, B.K., Singh, V.P., Bhanot, V.B. and Mehta, P.K. 1981a. Rb-Sr geochronological studies of the gneissic rocks of the Ranikhet and Masi area of Almora Crystallines. Lesser Himalaya, Kumaun, U.P. Presented in the XII Himalayan Geology Seminar (Dec. 14-16), Dehradun).

Pandey, B.K., Singh, V.P., Singh, R.P. and Bhanot, V.B., 1981b. Rb-Sr age data for the gneissic rocks from Dhakuri, Joshimath and Guptakashi areas of Central Crystalline zone. Kumaun Himalaya (U.P.). Presented in the Nat. Sym. on Mass. Spect., Dec. 21-23.

Paul, D.D., Chandy, K.C., Bhalla, J.K., Prasad, R. and Sengupta, N.R., 1982. Geochronology and Geochemistry of lingtse gneiss, Darjeeling-Sikkim Himalaya, Indian Journal of Earth Sciences, Vol.9, No.1, p.11-17.

Powell, C.M., Conaghan, P. 1973. Plate tectonics and the Himalayas. Earth Planet. Sci. Lett. 20, 1-12.

Powell, Crawford, A.R., Armstrong, R.L., Prakash, R., Wyane - Ed. H.R., 1979. Reconnaissance Rb-Sr dates for the Himalaya. Central Gn. NW, India, Ind. J. Earth Sci. 6(2), 139-157.

Raina, B.N. and Dungarkoti, B.D., 1975. Geology of the area between Nainital and Champawat, Kumaun Himalaya. Him. Geol. 5, 1-28.

Raju, B.V.N., Chabaria, T., Prasad, R. N., Mahadevan, T.M. and Bhalla, N.S., 1982. Early Proterozoic Rb-Sr isochron age for central crystalline rocks Bhilangana valley, Garhwal Himalaya. Him. Geol. 12, P. 196-205.

Raz, U. and Honegger, K., 1989. Magmatic and tectonic evolution of the Ladakh Block from field studies. Tectonophysics, 161, 107-118.

Sarkar S.N., 1980. Precambrian Statigraphy and Geochronology of peninsular India: A review. Ind. Jour. of Earth Sci. V. 7, No. 1, P. 12-26.

Sarkar, S.N., Polkanov, A.A., Gerling, E.K. and Chukrov, F.V., 1964. Geochronology of the Precambrians of Peninsular India, (a synopsis) Science and Culture, 30, 527-537.

Saxena, S.P., 1974. Geology of the Marchula-Bhikiasen area, U.P., with special reference to the South Almora Thrust. Him. Geol. 4: P. 630-647.

Saxena, M.N. and Miller, J.A., 1972. Metamorphism, magmatism and orogeny in the light of radiometric dates in north-western Himalaya, Bull. Ind. Geologists Assoc., 5(324), p.63-69.

Scharer, U., 1984. The effect of initial ^{230}Th disequilibrium on oung U-Pb ages: the Makalu case, Himalaya. Earth Planet Sci. Lett., 77, 191-204.

Scharer, U. and Allegre, C.J., 1983. The Palung granite (Himalaya), high resolution of U-Pb systematics in zircon and monazite. Earth Planet. Sci. Lett. 63, p. 423-432.

Scharer, U., Hamet, J. and Allegre, C.J., 1984a. The Transhimalaya (Kangdese) plutonism in the Ladakh region : an U-Pb and Rb-Sr study. Earth Planet. Sci. Lett. 67, P. 327-339.

Scharer, U., Xu, R.H., and Allegre, C.J., 1984b. U-Pb geochronology of Gangdese (Transhimalaya) plutonism in the Lhasa-Xigaze region. Tibet: Earth Planet. Sci. Letters, V. 69, p. 311-320.

Scharer, U., Xu, R.H., and Allegre, C.J., 1986. U, Th-Pb systematics and ages of Himalayan leucogranites, South Tibet, Earth Planet. Sci. Lett. 77, P. 35-48.

Seitz, J.F., Tiwari, A.P. and Obradorich, J., 1976. A note on the absolute age of the tourmaline granite. Arwa valley Garhwal Himalaya. Geol. Surv. Ind. Misc. Publ., 24, (Part II) p.332-337.

Shah, O.K. and Merh, S.S., 1976. Spilites of the Bhimtal-Bhowali area, District Nainital. Him. Geol. 6, P. 423-448.

Shah, S.K., 1980. Stratigraphy and tectonic setting of the Lesser Himalayan belt of Jammu. In: Stratigraphy and correlations of Lesser Himalyan Formations. (ed) Valdiya K S. and Bhatia, S.B., Hindustan Publishing corporation, Delhi. 152-160

Shah, S.K., Shrma, T.R., and Gupta, K.R., 1978. Trilobite trace fossils from the Bafliaz Formation. Wesern Pir Panjal and their significance. Journ. Geol. Soc.India. 19 (6) 273-276

Sharma, K.K., 1983. Granitoid belts of the Himalayas. Granites of Himalayas karakorum and Hindu Kush Sham F A (Ed) Institute of Geology, Punjab Uni. Lahore Pakistan pp 11-37.

Sharma, K.K. and Gupta, K.R., 1978. Some observations on the geology of the Indus and Shyok Valleys between Leh and Panamik, District Ladakh, Jammu and Kashmir, India. Recent Research in Geology, 7, 133-143.

Sharma, K.K., Sinha, A.K., Bagdasarian, G.P., Gukasian, R. Ch. 1978a. Potassium argon dating of Dras volcanics, Shyok volcanics and Ladakh granite, Ladakh, northwest Himalaya. In Himalayan Geology, 8(1), 288-295, Dehra Dun, India, Wadia Inst. Himalayan Geol.

Sharma, K.K., Saini, H.S. and Nagpaul, K.K., 1978b. Fission-track annealing, ages of apatites from Mandi granite and their applications to tectonic problem. Him. Geol. 8, 296.

Sharma, K.K. and Choubey, V.M., 1983. Petrology geochemistry and geochronology of the southern margin of the Ladakh batholith between Upshi and Chumathang. In: Geology of Indus Suture zone of Ladakh. (eds) V.C.Thakur and K.K.Sharma, W.I.G.H. Dehradun. P. 41-60.

Singh, R.P., Singh, V.P., Bhanot, V.B. and Mehta, P.K., 1986. Rb-Sr ages of the Gneissic Rocks of Rihee - Gangi, Bhatwari, Hanumanchatti and Naitwar areas of the Central Crystalline Zone of Kumaun Himalaya (U.P.), Symp. Isotope Based Studies on Problems of Indian Geology, Abstract, 13-14.

Singh, V.P., Bhanot, V.B. and Singh, R.P., 1985. Geochronology of the Granitic and Gneissic Rocks from Munisiari, Namik and Tawaghat areas of the Central Crystalline Zone, Kumaun, Himalaya (U.P.), Third National Symp. on Mass Spectrometry, Preprints Volume, E-8, 1-5.

Singh, V.P., Singh, R.P. and Bhanot, V.B., 1986. Rb-Sr Isotopic studies for the Granitic Rocks of Amritpur area of the Outer Lesser Himalaya of Kumaun, U.P., Symp. Isotope Based Studies on Problems of Indian Geology, Abstract, 15-16.

Sinha, A.K., 1975. Calcareous nanofossils from Simla Hills, with a discussion on their age in the tectonostragraphic column. Jour. Geol. Soc. India, **16** 69-77

Sinha, A.K. and Bagdasarian, G.P., 1977. Potassium - Argon dating of some magmatic and metamorphic rocks from Tethyan and Lesser zones of Kumaun and Garhwal Indian Himalaya and its implication in the Himalayan Tectogenesis, Colloqu. Intern. C.N.R.S. No.268, Ecologie et Geologie de L' Himalaya, p.387-394.

Sinha Roy, S. and Sen Gupta, S., 1986. Precambrian deformed granites of possible basement in the Himalayas, Precambrian Res., **31**, 209-235.

Stacey, J.S. and Hope, J. 1975. A programme for mass spectrometry control and data processing analyses in isotope geology written in Basic for an 8K Nov 1210 Computer, U.S.G.S. open file report, 75-127.

Steiger, R.H. and Jager, E., 1977. Sub-commission of geochronology convention of the use of decay constants in geo and cosmochronology, E.P.S.L., **36**, 359-364.

Stocklin J., 1977. Structural correlation of the Alpine ranges between Iran and Central Asia. Mem. Soc. geol. Fr. 8, P. 333-353.

Stoliczka, F., 1865. Geological sections across the Himalayan mountains from Wangtu bridge on the river Sutlej to Sundo on the Indus, with an account of the formations in split accompanies by a revision of all known fossils from that district. Mem. Geol. Surv. India, 5(1), 1-154.

Talalov, V., 1972. Geology and ores of Nepal, Kathmandu, His Majestys Geol. Surv., 4V.

Tapponnier, P., and 29 others. 1981. The Tibetan side of the India - Eurasia collision, Nature. **294**, 405-410.

Thakur, V.C., 1983. In : Granites of western Himalayas and Karakorum-Structral framework, geochronology and tectonics Granites of Himalayas karakorum and Hindu Kush, (ed) Sham, F.A, Institute of Geology, Punjab Univ., Lahore, Pakistan, pp 327-337.

Thakur, V.C. and Virdi, N. S., 1979. Lithostratigraphy, structural framework, deformation and metamorphism of the SE region of Ladakh, Kashmir Himalaya, India. Him.Geol.9, 63-78.

Tripathi, C., Dungrakoti, B.D, Jain, L.S., Kaura, S.C, Babu Roy, S. and Laxmipathi, N.S., 1980. Geology of Dirangoimara area, Kameng district, Arunachal Pradesh with special reference to structure and tectonics. Him. Gel. **10** pp 353-365.

Trivedi,J.R., Gopalan,K., and Valdiya, K.S., 1984. Rb-Sr ages of granitic rocks within the Lesser Himalayan nappes, Kumaun, India. Jour. Geol. Soc. India, V.25(10), 1984.

Tu, G.z., Zhang, .q., Zhao, Zh.l., Wang, Zh.q., 1981. Characteristics and evolution of granitoids of southern Xizang, In geological and Ecological Studies of Qinghai Xizang Plateau, **1**, 353-362, Beijing, Science Press.

Valdyia, K.S., 1962a. An outline of the stratigraphy and structure of the southern part of Pithoragarh Dist., U.P., J. Geol. Soc. Ind. **3**, 27-48.

Valdiya, K.S., 1962b. A study of the Champawat granodiorites and associated metamorphics of the Lohaghat subdivision Dist. Almora, U.P. with special reference to petrography and petrogenesis. Indian minerologist 3(1), 6-37.

Valdiya, K.S., 1970. Simla slates : the Precambrian flysch of Lesser Himalaya, its turbidites, sedimentry structures nd palaeocurrents. Geol. Soc. Amer. Bull., 81 pp 451-468.

Valdiya, K.S., 1976. Himalayan tranverse fault and faults and their parrallelism with subsurface structures of North Indian plains. Tectonophysics 32 pp 353-386.

Valdiya, K.S., 1978. Outline of the structure of Kumaun Lesser Himalaya, in Tectonic geology of the Himalaya Ed. Saklani, P.S., 1-14.

Valdiya, K.S., 1979. An outline of the structural set up of the Kumaun Himalaya. J. Geol. Soc. Ind. 20, 145-257.

Valdiya, K.S., 1980a. Geology of Kumaun Lesser Himalaya. Published by W.I.H.G. Dehradun.

Valdiya, K.S., 1980b. The two intracrustal boundary thrusts of the Himalaya. Tectonophysics 66, 323-348.

Valdiya, K.S., 1981. Tectonics of the central sector of the Himalaya. In Zagros, Hindu Kush, Himalaya, Geodynamic Evolution, Geodyn. Ser., 3, 87-110, Washington DC, Am Geophys. Union.

Valdiya, K.S., 1983. Tectonic settings of Himalayan Granites. In : Granites of Himalayas karakorum and Hindu Kush (ed) Sham, F.A., Institute of Geology, Punjab

Univ. Lahore, Pakistan, pp 39-53.

Valdiya, K.S., 1987. Trans-Himadri thrust and domal upwards immediately south of collision zone and tectonic implications Current Science 56(5) pp 200-209.

Varadarajan, S., 1977. Potassium-Argon age of the metabasites from Bhimtel Bhowali area Nainital dist., Kumaun Himalaya and its significance. In B.S.Tewari and V.J. Gupta (Eds.) Recent Researches in Geology, Vol. 3 (Pande Vol.), Hindustan Publ. Corp. Delhi, India, p. 233-243.

Varadarajan, S., 1978. Potassium-Argon ages of the Amritpur Granite, Dist.Nainital, Kumaun Himalaya and its stratigraphic position. J. Geol. Soc. Ind. 19, Nos. p.380-382.

Varadarajan, S. and Rawat, R.S., 1976. Some aspects of the Amritpur granite (NTL Dist.), Kumaun Himalaya. Him. Geol. 6, 467-484.

Verma, P.K. and Tandon, S.K., 1976. Geologic observations in a part of the Kameng District, Arunachal Pradesh (NEFA), Him. Geol. 6, 259-286.

Vidal, P., 1978. Rb-Sr systematics in granite from central Nepal (Manaslu) : Significance of the Oligocene age and high $^{87}Sr/^{86}Sr$ ratio in Himalayan orogeny : Comments to Hamet and Allegre (1976), Geology, 6, pp.196.

Vidal, P., Cocherie, A., Le Fort, P, 1982. Geochemical investigations of the origin of the Manaslu leucogranite (Himalaya, Nepal), Geochim Cosmochim Acta, 46, 2279-2292.

Wadia, D.N., 1935. Mem. Geol.Surv. India, **68**(2), 121-176.

Wadia, D., 1937. The Cretaceous volcanic series of Astro Deosai, Kashmir and its intrusions, Rec. Geol. Surv. India, **72**, 151-161.

Wang, J.W., Chien, Z.L., Gui, X.T., Xu and Y.Q. Zhang., 1981. Proceedings of Symposium on Qinghat Xizang (Tibet) Plateau (Beijing, China), **1**, pp.395-405, Science Press, Beijing and Gordon and Breach, New York, N.Y.

Wetherill, G.W. and Bickford, M.E., 1964. Primary and metamorphic Rb-Sr chronology in Central Colorado. Jour. Geophy. Res., 70, P. 4669.

Williamson, J.H., 1968. Least Square Fitting of a straight line : Canad. Jour. Phys., **46**, 1845.

Xu, R.H., Scharer, U.and Allegre, C.J., 1985. Magmatism and Metamorphism in the Lhasa Block (Tibet): A Geochronological Study. Tectonics, **4**, 127-151.

York, D., 1966. Least Square fitting of a straight line. Canad. Jour. Phys., **44**, 1079.

York, D., 1969. Least Square fitting of a straight line with correlated errors. Earth Planet. Sci. Lett., **5**, 320.

Zhang, Y.q., Dai, T.m., Hong, A.S., 1981. Isotopic geochronology of granitoid rocks in southern Xizang plateau. In Geological and Ecological Studies of Qinghai-Xizang Plateau, Beijing, Science Press, **1**, 483-496.

Zhou, Y.s., Zhang, Q., Jin, C., Deng, W.m., 1981. The migration and evolution of magmatism and metamorphism in Xizang since Cretaceous and their relation to the Indian Plate motion - a possible model for the uplift of Quinghai-Xizang plateau. In Geological and Ecological Studies of Qunghai-Xizang Plateau, Beijing, Science Press, **1**, pp 363-378.

LIST OF PUBLICATIONS OF THE AUTHOR

1. N.Bhandari, D.Lal, **J.R.Trivedi** and A.Bhatnagar, 1976.The Dhajala meteorite shower, Meteoritics, **11**, 137-147.
2. C.Bagolia, N.Doshi, S.K.Gupta, S.Kumar, D.Lal and **J.R.Trivedi**, 1977. The Dhajala meteorite shower: Atmospheric fragmentation and ablation based on cosmic ray track studies. Nuclear Track Detection **1**, pp.83-92.
3. D.Lal and **J.R.Trivedi**, 1977. Observation on the spatial distribution of the Dhajala meteorite fragments in the strewnfield. Proc. Ind. Acad. Sci. **86A**, pp.393-407.
4. K.Gopalan, **J.R.Trivedi**, S.S.Merh, P.P.Patel and S.G.Patel, 1979. Rb-Sr age of Godhra and related granites, Gujarat, India. Pro. Indian Acad. Sci. **88A**, pp.7-17.
5. K.Gopalan, **J.R.Trivedi**, M.N.Balasubrahmanyan, S.K.Ray and C.Anjaneya Sastry, 1979. Rb-Sr chronology of the Khetri copper belt, Rajasthan, J. Geol. Soc. India, **20**, pp.450-456.
6. S.N.Sarkar, K.Gopalan and **J.R.Trivedi**, 1981. New data on the geochronology of the Precambrians of Bhandara - Drug, Central India. Indian J. Earth. Sci., **8**, pp.131-151.
7. **J.R.Trivedi**, K.Gopalan, Kewal K. Sharma, K.R.Gupta and V.M.Choubbey, 1982. Rb-Sr age of Gaik granite, Ladakh betholith, Northwest Himalaya. Proc. Indian Acad. Sci. Earth Planet. Sci. **91** (1) pp.65-73.

8. **J.R.Trivedi**, K.Gopalan and K.S.Valdiya, 1984. Rb-Sr ages of granitic rocks within the Lesser Himalayan Nappes, Kumaun, India. Jr. Geol. Soc. India, **25**, pp.641-654.

9. A.Sarkar, **J.R.Trivedi**, K.Gopalan, P.N.Singh, B.K.Singh, A.K.Das and D.K.Paul, 1984. Rb-Sr Geochronology of the Bundelkhand granite complex in Jhansi-Babina-Talbehat sector, U.P., Indian J. Earth. Sci. CEISM Volume, pp.64-72.

10. S.N.Sarkar, **J.R.Trivedi** and K.Gopalan, 1986. Rb-Sr whole-rock and mineral isochron ages of Tirodi gneiss, Sausar group, Bhadara dist., Maharashtra, J. Geol. Soc. India, **27**, pp.30-37.

11. **J.R.Trivedi**, K.Gopalan and P.P.Patel, 1986. Whole-rock and mineral Rb-Sr isochron ages of the Idar granite, North Gujarat (1987). Recent Researches in Geology, (Ed. A.K.Saha), Hindustan Publishing Corporation, Vol. 13, pp.77-78.

12. D.P.Dhoundial, D.K.Paul, Amitabha Sarkar, **J.R.Trivedi**, K.Gopalan and P.J.Potts, 1987. Geochronology and Geochemistry of Precambrian granitic rocks of Goa, SW India, Precambrian Research, **36**, pp.287-302.