Morphotectonic and Paleoseismological Study around the Charnath Khola Area, Central Nepal

A DISSERTATION
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KIRTIPUR, KATHMANDU

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THE MASTER'S DEGREE OF SCIENCE IN GEOLOGY
(ENGINEERING GEOLOGICAL TECHNIQUES)
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Recommendation

Date: ....

It is certified that MRS. INDIRA SHIWAKOTI has worked satisfactorily for her Master's Degree dissertation under our guidance and supervision. She has worked enthusiastically with sincere interest. The dissertation entitled “MORPHOTECTONIC AND PALEOSEISMOLOGICAL STUDY AROUND THE CHARNATH KHOLA AREA, CENTRAL NEPAL” embodies the candidate’s own work. We, hereby, recommend the dissertation for approval.

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The dissertation presented by MRS. INDIRA SHIWAKOTI entitled "MORPHOTECTONIC AND PALEOSEISMOLOGICAL STUDY AROUND THE CHARNATH KHOLA AREA, CENTRAL NEPAL" has been accepted as the partial fulfilment of the requirements for the Master's Degree of Science in Geology.

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CHAPTER ONE
INTRODUCTION

The outer shell of the earth is made up of several big fragment of continental and oceanic crust with some portion of upper mantle (100–150) km called tectonic plate which floats over the viscous asthenosphere, slipping and sliding along each other's edge and generating earthquake. The Himalayan range is one of the most obvious results of the collision between Indian plate and Asia plate. The Indian plate started to drift northwards from southern latitudes about 70 Myrs ago. It collided with the southern edge of the Eurasian plate at ~10° N (Fig 1.1) about 50 Myrs ago. Overall, the India/Eurasia convergence velocity decreased from ~15 to ~4 cm/yr since then (e.g.: Molnar and Tapponnier, 1975; Patriat and Achache, 1984; Molnar and Stock, 2009; Copley et al., 2010). Depending on the exact age taken to coincide with the full contact between the two continents (40 to 55 Ma) (Fig 1.2) the amount of convergence absorbed by continental deformation varies from ~1800 km to ~3000 km. This convergence has been accommodated in part by the Himalayan thrust system, leading to crustal thickening, and by lateral extrusion of blocks of Asia towards the South East (e.g. Tapponnier et al., 1982, 2001). The large scale thrusting developed from north to south giving rise to Main Central Thrust (MCT) separating the Lesser Himalayas from Higher Himalayas, Main Boundary Thrust (MBT) separating the Lesser Himalayas from Sub Himalayas and Main Frontal Thrust (MFT) separating Sub Himalayas from Indo-Gangetic plain.

The northward convergence of the Indian plate keeps the entire Himalayan arc seismically active, which is responsible for the occurrence of large and moderate magnitude earthquake. The Himalayan region from Assam in the east to Kumaon in the west has experienced four great earthquakes in the last century. They are Shillong (1897), Kangra (1905), Bihar–Nepal (1934), Asam (1950) earthquakes (Kayal, 2010) (Fig 1.3).

Before inventing the seismometers there were not any instrumental records of Earthquakes. Digital seismology started after 1940 when Richter invented the seismometer. Then only earthquakes were measured instrumentally. Before this period all the quantification of the earthquakes were based on the description of damages and felt experiences. Tectonic setting of the region was not well understood and a seismotectonic model was not well developed. Searching a rupture in this situation was not very easy.

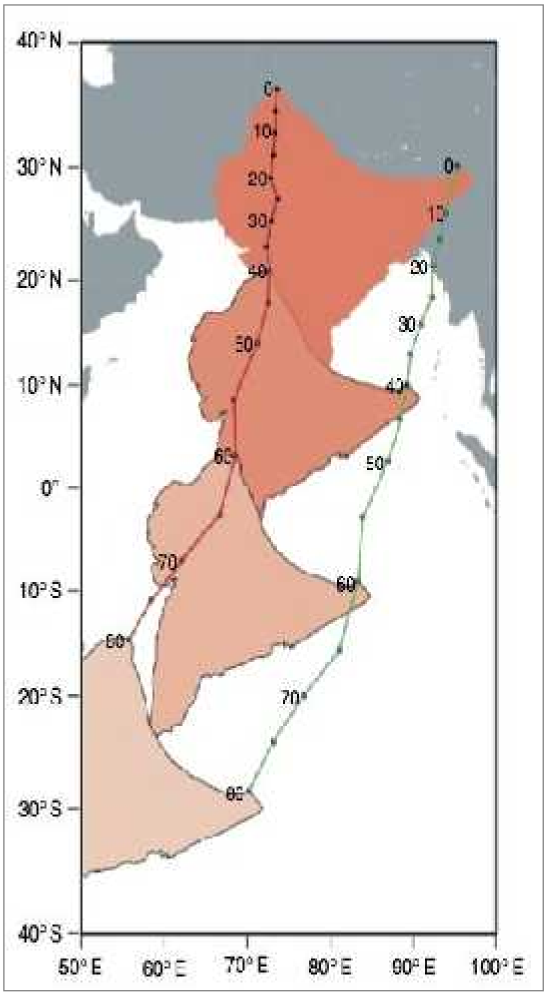

Fig 1.1. Plate motion of India relative to Eurasia. This kinematics was obtained from the recent synthesis of the magnetic anomalies of the Indian Ocean (Royer and Patriat, 2002) (see Patriat and Segoufin (1988) for a former similar analysis). The India/Africa relative motion derived from the analysis of this data set was referenced to Eurasia through an Africa/North America and North America/Eurasia plate circuit across the Atlantic Sea. Convergence rates were computed at points attached to the Indian Plate located at the current position of the eastern and western Himalaya. The modern velocities computed at these same points from a plate model determined from geodetic measurements (Bettinelli, et al., 2006) are shown for comparison (dashed lines). The abrupt decrease of the convergence rate starting at about 50Ma is thought to relate to the onset of the India¨CAsia continental collision (Molnar and Tapponnier, 1975). (Treatise on Geophysics, vol. 6, pp. 377-439)

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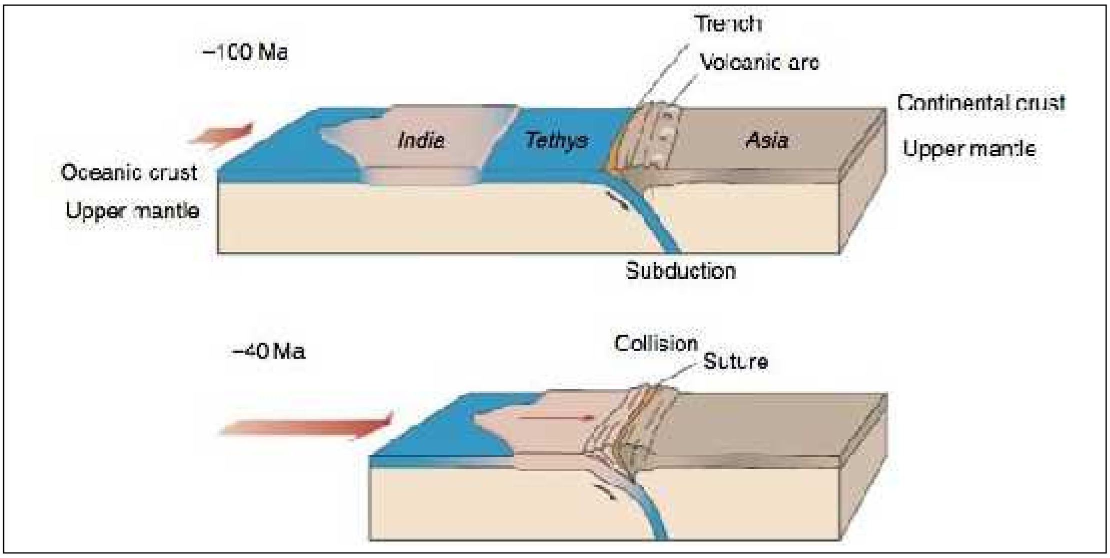

Fig 1.2. Collision of Indian Plate and Asian plate prior to the collision, an ocean (the Tethys Sea) used to separate the northern margin of India and Eurasia. The southern margin of Asia was an active margin with a subduction zone similar, for example, to the Andean subduction zone bordering the western margin of South America. Modified from Malavieille J, Marcoux J, and De Wever P (2002b) L'ocean perdu. In: Museum National D9Histoire Naturelle (France), Avouac J-P, and De Wever P (eds.) Himalaya-Tibet, Le choc des continents, pp. 32¨C39. Paris: CNRS Editions et Museum national de'Histoire naturelle. (Treatise on Geophysics, vol. 6, pp. 377-439)

The signatures of these earthquakes are buried inside the earth which is studied by paleoseismology. Due to rapid deposition or degradation, the tectonic landforms are buried, making it difficult in identifying adequate sites to undertake paleoseismic investigations. Paleoseismological studies of past earthquakes have been carried out by excavating trenches across presumed active fault structures on the surface of earth. Documentation of the historical and pre-historical earthquakes using the evidence of its signature is the main objective of the present thesis.

1.1 Overview of Tectonic Settings

About 50 Ma ago the Indian continental passive margin collided with the southern edge of Eurasia along the Indus Tsangpo Suture Zone (ITSZ) (e.g. Monlar and Tapponnier, 1975). Later on, India and stable Eurasia kept on converging at the rate of about 5cm/yr [Patriat and Achache, 1984]. A fraction of this convergence has been absorbed by crustal thickening of the Indian northern margin, thanks to the activation several major thrust zones. Major thrust faults have been activated along or north of Indus-Tsangpo Suture Zone [Yin et al., 1994]. The deformation then migrated southward with the successive activation of the Main Central Thrust (MCT) and the Main Boundary Trust (MBT) (Fig 1.4 and Fig 1.5) [Gansser, 1994; Le Fort, 1987; Brunel, 1986; Ratschbacher et al., 1994]. The Indo Gangatic foreland formed at front of the rising Himalayan ranges and trapped a fraction of the material eroded away from the high reliefs. Main Frontal Thrust (MFT) is lies in between Siwaliks and Indo-Gangatic plain.

Convergence Rate along the Himalaya

The rate of thrusting across the Himalaya was estimated by different indirect ways that yielded relatively close results. One estimate is based on the sedimentological record in the Indo-Gangatic fore deep. Distal facies in the Lower Siwalik grades upward into coarser, more proximal facies, in the Upper Siwaliks [Karunakaran and Ranga Rao, 1997; Mathur and Evans, 1964; Sahni and Mathur, 1964]. Well data indicate that this grading is related to southward migration of proximal facies during sedimentation [Karunakaran and Ranga Rao, 1979; Sastri, 1979; Sastri et al., 1971]. Assuming southward migration of a steady state accertionary prism, (Lyon-Cean and Monlar, 1985) deduce an average thrusting rate of 10 to 15 mm/yr over the last 15 to 20Myr. In their study of the south Tibetan garben, Armijo et al., [1986] obtain a shorting rate across the Himalaya of 20±10mm/yr. More recently Bilham et al., [1997] reported GPS measurements collected between 1991 and 1995, that indicate 17.7±2mm/yr of horizontal contraction in the Nepal Himalaya. The present rate of thrusting across the Himalaya, averages over the seismic cycle, is probably of the order of 15 to 25mm/yr. Continued activity is manifest in present day northward movement of the Indian plate at a rate of 5cm per year and in occurrence of frequent seismic events along the mountain range and in its surrounding (Bilham et al., 1997, 1998). The mean convergence rate across central and eastern Nepal is estimated to 19±2.5mm/yr and 13.5±5 in western Nepal on the basis of an elastic dislocation model of interseismic strain (Bettinelline et.al., 2006). Rate of thrusting along MFT has absorbed 21±1.5 mm/yr of N–S shortening on average over the Holocene period (Lave et.al., 2000). In the last 5000 yrs or so (Late Holocene), the average rate of uplift on the southern branch of the Main Frontal Thrust across the Ratu Nadi has been on order of ~1 ± 0.2 cm/yr (Sapkota, 2011).

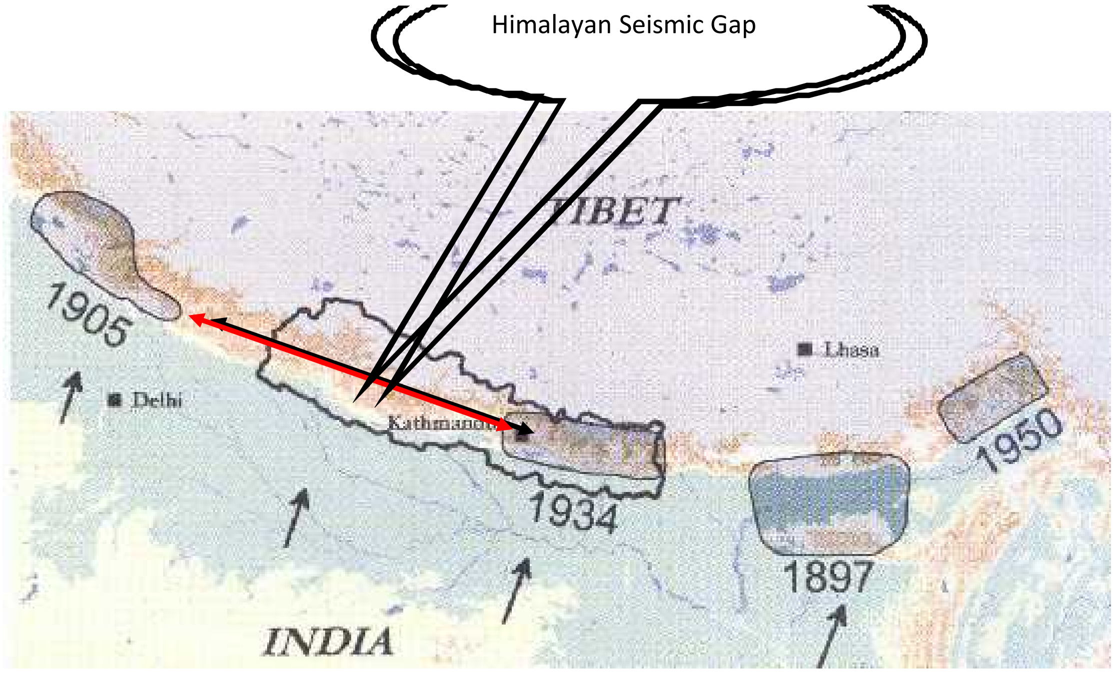

***Fig 1.3 Four great Himalayan earthquakes with their probable rupture extent** (Kayal, 2010).*

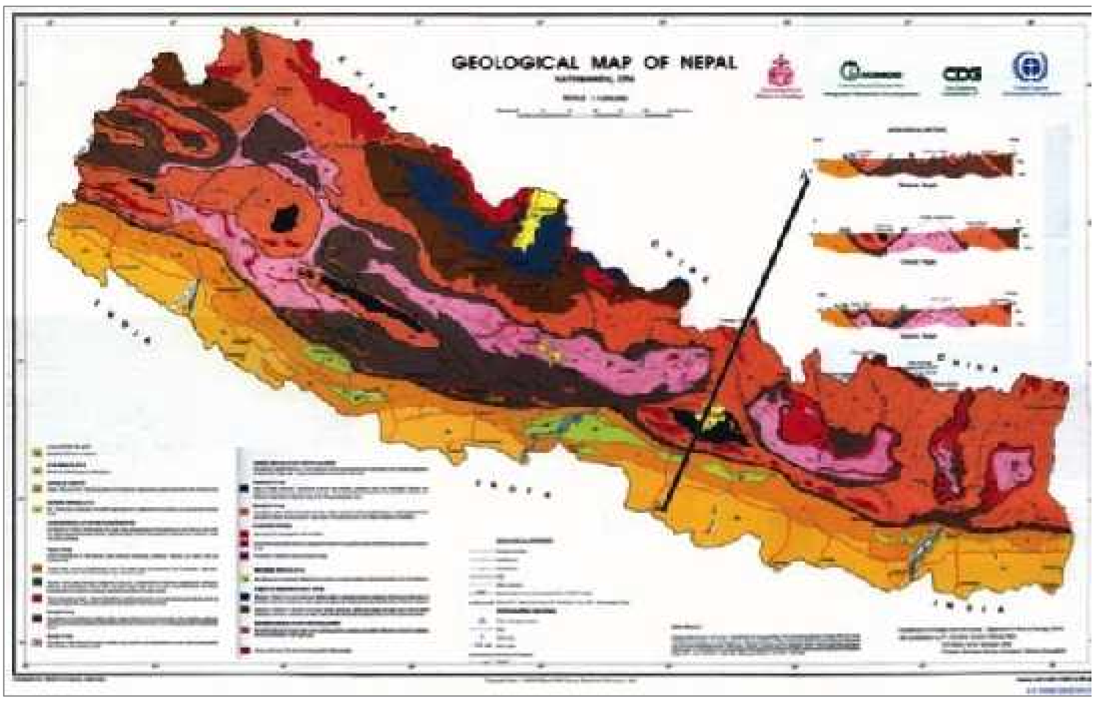

Fig 1.4: Geological Map of Nepal with section across Eastern Central Nepal (DMG).

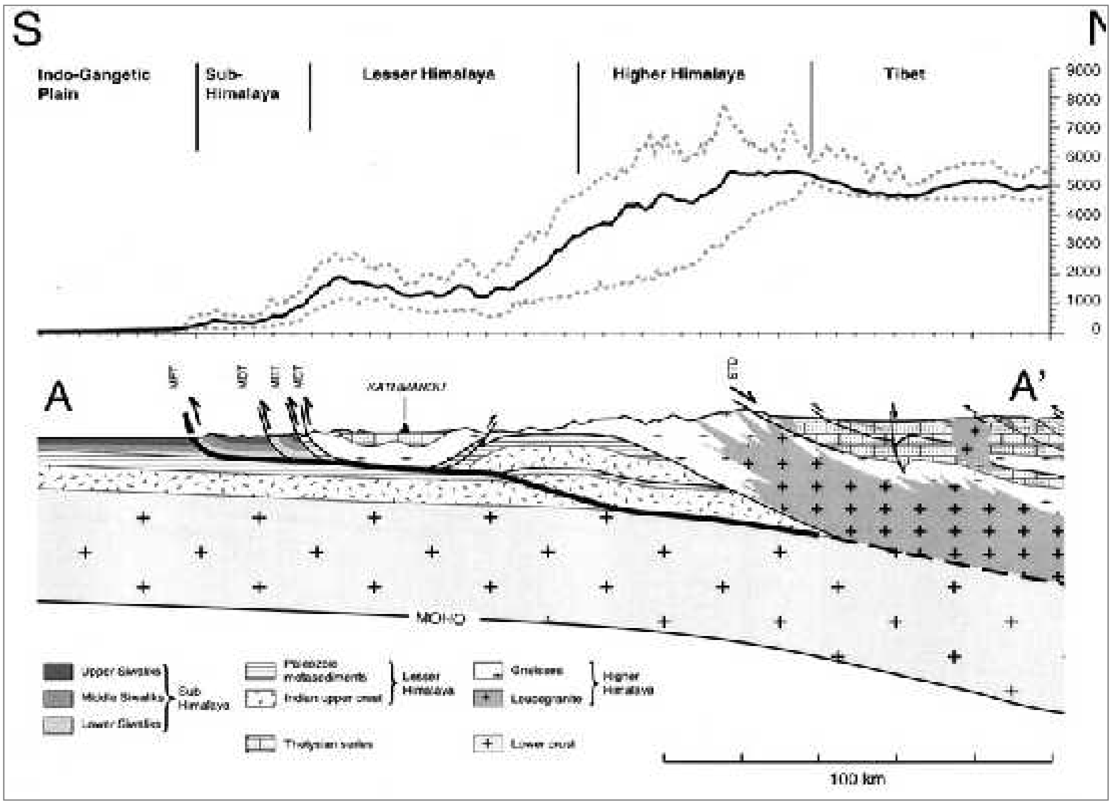

Fig 1.5: Synthetic N18E Geological cross-section across the central Himalayas of Nepal (see Fig 1.4 for location) (from Lavé and Avouac, 2001 modified from Brunel, 1986, Schelling, 1992, and Pandey et al., 1995). The thick dashed line that continues the MCT beneath the Higher Himalaya and southern Tibet is taken to coincide with the midcrustal reflector seen 200 km farther east in the INDEPTH profile (MHT) (Zhao et al., 1993). The mean (solid line), maximum and minimum elevation profiles (thick dashed lines), corresponding to a 50-km swath along the section, are shown.

Location and Accessibility

The study area is located in the foothill of Siwaliks of the Dhanusha district around the Charnath Khola section which is bounded within 86° 03’ 48”E to 86° 06’ 14” E and 26° 54 21 N to 27° 00’ 00” N (Fig 1.6). Especially the trenching is done in the Bharatpur V.D.C-4, left bank of the Charnath Khola.

The study area is linked by highways, road section and cart tract. The study area is due north from Birendra Bajar which is linked to Mahendra Rajmarg by cart tract. The excavator can be drive easily to the trenching site.

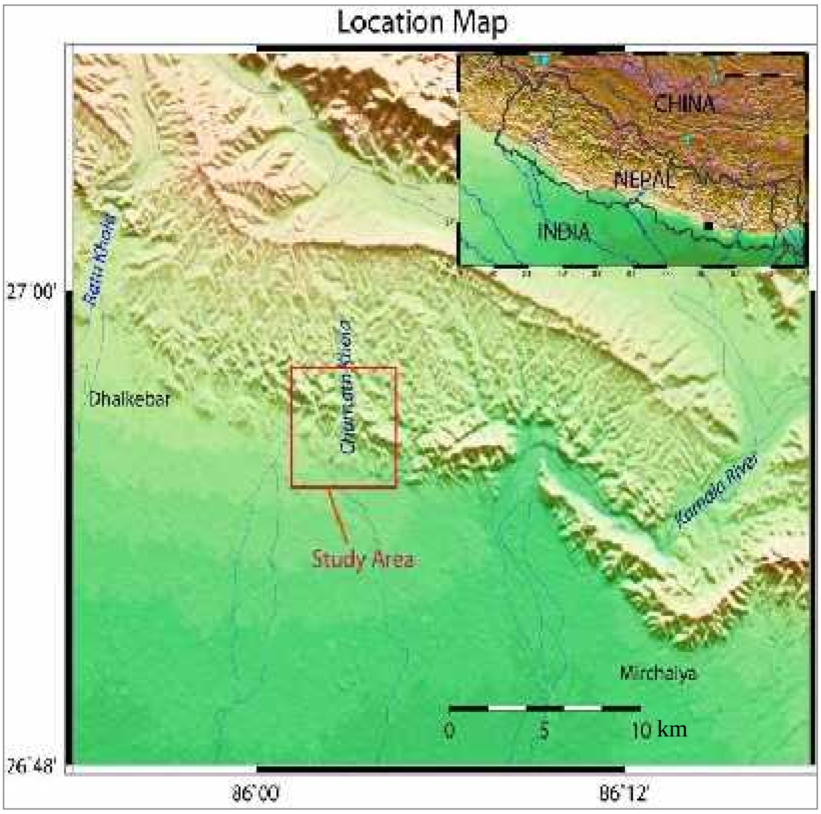

Fig 1.6. Location map of the study area.

Objectives

The specific objectives of the study are:

1) Review of seismological and paleoseismological works done in Nepal.

2) Understanding methodologies used in paleoseismological study.

3) Locating the best trenching site.

4) Documentation of past rupure using different dating techniques.

5) Finally constructing a seismic history of the region.

Scopes of Paleoseismology

Paleoseismology is a good tool to document pre-historical and historical earthquakes that are large enough to produce significant ground surface ruptures. It is usually most efficient when the regional tectonic context is well understood and the active faults are clearly identified. In Nepal, since the beginning of the 1990's, a continuing effort to improve the mapping of the active faults, to determine the slip rate on them and to install permanent or temporary networks of seismometers and GPS stations has led to a better understanding of the regional tectonic context and has opened doors to more efficient paleoseismological investigations.

The main scopes of paleoseismology are:

1) Find out the magnitude of past earthquakes

2) Documentation the surface ruptures of prehistoric and historical earthquakes with timing.

3) Estimation of possible return period of great earthquakes.

Limitation of Paleoseismology

Paleoseismology is based on the observation that surface ruptures of large earthquakes are preserved in the sedimentary record within relatively shallow ground layers (e.g. Sieh, 1978) but there are some limitations:

1) The paleoseismologist can only study earthquakes that produce recognizable surface deformation and rupture.

2) Only the great earthquakes can be studied by paleoseismology because geologic evidence of small and moderated-sized earthquakes is rarely preserved near the surface.

3) Paleoseismology is effective where the micro topography is well understood. In case of Nepal Himalaya, the available topography maps cannot resolve the problem of paleoseismology.

4) Charcoal collected to date the rupture may be detrital which makes difficult to bracket the earthquakes.

CHAPTER TWO
GEOLOGY OF THE STUDY AREA

The Nepal Himalaya extends for about one third (800km) of its total length running from the Mechi River to the Mahakali River. It is divided into five major tectonic zones. From south to north they are Terai, Sub Himalaya, Lower Himalaya, Higher Himalaya and Tethys Himalaya (Gansser, 1964) (Fig 1.4 and Fig 1.5). These zones extend approximately parallel to each other, each characterized by their own lithology, tectonics, structures and geological history. Terai zone represents the northern edge of the Indo-Gangetic plain and forms southernmost tectonic unit of Nepal. It is a Himalayan foreland basin and is separated from the Sub-Himalaya to the north by the Main Frontal Thrust (MFT). The Pleistocene to recent alluvial deposits cover the Terai plain. Sub Himalaya represents low hills, the Churia range. To the north, it is bounded by the MBT. It is composed of fluvial deposits of the middle Miocene to early Pleistocene age containing vertebrate fossils (Corvinus, 1988). This zone is sub-divided into the Lower Siwalik, the Middle Siwalik and the Upper Siwalik (Auden, 1935). The Lower Siwalik comprises ash grey and red-brown, fine-grained sandstone with pseudo-conglomerate containing pebbles of Siwalik fragments, inter-bedded with purple, grey mudstone and siltstone The Middle Siwalik comprises relatively coarse, arkosic to lithic, grey sandstone with small proportion of green and grey mudstone and siltstone. The Upper Siwalik represents dominant coarse conglomerate beds with minor sandstone and mudstone beds. Lesser Himalaya lies between the Sub-Himalaya and the Higher Himalaya separated by the MBT and the MCT respectively. It is mostly made up of unfossiliferous sedimentary and metasedimentary rocks such as shale, sandstone, conglomerate, slate, phyllite, schist, quartzite, limestone and dolomite ranging in age from the Precambrian to the Oligocene (Bordet, 1961; Hagen, 1969; Valdiya, 1995, Sakai 1983, 1985; Lefort et al. 1999). Higher Himalaya is made up of the Precambrian mainly the high grade metamorphic rock and granitic gneiss situated between the fossiliferous Tibetan sedimentary zone to the north and the MCT in the south. It comprises mainly kyanite-sillimanite bearing gneiss, schist and marble and granite. Tethys Himalaya is generally begins at the top of the Higher Himalayan Zone and extends to the north into Tibet, made up of the Late Precambrian-Early Paleozoic to the Upper Cretaceous (Colchen et al., 1980), richly fossiliferous clastic and carbonate sediments deposited in the Tethys ocean. It is composed of shale, limestone and sandstone. It lies between the STDS in the south and the Indus-Tsangpo Suture Zone (ITS) in the north. It is also divided into four transverse geological zones namely Eastern Nepal, Central Nepal, Western Nepal and Far western Nepal separated by a major river.

Detailed Geology of Study Area

Although Geological mapping is not the objective of thesis we should familiar with the general geology of that area. Without knowing general geology we cannot manage the paleoseismological work because trench shape, excavation logistics and geophysical technique (for case of seismic refraction amount of dynamite, spacing of shots point and depth of the shooting holes) are govern by it. Petroleum Exploration Promotion Project (PEPP) of Department of Mines and Geology (DMG) has prepared map on 1:63360 scale. By taking this map as reference and new geological map is prepared on scale 1:25000. Geologically the study area is located in Siwaliks and Terai (fig 2.1).

Siwalik Group

The Siwalik group is exposed in the southern part of the Main Boundary Thrust (MBT) and upper part of Main Frontal Thrust (MFT). The lower part of this sequence comprises of fine grained sandstone, siltstone and variegated mudstone and upper part consists of coarse to very coarse grained arkosic sandstone and conglomerate. Based on the lithology this group is classified into three formations namely lower Siwalik, middle Siwalik and upper Siwalik. Again middle Siwalik is subdivided into lower middle Siwalik ($MS_{1)}$ and upper middle Siwalik ($MS_{2)}$. Invertebrate and plant fossils are common in lower and middle Siwalik. Among these three formations of Siwalik the study area covers middle and part of upper Siwalik.

Middle Siwalik

On the basis of lithology the Middle Siwalik is divided into two sub-group namely upper Middle Siwalik (MS_2) and Lower Middle Siwalik ($MS_{1)}$.

Lower Middle Siwalik (MS_1)

Lower Middle Siwalik is exposed in southern part of area just above the MFT. This comprises of siltstone, sandstone, claystone, clay and mudstone. The sandstone is fine to medium grained, grey in color and thickly bedded. Current and climbing ripple laminations are present. Intraformational mud clasts are also present. The siltstones are grey, thinly to thickly bedded, sometime calcareous concretions are present at surface. Plant fossils monocot and dicot are observed in siltstone. The mudstones are generally grey in color. They show spherical and nodular weathering behavior in the surface. Clays and claystones are dominantly light grey to grey in color. They also show spherical and nodular weathering behavior in the surface. There are synclines and anticlines structure are present within this member.

Upper Middle Siwalik (MS_2)

The Upper Middle Siwalik succeeded gradually over the Lower Middle Siwalik. This unit is dominantly composed of arkosic sandstone, pebbly sandstone and few amounts of clay, claystone, mudstone and siltstone. The sandstones are grey colored, medium to coarse grained, thickly bedded to massive, friable and soft. Two micas (muscovite and biotite) are abundant in arkosic sandstone. Large scale current beddings are commonly present in sandstone. The upper part of this unit is comprises of pebbly sandstone. The pebbles are mainly quartzite, sandstone and few amounts of dolomite, phyllite, and granite having different shape and size. Coal lenses are commonly present in sandstone. Its contact with lower and upper unit is normal and gradational.

Upper Siwalik

The band of Upper Siwalik (US) is exposed in northern part of the study area. It is generally composed of dominantly conglomerate and clays and subordinate amount of coarse grained sandstone. Conglomerates are generally grayish white. Cobbles- pebbles are composed of quartzite, sandstone, dolomite, schist, phyllite of adjacent lesser Himalaya. The pebbles and cobbles are subrounded to rounded in shape. The matrix is brownish grayish clayey and sandy materials. The conglomerate beds are graded into large cobble and pebble at the bottom and smaller to the top showing fining upward sequence. The clays are silty, and sandy in nature. The sandstones are coarse grained, friable, loosely packed and grey in color.

Terai Zone

The Main Frontal Thrust (MFT) marks the boundary between the southernmost tectonic unit of the Nepal Himalayas and the vast alluvial indogangetic foreland basin.). The sediments deposited in the northern part of Terai are generally coarser than those in the southern part. The northern sediments belong to what is called the Bhabar zone, considered to be the recharge zone for the Terai ground water system. The basement topography of the Ganges basin below the alluvium is not a uniform, shallow North-dipping surface, and hence the depth to the basement varies significantly both along and across strike (Valdiya, 1988). The sediments of the Terai (Pleistocene to Recent) in Nepal rest on the Siwaliks (Middle Miocene to Pliocene), which in turn rest on Eocene - Oligocene rocks (reddish sandstones and conglomerates, a lateral equivalent of the Murrees farther west) and/or on rocks belonging to the Gondwanas sequence farther down (rocks of Peninsular India that are mostly of Permo-Carboniferous age).

Table 2.1 Lithostratigraphy of study area (Source: PEPP)

Age	***Group***	***Formation***	***Lithology***
Quaternary		Recent	Loose unconsolidated gravels, sand and clay with remains of animals and plants.
.................................Main Frontal Thrust...			
Middle Miocene to Early Pleistocene	SIWALIKS	Upper Siwalik (US)	Conglomerate of heterogeneous to homogeneous composition loosely packed, poorly sorted, interbedded with coarse grained micaceous sandstone and grey to yellow clay with coal patches.
		Middle Siwalik (MS_2)	Medium to coarse grained sandstone which is micaceous arkoses, gritty to pebbly sandstone with grey clay, siltstone, mudstone and coal patches.
		Middle Siwalik (MS_1)	Fine to medium grained, grey to greenish grey, hard, sandstone and mudstone. Plant remains are poorly preserved.
		Lower Siwalik (LS)	Verigated mustone and fine grained quartose to lithic sandstone. The mudstone is light red, purple, yellow and grey to dark grey often bioturbated and mottled. Sandstone beds are highly indurated,fine to rarely medium grained and generally grey to brown in color.

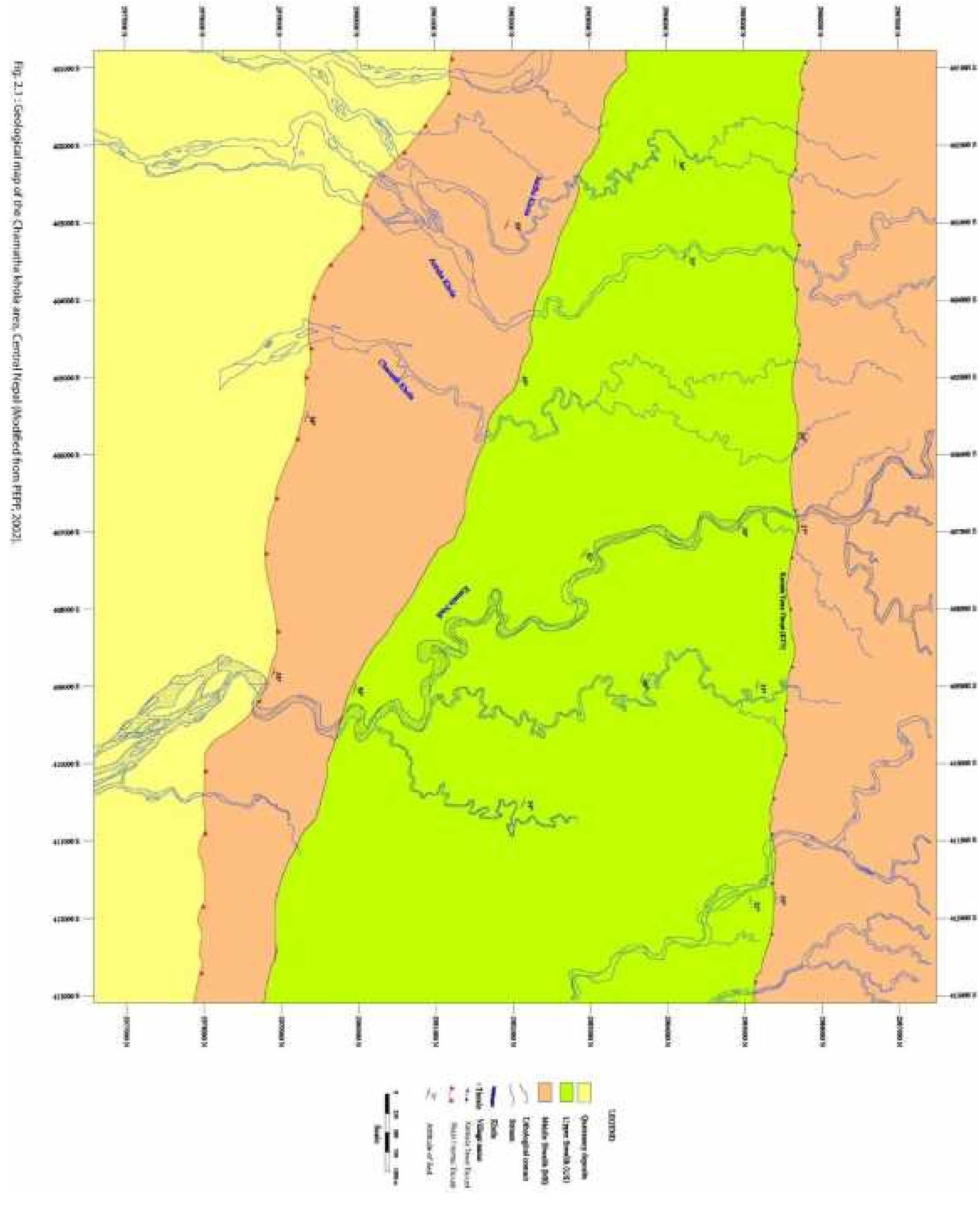

Fig 2.1 Geological map of the Charnath Khola area.

CHAPTRE THREE
OVERVIEW OF SEISMOLOGICAL WORK IN NEPAL HIMALAYA

To understand the caused and devastating effect of the earthquake and to be able to mitigate the associated destruction, the scientists throughout the world have been monitoring and evaluating the seismic activities by using various equipment and techniques since late forties. Locating earthquake before this period was not straightforward. Uncertainties arise to locate the 1934 earthquake. There was a tradition to locate the seismic event using the intensity that is why 1934 earthquake is used to call Bihar–Nepal earthquake although its epicenter was at Sangkhuwasabha of Himalayan country Nepal.

Recording and monitoring of earthquake has been started by Nepal Government Department of Mines and Geology (DMG), from 1978 by installing one component vertical short period station near Phulchoki., in collaboration with The Laboratoire de Geophysique Applique (LGA) Paris University. The signals from this station were telemetered to the Seismological Laboratory of DMG at Lainchaur, Kathmandu,Nepal. After the successful operation of this station, five telemetric stations were installed in central Nepal by1985. Only after the 1988 Udayapur earthquake, necessity of a national network of more seismic stations to cover the whole area of Nepal was realized due to uncertainties in epicenter location during the seismic crisis. The project of National Seismological Network covering the entire country begins in 1991 with financial and technical support from the French Government. The NSC at Kathmandu within the promise of the Department of Mines and Geology is operating for mid 1994.

National Seismological Network

There are two independent recording centers, one in Lainchaur, Kathmandu and another in Birendranagar, Surkhet. National Seismological Network currently has 21 seismic stations operating in Nepal Himalaya (Fig 3.1). National Seismological Centre (NSC), Kathmandu records the data from the stations of Lukagoan (Pyuthan), Koldada (Palpa), Dansing (Kaski),Gorkha (Gorkha), Daman (Makunpur), Kakani (Nuwakot), Phulchoki (Lalitpur),Gumba (Sindhupalchok),Jiri (Dolakha), Ramite (Udapur), Odare (Dhankuta) and Taplejung (Taplejung). It is equipped with an electronic maintenance and control laboratory. It administrates and controls the above twelve stations of the network. The National Seismological Centre has an automatic Technical Alert System (TAS) in case

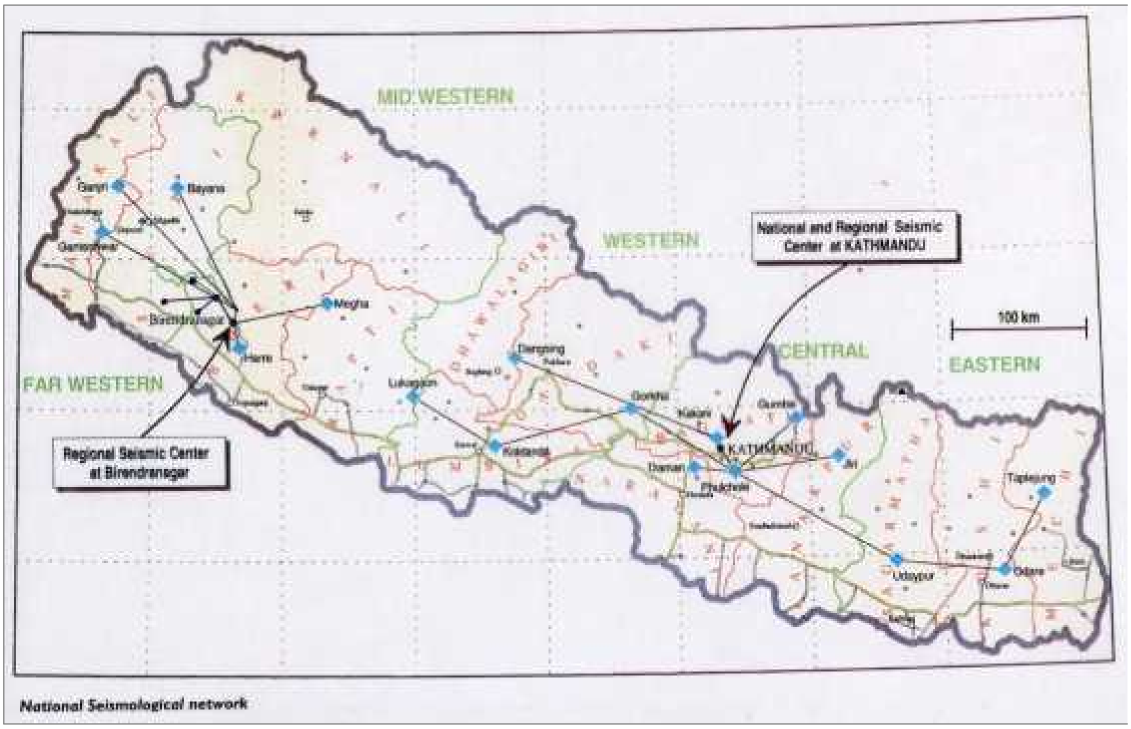

Fig 3.1. National Seismological Network Map.

of technical failure on the network. This centre is also equipped with data processing Ethernet network for the routine processing, mixing and analysis of the seismic data acquired by Regional Seismological Centre (RSC) and NSC. The acquired data in NSC are directly linked to the data processing network of National Seismological Centre. It compiles a weekly seismological bulletin reporting arrival time and date of seismic events recorded by the network. Data processing system of NSC has been upgraded in 2001 by replacing the old ISIS system by new powerful software Jade/Onyx. The processing of seismic signals is done in near real time. Processing results are linked with GIS system that facilitates the direct plotting of the epicentre on the globe. NSC is also equipped with automatic Seismic Alert System (SAS) designed for informing the concerned personnel. In case of any earthquake with local magnitude greater than 4.0 occurring inside the Nepal is reported to concerned authorities and media as soon as possible so as to provide rescue and relief operation at the earliest. The centre has recorded 146954 earthquakes by the June 2011 among which 94315 are tele and 52639 are local and regional earthquakes. Regional Seismological Centre, (RSC), Birendranagar is an autonomous centre for recording and processing of the data obtained from eight station of the National Seismological Network including the four seismic station of Karnali basin. The centre is responsible for the operation and maintenance of these stations at Ghanteshwar (Daduldhara), Gangri (Baitadi), Badegauja (Kailali), Pusma (Surkhet), Bayana (Bajhing), Gainekanda (Surkhet), Gaibana (Surkhet) and Harre (Surkhet).This RSC is also equipped with data processing and earthquake location facility as well as Technical Alert System (TAS) and Seismic Alert System (SAS).

Signals received from these networks are processed at NSC in Kathmandu and at RSC in Surkhet separately. Data from these two independent seismic networks are merged and prepared a single catalogue with event information like origin time, azimuth and arrival time in each station and its spatial location. Microseismic Epicentre Map of different scales is prepared by this catalogue (Fig 3.2). This map is serving as a basic input to assess the seismic hazard of any region in Nepal. These digital data with magnitude greater than four are in sale for the concern infrastructure development agency.

NSC is conducting many collaborative research projects on geophysics, geomorphology, geodesy and paleoseismolgy. On top of that NSC is providing seismic information of earthquake of magnitude greater than four as soon as possible to Home Ministry and other concerned media. Flow chart for this purpose is presented in Fig 3.3.

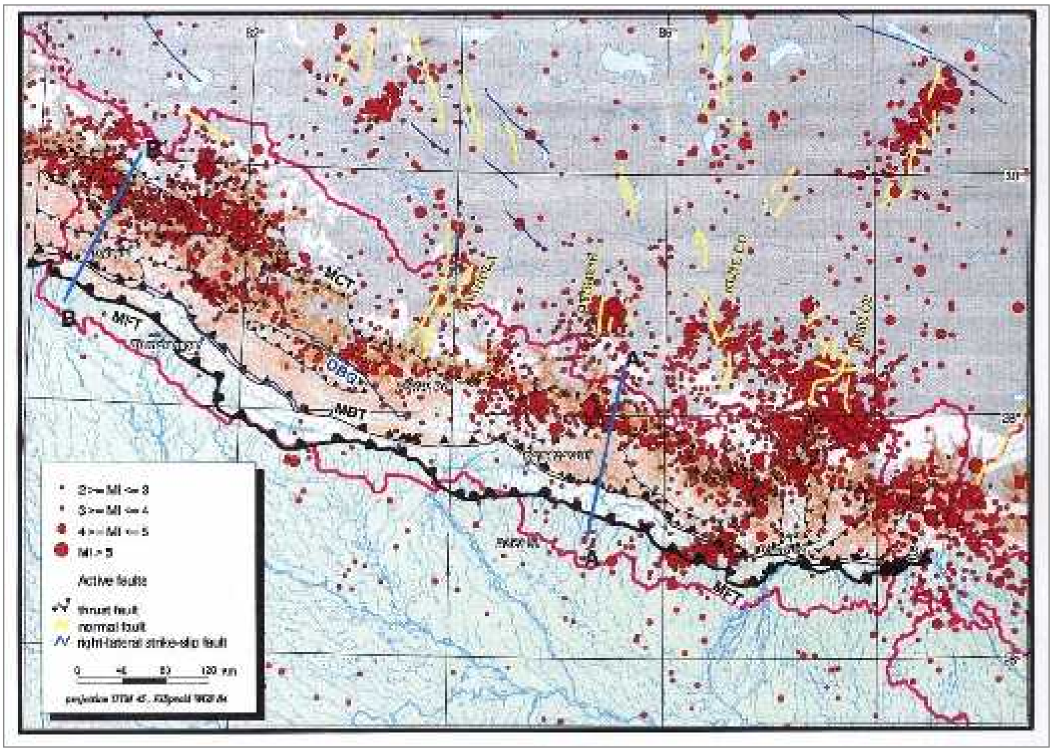

Fig 3.2. Microseismicity map of Nepal Himalaya (after Pandey et al, 1999).

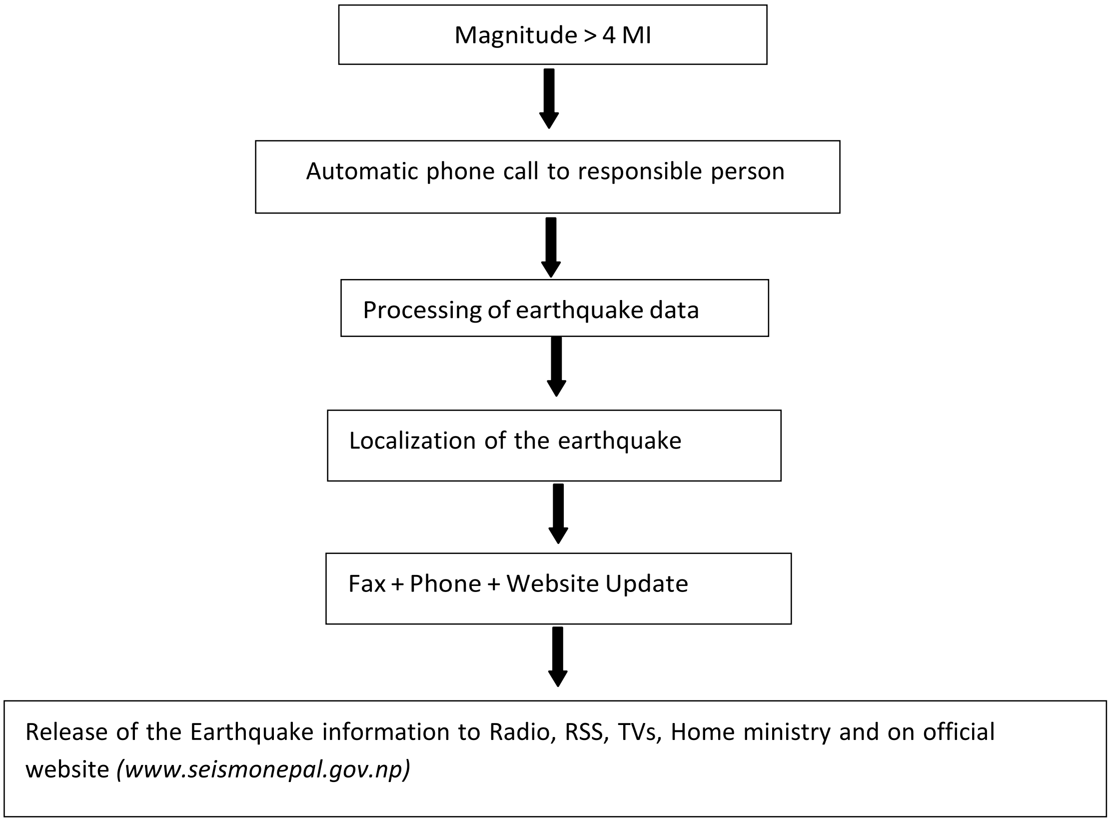

Fig 3.3. Flow chart to release the earthquake information.

Global Positioning System (GPS)

The understanding of the seismic cycle in the Himalaya, has greatly improved due to research activities carried out in the field of seismology, geology and geophysics. Over the last decade on geodetic monitoring from permanent GPS stations have emerged as a most complement to the investigations. This technique offers the probability to measure crustal deformation that may be too slow to generate seismic waves. Such transient deformation events have been detected along some subduction zones, and probably it might also occur in an intra-continental setting such as along the Himalaya. If transient aseismic deformation occurs at seismogenic depth in the Himalaya, it would have direct implication for seismic hazard assessment because all the deformation might not need to be absorbed only by major recurring earthquakes. Also there is a possibility that the rate of deformation might vary during the seismic cycle and could provide some indication on the timing of future earthquakes. In 2003, DMG/CALTECH/DASE has agreed to install 29 permanent continuous GPS stations encompassing the zone of interseismic straining across the range to continuously the crustal deformation. This additional network would complement the existing seismic network that has been in operation since

1994 in collaboration between DMG/Nepal and DASE/France. The first phase led to the deployment of 10 continuous GPS stations between January and May 2004. A second phase is planned for autumn 2006 to deploy the rest 13 continuous GPS stations. Now there are 29 GPS stations (Fig 3.4).

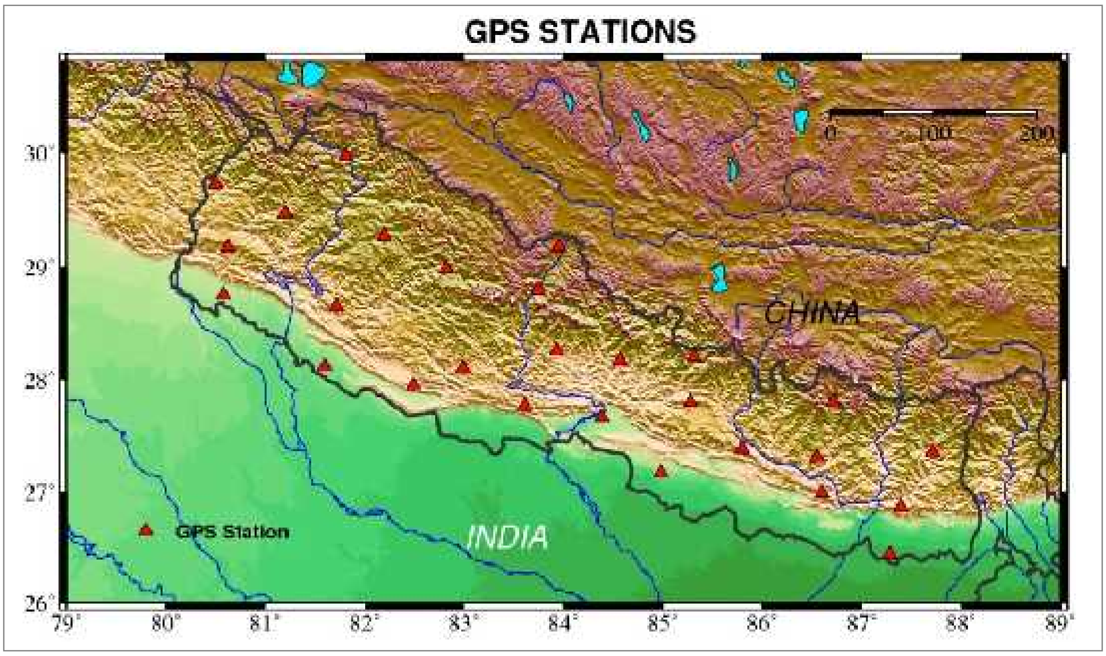

Fig 3.4. GPS station map of Nepal.

The movement of plates can be precisely monitored using Global Positioning System (GPS). Monitoring of crustal movements in a region like the Himalaya could reveal the geometry of locked portion (Fig 3.5) of the characteristic faults and its activity, which could help to assess the seismic hazard. GPS data can also reveal if any portion is slipping without generating big earthquakes i.e slow event.

Research Activities

Microtremor study

Microtremor studies carried out by the department shows the variation of peak amplitude value of displacement power spectrum at different site and correlates with the reported devastation and distribution of intensity in Kathmandu Valley due to Great Earthquake of 1934. Similarly peak frequency correspond to greatest peak power amplitude also varies from place to place depending upon the local site condition. Therefore microtremor survey helps to understand local geological condition or site effects. It also helps to characterize the building types measuring its fundamental period which will help in the damage estimation of the future earthquakes enabling retrofitting of the present building.

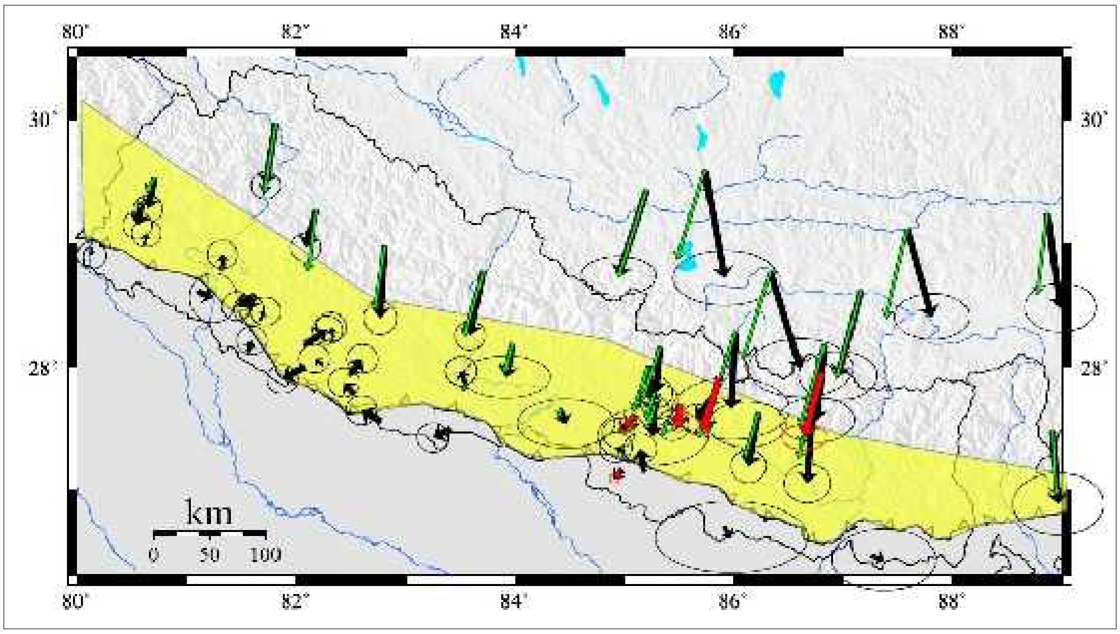

Fig 3.5. GPS data indicating the MHT locked at depth less than about 20km and creeping at about 20mm/yr below the high range and southern Tibet (Bettinelli et al, 2006)

Paleoseismological study

In Nepal the historical records of earthquakes don't go back beyond 1255 and instrumental recoding of earthquake doesn't go back beyond last 100 years globally. NSC started instrumentally recording earthquakes only since last 25 years and so both historical records of earthquakes and recent records are not sufficient to assess seismic hazard statistically. To complement such scenario, paleoseismological study of the past earthquakes have been carried out by excavating trenches across presumed active fault structures on the surface of the earth as determined from the study of aerial photo, satellite images and other geomorphological means. NSC in cooperation with scientists from France and USA has carried out such studies at many places across the MFT. Such study may help to identify past earthquakes and their recurrence period and ultimately assisting in the assessment of seismic hazard. Details about history, methodology and results from this study are described in following chapter.

Historical earthquake in Nepal

Recorded History of earthquake in Nepal Himalaya does not go back beyond 1255 A. D. Details about 1255 earthquake has been described by Mahesh pant. Most of the published data on historical and recent earthquake are presented in following table. Elaborative description of the recent earthquake is also presented in the text.

Bajhang Earthquake 1980: On 29 July 1980 (2037/4/14 BS) at 8:41 PM, Far West Nepal was hit by an earthquake of magnitude 6.5. There were 15 felt-aftershocks throughout the Night. The epicenter of this earthquake was in Bajhang district (29.62N, 81.09E). It was felt in most part of Western Nepal (Darchula, Baitadi, Dadeldhura, Bajhang ,Bajura, Doti, Achham, Humla, Mugu, Jumla, Kalikot, Dailekh, Jajarkot, Surkhet, Rukum, Salyan) . The total numbers of casualties were 103. Among 270653 houses, 25,086 were completely destroyed and 11670 were cracked (Fig 3.6). Intensity map of this earthquake is shown in Fig 3.7.

Table 3.1. Some Great Earthquakes of Nepal (Source: News Bulletin, Geological Society and National Seismological Center)

Date in A.D.	Lat. N	Long. E	Mag.	Intensity	Location
1255	-	-	-	X	-
1408	-	-	-	X	-
1681	-	-	-	IX	-
1810	-	-	-	IX	-
26/08/1833	28.0	85.0	7.0	X	Trisuli
04/08/1833	27.0	85.0	7.0	IX	Kalaiya
23/05/1866	27.7	85.3	7.0	X	Kathmandu
15/01/1934	26.5	86.5	8.4	IX-X	Bihar-Nepal Bord.
27/05/1936	28.5	83.5	7.0	-	Dhaulagiri
29/07/1980	29.62	81.09	6.4	VII	Bajang
20/08/1988	26.77	86.61	6.7	VIII	Udapur
20/10/1991	30.22	78.24	6.7		Uttarkaski
1997	29.79	80.59	5.3	VI	Baitadi
31/01/1997	28.09	85.29	5.6	VI	Sharshin
29/03/1999	30.45	79.3	6.2-6.4	VIII	Chamoli
18/09/2011	27.69	88.24	6.8		Taplejung-Sikkim

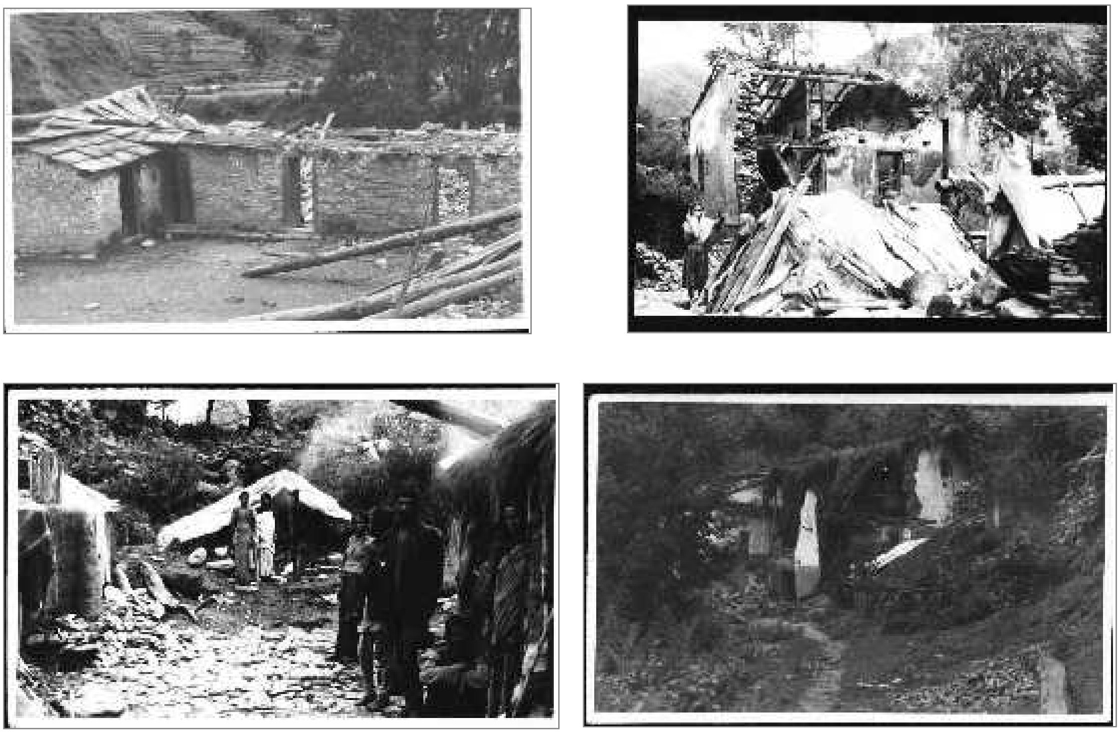

Fig 3.6. Photographs which were taken after the earthquake of Bajhang on 29 July 1980. Archives of the National Seismological Centre, Kathmandu (Source: Sapkota, 2011).

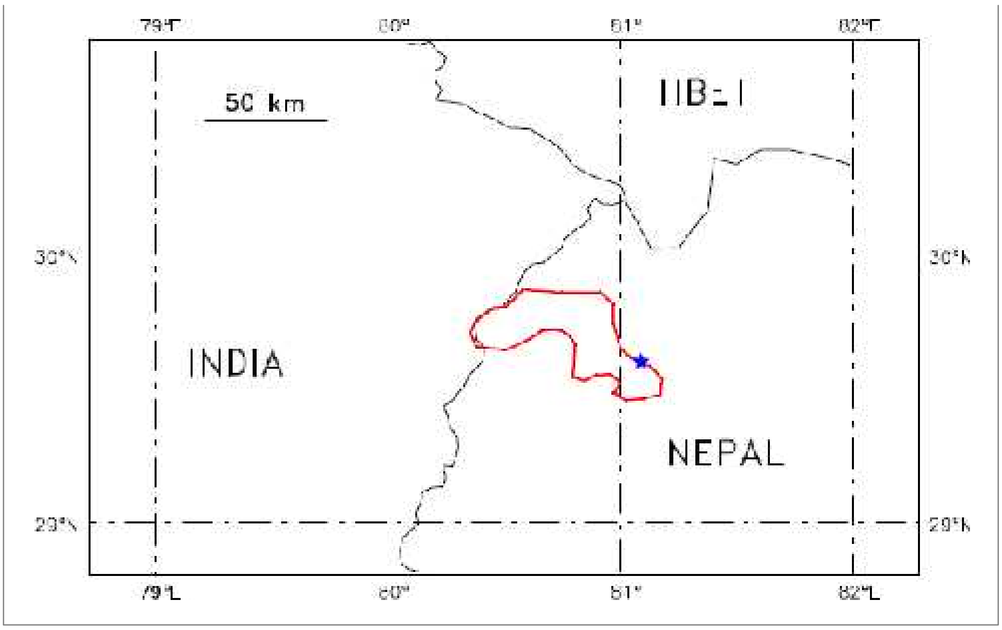

Fig 3.7. Intensity map of Bajhang earthquake (Singh. 1985).

Udayapur Earthquake 1988: On 20 August 1988 (2045/5/5 BS) at 4:55 AM, Eastern Nepal was hit by an earthquake of Magnitude 6.6. There were about 27 felt-aftershocks. The epicenter of this quake was in Udayapur district (26.77N, 86.61E). The earthquake was felt in most part of Eastern, Central and Western Nepal. The total number of casualties was 721. There were 16945 houses completely destroyed (Fig 3.8). This is the unusual earthquake with depth 57 Km i.e. mantle earthquake. Intensity of this earthquake was mapped by A. M. Dixit from DMG (Fig 3.9).

Fig 3.8. Photographs taken after the earthquake of Udaypur on August 21, 1988. Houses damaged in Dharan and Lahan Gaighat road (right). Photos Umesh Gautam, DMG/NSC archives. (Source: Sapkota, 2011).

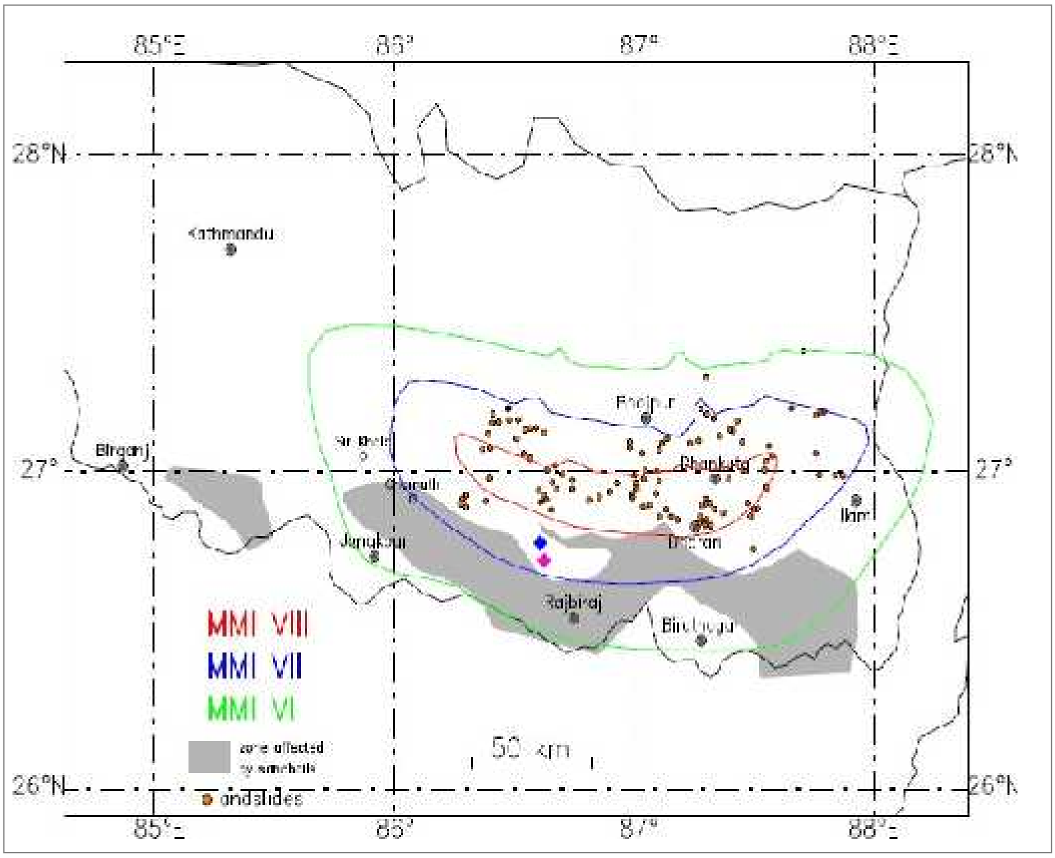

Fig 3.9. Intensity map of Udayapur earthquake.

Uttarkashi 1991: On 20 October 1991 Uttarkashi earthquake with a magnitude Mw of the order of 6.7 killed over 1000 people with large number of victims and considerable damage in NW India. It is also the first Himalayan earthquake for which accelerometry data are available in near field. Note also that this earthquake was preceded by three pre shocks of magnitude greater than 4 for a period of about 30 minutes, about 9 hours before the main shock (Kayal, 1996). The earthquake was followed by a large number of aftersocks having the magnitude greater than four.

Baitadi Earthquake 1997: On January 5, 1997 The earthquake of magnitude (Mb) of 5.4 in Baitadi was felt. It caused no victims identified but it was felt in all districts of the far west of the Nepal, particularly in Darchula, Baitadi and Bajhang, Doti Dandeldhura districts. It was even felt by the Baitadi district, a building was entirely destroyed, several other houses were partially destroyed, but more than 75% of homes were affected by damage of lesser magnitude. The nature of the damage depended on the distance to the epicenter, technique of construction, the site and the materials used heavily. In General, 80% of the homes in Baitadi and Darchula districts were affected.

Sarsin Earthquake 1997: On 31 January 1997 (2053/10/19 BS) at 1:47 AM, Central Nepal was hit by an earthquake of magnitude 5.6 and intensity VI-V (Fig 3.10). One fore-shock of magnitude 5 had occurred in the same area three hours before the main shock. There were eight felt-aftershocks. The epicenter of this earthquake was in Rasuwa district (28.09N, 85.29E). There were more than 100 aftershocks. The distribution of the aftershocks seems to be oriented in NE-SW direction. The estimated rupture length of the fault is about 12 Km. The earthquake was felt in most part of central Nepal (Rasuwa, Nuwakot, Dhading and Kathmandu valley). The main event triggered the accelerometer installed by NSC at Kakani which was 30 Km south of the epicenter. The maximum peak ground acceleration recorded at Kakani was 0.145g. There were 113 houses completely destroyed and 123 families directly affected with an estimated loss of 871000 Rupees in Rasuwa district.

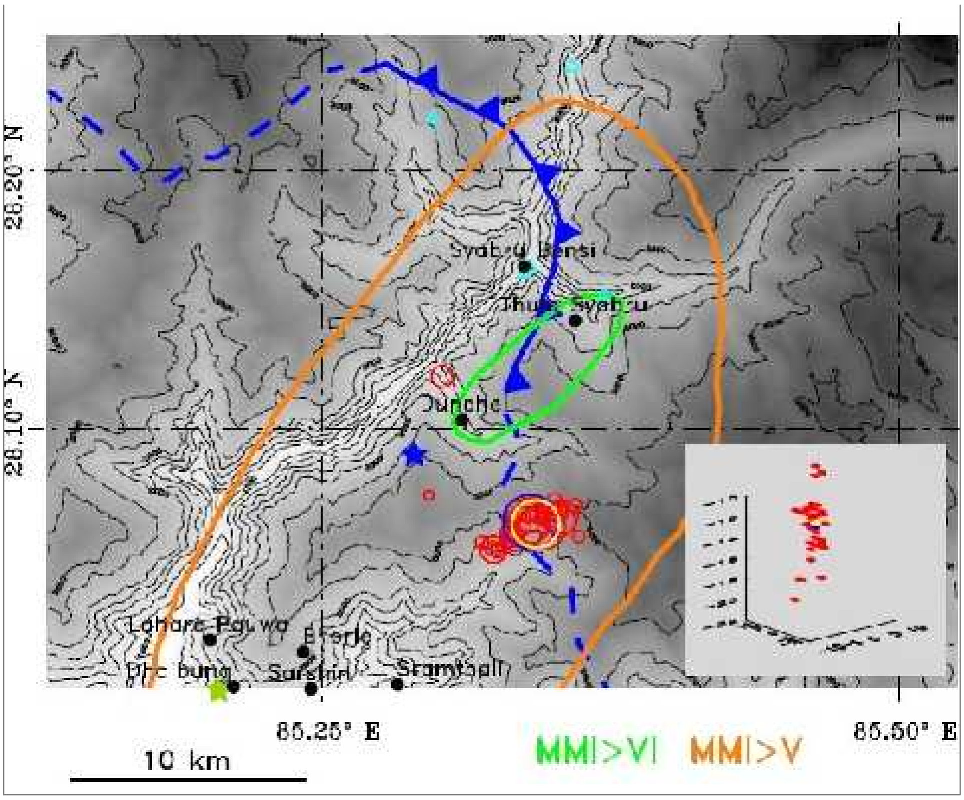

Fig 3.10. Intensity map of Sarsin earthquake (Kumar.B. 1985)

Chamoli Earthquake 1999 : On March 29, 1999 Chamoli earthquake of magnitude Mw 6 2 - 6 4 and hypocenter located approximately 12 km of depth, is comparable to the earthquake of Bajhang is relatively closed. It caused however more victims, with more than 103 identified dead and more than 2,000 houses destroyed. In the Epicentral area of Chamoli, a large number of victims were caused by the collapse of traditional houses which were constructed by the slabs of concrete, a dangerous practice which is also common in the Nepal and Pakistan. The first victims of this type of rack earthquake response were also found from the Bajhang earthquake in 1980. Note that consecutive to such constructions dramas have not led to best current construction practices, as can be seen across the Nepal.

Fig 3.11. Photographs taken after the March 29, 1999 Chamoli earthquake (Source: Sapkota 2011).

CHAPTER FOUR
PREVIOUS WORK AND TECHNIQUES IN PALEOSEISMOLOGY

Paleoseismological study has grown faster in countries where rates of tectonic processes are high and where geological investigations are supported by a sophisticated scientific infrastructure. At first the study was focused in the United State, Japan, Russia, and New Zealand. The dramatic topography of some regions is created little by little during repeated earthquakes. The concept of recent fault has been created from late 1800s, for example Mc Kay (1886) recognized that scarps produced by earthquakes in New Zealand in 1848 and 1855 were identical to large fault-zone features with similar origins, and ruptures produced by the 1891 Nobi earthquake in central Japan led Koto (1893) to similar conclusions. Likely, paleoseismological researches have been conducting in different parts of Nepal.

4.1 Previous work

Systematic mapping of active faults in the Himalayan region was started in the seventies by Nakata (Nakata, 1972; Nakata, 1989; Nakata et al., 1998; Upreti et.al., 2000). He has used aerial photographs and topographic maps, in conjunction with field observations, to produce maps of escarpments inferred to result from tectonic faulting. These maps have been used as a reference for the present studies. Himalayan paleoseismological works conducted by different authors in the field of paleoseismology in the Himalaya region are shown in Fig 4.1.

Although the paleoseismological study is not conducted in the study area previously, the research of that is continuing further in different places along Main Frontal Thrust. D.Yule et al. worked in central eastern Nepal at Mahra Khola section and in western Nepal at near Mohana Khola section. They resulted that the paleoseismic evidence of east central Nepal shows large surface rupture of the Main Frontal Thrust at ~A.D. 1100 and surface rupture in western Nepal documented past ~ A.D. 1450. At both sites, surface rupturing events on the MFT appear to be associated with scarp height of 7-8m and large displacement of 15-20m. Surface slip of this magnitude may occur during earthquakes that are larger than known, post 18th century that is eastern Nepal associated with smaller ($<M_w$ 8) earthquake. Other paleoseismological works done by the different researchers are summarized in table 4.1.

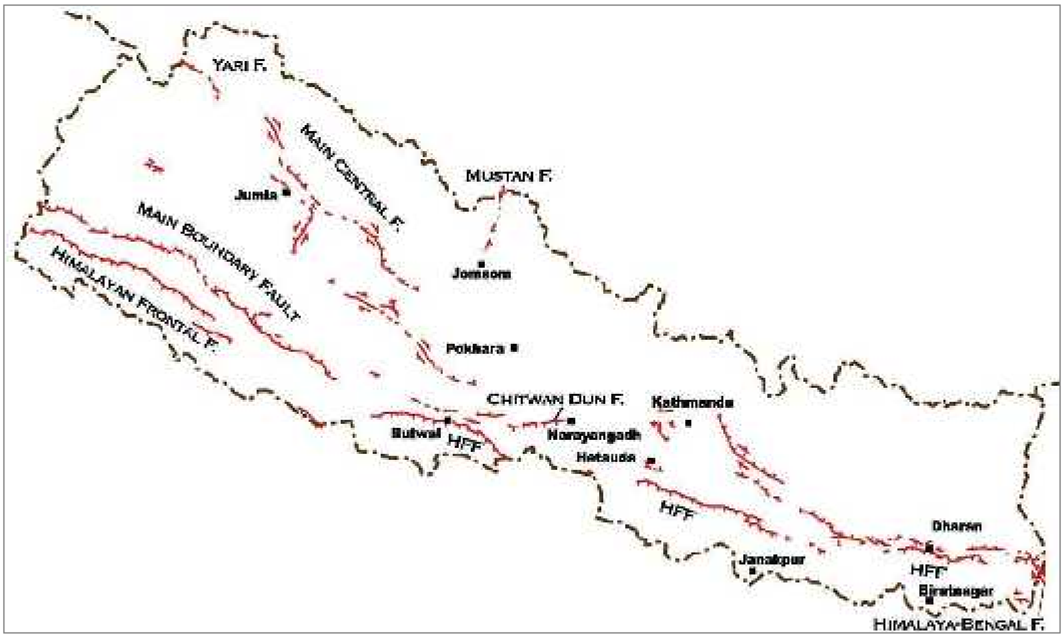

Fig 4.1. Atlas of Active Faults in Nepal Himalayas Described and Compiled by T. Nakata.'s group.

Although there were many research in the field of paleoseismology in different locations, no evidence of 1934 Bihar-Nepal earthquake found. To conform this evidence further research should be continued. The places such as Sir khola and Ratu khola of Mohattari district, Charnath khola of Dhanusha district and Mirchaeya are selected for the study.

Field techniques in Paleoseismology

The methods fall into two broad categories, depending on whether paleoseismic features are landforms and have stratigraphic expression. Basic geomorphic techniques include locating paleoseismic features with remotely sensed imagery and making detailed topographic maps of paleoseismic landform. Stratigraphic technique emphasizes the mapping of paleoseismic deformation in surface exposure and the finding of buried faults with geophysical and trenching method.

Mapping Paleoseismic Landforms

The first, and often most fruitful, approach to paleoseismic reconstruction should be careful mapping of Quaternary landforms and deposit in the zone of deformation. Sacrificial geological mapping helps to identify deformed geomorphic surface and reveals trends in deformation styles and rate across landforms of different ages. Geomorphic mapping helps to indicate whether the fault traces are the result of single verses multiple events, the appropriate timing of paleoearthquakes, and whether paleoearthquakes are within the range of certain dating techniques.

Table 4.1. List of paleoseismological works along the Nepal Himalaya

Location of Locality	**Location**	**Size of Trench**	**Number of Events**	**Charcoal samples**	**Age AD**	**Coseismic Slip and uplift**
Mohana FW Nepal	80.528^0E 28.916^0N	25m×4m 60m×7m	Single	17	1450 – 1630	18m & 7.5m
Rajpur Khola Butwal Nepal	83.397^0E 27.690^0N	Natural Exposure	Single	2	NA	20m & 10m
Bandel Pokhari Butwal	83.463^0E 27.695^0N	15m×3.5m	Single	11	790BC-1630AD	9m of net slip
Mahra Central Nepal	85.819^0E 27.052^0N	60m×5m 2 trench	Single	20	1100 AD	17 m
Bardibas Central Nepal	85..889^{0}E 26.997^0N	40m×5m	None	20	-------	---------
HokseKhola Eastern Nepal	88.160^0E 268.916^0N	12m×4.5m	Single	2	1000AD-1200AD	----
Tokla tea Gardeen	88.066^0E 26.650^0N	5m×2.8	Single	2	1200 AD	4m

Locating Surface Deformation

The first steps in collecting primary paleoseismic evidence are to identify and map a zone or are of crustal deformation. Active fault traces are the easiest features to map, and they are expressed at the surface as linear belts of landforms across which vertical relief is evident (dip-slip fault) or where terrain elements are shifted laterally (strike-slip fault).

Detailed Topographic Mapping

Many landforms produced by paleoseismic deformation are too small (<1 to 5 m high) to be well characterized on existing topographic maps (typical contour interval of 3 to 15 m). Documenting the critical geomorphic details of faulting, from which net displacement or recurrent movement might be deduced, can be done in two ways. Detailed maps are very useful for measuring horizontal offset along strike-slip or oblique-slip faults (e.g. McGill and Sieh, 1991).

Topographic Profiling

Topographic profiling is often the easiest method of documenting the vertical component of paleoseismic faulting, folding, or tilt. Profiles measure at right angle to the fault scarps provides a measurement of vertical surface offset, which is related to fault displacement by geometric relationship.

Fault scarp profiling

Fault scarp profiles are the main sources of data on vertical displacement and age of faulting in reconnaissance paleoseismic investigation of dip-slip fault (Wallace, 1977; Bucknam and Anderson, 1979; Haller, 1988). Most fault scarp profiles are oriented perpendicular to the scarp so that the surface offset measured from the profile can be graphically related to the vertical component of fault displacement but the preferred method of fault scarp profiling is depend on the degree of surface vegetation cover.

Terrace riser profiling

Terrace risers are created by fluvial or coastal erosion and define linear geomorphic datums that can record paleosseismic deformation. The most commonly used terrace riser in paleoseismic is the wave cut cliff at the landward edge of a marine terrace.

Mapping Paleoseismic Stratigraphy

The stratigraphic expression of paleoearthquakes can range from displaced strata and angular unconformities (primary evidence) to clastic dikes and soft-sediment deformation (secondary evidence). There is concentration on early paleoseismic investigation because natural vertical exposures in fault zone are rare. In the absence of such exposure, however, early paleoseismic investigators were faced with the choice of

1. Relying only on geomorphic data for the paleoseismic analysis,
2. Drilling borehole or collecting geophysical data, and

3. Excavating artificial trench exposures across deformation zone

Trenching

Excavation of trenches in deformation zones has become a major element of paleoseismic study. Trenching technique has expanded to address problem of paleoearthquake faulting, folding, ground failure, and faulting induced sedimentation. Paleoseismic evidences may destroy by trenching so there should be careful for sketching the trenching wall.

Location, orientation, and pattern of trenches

The best location, orientation, and pattern for trenches are highly site dependent, so only the most guidelines are described here. Trenches across faults are typically sited to optimize data on either paleoearthqake recurrence (Sieh, 1981).

Trench location is dictated by the number of paleoearthquakes the investigator wish to observe. Trenches across faults on very young quaternary surfaces may only one or two paleoearthquake displacements, so trench structure and stratigraphy may be relatively simple. Trenches on progressively older surfaces are likely to expose the cumulative deformation from many paleoearthquakes, where the effects of earlier displacements are obscured by those of later displacements. Trench location is then partly dictated by the goal of investigation as

1. To characterize only the most recent paleoearthquakes (by trenching young deposit)
2. To compiles long history of deformation (by trenching old deposit)
3. Road access, land ownership, previous ground surface disturbance
4. Area of highly develop scarps

Trench orientation is dictated by the inferred sense of fault displacement, with trenches being aligned roughly parallel to the sense of movement. Fault perpendicular trenches are often used to locate and define the width of strike-slip fault zone

Excavation logistics

The choice of excavating equipment, trench cross-sectional shape, and shoring strategy are all interrelated and depend on what kind of material is being trenches, the topography of the trench site, how deep the trench is, how stable trench walls are, and whether the wall need to be photographed. Trenches in unconsolidated deposits are usually excavated by hand if fault scarps are very small (less than 2 m high). Large trenches require backhoes or bulldozers. Bulldozer trenches are much wider than backhoes trenches. Benching method is suitable for excavation the trench because it prevent from the collapse of trench.

Preparing for logging

Before the trench can be logged the wall must be cleaned and referenced coordinate system must be established. Trenches walls are scraped off with various tools to remove soil smeared on wall during excavation: typically 2 to 5 cm will be removed. In very cohesive soil, the wide blade of a mattock or ice axe is necessary to chip loose these surface layers, whereas in less cohesive silt and fine sands, trowels and hoes are effective in scarping thin layers from the trench walls. In granular, coarse cohesionless deposits such as fluvial or deltaic gravels walls are best cleaned with whisk brooms, paintbrushes, or by blast of compress air.

After the walls between the shores are cleaned, a reference grid for mapping must be constructed if the trench is to be logged manually. Typically the grid is composed of horizontal line of low-stretch nylon string, spaced 1 m apart, attached to the trench wall by large (5 mm X 5 cm) nails. Flagging or tape attached to these lines at 1 m intervals provides the horizontal control or, alternatively, vertical string lines can be placed on 1 m centers. It is often difficult to attach nail to trench walls composed of noncohesive gravelly or friable material. In such case the level line may be attached directly to a shore or fence post driven into the trench floor. However, it is best to keep the grid lines entirely separate from the shoring system, because a shift in shoring units will distort the grid line.

After the first horizontal line is set, others are set parallel to it at 1 m vertical intervals. The horizontality of each successive line can be checked by the line (bubble) level, and by measuring the vertical distance between successive horizontal string lines. The error should not be exceeding more than 2%.

There are different types of unit can be seen after cleaning the wall. It is not possible to map all the features seen in the trench but there should be focus on mappable and important unit. The mapable unit define in trench exposure are based on experience of the trench logger. As a general rule, units are distinguished as discrete deposits that are composed of consistent lithology and weathering characteristic (Miall, 1990). A typical lithologic description of a unit will include the following:

1. Color
2. Dominant grain size class (gravel, sand, silt, clay), with appropriate modifiers
3. Volume percentage of clasts > 2 mm in diameter (gravel)
4. Clast diameter (average and maximum)
5. Clast shape
6. Clast sorting
7. Matrix grain size
8. Matrix compaction
9. Bedding thickness
10. Sedimentary structures
11. Weathering or soil formation
12. Fossils
13. Nature of bounding contact
14. Deformation structure
15. Genetic interpretation

Soil is also the important part of trench because they indicate location of past ground surface in the stratigraphic sequence, and their degree of development may indicate the length of time that surface was stabilized.

Identifying and marking contacts

Lithologic units are differentiated as discrete sedimentary deposits characterized by a consistent texture, sorting, bedding, fabric, or color. Soil units, in contrast, are weathering zones or profiles which may be developed on a single unit, or may be developed across multiple lithologic units. Relief can sometimes be created by repeat brushing of the face with brooms or paintbrushes. Some contacts appear sharper when moist, so walls can be sprayed or misted with a portable water sprayer immediately before logging.

Contacts identified visually are usually accentuated by scribing a line on the trench wall with a knife or edge of a trowel (in cohesive sediments), or placing nails with attached colored flagging along the contact (in cohesionless sediments). In the corresponding trench logging, tectonic features (faults, tension crack, and liquefaction) rendered with the thickest lines, lithologic contacts with thinner lines, and soil horizon boundaries or facies boundaries within major depositional units with very thin or dashed line.

Fault gauge, created by mechanical crusting of rock and smearing along the fault plane, is rare in unconsolidated deposit because confining pressure near the surface is too low. However, thin (2 to 5 cm), boulder bodies of translocated sediment are often found along fault planes. Fault zones in clast rich deposits are usually identified by a consistent clast fabric different from the observed in adjacent strata. Shear on the fault may rotate clast along axes parallel to the fault plane, resulting in what the term shear fabric.

Geophysical technique in paleoseismology

Geophysical methods can be useful in paleoseismology in three ways

1. For detecting burried faults that have no surface expression
2. For characterizing the subsurface geology in mapped fault zones
3. For characterizing subsurface deformation feature.

Paleoseismology requires geophysical system with high spatial resolution and ability of distinguishing between unconsolidated deposits with very similar material properties. Depth penetration of more than 10 m is usually not requiring because the data of interest lie only a few meters below the surface. Geophysical methods used in paleoseismology are:

1. Seismic methods (seismic refraction and seismic reflection method)
2. Ground -Penetrating Radar(GPR)
3. Electrical resistivity tomography (ERT)

All these methods are used in the present study due to time constrain to process all these data , only shallow seismic refraction is included in this thesis.

4.4. Dating of Paleo Earthquake

Dating methods applicable to the late quaternary (the past 130000 years) are a critical aspect of neotectonics studies. Without age we cannot determine rate of tectonic processes over time span longer than those of historic records. The central role of dating in paleoseismology, especially as applied in earthquake hazard assessment, is now well recognized (C.R. Allen, 1986; Crone and Omdahl, 1987). Such recognition has helped simulate the development of methods with the greatest potential for dating recent earth deformation such as optical dating (e.g., Forman, 1989; Fain et al., 1992), high-precision conventional and accelerator mass spectrometer (AMS) radiocarbon dating (Linick et al., 1989; Atwater et al., 1991; Sieh et al., 1989; Nelson and Atwater, 1993), surface exposure dating (Dorn and Philips, 1991) and tree-ring dating (Jacoby, 1989).

Following Colman et al. (1987), Quaternary dating methods can be grouped into numerical age, calibrated age, and correlated age methods based on the type of the result they produce. *Numerical age* methods yield ages with stated errors derived from analytical standards. *Calibrated ages* are based on systematic changes that depend on environmental variables such as temperature and must be calibrated using numerical ages [this use of the term calibrated differs from that used in radiocarbon dating (Stuiver and Kra, 1986), which is a numerical age method]. *Relative age* methods provide only a relative ranking of ages in an ordinal scale. *Correlated age* methods are not really dating methods; they rely on a comparison to a standardized series of measurements (Rutter et al., 1989). Although they do not yield ages with easily quantified errors, relative age and correlated age methods are of fundamental importance in providing crosschecks on numerical ages and in allowing numerical ages to be applied to other sites that lack numerical age control. Detailed description of each methods are given below

Radio Carbon Dating

Radiocarbon dating (sometimes simply known as carbon dating) is a radiometric dating method that uses the naturally occurring radioisotope carbon-14 (^{14}C) to estimate the age of carbon-bearing materials up to about 58,000 to 62,000 years. Raw, i.e. uncalibrated, radiocarbon ages are usually reported in radiocarbon years "Before Present" (BP), "Present" being defined as 1950. Such raw ages can be calibrated to give calendar dates. One of the most frequent uses of radiocarbon dating is to estimate the age of organic remains from archaeological sites. When plants fix atmospheric carbon dioxide (CO_2) into organic material during photosynthesis they incorporate a quantity of ^{14}C that approximately matches the level of this isotope in the atmosphere (a small difference occurs because of isotope fractionation, but this is corrected after laboratory analysis. After plants die or they are consumed by other organisms (for example, by humans or other animals) the ^{14}C fraction of this organic material declines at a fixed exponential rate due to the radioactive decay of ^{14}C. Comparing the remaining ^{14}C fraction of a sample to that expected from atmospheric ^{14}C allows the age of the sample to be estimated.

Optically Stimulated Luminescence (OSL) dating

Optically Stimulated Luminescence (OSL) is a method for measuring doses from ionizing radiation. This method makes use of electrons trapped between the valence and conduction bands in the crystalline structure of certain types of matter (such as quartz, feldspar, and aluminum oxide). The trapping sites are imperfections of the lattice - impurities or defects. The ionizing radiation produces electron-hole pairs - electrons are in the conduction band and holes in the valence band. The electrons which have been excited to the conduction band may become entrapped in the electron or hole traps. Under stimulation of light the electrons may free themselves from the trap and get into the conduction band. From the conduction band they may recombine with holes trapped in hole traps. If the centre with the hole is a luminescence centre (radiative recombination centre) emission of light will occur. The photons are detected using a photomultiplier tube. The signal from the tube is then used to calculate the dose that the material had absorbed.

Generally OSL is used for two different purposes; dating of sediments and dating of fired pottery, bricks etc. Although in the latter case thermoluminescence dating is more often used. In order to carry out OSL dating, mineral grains have to be extracted from the sample. Most commonly these are so-called coarse grains - 100–200 μm, or fine grains - 4–11 μm.

The difference between radiocarbon dating and OSL is that the former is used to date organic materials, while the later is used to date minerals. Events that can be dated using OSL are, for example, the mineral's last exposure to sunlight.

4.4.5 Mass spectrometric measurement of ^{10}Be, ^{26}Al, ^{3}He

Cosmogenic isotopes and isotopes produced in minerals by cosmic ray can potentially be used to date geomorphic surfaces. Many fault studies depend on detailed stratigraphy of regolith units such as soils, fluvial sediments, organic lacustrine deposit, etc to determine the age of last movement or the frequency of recurrent movement. Dating by ^{14}c is applicable to dating in causes where organic material is preserved but in many cause organic material is absent or is too old to be usefully dated. The developments of accelerometer mass spectrometer measurements of many low abundance isotopes may provide methods of dating materials that have not been directly datable.

Accelerator mass spectrometry facilitates the determination of extremely small ratios the atmosphere of several geologically useful isotopes produced by cosmic rays in or at the earth's surface. Radioactive isotopes such as ^{10}Be (1.5-ma half-life) ^{26} Al(0.7 on a half life) and ^{36}Cl 10.3 ma half life and stable ^{3}He occur in very low quantities relative to their more abundant stable isotopes . These isotopes occur in measurable qualities in a variety of surfacing materials such as soils saprolite quartz grains, and in the case of ^{10}Be and ^{36}Cl, in solutions. The usefulness of these techniques to paleoseismologists depends on a sufficient understanding to the field situation. As With ^{14}C dating of organic material sampling and sample history can only be critically evaluated in the context to the field problem. Perhaps the most relevant application to paleoseismic studies would be to investigate the inventories of ^{10}Be on fluvial or marine terraces offset by faulting. ^{10}Be inventories can be used continuously to estimate soil ages and erosion histories (Pavich and others, 1986). In a small area where the delivery flux of ^{10}Be can be assumed to be constant over the area, terrace soil inventories could be extremely useful in determining relative ages of terraces across a fault or along a fault thorough bounded river. Rock surfaces exposed by faulting might be dated by measurement of in situ isotope production.

CHAPTER FIVE
GEOMORPHOLOGY OF THE AREA

Stratigraphic and geomorphic features formed by compressive faulting are more diverse and occasionally more subtle than those formed by extensional or strike-slip faulting. Most field evidence for compressive paleo-earthquales reflects sudden change in local rates of deposition or erosion that indirectly result from earthquake-induced surface deformation. River pattern, tone, change in elevation, scarp pattern, level of terraces etc are the key geomorphic indicator for the recognition of active faults.

5 .1 Geomorphic evidence of thrust paleo-earthquakes

The most direct geomorphic evidence of a paleoearthquake in continental compression environment is a thrust fault scarp. A fault scarp is the topographic expression of faulting attributed to the displacement of the land surface by movement along fault. They are exhibited either by differential movement and subsequent erosion along an old inactive geologic fault or by a movement on recent active fault. The height of the scarp formation is equal to the vertical displacement along the fault. Active scarp are usually formed by tectonic displacement. If thrust fault scarps are created, they are typically more sinuous and irregular than for the other type, being composed of other short, disconnected section (Gordon and Lewis, 1980; Crone et al., 1992) or producing continuous but serrated rupture traces with zigzags on the scale of meter.

The control on scarp morphology includes amount of slip, sense of slip, properties of surfacial material and topography (Weber and Cotton, 1980, p.20; Philip et al., 1992 P144). According to such above factor different types of fault scarp are developed, such as steeply dipping ($>45^0$), reverse faults in bedrock produce simple thrusting scarps, steep fault in brittle unconsolidated materials result in hinging wall collapse scarps which is result when the overhanging scarp collapses (Fig 5.1) usually during seismic shaking. At lower dip angle thrust fault produces pressure ridge. In case of unconsolidated deposits if the surface displacement on a single thrust fault plane initially results in an overhanging scarp, such overhanging collapse during or soon after creation. The collapse tip of the hinging wall thus creates a free face and the steep debris slopes that buried the fault tip. If the free face exceed the angle of repose in unconsolidated materials, the scarp will progress through successive gravity-, debris-, wash dominated degradation stage.

Due to irregular nature of MFT we have difficulties to map free face and pressure ridge along the strike of the MFT. Clear scarps of active faults are mapped during this study.

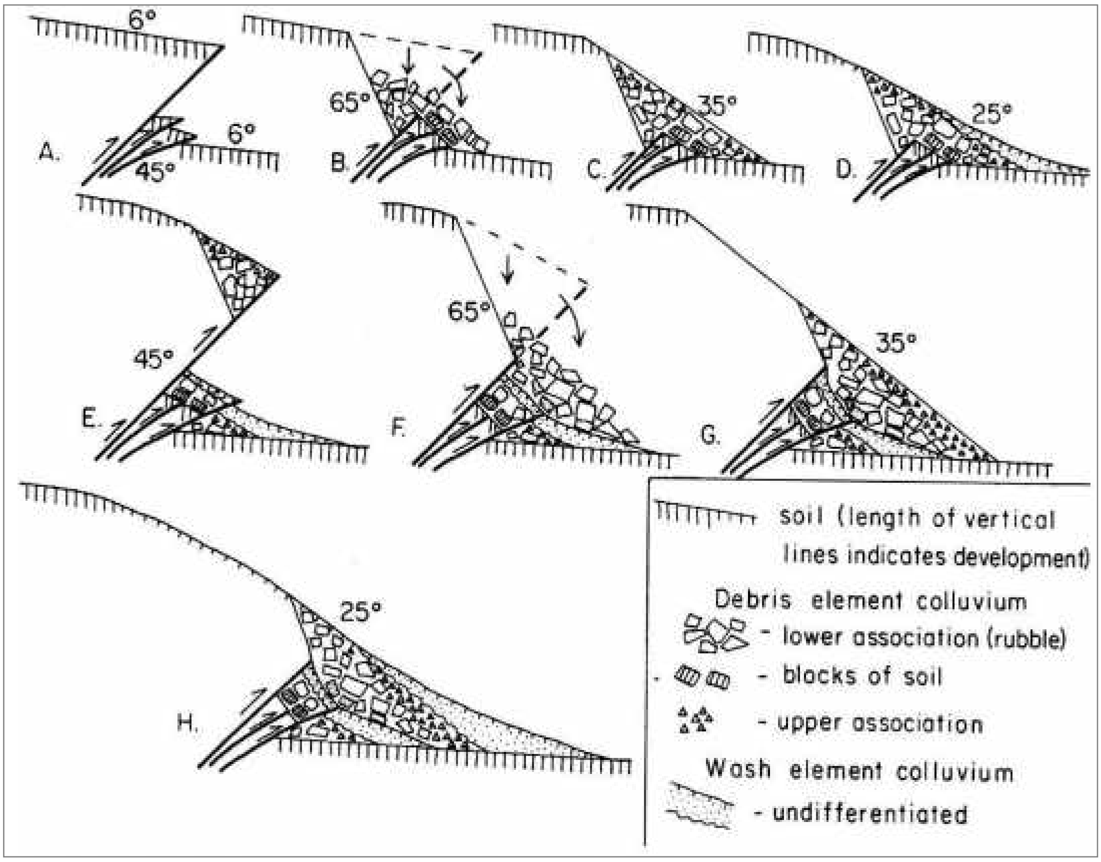

Fig 5.1. (After McCalpin, 1996): Schematic diagram showing deposition of scarp colluviums from two reverse fault events. Vertical offset in each event is envisioned to range between 0.5 and 3m. A) Initial faulting (45° dip) cuts sloping (60 slope) geomorphic surface with well developed soil. Faulting creates an overhanging scarp: note two subsidiary thrusts at the scarp base. B) Overhanging part of scarp collapses and forms rubble apron. The lower association of debris elements is composed of soil blocks and hanging wall material. C) Free face retreats, and upper association of debris elements plus finer colluvium is deposited. Colluvium apron stabilises at 350 angle of repose once the free face completely degrades D) Wash colluvium is deposited as scarp slope decreases (shown here at a maximum angle of 25°); a weak soil forms. E) Second faulting event produces new overhanging scarps roughly doubling total scarp height. Note that lower subsidiary fault is reactivated, while upper one is not. F) Overhanging part of the new scarp collapses. Proximal, deepest part of the first colluvium wedge is translocated mostly on footwall at base material recycled from proximal colluvial wedges of first event yielding more complex stratigraphy than for normal fault scarps. G) Free face retreats and upper association of debris of rejuvenated scarp. Debris elements colluvium deposited after second event thus includes element colluvium is deposited. H) Wash colluvium is finally deposited. Two faulting events are deduced from (1) existence of two colluvium wedges. (2) The fact that

lower wedge is truncated by fault plane and upper wedge is bound by steep depositional contact with edge of receding hanging wall. (3) That subsidiary faults terminate upwards at different stratigraphic levels, complicates the picture, and might be taken as suggestive of a 3rd event if dating is not adequate or stratigraphic record discontinuous.

Fluvial terraces

A terrace is a step like landform. A terrace consists of a flat or gently sloping geomorphic surface that is typically bounded one side by steeper ascending slopes i.e. riser or scarp on one side and a steeper descending slope (riser or scarp) on its other side. The flat or gently sloping surface of a terrace is typically called trend. Among different types of terrace fluvial terraces are remnants of the former floodplains of a stream of river. They are formed by the downcutting of a river or stream channel into and the abandonment and lateral erosion of its former floodplain as shown in Fig 5.2. The downcutting, abandonment, and lateral erosion of a former floodplain can be the result of either changes in sea level, local or regional tectonic uplift; changes in local or regional climate; changes the amount of sediment being carried by the river or stream; change in discharge of the river; or a complex mixture of these and other factors. The most common sources of the variations in rivers and streams that create fluvial terraces are vegetative, geomorphic, and hydrologic responses to climate. More recently, the direct modification of rivers and streams and their watersheds by cultural processes have result in the development of terraces along many rivers and streams. If terraces are the result of processes independent of movement on the fault, offset produces vertical displacement of terrace profile. Paleoseismic events or groups of events are thus recorded by sequentially larger vertical separations on higher regional terraces. Paleoseismic records are also formed when faulting crosses actively aggrading floodplains.

Methods of terrace mapping

Terraces are formed by the downcutting of a river or stream channel into and the abandonment and lateral erosion of its former floodplain. This is happen when tectonic uplift is more than the erosion then river left its previous channel. Terraces are the indicators for tectonoc history and climate change of the region. Details of process of terrace formation are described in Fig 5.2. Before making any field measurement terrace can be mapped by using different sources of imagery for example Aerial photograph of different time series, google imagery, detailed high resolution topographic mapping, DEM etc. After analysing the imagery of different platform a preliminerary geomorphic map is prepared and is finalised after intensive field verification. For the present study first aerial photograph of 1964 and 1995 were studied to make the change detection in the river morphology over 50 year time span. Charnath Khola has changed its course at least two times before being in its present situation. This can be clearly mapped in the aerial photograph as well as the google imagery.

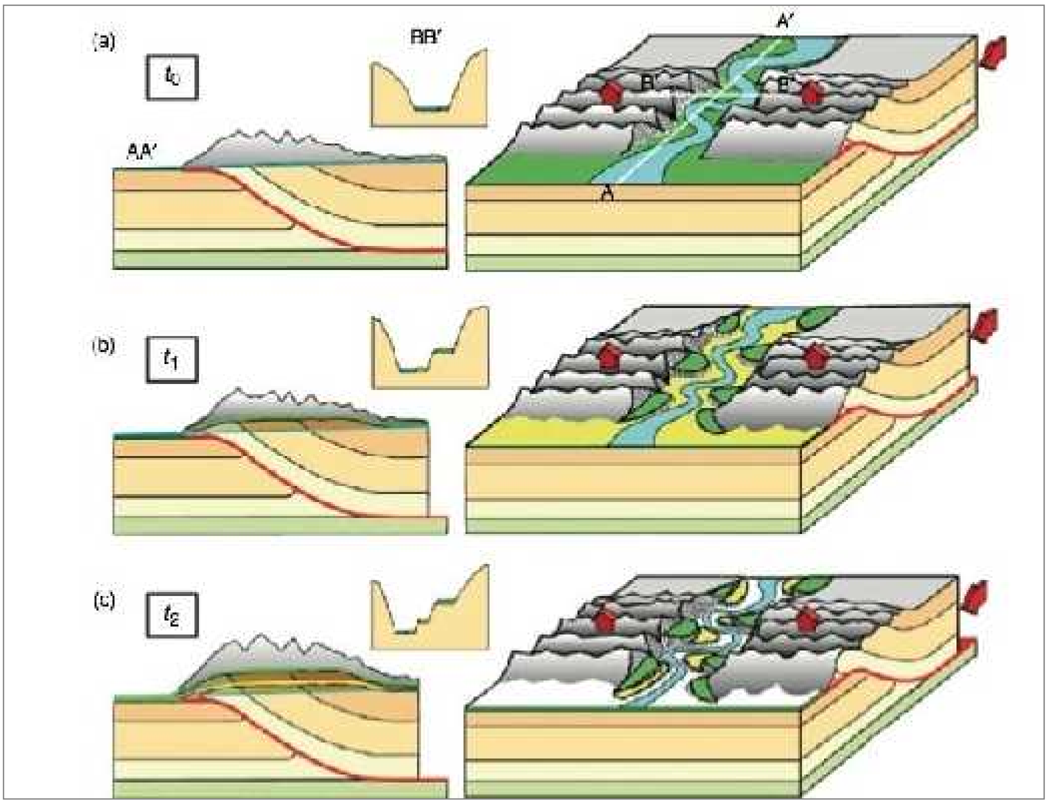

Fig 5.2. Diagram showing the formation, abandonment, and warping of fluvial terraces. (a) Initially the river has enough stream power to gain the width of channel. At time t_0 due to some decrease in stream power (of possibly climate origin), the river start entrenching in to a narrow channel. (b) at time t_1, a paired terrace, corresponding to the river channel at time t_0 is preserved in the landscape (lebeled T_0). (c) at timt t_2, two paired terraces, corresponding to the river channel at time t_0 and t_1 are preserved. (Modified fron Lave J and Avouac JP 2000) Active folding of fluvial terraces across the Siwaliks Hills, Himalaya of central Nepal. Journal of Geophysical Reaearch 105:5735-5770.

Following steps were taken for the mapping of geomorphic features in the Google imagery.

1. The study area was selected in Google imagery on scale at which elements can be identified easily.

2. Elevations of different points were noted over the image (Fig 5.3).
3. Different elevations were ranges like <155m, 155-160m, 160-165m, 165-170m, and >170m, because the terraces are not fully flat, these are somehow tilted.
4. According to the above range terraces were named as T0, T1, T2, T3 and T4 (Fig 5.4).
5. Elevation changes are not only reference of terrace separation, field knowledge and ages are also key elements.
6. After all this information teraces are marked and transferred in the topographic map as well as helicopter captured field photograph as presented in Fig (5.4).

To know the information about terrace age and uplift rate, three samples from the bottom of three different pits were collected. Three charcoals from the bottom of three different pits yielded ages of 175 ± 30, 5 ± 30, and 565 ± 30 yrs BP. All these samples come from slightly lower areas of the terrace, that with the youngest age from inside a primary channel. One fourth sample, from one of three additional pits dug at the very top of the same terrace on the other side of Tintale creek (also Kariya Khola), found in sand layers with small pebbles below brick fragments in dark clays, yielded the oldest age, 1080 ± 30 yrs BP. In the absence of denser sampling and more redundant dates, one might assume that this latter age reflects that of the Tintale terrace. However, the terrace height above the river (≈ 16 m) and the existence of three significant terrace levels below it (locally T3, T2, T1) suggest it might correspond instead to the older T.’3 level. About 2.5 km south of Tintale, on the Saphilphubariya footwall terrace (Fig 5.8) a level that correlates well regionally with the Tintale terrace, one cm size detrital charcoal fragment found ≈ 1 m-deep beneath gravels in a reservoir excavation did yield a more ancient age (1260 ± 40 yrs BP). Hence, even though the location of this sample is fairly far from the MFT, and not on the uplifted hanging-wall, we conclude for now that the age of the Tintale terrace (labeled T4) might be between 1050 and 1300 yrs BP. We also retrieved four datable samples from sandy deposits in two different pits on the uplifted terrace T2 in the Kariya Khola valley (Tintale creek). The ages obtained (75 ± 30 yrs BP, 105 ± 30 yrs BP, 150 ± 30 yrs BP, and 197 ± 30 yrs BP;) indicate that this terrace level is quite young (at most 3 centuries), despite its present elevation (4 to 7 m) above the Saphi and Kariya Khola river-beds.

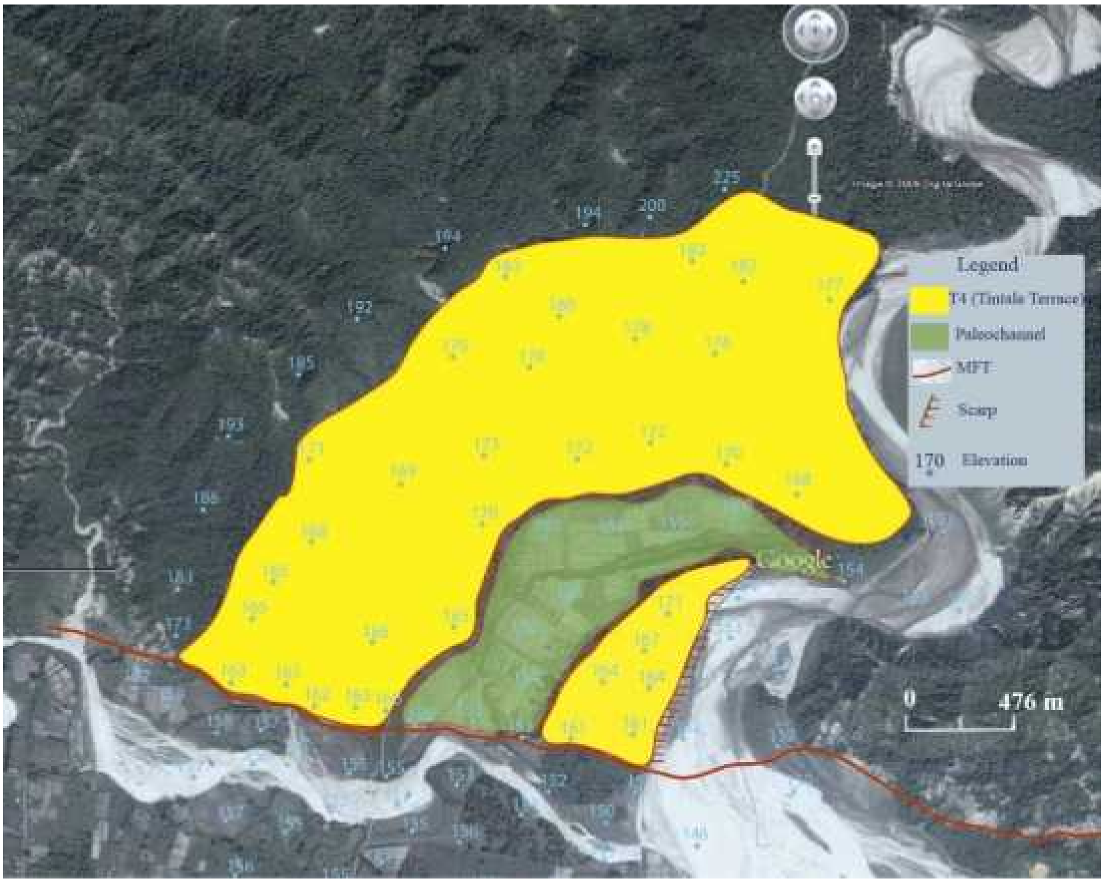

Fig 5.3. Elevation measurement in Charnath Khola area for recognization of different levels terrace and other geomorphic features.

Fig 5.4.Different level of terraces in Charnath Khola area on helicopter viewed photograph.

The observations between Tintale and Ratmate, around the Charnath Khola outlet onto the Terai plain, help constrain the local position and dip of the Main Frontal Thrust, yielding also new insights on the structure of the hanging wall, which displays a slice of overturned limb at its tip. This is indicative of fault-propagation, and thus perhaps of a particularly young localization of this strand of the thrust. Documentation the uplift heights of different young terrace surfaces from 20-25 meter, whose ages may not exceed a couple thousand of years. Specifically, taking lower and upper bounds on the age of the 14 -16 m high Tintale terrace to be 1050 and 1300 yrs BP, respectively, implies uplift rates ranging between 10.5 and 14.5 mm/yr, with perhaps a more likely value of 12.7 ± 1 mm/yr. Terrace uplift apparently took place in several increments, the last of which leading to the final abandonment of the deepest channel in the meander west of the Charnath valley, and to the uplift of the lowest terrace (T2) in the Kariya Khola gully. This event, which was probably associated with an uplift of 4 to 7 m, must have happened quite recently. According to the ages available for now, it could not have occurred earlier than about 3 centuries ago, but might well be a 20th century event. So for that only the possible candidate would be the 1934 Bihar Nepal earthquake.

Morphological evidence for active deformation

Topographical Evidence

The topography provides a first line of evidence of active uplift in Siwalik hill. There is flat topography in Indo-Gangatic plane and it rises abruptly. Topographical change can also be seen directly by gradual change in vegetation. There are also some small scale landslides which are still active; it is also the next indicator of active deformation. MFT is zone of active deformation so it is not easy to outline directly from topography but tentative idea can be given. Fig 5.5 shows MFT trace on the basis of topography.

Drainage pattern

Drainage pattern is also the good evidence of active uplift in the front of the Siwalik Hills. In the footwall of MFT braided channel deposits an undisturbed flat alluvium. The relatively uniform channel pattern suggests uniform aggradations. On the hanging wall of MFT, drainage insisted a rugged topography. This sharp contrast could reflect some differential uplift between the Siwalik Hills and Indo-Gangatic plain. Change in width of

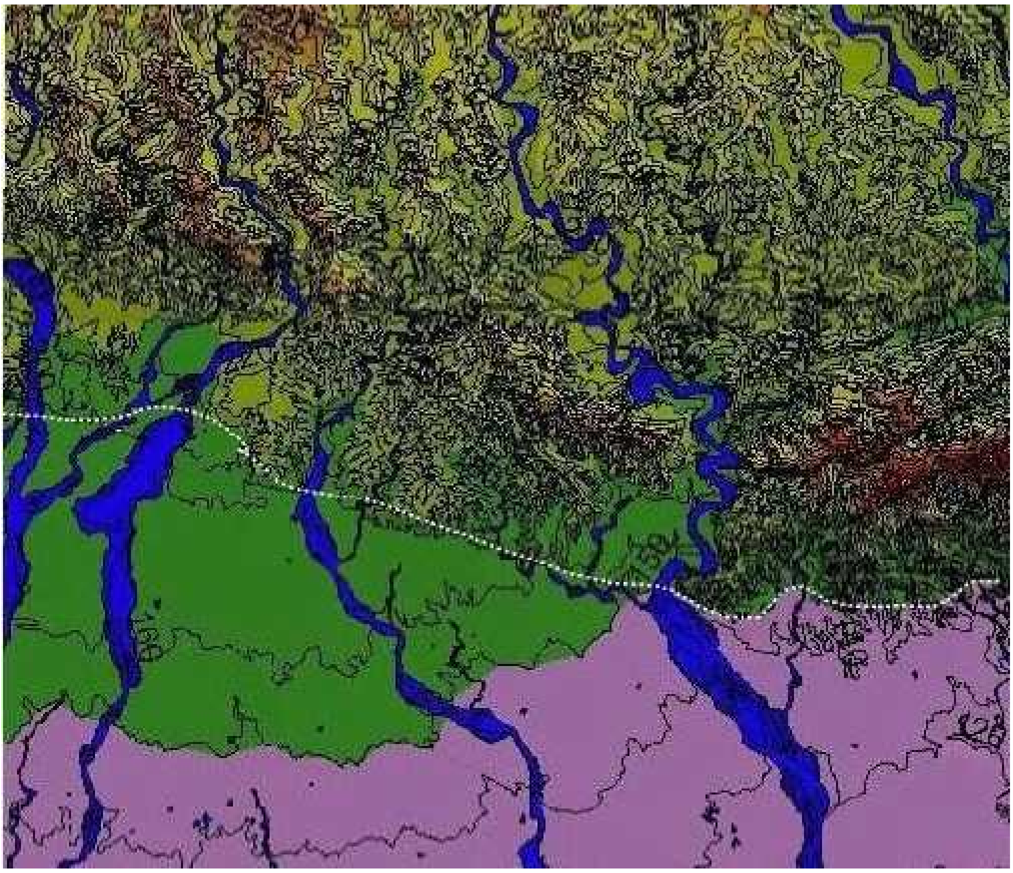

Fig 5.5 DEM derived from 1:25000 scale survey department digital topo map with contour interval of 10m white dash line is surface indication of the MFT in the study area.

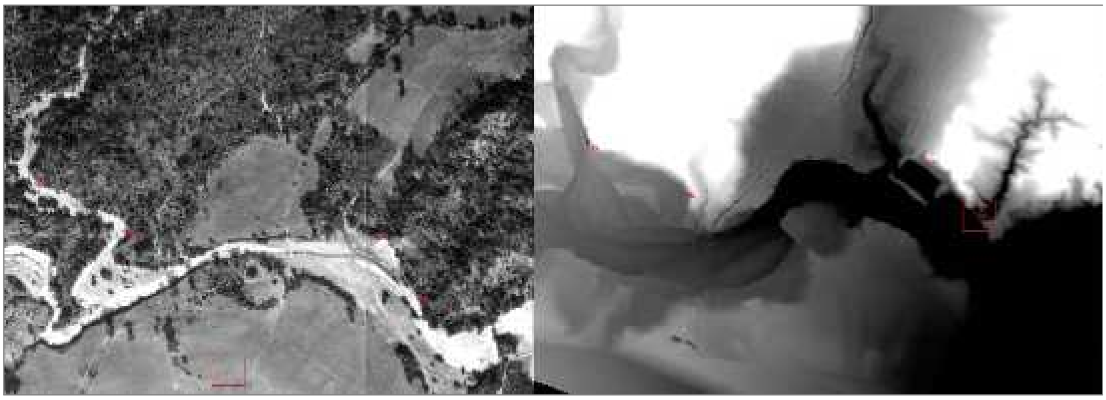

Fig 5.6 Example of the wrapping of the 1962 aerial photographs on total station high resolution DEM of Charnath Khola area. In red, ground control points.

the main river i.e. smaller width in north of MFT and becoming wide in south of MFT is also the good remark for active faulting. Moreover, avulsions of these rivers can occur on only decadal time scales. On the 1962 air photo Fig 5.6 for example, one meander of the Kariya Khola, now paved with paddy fields, is still seen to be actively cutting the base of the MFT escarpment. Finally, while making assessments of the geomorphology more delicate, lateral cutting by such.“ scarp base-guided.” river courses also causes riser collapse, whose stratigraphy may be hard to distinguish from that of wedge collapse following coseismic throw at the base of a fault escarpment (Fig 5.1).

Abandoned channel

The channel which changes the course and leaves as abandoned terrace is known as abandoned channel. There are different causes of forming the abandoned channel. They are formed either filling the large amount of sediment or by blocking the river when flooding or by tectonics. The cause can be identified by asking history to the local people or careful observation the surroundings. In Charnath Khola area the river change its way three times. One time it sifted and leave Tintale terrace, second time it changed the course and formed paleochannel (yellow color in Fig 5.7) and finally it is in the present condition. It is not possible by slow tectonic movement. So we can conclude that changing the course of river by the movement of any two great earthquakes.

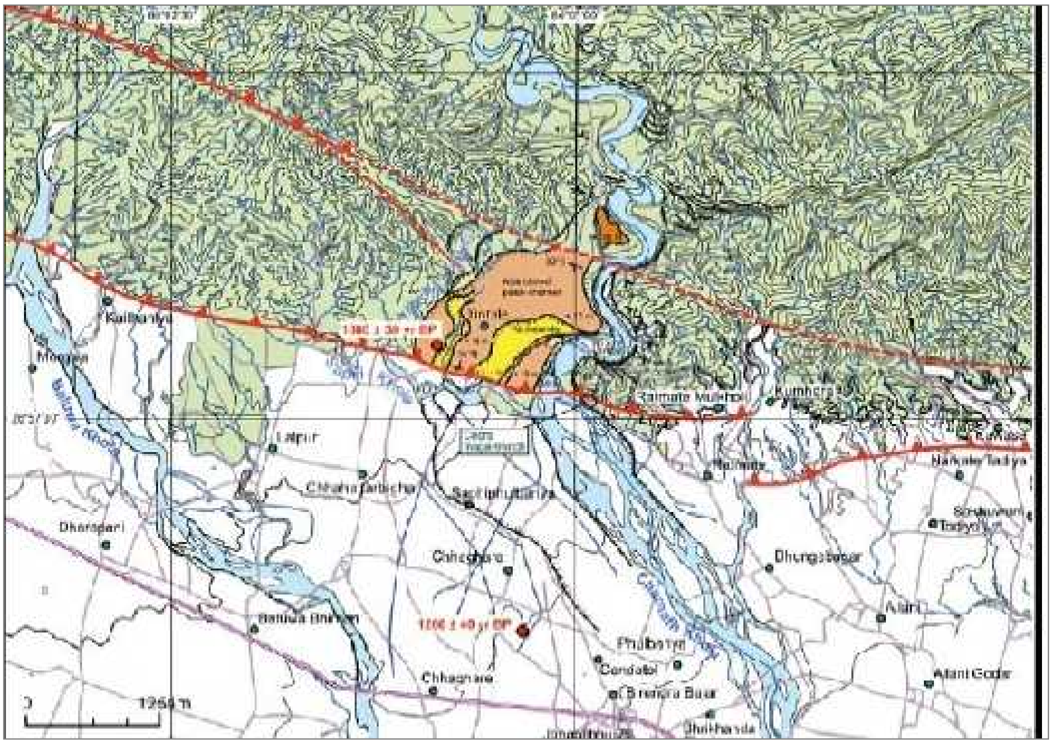

Fig 5.7. Topographical map of Tintale/Ratmatae area with MFT traces and abandoned Charnath Khola channel after Sapkota 2011.

Fig 5.8. Aerial photograph of Charnath Khola(1964).

CHAPTER SIX
PALEOSEISMIC METHODS AND ITS RESULT

The Tintale - Charnath Khola area was selected for the morphotectonc study as well as for paleoseismic study from the pre interpreted imagery of different platform. Comparatively fresh scarp and young terraces are the key features to select this srea for the present study. We have already described the quantitative and qualitative geomorphology of the area in chapter 5. Main objective of the paleoseismic trenching was to uncover the evidence of past earthquake in subsurface. We have integrated different methods to constrain the locus of the active fault at depth.

Trenching

Identify and date layers within a stratigraphic succession that contain information about the faulting history and document the amount of displacement from faulting activity are the main objectives of trenching. To fulfill these objectives Trenches should contain abundant datable material, provide structural and stratigraphic markers, preferentially thinly bedded deposits. Trench should oriented perpendicular to fault trace. Depth of the trench should be appropriate for scale of fault and length of the trench should be long enough to cover the deformation zone in portion of hanging wall and footwall. There are other some criteria for selecting trenching site

1. Area contains clear fault scarps but not so high
2. Accessible to bring excavation logistics
3. Far from river channel to avoid the contaminations from the recent flooding episodes.

After selecting the appropriate site as shown in (Fig 6.1a) we should outline the trench shape (Fig 6.1b). The excavator was used to excavate the trench as in Fig 6.1c.

A 70m long, 5m wide, 8-15m (Fig 6.2) deep megatrench was excavated east of the Charnath River, but only incompletely sampled and logged because of partial collapse of one wall. After collapsing the trench the whole trench was benched into three parts such as one bench in front and one-one benches in sidewall. The trench was made as benches because the walls are not more stable which are composed of loose materials when coming outside the trench. The trench was excavated across the fault by using excavator and loader as excavation logistics. Excavator only gives the shape, size and depth of the trench. But the all elements of trench weren't seen clearly. The workers were invited with comfortable wedges and ladder. They made the sidewall smooth and clear. Then these walls were swept and brushed then all elements of trench become identifiable and able to interpret correctly.

a

b

c

Fig 6.1. Photograph showing methods of trenching: a. selected site for trenching, b. outlining of trench shape and c. starting of trench by excavator.

A 70m long, 5m wide,8-15m (Fig 6.2) deep megatrench was excavated east of the Charnath Khola, but only incompletely sampled and logged because of partial collapse of one wall. After collapsing the trench the whole trench was benched into three parts such as one bench in front and one-one benches in sidewall. The trench was made as benches because the walls are not more stable which are composed of loose materials when coming outside the trench. The trench was excavated across the fault by using excavator and loader as excavation logistics. Excavator only gives the shape, size and depth of the trench. But the all elements of trench weren't seen clearly. The workers were invited with comfortable wedges and ladder. They made the sidewall smooth and clear. Then these walls were swept and brushed then all elements of trench become identifiable and able to interpret correctly.

After clearing the trench walls it is ready for logging. The trench was logged manually gridding (Fig 6.3). Typically the grid is composed of horizontal lines of low- stretch nylon string spaced 1m apart. The horizontally of each successive line can be checked by the line (bubble) level. Horizontal distances were marked between the parallel string lines of 1m vertical height by means of plumb line. These plumb line measurements were checked on each horizontal line by measuring between horizontal tape marks to ensure 2 percentage precision. There is no problem if the trench wall is vertical but if not vertical, the vertical string line may diverse significantly from the trench wall. For that case the trench wall must be trigonometrically corrected later to project onto a vertical plane.

After completing the gridding or logging, overlapping photos of each grid were taken. If the photos are not taken carefully there is problem in interpretation of units and actual image of trench cannot be seen. These photos were attached together of each side which give the real image of trench so that it is easy to identify the units. There are different types of units such as recent sandy layer, muddy layer, colluviums wedge, cobble/pebble unit, layer containing black layer (fault gauge), Siwalik bed (Fig 6.4.). By study of the position and character of different units, the different earthquake events can be interpreted. All units of the trench were identified and marked contact between different stratigraphic unit and relation with the colluvium wedges. Some displaced parts were seen in the continuation of the stratigraphy. Large thrust planes dipping N35^{0-}59^{0}N (Fig 6.5) were exposed on either wall, emplacing more steeply north dipping, overtruncated Siwalik beds over truncated strath cobble beds, deformed colluviums wedges and unconsolidated fluvial sand. We know the all units but we cannot interpret when and how does it happened without age. To determine the age of such event we had collected about 300 charcoal samples. And these samples were send to France to determine date. Some of them cannot give real information but mostly were able to provide real ages. Dating of these samples is in process in France.

Fig 6.2. Photograph of trench having 70m long, 5m wide, and 8-15m dimension.

Fig 6.3. Photograph of mannual logging.

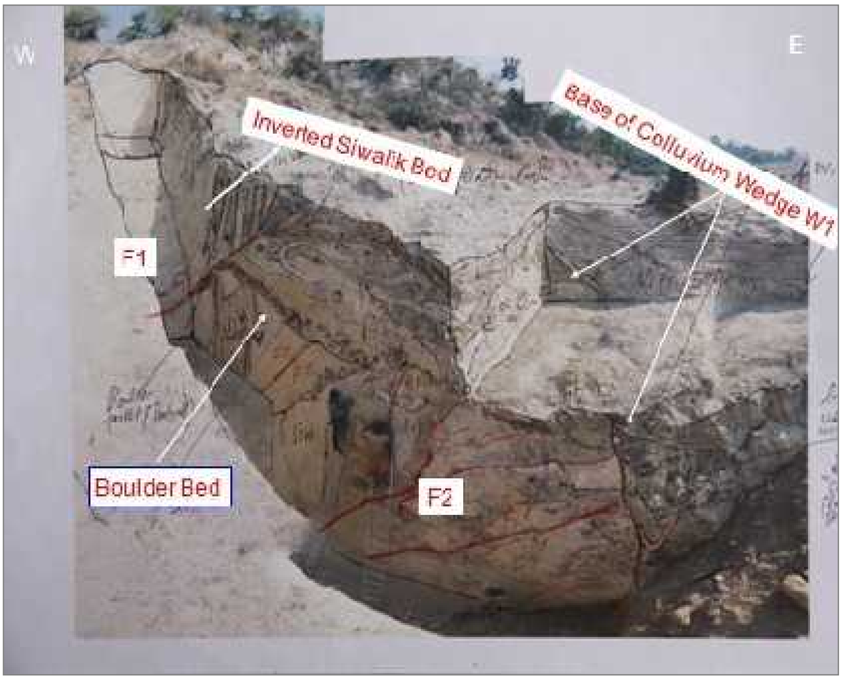

Fig 6.4. East wall of trench with different units.

Fig 6.5. In trench, south-looking view of ≈ 40°N-dipping thrusts beneath overturned Siwaliks after Sapkota 2011.

Method used for charcoal collection and its result

After the whole units of trench are identifiable, the charcoal collection is also started. Collection of charcoal before clearing the wall is not meaningful because dating of sample cannot correlate with units. Here dating of each unit is important. Firstly the clear sample bags of aluminum foil were made. If we see the charcoal we had taken it by clear instrument carefully without contaminations. The samples are kept into sample bag and named it according to the sample order. The same name was written in white paper to attach (with the help of nail) in place from where charcoal is taken. All charcoals were taken as same manner. The detail information of each charcoal was written in notebook. The information includes size, shape, color, location, whether it is fractured or not. Photos of all sample number attached in wall were taken (Fig 6.6) but we are waiting for dating results.

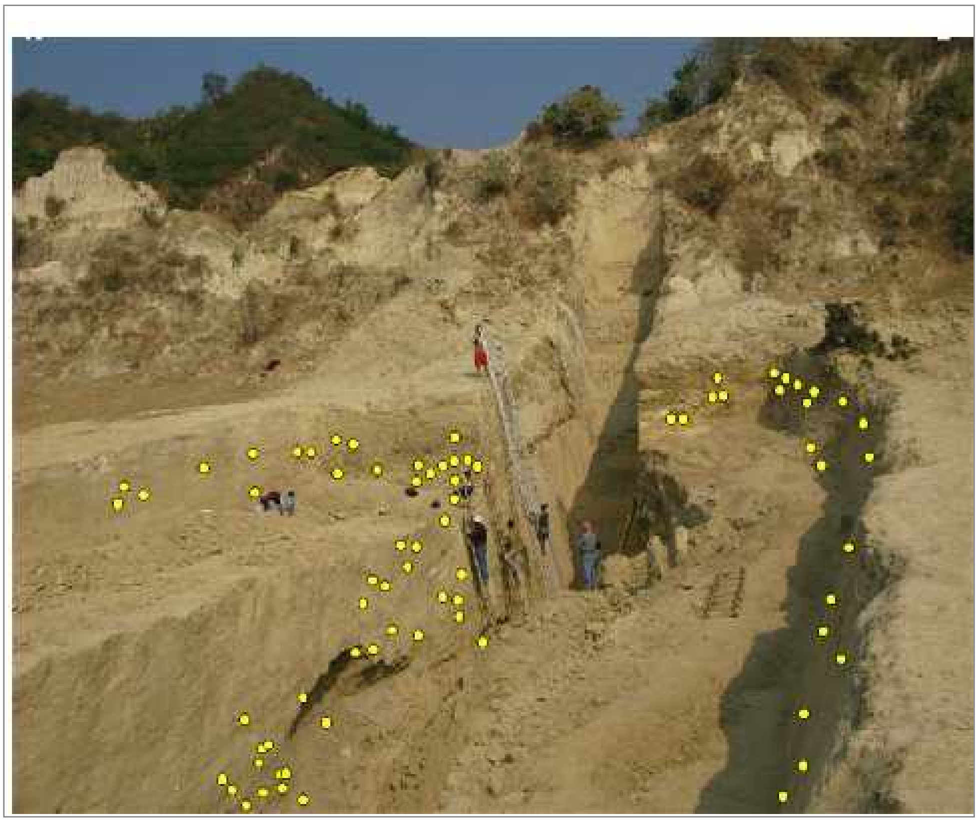

Fig 6.6. About 300 charcoal sampled in megatrench of Charnath.

Risk in trenching

Trenching is the best method of documentation of buried fault and study of historic and orehistoric earthquakes. To investigate such fault we should dig small as well as mega trench depending upon the character of fault whether it is reached to the surface or blind. In Charnath mega trench of dimension 70m long, 5m wide, and 8-15m deep was excavated. There are different types of risk associated with the trenching. Attack by the cobra was preliminary risk on starting the trench (Fig 6.7)

At first the shape of trench was rectangular i.e. there was no benches. When excavator excavated the trench to required depth the crack was developed in east wall (Fig 6.8) then it get collapsed at night. If the wall was collapsed on working time there may be great accident. This forward the message to paleoseismologist that benched trench is suitable in case loose sediments like in Charnath otherwise alternative supporting mechanism should be adopted.

Shallow Seismic Refraction

Geophysical surveys including a shallow seismic profile - sub-contracted to BRGM, Orleans, France (A. Bitri, and S. Bes de Berq), which add invaluable information at various depths. In Nepal, this is the first effort of this kind to study the MFT at such a detailed scale in combination with paleo-seismological trenching. The seismic survey was quite successful, providing excellent data, even beyond the depths expected in view of the relatively shallow burial (10.7 to 1.5 m depth)) of the 100 g dynamite rods into superficial, unconsolidated river gravels. Shots (Fig 6.9.) were fired at 10 m intervals and recorded by 40 Hz geophones spaced 5 m (2 sec. record length; 48 traces; 12 nominal fold; 270 m maximum offset). Standard processing procedures included amplitude correction, geometry spreading compensation, random noise attenuation, band-pass filtering (30Hz-95Hz), high precision stacking, and 2D FX post-stack time and depth migration. The 1.2-1.5 km-long, migrated seismic profile shot across the thrust in Charnath valleys. The profile reveals quite clearly hanging-wall and footwall structures, as well as the positions and attitudes of the shallow active thrust-planes, down to ~300 - 400m-depths. They provide in fact the first direct vision of the MFT to such depths.

Given the excellent quality of the data, even without interpretative line drawing, the thrusts appear to plunge northwards by 30 to 45 degrees (Fig 6.10), between a hangingwall with dipping, folded Siwaliks and a footwall with mostly flatter Terai deposits. Note however, that there is some shortening in the footwall sediments, in the form of incipient thrusting and folding.

Fig 6.7. Cobra in trench killed by the excavator.

Fig 6.8. Crack developed in trench.

Fig 6.9. Example of dynamite shot in Charnath valley near inferred thrust emergence.

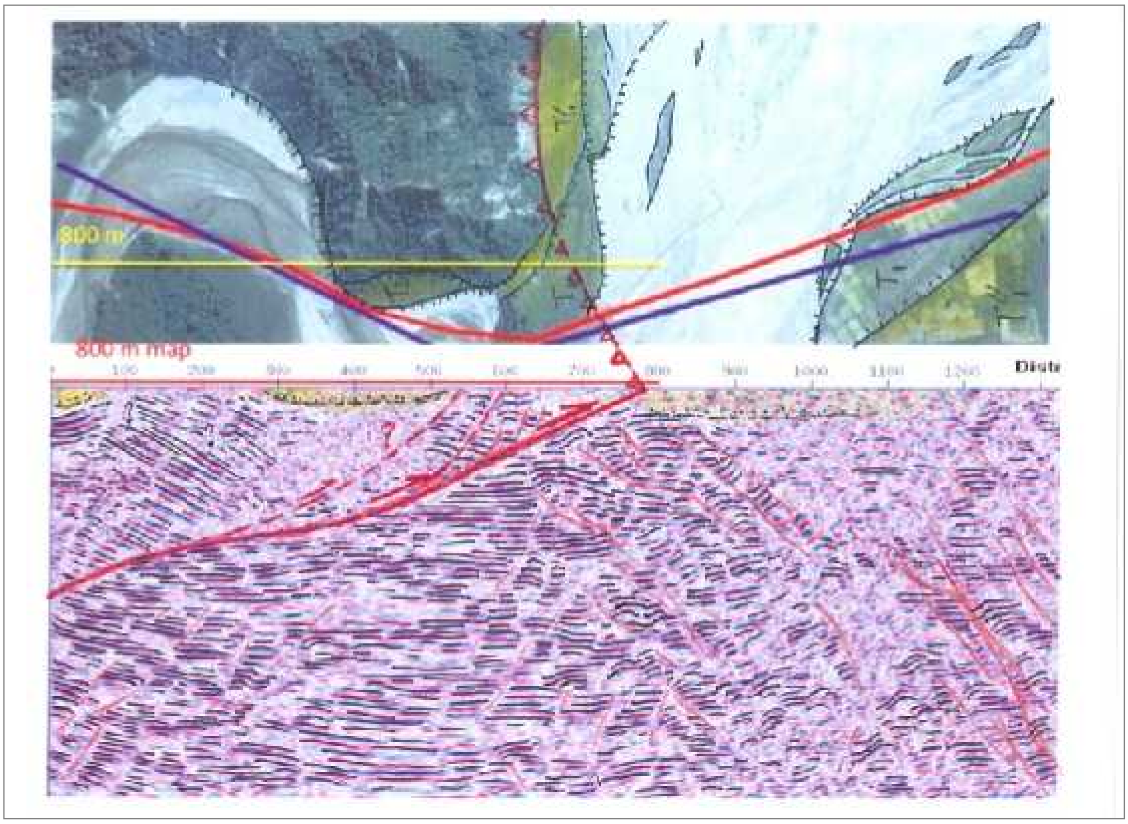

Fig 6.10 Migrated seismic profile across MFT along Charnath valley On north side of section, ~ 45°S-dipping Siwalik beds in hanging wall appear to ride atop 30°N-dipping thrust - surfacing between 700 and 800 m - and flatter footwall sediments. Here also, localized, footwall folding buried beneath modern alluvium south of topographic thrust-front may be related to presence of a blind ramp.

CHAPTER SEVEN
CONCLUSION AND RECOMENDATION

Nepal is situated within the seismically active Himalayan mountain belt. The northward convergence of the Indian plate keeps the entire Himalayan arc seismically active, which is responsible for the occurrence of large and moderate magnitude earthquake and the large scale thrusting at the present rate of thrusting across the Himalaya, averages over the seismic cycle, is probably of the order of15 to 25mm/yr, developed from north to south giving rise to Main Central Thrust (MCT) separating the Lesser Himalayas from Higher Himalayas, Main Boundary Thrust (MBT) separating the Lesser Himalayas from Sub Himalayas and Main Frontal Thrust (MFT) separating Sub Himalayas from Indo-Gangetic plain.

Geologically the study area lies in MFT area most active fault of Himalaya. This fault is locked during the interseismic period and manifests all the surface rupture to the surface. Many authors has described MFT as a blind thrust at depth but present study reveals that MFT is not a blind but an emergent fault and its escarpment is due to the cumulative effect of recurrent earthquake. Presence of abandonment of very young river channel and very young terraces at the surface is the result of recent seismic activity in the area.

Fresh escarpment and different level of terraces in the area is the first guide to select the area. Mainly four level of terraces are mapped and studied namely T1, T2, T3 and T4 (figure 5.4). These four terraces lies in the hanging wall of the MFT. Charcoal samples were taken from the surface of these terraces by digging a pit on the surface to calculate the date of abandonment of these terraces.. Dating result shows that the highest level of terrace called Tintale terrace has abandoned (1050–1300) yrs BP and terrace height ~16m above the river. One charcoal from footwall near Birendra bazaar (Saphilphubariya) also give the nearly same age (1260±40) as Tintale terrace. From these information we can conclude that about 1000 yrs before two terraces i.e. Tintale and Saphilphubariya were in same level. They are uplifted and gain ~16 m height during 1000 yrs. This uplift rate nearly 6cm/year is not possible by a slow tectonic process, these surface might be abruptly uplifted by two or more earthquake. T2 level of terraces are uplifted 4-7 m above the present Kariya Khola and Saphi khola bed. Dating material C14 which is sampled from its surface revealed the age of 75-197 yrs BP indicate that the terrace is quiet young. From these dates it can be inferred that this area has affected by at least two earthquake between terraces T4 and T2. With these date the youngest terrace might be uplifted by 1934 earthquake and older T4 terraces might be affected by two earthquakes around 1200 BP. Historically, it is also possible that this area might be affected by 1934 and 1255 earthquake in past.

By the study of the river pattern of Kariya Khola on photo of 1962 and photo of recent, it shows that one meander belt was paved with paddy field, which is a good indicator of channel shifting due to active movement. Likely clear views of abandoned channels are also good indicator for the active movement of the area. Charnath Khola has already changed its course three times. At first, it changed its course and leave Tintale terrace, secondly, it leave paleo-channel and finally it is in present condition. It is also not possible by the slow tectonic movement. So it is also concluded that there might be effect of seismic activity.

A mega trench with dimension of 70 m long, 5 m wide and depth of 8-15 m was excavated and which is the biggest trench excavated across the MFT in the Himalaya region. Paleoseismological study conducted by DMG in far western Nepal found a vertical throw of more than 7m by single event. To get the multiple events in single trench we must deal with the trench more than 15 meter in depth at the faulting area. If two fault are revealed and well documented stratigraphically and chronologically we can calculate the return period and slip during the big events which will help finally to constrain the seismic risk of the country. After analyzing the trench log it appears that major two faults are coming to the surface and has intersected by two colluvium wedges led us to think about two big earthquakes in the area. C14 samples are still on the laboratory for dating in France we will quantify it after the results of dating.

From Geomorphological and paleoseismical result it can be concluded that 1934 earthquake might be a repetition of AD 1255 event, implying a characteristic return time of 600-700 years in Eastern Nepal.

It is recommended that 1934 earthquake might have ruptured more than 299 km and we should continue such studies along the stretch of the rupture all the way to Nepal India boarder in East. DMG should continue this work at least in two to three places to mapped the rupture in space and time.

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ANNEX

Tintale creek

S. N.	Sample reference	Lab reference	$D^{13}C$	Age BP Calibrated Age	Sampling date/ Photo	Lab date	Note
1	TC09-07	21570 SUERC-29629	-28.5	125±30 1670-1940AD		14/05/10	Tintale Creek
2	TC09-08	21571 SUERC-29630	-25.0	115±30 1640-1960AD		14/05/10	Tintale Creek
3	TCO9-112	21572	Failed			14/05/10	Tintale Creek
4	TC09-103	21573 SUERC-29631	-27.3			14/05/10	Tintale Creek
5	TC09-13	21574	Failed			14/05/10	Tintale Creek
6	BBT-01	21575 SUERC-29632	-27.7	1260±40 660-870AD		14/05/10	
7	TTC1	21576 SUERC-29633	-27.7	75±30 1690-1930 AD	F2010 P133	14/05/10	Alternative name TS09-01
8	TTC2	21577 SUERC-29634	-28.7	105±30 1680-1940 AD	F2010 P133	14/05/10	Alternative name TS09-02
9	4TT1	21578	Failed		F2010 P132	14/05/10	4th peat Tintale Terrace Alternative name

							TS09-03
10	4TT1	21579 SUERC-29635	-25.6	175±30 1650-1960 AD	F2010 P132	14/05/10	4th peat Tintale Terrace Alternative name TS09-03
11	TTC3	21570 SUERC-29639	-27.5	195±30 1640-1960 AD	F2010 P133	14/05/10	Alternative name TS09-04 or 5TT3
12	1TT2	21581 SUERC-29640	-27.5	535±30 1310-1440 AD		14/05/10	1st peat Tintale Terrace Alternative name TS09-05
13	2TT1	21582 SUERC-29641	-26.0	565±30 1300-1430 AD	F2010 P130	14/05/10	2nd peat Tintale Terrace Alternative name TS09-06
14	TCT3-1	21583 SUERC-29642	-26.3	150±30 1660-1960 AD	F2010P136	14/05/10	Terrace T3 Alternative name TS09-07
15	TCT4a1	21584 SUERC-29643	Assume @25.0	1080±30 890-1020 AD	F2010 P138	14/05/10	Terrace T4 Alternative name TS09-08
16	TCT4a3	21585	Failed		F2010 P138	14/05/10	Terrace T4 Alternative name TS09-09
17	TCT2a4	21586	Failed		F2010 P144	14/05/10	Terrace T4 Alternative name TS09-10