Summary of the thesis

entitled as

^{40}Ar-^{39}Ar Thermochronological study of the Trans Himalaya in Ladakh sector, India.

Submitted to
The M.S. University of Baroda

For the degree of
Doctor of Philosophy

in
Geology

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September 2001

Summary of the thesis

Collision of Indian continental plate with Asian continental plate caused deformation of a vast region in both the plates resulting in spectacular Himalayan mountain range and Tibetan Plateau. Himalayan-Tibetan orogenic system has been active for last ~ 50 Ma and provided an excellent natural laboratory to understand collision related processes. Trans Himalayan zone consisting of the suture between the two plates also contains pre- syn- and post-collision metamorphic and magmatic rocks. The change in sedimentation from the marine to continental environments also is preserved in various sections of Trans Himalaya.

The Ladakh region of Trans Himalaya, area of the present study, is probably the best sector in the entire 2500 km long collision zone, because it has preserved almost the complete history of Paleozoic Indian passive margin to the post collision molasses. There have been several episodes of volcanism in the Ladakh region represented by the volcanic rocks of varying chemistry. These rocks form linear suites and their inter-relationship as well as their relationship with the plutonic volcanism is not clear (Fig.1). These vary from island-arc type Dras volcanics to baslatic-andesitic Shyok volcanics to the rhyolite of Khardung volcanics. To gain understanding of the temporal relationship between the different volcanics, the cooling history of the plutonic rocks of Ladakh batholith and effect of collision related deformation on the trapped ophiolites are the main objectives of this study. The ^{40}Ar-^{39}Ar technique used in the present study is temperature sensitive and provides clues of tectono-thermal history experienced by different rocks. The results thus obtained help in building a scenario for the tectono-thermal evolution of Trans Himalaya in Ladakh sector in particular and India-Asia collision zone in general.

Samples were collected in five main traverses across Ladakh sector in north west Trans Himalaya, covering Indus Suture ophiolites, Dras volcanics, Ladakh batholith, Khardung volcanics and Shyok Suture volcanics. The names of major nearby places of sample locations are given in fig.1. A total number of thirty samples were analyzed for ^{40}Ar-^{39}Ar isotopic composition including seven serpentinites and one ultramafic rock. Serpentinites and ultramafic rock did not yield useful results due to high amount of trapped gasses masking the signal. Mineral separation was done from the plutonic rocks of the Ladakh batholith. A biotite and a muscovite, from granodiorite and leucogranite respectively, were also analyzed along with their whole rock samples. The fine-grained rocks from the other volcanic units were analyzed as whole rock samples. The results of all the sample are summarized in table 1.

Basalts from Indus Suture ophiolites show post collision resetting of Ar isotopic signatures. These samples show a rapid cooling initially and slower subsequent cooling. This is interpreted to be due to a large-scale tectonic event with an associated temperature increase sufficient to reset the argon clock of these older suture ophiolites. The initial rapid cooling indicates the termination of this event and the subsequent slow cooling could be due to exhumation through erosion if these were subjected to burial by this tectonic event. The ages for this event registered by these two sample were ~38 Ma and ~46 Ma. The difference in ages indicates the protracted nature of this event. However, not all the ophiolites of Indus Suture Zone are affected by subsequent reheating as revealed by a pillow lava which yielded an age of ~ 128 Ma.

Muscovite from Himia leucogranite of the Ladakh batholith yielded good plateau ages of ~ 29 Ma. A biotite of Leh granodiorite yielded a good plateau ages of ~ 44 Ma. The whole rock age spectra of these rocks yield maximum plateau-like ages of ~ 38 Ma & ~ 46 Ma respectively. These cooling ages indicate high post-collision thermal regime in suture zone. The whole rock and muscovite ages for the Himia leucogranite indicate that these samples have certainly experienced temperatures, higher than ~ 350°C (closure temperature for muscovite), and probably represent the cooling after the post-collision crystallization. Such young post-collision cooling and crystallization ages are reported from the Kohistan batholith leucogranites.

Shyok Suture volcanics, which range from basalt to andesite, show disturbed and complex age spectra. However, all samples from Shyok suture volcanics yielded consistent age spectra. These age spectra indicate strong tectono-thermal events between ~ 25 to 12 Ma, superimposed on older signatures. The rhyolitic Khardung volcanics in juxtaposition with Shyok volcanics in Shyok-Nubra valley did not yield similar patterns in the age spectrum. They yielded plateau ages and plateau-like ages between ~ 52 Ma and ~64 Ma. The contrast in age spectra of the two nearby volcanic units is very significant. A sample taken from the Karakoram fault zone along the Nubra river yielded a good plateau age of ~ 14 Ma. Based on the similarity of Shyok volcanics and its corresponding volcanic units of Kohitan in the west, to island-arc, and Khardung volcanics and other magmatic rocks to the east of it to continental arc, it has been proposed that the two evolved independently along the Asian plate boundary, as depicted diagrammatically in fig.2. Other geological evidences have also indicated that continental arc and island arc evolved independently and simultaneously. This requires that pre-collision margin of Asian plate was made up of small portion of oceanic crust at its western end. The juxtaposition of the two type of rocks were facilitated by the Karakoram strike slip fault at ~ 14 Ma.

By synthesizing the thermochronological data from this study and those from other regions of the collision zone, a general scenario of the India-Asia collision zone and a sequence of crustal accommodation is proposed (Fig.3). Deformation has been propagating away from the plate boundaries with time since the initiation of the collision. The corresponding accommodation of crust also has been taking place away from the plate boundaries with time. The major episodes of crustal accommodation and deformation are manifested in the uplift of Tibetan plateau and the formation of large-scale thrusts in Himalayas. Most of the present accommodation of crust seems to be taking place in eastward motion along the large-scale strike slip faults in Tibet and in consequent detachment zone.

***Table 1** Summary of the results.*

Geological Unit	Sample and Location	Age Ma	Remark	Implication
INDUS SUTURE ZONE	LK182 Sumdo	38.3 ± 0.6	Highest temp. plateau-like	Reset or syn-collisional?
	LK176 Sumdo	46.75 ± 0.7	Mid temp. plateau	Resetting event
	LK209 Chiktan	128.2 ± 2.6	Plateau age*, Isochron and the Integrated age	Age of the formation
DRAS VOLCANICS	LG290 Dras	85.6 ± 0.6	Plateau like	Formation age

LADAKH BATHOLITH	LK198 Himia	36.04 ± 0.4	Cooling pattern	Slow exhumation
	LK198-Muscovite	29.82 ± 0.2	Plateau age*	High thermal regime
	LK24 Leh	46.25 ± 0.6	Mid temp. Plateau-like	Upper limit for the end of Subduction
	LK24-Biotite	44.63 ± 0.6	Plateau age*	High thermal regime
KARAKORAM FAULT ZONE	LK47 Murgi	13.9 ± 0.1	Plateau Age*	Age of Karakoram fault activation
SHYOK SUTURE ZONE	LG166 Hunder		Excess Argon Pattern	
	Lg197 Tegar	~ 30 Ma	Excess Argon Pattern	The maximum limit
	LG188 Tegar	Min age ~12 Ma, Max age ~30 Ma	Cooling Pattern	Reset signatures
	LK48 Murgi	Min. age ~12 Ma, Max. age ~ 20 Ma	Cooling pattern	Reflecting a major tectonothermal event at ~20 Ma
	LK57 Panamik	Max age ~20 Ma at intermediate Temperatures	Two cooling patterns, the higher temperatures giving very high age	Overprinting of a Tectonothermal event at ~20 Ma

	LK67 Tegar	Max. age ~20 Ma at intermediate Temperatures	Two cooling patterns, the higher temperatures giving very high age	Overprinting of a Tectonothermal event at ~20 Ma
	LK68 Tegar	Max. age ~30 Ma at intermediate Temperatures	Two cooling patterns, the higher temperatures giving very high age	Overprinting of a Tectonothermal event at ~20 Ma
	LK70 Tirit	Max. age ~35 Ma at intermediate Temperatures	Two cooling patterns, the higher temperatures giving very high age	Overprinting of a Tectonothermal event at ~20 Ma
KHARDUNG VOLCANICS	LK86 Tirit	Max. age ~60 Ma at intermediate steps	Two cooling patterns	Overprinting of a tectonothermal event at ~60 Ma.
	LK88 Khardung	52.4 ± 0.4	Plateau age*	Age of the volcanism
	LK90 Khardung	56.4 ± 0.4	Plateau age*	Age of the volcanism
	LG87 Chushul	57.0 ± 0.3	Plateau age*	Age of the volcanism
	LG601 Dungti	64.0 ±1.2	Plateau age*	Age of the volcanism

- *Trapped $^{40}Ar/^{36}Ar$ ratio for the Plateau age is atmospheric within error.
- The MMHb-1 of 520.4 ± 1.7 Ma standard used for all the samples.
  The errors quoted are 2σ.

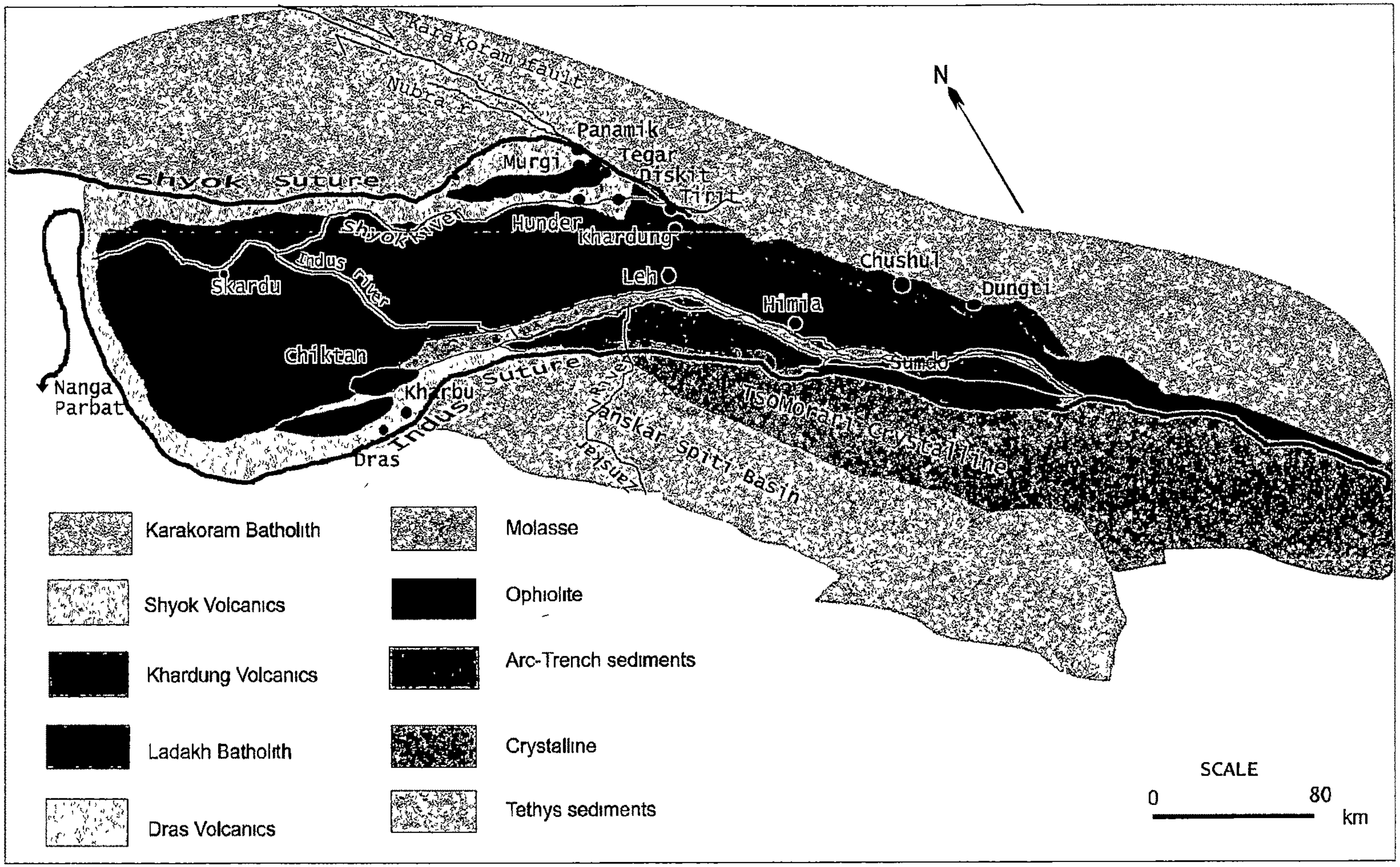

Fig. 1 *Geological map of Ladakh showing the sample locations (Modified from Sharma, 1991)*

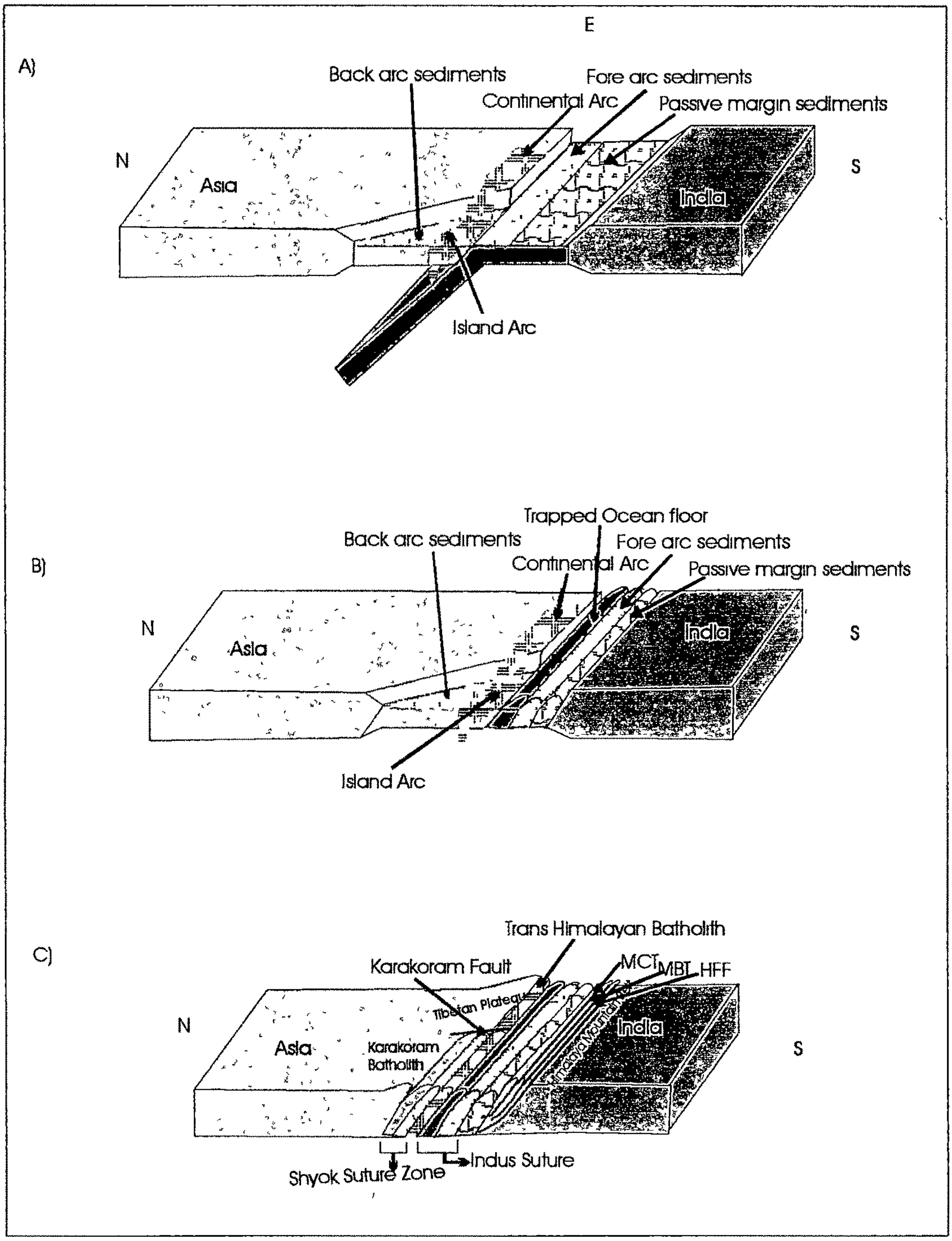

***Fig. 2** Cartoon diagram showing the evolution of the southern margin of the Asian plate. (A) Pre-collision boundary of the southern margin of Asian plate was partly oceanic at western end which subsequently gave rise to island arc magmatism and the back arc sedimentation while at the same time the continental margin of the plate was having the continental arc magmatism. (B). The Indus Suture closed as the Tethys ocean completely subducted. (C). The small part of the oceanic plate along the Asian continental plate formed the Shyok Suture Zone with the characteristic ophiolites and flyshoids. The boundary between the continent and ocean later acted as plane of weakness to facilitate the formation of Karakoram Fault.*

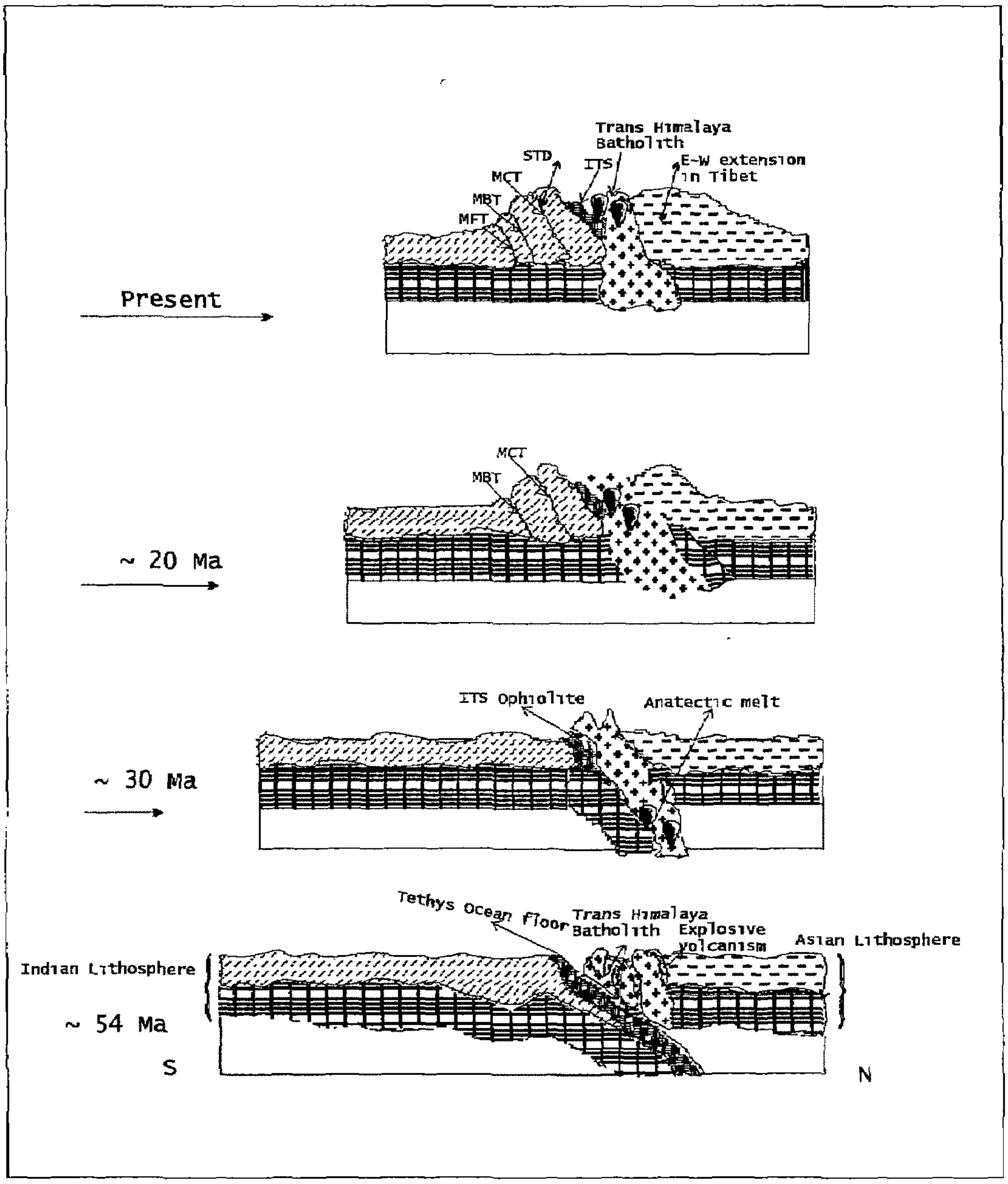

***Fig. 3** Cartoon diagram showing the evolution of India-Asia collision zone with time. Four main stages are shown here. Collision started at ~54 Ma ago and depicted here as showing the completion of suturing of the continents with trapped/obducted Tethys ocean and cessation of subduction related magmatism forming the Trans Himalayan batholith. Till ~ 30 Ma ago most of the deformation and crustal accommodation was restricted to plate boundary, resulting southward thrusting of the ophiolites and thickening of the Trans Himalayan batholith and southern margin of the Tibet. The thrusting at boundary and thickening of the crust generated partial anatectic melt at this time. In the next stage ~ 20 Ma ago, most of the crust accommodated in thrusting along the MCT(Main Central Thrust) in Himalayas and uplifting the Tibetan plateau in the north. Later stage the deformation propagated farther away from the boundary and manifested in the form of MBT(Main Boundary Thrust), and MFT(Main Frontal Thrust)/HFF(Himalayan Frontal Fault) in the south and thickening of the northern margin of the Tibetan plateau. Accommodation of the crust is now taking place mostly in the strike slip movement of large faults in Tibetan region and E-W extension of Tibet*