Chapter One

Introduction

1.1 Preamble

The collision between continents is a natural consequence of plate-tectonics and results not only in high mountains and vast plateaus but also adds up new continental crust and converts continents to supercontinents thus affecting the global atmospheric, oceanic and biological evolution (Molnar and England, 1990; Ruddiman and Kutzbach, 1991; Krishnaswami et al., 1992; Richter et al., 1992). Most of the mountain belts on the globe are a result of continent-continent collision. The continental part of a lithospheric plate ultimately collides with another continental plate after the intermediate oceanic plate subducts back into the Earth (Fig.1.1). The subducting oceanic plate gives rise to magmatic activity on the overriding plate forming island arc or continental arc, depending on the overriding plate. A few mountain ranges are such continental arcs only. Andes of South America is a typical example of such mountain chains. Though the plate tectonics theory provides a broad framework for understanding mountain building processes, a number of questions related to the genesis of collision related orogenic systems, pre-, syn-, and post-collision magmatism, mechanisms and processes of deformation responsible for uplift of the terrain into high mountain ranges, consequent effects on the atmosphere and ocean and on global climate, remains to be answered. Mountain-building process related to continental collision has been operative throughout the earth's history. Older mountain belts are now exposed as long linear ranges of highly deformed sedimentary and magmatic rocks. Some examples of the continent-continent collision mountain belts in the Phanerozoic are the Appalachian mountain belt of North America and Ural mountains in central Eurasia, which are more than thousands of kilometers along the strike (Fig. 1.2). Still older mountains of the Precambrian are now present in shield areas such as the Indian Peninsula and Greenville in Canada. These ancient mountain building episodes are recognized mainly on the basis of the understanding developed by studying the younger and present mountain belts.

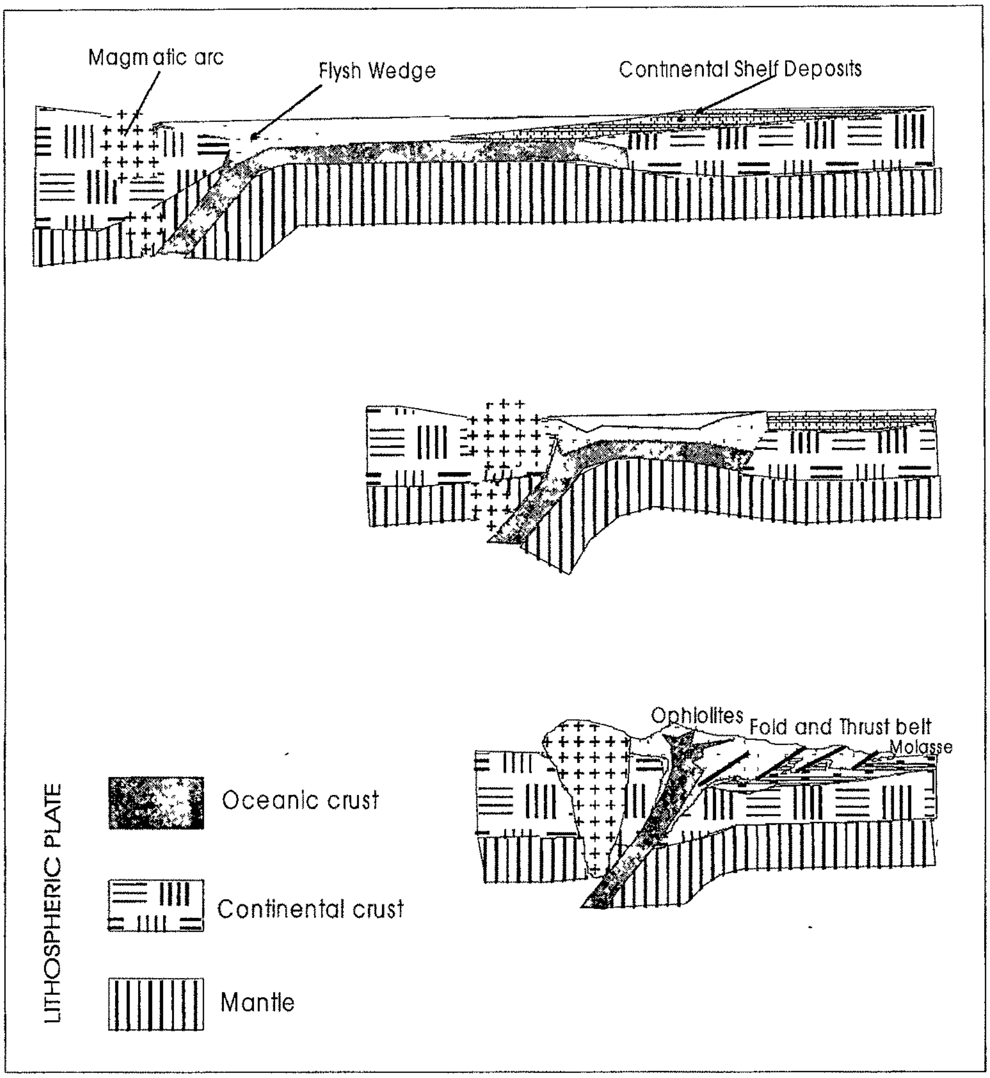

***Fig. 1.1** Diagram showing continent-continent collision. Subducting oceanic plate, beneath the overriding continental plate gives rise to magmatism and continental arc, the sediments on the oceanic floor progressively gets deformed forming flysch wedges along the trench. After the complete subduction of the intermediate oceanic crust some part of it gets trapped/obducted onto the continents. The collision is said to be started with complete subduction of the intermediate oceanic crust.*

The ongoing India-Asia collision for the last 60-50 Ma started following the closure of the Tethys ocean between two great masses since the Paleozoic, Laurasia in the north and Gondwana in the south. The related deformation has affected a vast area of southeast Asia (Fig. 1.3) and resulted in the most spectacular Himalayan-Tibetan orogen, comprising of Himalaya and Karakoram ranges in the south and the vast Tibetan plateau in the north and is more than 2500 km long, along the strike. This system is a part of the greater Himalayan-Alpine system that extends from the Mediterranean Sea in the west to the Sumatra arc of Indonesia in the east over a distance of more than 7000 km. The better known mountain ranges of this system are Atlas (NW Africa) Pyrenees, Apennines, Alps, Carpathians, Balkan, Caucasus, Zagros, Himalaya, Karakoram, Indo-Burmese mountain chains The Himalayan-Tibetan system has been acknowledged by a vast community of all the branches of Earth scientists to be the most suitable and important system to understand collision related processes for the following reasons. First, collision being active today, geophysical and geological monitoring can be done and relationships demonstrated. (Armijo et al., 1989; Abbott et al., 1997; Bilham et al., 1997). Second, the contrasting style of deformation in Himalaya and Tibet helps in understanding the control of the lithospheric properties on deformation and strain partitioning (Bird, 1978; Davis et al., 1983; England and Houseman, 1986; Dalhen and Barr, 1989; Houseman and England, 1993; Houseman and England, 1996; Kong and Bird, 1996; McCaferey and Nalbek, 1998). Third, the variety of pre-, syn-, and post-collision magmatism associated with this system along with large scale thrusting, strike-slip and normal faulting and other regional structures help in understanding the processes deep in the lithosphere and the large scale dynamics of the collision (Tapponier et al.,1975; Valdiya, 1976; Misra, 1979; Honegger, et al., 1982; Arita, 1983; Trivedi et al., 1984; Le Fort, 1986; Hodges et al., 1988; Khan et al., 1989; Weinberg and Dunlop, 2000). Fourth, the preserved geological sequences of pre-collision oceanic basins at some places help in reconstructing the history of continental margin and oceanic basins (Brookfield and Andrews-Speed, 1984; Gaetani and Garzanti, 1991; Beck et al., 1995; Rowley, 1996; Acharyya, 1997; Searle et. al., 1997; Burbank et al., 1997; Najaman et al., 2001). Because of its immense size and elevations the Himalyan-Tibetan system is believed to have played a significant role in the global climate change and climate in turn might have affected the erosion rate and altered the dynamics of the Himalayan evolution. (Ruddiman and Kutzbach, 1989; Molnar and England, 1990; Molnar et al., 1993;). Therefore, earth scientists all over the world have been studying various aspects of this system in various geographical locations for more than a century (Lydekker, 1883; Hayden, 1907; Auden, 1935; Wadia, 1937; Heim and Ganser 1939; Ganser, 1964; Acharyya and Sastry, 1979; Tahirkheli and Jan, 1979). Studies done and information gathered from different locations help in building up a coherent and self-consistent picture of the spatial and temporal evolution of the Himalayan-Tibetan system and its implications to global Earth System processes.

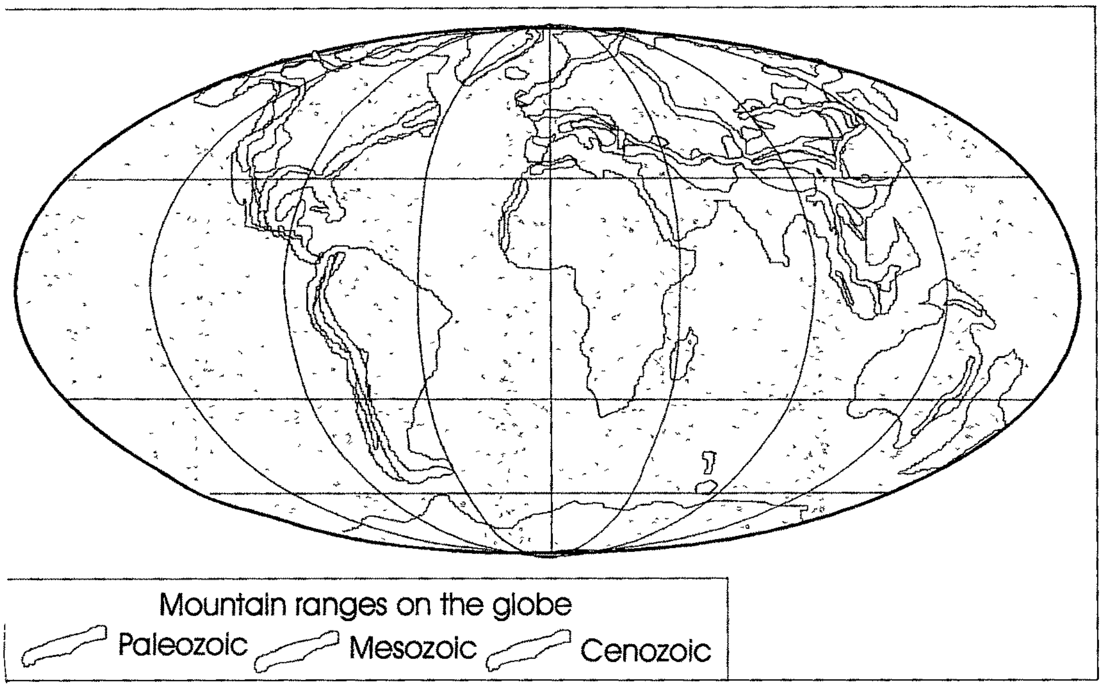

***Fig. 1.2** Phanerozoic mountain ranges on the globe.*

1.2 Motivation for the present study

The collision zone in Trans Himalaya, comprising of plate boundaries and associated sedimentation and magmatism, has proved to be an excellent natural laboratory to understand the various processes associated with continent-continent collision. It has yielded a wealth of geological and geophysical information regarding the present day structures, stratigraphy, seismic activity, geodetic changes; and with the help of recent technical advances, such as the GPS measurements, quite precise estimates of the present day crustal convergence and strain partitioning into different regions of the collision zone have been obtained. (Harrison et al., 1992; Wittlinger et al., 1998). Despite all this information and insights available; details of the precise timing and mechanisms responsible for the formation of Himalaya and Tibetan plateau remain subjects of considerable debate even today. This is because most of the information we have about the collision zone provides us the details of present day structures and activities, which can not be extrapolated back in time to understand the evolution of Himalaya and Tibet.

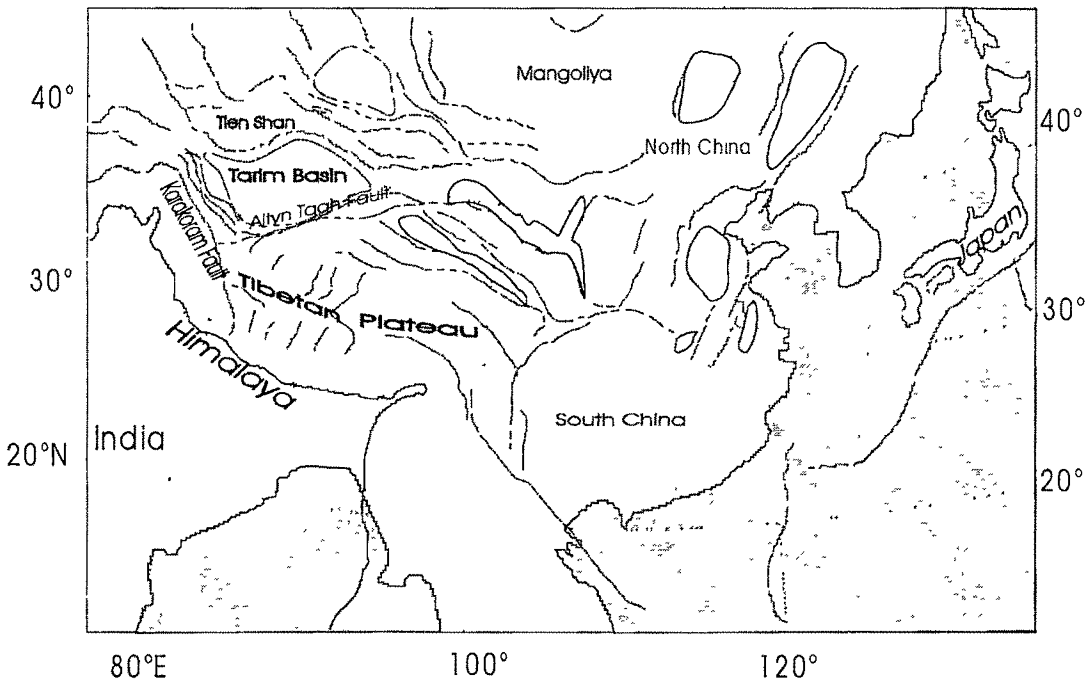

***Fig. 1.3** Regions affected by India-Asia collision. The lines show active faults (Yin and Harrison 2000).*

To fully appreciate the mechanism of the evolution of the collision zone to the present day level we must have constraints on crustal deformation over the entire period since the onset of collision. Though stratigraphic observations in some regions of the collision zone permit us to infer the timing of some of the large events such as ophiolite obduction and initiation of the collision, it is usually very difficult to correlate information from different regions. This is the main reason why the most fundamental question regarding the timing of the initiation of the collision has remained unsettled (Beck et al., 1995; Rowley, 1996; Searle et al., 1997). The consequent problems of deriving the continuous history of uplift and deformation in the collision zone since the initiation of the collision has led to the proposals of several theoretical tectonic models (Tapponier et al., 1975; Davis et al., 1983; England and Houseman, 1986; Dalhen and Barr, 1989; Harrison et al., 1992; Houseman and England, 1993) which are primarily aimed at explaining some of the key present day geological observations. Lack of time constraints for various processes over the history of the collision is, however, a major hurdle for a complete understanding of the collision process. This shortcoming has been recognized lately by several workers and recently several attempts to provide time constraints on the uplift and subsequent sedimentation, from samples selected from different Himalayan regions using various chronometers have been made (Searle et al., 1999). The Ladakh region of Trans Himalaya, area of the present study, is probably the best sector in the entire 2500 km long suture zone, because it has preserved almost the complete history of Paleozoic Indian passive margin to the post collision molasses (Ravishankar et al., 1989; Weinberg and Dunlop, 2000). Collision preceded a long episode of subduction of the Tethys oceanic lithosphere beneath the Asian continent, which gave rise to Trans Himalayan Batholith (THB) all along the southern margin of the Asian continent. Ladakh Batholith (LB) is part of this subduction related calc-alkaline plutonic magmatism (Honegger et. al., 1982). LB now forms high mountain ridges separating the Nubra-Shyok valley from the Indus Valley (Fig. 2.1). The uplift of these deep-seated rocks to such an elevation requires large scale tectonic events which are caused by the ongoing collision; however, information about the timing and the rate of uplift is required to understand the response of collision and subsequent deformation. There have been several episodes of volcanism in the Ladakh region represented by the volcanic rocks of varying chemistry (Sharma 1991). These rocks form linear suites and their inter-relationship as well as their relationship with the plutonic volcanism is not clear. These vary from island-arc type Dras volcanics to baslatic-andesitic Shyok volcanics to the rhyolite of Khardung volcanics (Venkatesan et al., 1994; Rolland et al., 2000). Do they represent different tectonic settings at the time of their formation? Are they pre-collision or do they represent collision induced magmatism? These are some of the unanswered questions about these volcanic rocks. I have attempted to provide a geochronological framework for these rocks. Their thermal history might provide an important clue regarding their origin and inter-relationship. Apart from these rocks there are basalts of obducted oceanic lithosphere. These ophiolites of the southern margin of the LB are recognized to be the part of the continuous belt running all along the 2500 km of THB. The effect of the ongoing collision on these trapped ophiolites with respect to their radioactive clocks has not yet been explored. Absolute dating of rocks from the ophiolitic melange in principle should give the age of the formation of the ocean floor. The tectonic setting of this ocean floor, however, is difficult to ascertain due to variable geochemical signatures (Thakur and Bhatt, 1983; Hebbert et al., 2000). The effect of collision related deformation on ophiolites being unknown, the interpretation of the absolute ages of ophiolites is difficult. However, temperature sensitive radio-isotopic technique such as ^{40}Ar-^{39}Ar might provide clues of the tectono-thermal history experienced by the rocks of the ophiolite suite. Similar ophiolites found along the northern margin of the Ladakh Batholith(LB), named as Shyok Suture, are truncated in eastern Ladakh. A recent study (Rolland et al., 2000) reveals that the chemistry of volcanics of the northern portion of Ladakh sector is different from that of the northern Kohistan sector of Pakistan, thus questioning the prevailing belief of Kohistan-Ladakh island arc.

The present study attempts to provide a scenario for the evolution of Ladakh sector along its northern and southern margins, cooling history of the plutonic rocks of LB, geochronological framework for the volcanism in Ladakh, and attempts to look for the signatures of the ongoing collision in the trapped ophiolites of both the sutures to build a scenario of thermochronological evolution the Ladakh terrain of Trans Himalaya in particular, and India Asia collision zone in general. For this, $^{40}Ar/^{39}Ar$ systematics is used, which is sensitive to the temperatures ranging from ~600°C to 150°C, the closure temperatures for Hornblende and K-feldspar. (McDougall and Harrison, 1999). In addition, for the first time, I have attempted to retrieve the thermochronological information from bulk rock samples instead of the conventional 'mineral closure temperatures versus age' technique, which is limited mainly to plutonic rocks due to the difficulty in mineral separation from the volcanic rocks. Such a time-temperature information is very useful in deciphering a nearly continuous deformational history. I have attempted to build a scenario for the collision zone evolution by synthesizing available thermochronological data from the different geographical locations of the India-Asia collision zone, including this study (Ladakh region). Such a reconstruction assumes that the change in the rate of cooling, as inferred from the thermochronological studies, indicates a change of processes responsible for the cooling. Rapid cooling periods would indicate high tectonic activity at that time and region. Thus thermochronological data can provide helpful constraints for building up a model for the evolution and crustal accommodation in India-Asia collision zone in time and space.