GEOCHEMISTRY OF PROGLACIAL LAKE DEPOSITS OF UPPER ALAKNANDA BASIN

Project submitted to the Central University of Punjab

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In

Geology

BY

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May 2018

CERTIFICATE

I declare that the project entitled **"GEOCHEMISTRY OF PROGLACIAL LAKE DEPOSITS OF UPPER ALAKNANDA BASIN"** has been prepared by me under the guidance of Dr. Jitendra Kumar Pattanaik, Assistant Professor, Department of Geography and Geology, School for Environmental and Earth Sciences, Central University of Punjab. No part of this project has formed the basis for the award of any degree or fellowship previously.

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CERTIFICATE

I certify that Yousuf Ali has prepared his project entitled **"GEOCHEMISTRY OF PROGLACIAL LAKE DEPOSITS OF UPPER ALAKNANDA BASIN"** for the award of M.Sc. degree of the Central University of Punjab, under my guidance. He has carried out this work at the Centre for Geography and Geology, School for Environmental and Erath Sciences, Central University of Punjab.

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ABSTRACT

GEOCHEMISTRY OF PROGLACIAL LAKE DEPOSITS OF UPPER ALAKNANDA BASINS

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Many researchers have recorded climatic upheaval in the Himalaya during the Late Quaternary. The chemical weathering in the Upper Alaknanda basin has changed during the glacial and interglacial period. Different sediment archives such as pro-glacial deposits and terrace deposits act as repository to understand the paleo-weathering intensity of the sediment.In this study geochemistry of sediments of pro-glacial lake deposits found in the Badirinath valley of upper Alaknanda basin was carried out to understand the paleo-climate of the study area by identifying the clay minerals, intensity of chemical weathering and to estimate the distance travelled from the source. The lake deposits are thinly laminated and lack boulder and pebble layers. Sediment deposits at the right bank of Alaknanda River near Bamini village are more likely lake deposits as compare to left bank deposits which is terrace. By clay mineral identification, it is concluded that the paleo-climate of the pro-glacial lake deposits were cold and is deposited during glacial period. XRF analysis in terms of CIA calculation, A-CN-K plot and A-CNK-FM plot suggests that there is low degree of chemical weathering occurred in the study area. The percentage of clay silt fractionation calculation by gravity setting method conforms that the sediment were not travelled far from their source.

(Yousuf Ali) (Dr.Jitendra Kumar Pattanaik)

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Yousuf Ali

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Sr. No.	Full form	Abbreviation
1.	Mega-annum	Ma
2.	Degree Celsius	°C
3.	Beryllium	Be
4.	North-east	NE
5.	Kilometre	Km
6.	Metres	M
7.	Metres above sea level	Masl
8.	North	N
9.	East	E
10.	Kilo-annum	Ka
11.	Millimetres	Mm
12.	South-east	SE
13.	Centimetres	Cm
14.	Grams	G
15.	X-ray diffraction	XRD
16.	Miliampere	mA
17.	Kilovolt	kV
18.	Sodium	Na
19.	Calcium	Ca
20.	High Himalayan Crystalline Sequence	HHCS
21.	X-ray fluorescence	XRF
21.	Silicon	Si
22.	Water	H_2O
23.	Strontium	Sr
24.	Neodymium	Nd
25.	Kilo year	Kyr
26.	Million ton	Mt
27	Bamini Village	BM
28	Hanuman Chatti	HC
29	Rarang Chatti	RC

CHAPTER-1

1.1 INTRODUCTION

Our universe being created about 13.8 billion years ago from an incredibly hot and dense point as per the widely accepted theory of the origin and evolution of universe i.e Big Bang Theory and our planet Earth is about 4.6 billion years old (Friedmann,1922, Lemaître 1927,). The earth has evolved throughout its history, and will continue to evolve. It faces several ice ages. An ice age is aninterval of long-term reduction within the temperature of earth's floor and environment, ensuing within the presence or enlargement of continental and polar ice sheets and alpine glaciers. Our earth faces two types of phases alternatively i.e glacial duration, which is also known as “glacial”, or “glaciations” or informally as “ice age” and an intermittent warm phase known as “interglacial”. In geological time scale, the quaternary period ranges from ~2.6 Ma to recent. It best known for the period of ice age, it has a distinctive nature, and feature, as earth was between glacial and interglacial mode, there is a repeated oscillations of cold and warm climate. It is recorded that during ice age the earth’s temperature was about 10°c in equatorial zone and 5°c in tropics. The Solar radiation controlled the variation of glacial-interglacial climate change. One can see measurable and dramatic changes in humans (physical and cultural change), climate and environment during quaternary earth history. In geological time scale, the Quaternary period subdivided into two epoch’s i.e Holocene and Pleistocene.The Pleistocene is well known period of ice age and it is further sub divided into Early Pleistocene (1.8 Ma to 0.7 Ma, which was paleo magnetic reversal), Middle Pleistocene (0.79 Ma to beginning of the last interglacial period), Late Pleistocene (last interglacial to present interglacial or Holocene). The Holocene epoch began about 11,500 years ago and sometime denoted as recent/present. There are about 30-50 glacial and interglacial cycles are recorded in the quaternary period.

In the Himalayan Valleys, glaciers affected by Quaternary climate change. According to Sharma and Owen et al., 1996,glaciers in large area responded to change in the strength of Indian Summer Monsoon (ISM) throughout the quaternary period. Due to the variation in circulation of Indian summer monsoon intensity from million year time scale causes variable changes on hill slope and fluvial transport processes and hence on landscape development. Bookhagen et al, 2005, the Himalayan monsoonal circulation has varied at millennial, centennial and decadal time scales, which have left strong imprints on landscape evolution and sedimentation. The Indian summer monsoon is a major source for moisture in the central Himalaya. Increase in precipitation rate will make hill slope erosion more prominent by increasing pore water pressure as a result accelerated sediment distribution into the main streams through landslide. Consequently, the valley floor deposition and incision begins with decrease in hill slope. Recent studies reveals that hill terraces in the north-western Himalaya indicate that phase of fluvial aggradations is correlated with the intervals of intensified Indian summer monsoon (ISM). According to Juyal and Sundriyal, et al., 2010, the re-incision of the deposited sediments corresponds with periods of weak Indian summer monsoon (ISM). Indian summer monsoon is the consequence of a thermal gradient betweena low-pressure cell above Tibet and high pressure above the oceans,which causes counterclockwise moisture transport from the Bay of Bengal along the southern Himalayan front toward the northwest.

Bookhagen et al., 2005, Glacial advancement and retreat played important role in formation of Glacial landform such as moraines, river terraces, till and proglacial lake. Barnard et al., 2004, In Gori Ganga valley, he collected boulders from moraines and dated using TCN ^{10}Be, concluded that moraines formed during Holocene, late Holocene, Little ice age (LIA) and glacial interstadial. In his study area, fans and river terraces formed due to debris flow and flood processes during deglaciation stages. This study shows importance of climate controls on landscape and topographic evolutions of earth surface processes. According to Sundriyal et al., 2008 force behind the orogenic deformation in Himalayan ranges are climate and rainfall variations.

1.2 UPPER ALAKNANDA BASIN

The Alaknanda Basin extended between latitude 30.0^0N to 31.0^0 N and longitude 78.75^0 E to 80.0^0 E, covering an area about 10882 Km^2, represents the eastern part of the Garhwal Himalaya of Uttarakhand state of India. Out of the total area of the basin, 433 km^2 is under glacier landscape and rest of 288 km^2 is under fluvial landscape. The land under agriculture is 644.22 Km^2, which is 5.9 percent of the total geographical area while only 64.8 Km^2 (0.6%) land is under the horticultural crops.

1.3 GLACIERS

The Alaknanda River is a perennial and occupies a large glaciated area of Uttarakhand. In the Central Himalaya the longest glacier (~29 km) is the Gangotri glacier, flows longitudinally from the northern slopes of the Chaukhamba peaks down to the Gaumukh in a WNW direction occupies an area of about 50 sq. km. The Mana, Kamet, Chaturangi, Swetvarna are the tributary glaciers to Satopanth. These glaciers named based upon the colour of the surrounding rocks. The valley is wide and U-shaped from Gaumukh to the Satopanth Temple. According to the International Center for Integrated Mountain Development (ICIMOD), 2011 published, about 374 numbers of glaciers are exist at and around Satopanth Glacier area and among them, Bhagirathi glacier is the largest glacier covering an area of 262.53 sq.km.

1.4 Glacier Landform

Glacial landform provides evidences about their mode of formation, depositional environment and surficial process. Moraines, relict lake deposits, river terraces etc. indicates extent of past glaciation and paleo-climatic condition. According to Owen *et al*., 1998 these features are formed number of kilometers downstream the present day snout. According to the current studies conducted in the Himalayan region on lateral moraines, recessional moraines and related landforms suggest that the area has been undergone multiple glaciations and thus the estimation of timing of glaciation is scanty. Due to the lack of organic on moraines, standard radiocarbon method has no use. Recent studies shows that glaciers, which are prone to change in precipitation, situated in orographically shield areas where as glaciers, which are subjected to high amount of precipitation are feeble or delicate to changes in temperature.

The Himalaya divided into three regions western Himalaya, central Himalaya and eastern Himalaya. The eastern Himalaya is largely affected by the ISM (Indian Summer Monsoon), signifying that during summers it mostly receives snowfall while the western Himalaya experience snowfall during winters and it is influenced by the mid-latitude westerlies.Benn and Owen,1998 the central Himalaya experience snowfall due to mid-latitude westerlies but ISM (Indian Monsoons) is dominant.Owen *et al*.,1996 when inter tropical convergence zone (ITCZ) drops towards south of the equator during winter in the northern hemisphere , maximum glaciers growth is seen in the western Himalayas but approximately no growth in central and eastern Himalaya.

There are two main glaciers in my study area i.e Satopanth and Bhagirathi Kharak glaciers, which are the source of the Alaknanada River, major tributaries of Ganga. According to Nainwal *et al*. ,2008 these glaciers situated above the Alaknanda basin and located between latitude 30°42´55˝-30°50´32˝ N longitude 79°13´55˝-79°29´40˝ E. According to Nainwal*et al*., 2007, this glacial is associated with the Little Ice Age (LIA).

Table1: Glaciers in the Upper Alaknanda Basin.

Glaciers	Length (km)	Width (m)	Area (km^2)
Satopanth glacier	13	~750-850	~21.17
Bhagirathi Kharak Glacier	~18.5	~850	~31.17

1.4 Relict and Proglacial Lake Deposits

Proglacial lake deposits that have been preserved in past and can be formed after very long period is called relict lake deposits. This type of lake deposits formed by various processes either by damming action or by meltwater, which have trapped against an ice sheet because of isostatic depression of the crust where ice sheet was present. Inland depressions containing standing water termed as lakes, mostly found in high latitude and mountainous regions. The glacial erosion and deposition, shifts in earth's crust, craters of some extinct volcano and landslide dumping form lakes. The lake basins found in glacial environment formed by depositing materials over streamed, gouging holes in loose soil or soft bedrock, or leaving buried chunks of ice that later melted to leave lake basins. When these natural depressions or impoundments filled with water, it transformed into lakes. The melted ice and snow filled a basin in the Andes Mountains that was formed by the folding of the mountains that caused cracks or faults in the earth's crust is the type of shifts in earth's crust lake. The dammed lakes which are formed due to the result of landslides, collapses or debris flows or ice sediments, arrest rivers which exist all over the world. The dammed lakes formed with approximately stable dam and water in dynamic balance and after sometime period of stable deposition, lake deposits are produced (Wang *et al*., 2014).

1.5: Importance of relict lake deposits

Wang et al., 2014. Lacustrine sediments generally can record the events, which occurred during their deposition. The summer monsoon changes during quaternary period can beregenerate by the examination of proglacial lake deposits. Sedimentary structures, high-resolutionmagnetic and geochemical data gives the monsoonal fluctuation faced by the lacustrine environment. The sediment deposits in proglacial lakesare more continuous so, it canbe remodel complete record of past climatic changes. Proglacial lake sediments formed due to the ice volume changing in glacier valleys. Hence, it used to rebuild high definition sedimentary records of glacial activity over many years in the catchment.

1.6: Research Problem

Many researchers have recorded climatic upheaval in the Himalaya during the Late Quaternary. In the upper Alaknanda basin late Quaternary glaciations recorded at many places. The chemical weathering in the Upper Alaknanda basin has changed during the glacial and interglacial period. Different sediment archives such as pro-glacial deposits and terrace deposits act as repository to understand the paleo-weathering intensity of the sediment.

1.7: Objectives

To understand the above problem following objective has mentioned:

I. Clay mineral identification and quantification of pro-glacial lake deposit sediments collected from Badrinath valley.

II. Geochemical analysis of the sediments to understand the chemical weathering intensity.

CHAPTER-2

2.1 Literature Review

Many researchers worked in this field and published many papers until date. Change in climate with time may structure the physiography of this area. Theide et al., 2004; Ray and Srivastava, 2010; Juyal*et al*., 2010; suggested that at different scale of time and space in past, the climate, have been significantly altering, affecting surface operations like river erosion, transportation, aggradations by studying the geomorphology, stratigraphy and optical dating of the fluvial sediment. The methods used are organic and apatite inorganic phosphorus fractions, environmental magnetic parameters, namely magnetic susceptibility (xLF), an-hysteretic remnant magnetization (ARM), isothermal remnant magnetization (IRM) and grain size analysis.

The landscape of the study area has come to present state by various natural factors and processes. The main factors are lithology, tectonics, climate and structure. The study area mainly influenced by the Indian Summer Monsoon (ISM) as from the research and study by various researchers(Bookhagen et al., 2005; Sundriyal et al., 2007; Juyal et al., 2009; Phartiyal et al., 2009). All these researchers concluded that in these high mountains the dominating factor for natural denudation and landscape evolution is probably the monsoon. They come to this conclusion by studying the nature and timing of fan sedimentation in their study area and by calculating the incision rates of bedrocks and fans (P.L Barnard)

Ahmed et al, 2000. UpperAlakananda basin situated in the Higher Himalayan Crystalline Series, which is separated from Tibettan Sedimentary Series by south Tibetan detachment system on top and bottom by the Vaikrita thrust. There is a different grade of metamorphism between Munsiari formation and Vaikrita group.

The litho-stratigraphic units in this area are Tethyan Sedimentary Sequence (TSS), Vaikrita group, Munsiari group in both Higher Himalayan Crystalline Series

(HHCS) and Lesser Himalayan Series (LHS). The Tethyan Sedimentary Sequence separated from Higher Himalayan Crystalline Series by South Indian detachment system, Vaikrita Group separated from Munsiari group by Vaikrita thrust and the Munsiari group separated from Lesser Himalayan sequence by Munsiari thrust. There are three phases of folding in Munsiari and four phases of folding in Vaikrita group.

S.S Bhakuni in his paper The Structure of The Great Himalayan in Chamoli and Uttarkashi districts, Kumaun Himalaya suggested that there is a thrust between Munsiari formation and Vaikrita group known as Vaikrita thrust. This thrust has played an important role in the upliftment of great Himalayan and in the development of folds and stretching lineations.

McGregor and Nieuwolt, 1998; Colin *et al*., 1998,The Indian summer monsoon is the major component of the tropical climate system, which is caused due to differential land–sea thermal heating, producing seasonal reversal in wind direction and intense rainfall during the summer. In winter, dry cold winds from the Asian continent flow offshore, whereas in central Asia westerly winds flow around the Tibetan Plateau.

Clemens and Prell, 1991; Prell and Kutzbach, 1992 the incoming solar radiation, interhemispheric transport of heat, high-latitude glacial and interglacial boundary conditions are the important forcing factors controlling the monsoon variability on multi-millennial timescales (103– 105 years).The short-term climatic fluctuations probably caused by variations in cross-equatorial heat transport by the ocean surface currents (thermohaline circulation), mainly in the monsoon dominated region, and were probably independent of insolation changes (Sirocko et al., 1993, 1996; Heusser and Sirocko, 1997). The Himalaya and Tibetan plateau hasagreat importance in global climate change in general and the Asian monsoon system in particular (Prell and Kutzbach, 1992)Srivastava, 2008.

Garhwal Himalaya comes under the Uttarakhand state of India, close to China. Total 968 glaciers are present in the Garhwal Himalaya, covering 2885 km^2.Thayyen and Gergan2010, Summer monsoon and the winter snow regimes mainly fed the Garhwal Himalayan glaciers in Uttarakhand .Rakesh Bhambri *et al* 2011 has reported 83 glaciers in the Saraswati/Alaknanda basin from ASTER images (2006), extending an area of 311.4 +/- 9.8 km^2.

Chaujar and others, 1993, the debris in upper Bhagirathi basin mainly consists of granite, granitic gneiss and sheared granitic gneiss. Woodward 2009, during the Quaternary Period the mountains surrounding the Mediterranean Sea repeatedly glaciated. The glacial processes are important agents of long-term landscape modification and classic glacial scenery has documented across this region. In the other parts of the world,influence of these glaciers were not confine to uplands because meltwaters carried large volumes of outwash sediment through the downstream reaches to river basins. The geomorphological and sedimentological record of glaciation in these mountains provides valuable information on past climates as the variability of glaciers areclosely related to the atmospheric air, temperatures and moisture supply.

Barnard *et al* 2004;high Himalayan valleys, Nanda Devi, Gori Ganga and NE Garhwal are influenced by Holocene landscape evolution of monsoon. In this study shown the impact of climate on landscape evolution and suggest a strong monsoonal control on the dynamics of earth surface processes in the Garhwal Himalaya. They also suggested that rivers were turbulent during approximately 1-2, 4-5 and 7-8 ka.Phartiyal*et al* (2009) to understand the intensity of monsoon and surface processes during the Late Pleistocene-Holocene in Trans Himalayas region, the relict lake deposit exposed along the Spiti valley and investigated, found that there is a thick lacustrine unit within the relict sedimentary sequence all over the valley. They estimated the age of upper valley 14-6 ka and lower valley about 50-30 ka using Optically Stimulated Luminescence (OSL) dating of quartz from lacustrine deposits.

Chapter-3

3.1: Study Area

The Garhwal Himalaya region comes under the Uttarakhand state of India. Based on the glacier data of India, 968 glaciers exist in the Garhwal Himalaya, covering 2885 km^2 area. My research area is in the Upper Alaknanda basin. The Bhagirathi river and Alaknanda Rivers are the main source stream of the Ganga river, which originates from the snout of Gangotri Glacier and Satopanth and Bhagirathi Kharak Glacier respectively.

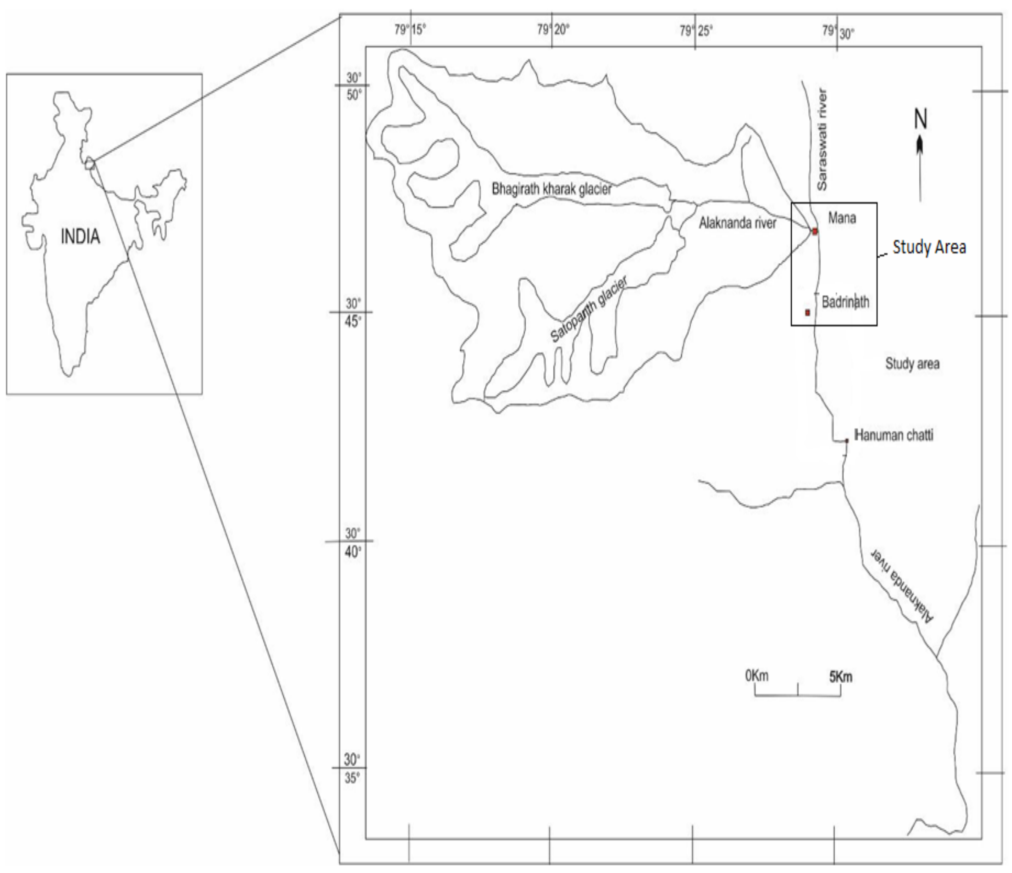


Fig. 1: Location map of the study area. Origin of Alaknanda River from Satopanthand Bhagirath-Kharak glaciers, confluence at Mana of Alaknanda and Saraswati rivers and Upper AlaknandaValley are shown.

The Alaknanda basin has 407 glaciers covering 1229 km^2, while the Bhagirathi basin contains 238 glaciers covering 755 km^2. The study area of the Alaknanda basin extends from Mana Pass to Badrinath Temple including Arwa Valley and the Western Kamet Group. It occupies 970km^2 with an elevation range of 3100–7756ma.s.l. at Mount Kamet. The Pawegarh Ridge (5288–6165 m a.s.l.) is divide between Alaknanda and Saraswati catchments. Garhwal Himalayan glaciers fed by summer monsoon and winter snow regimes.The Alaknanda river and Sarswati river meets at Mana Pass, India and Alaknanda river and Bhagirathi river meets at Devprayag. Sundriyal et al., 2007 the highest point of Alaknanda basin is Nanda Devi hill. Alaknanda river has turbulent flow during mid-June and mid-September. Main tributaries of this river are Mandakini, Nandakini, Dhauliganga and Pindari River. Komal*et al*. 2016, AlaknandaRiver passes through the Chamoli, Tehri and Pauri district of Uttarakhand.

Along its course, Alaknanda River drains through different litho-units such as Tethyan Himalaya, Higher Himalaya and Lesser Himalaya, which bounded by major geological structures. The South Tibetan detachment system (STDS) separates the Tethyan sediments from Higher Himalayan crystalline, the Main Central Thrust (MCT) separates the Higher Himalayan crystalline from the Lesser Himalayan rocks and Main Boundary Thrust (MBT); separates the Lesser Himalayan rocks from the Sub-Himalayan rocks **(**Srivastava and Ahmad, 1979; Srivastava and Mitra, 1994; Ahmad et al., 2000). The Alaknanda River basin relief is about 7012 m and it receives an average of 1500 mm of rainfall annually, most of which occurs during the monsoon (Juyal et al.,2010).Sediment samples of relict lake deposits were collected from 5 different locations between Bamani village to Hanuman-Chatti of Badrinath valley. The main relief of this area is deep gorges and trough peaks. Various disjointed hills, heavy rainfall and complex tectonic setting with different geomorphology of steep slopes are responsible for landslides in this area.

The Vaikrita Group of HHCS starts from South-Tibetan Detachment System to theVaikrita Thrust, this is marked the location of the Main Central Thrust (MCT) (Ahmad et al. 2000). HHCS comprises of old crystalline rocks of the Himalaya and covers the Upper Alaknanda Basins. Vaikrita Group is exposed from Vishnuprayag and Mana Village, it is situated over Garhwal Group and comprises of schists, gneiss and granite rocks. The thrust in this area shows a regular direction of NW-SE parallel to the Himalayan Range but perpendicular to the Alaknandariver.

From Vaikrita Thrust, Munsiari Group starts and end at Munsiari Thrust. After this thrust rocks of the Lesser Himalayan Series starts. The Upper Alaknanda Basin within the MCT zone is in tectonically active region and at Karnprayag active Alaknanda Fault is present. Faults that traverses the Alaknanda river are Trans-Himalayan Fault, MCT, Alaknanda Fault, and the North Almora Thrust locally called Srinager Fault (Tyagi et al.). Compared toVaikrita Thrust and Munsiari Thrust the above faults are very active, however the Alaknanda Fault is outpacing erosion processes making it the most active (Tyagi et al. 2009)

3.2: Lithology and Lithostratigraphy

Dudhatoli Group, the Garhwal group and the Central crystalline group are three major lithostratigraphic unit in Alaknanda valley. One can see Dudhatoli Group exposed between Devprayag and Koteshwar, and separated from the Garhwal group by a NW-SE trending thrust known as North Almora Thrust (NAT). In between Koteshwar to Vishnuprayag, we may found the Garhwal group and it is separated from the Central Crystalline group by Main Central Thrust (MCT), which is trending NW-SE direction. There are so many shear and fracture zones in this area. Along the Alaknanda and Dhualiganga River from Vishnuprayag to Mana village, we may get exposed rocks of central crystalline group. It comprises of schist, gneiss and granite rocks, which situated over the Garhwal group.

The thrust zone in my study area shows a regular direction of NW-SE parallel to the Himalaya range but perpendicular to the Alaknanda River as it flows in NE-SW direction. The central crystalline group exposed in the Greater Himalaya and occurs in a linear zone in the Alaknanda Basin. The rocks found in this area are gneisses, migmatites, crystalline schist, quartzite with conspicuous horizons of calcsilicates with psammite gneisses in the upper part. In the Alaknanda valley between Helang (south of Joshimath) and Badrinathone can see well exposure of this group. This group composed of Ragsi formation, Bhimgora quartzite formation, Joshinath formation, Pandukeshwar formation and Badrinath formation.

1. Ragsi Formation: It is also known as the Ragsi schist and gneiss Member of the Tungnath formation. It is in contact with the Garhwal Group along Main Central Thrust and Bhimgora Quartzite rest on it. One can get exposures of marble, gneisses and paraamphibolite in the Alaknanda valley and kyanite-staurolite schist, quartzo-feldspathic schist and hornblende- schist in Mandakini valley. The Bhimgora Quartzite and Ragsi formation in Pinder River is cut-off by the Main Central Thrust (MCT).
2. Bhimgora Formation: It may found from Bhimgora in Nagol Gad to the north of Helang in the Alaknanda valley and it is associated with chlorite phyllite. The lithology of this formation is white coloured, fine-grained recrystallized quartzite with abundant sericite flakes. It's name is derived from Bhimgora Chatti.
3. Joshimath Formation: It comprises of a regionally metamorphosed banded psammitic and pelitic sediments. It extended westward and mapped as the Chandersila Schist of the Tungnath Formation.
4. Pandukeshwar Formation: At Pandukeshwar, bedded quartzites and banded quartzitic gneisses with sedimentary structures such as cross bedding are exposed in the psammitic series of the Alaknanda.
5. Badrinath Formation: In the Alaknanda valley, the Badrinath Formation is well exposed between Hanuman Chatti and Badrinath. It is made up of calc-silicate, migmatites, garnet, sillimanite, mica schist, muscovite and kyanite-bearing gneissand garnet amphibolites inferred by leucogranite and pegmatite.

Table 2: Stratigraphy and Lithology of the study area

	Formation	Lithology
The Central Crystalline Group	Badrinath Formation	Mica schist, muscovite, migmatite, garnet, calcsilicate, kyanite-beraing gneiss, sillimanite
	Pandukeshwar Formation	Para-amphibolites, banded quartzite gneiss
	Joshinath Formation	Sillimanite-kyanite schist, garnet-mica-schist
	Bhimgora Quartzite	White quartzite
	Ragsi Formation	Para-amphibolite, kyanite-mica schist, gneiss

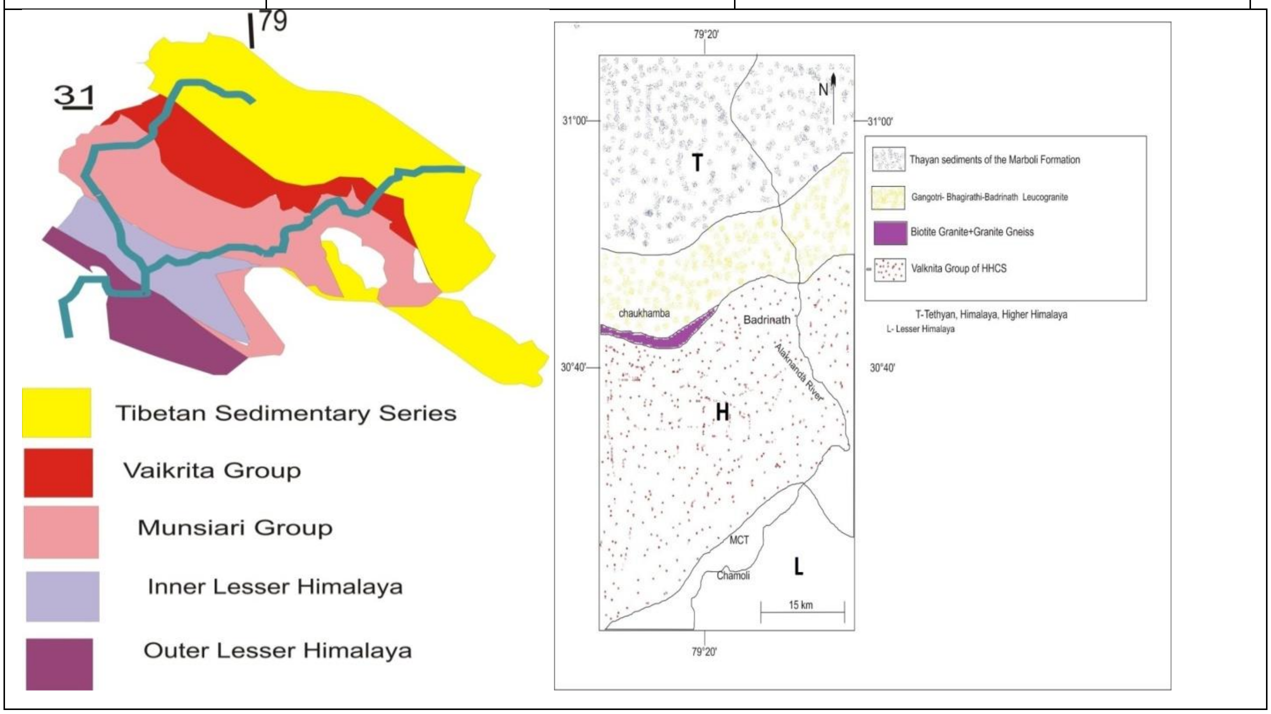


Fig. 2: Figure showing Lithostratigraphy of the study area

3.3: Structure

In my study area, the Central Crystalline rocks thrust over Garhwal Group of rocks along Main Central Thrust (MCT), which is a northerly dipping major tectonic discontinuity, exposed across the Alaknanda River at Helang. The main central thrust is a major structural discontinuity of Himalaya trending northwest to southeast direction that traverses through central portion of the study area. Along this, a number of local or regional weak planes also exist in this area. The rock masses around these are structurally weak and thus highly vulnerable to mass wastage. The moving water and gravity in this area easily displace the saturated debris together with fractured, jointed and sheared rocks on the hill slopes. From the research paper of Nainwal et al., 2007, the Pindari thrust, which passes through Hanuman Chatti, is the major structural feature in the study area. These substitute two different basins, which are Badrinath (U-shaped) basin and Pandukeshwar (V-shaped). The Southern zone of Alaknanda basin surrounded by linear ridges, which lie on the Highest Nilkanth peak (5960masl).

3.4: GEOMORPHOLOGY

There are different geomorphic features in the Uttarakhand Himalaya, which give unique characteristics to each geological unit, namely Higher Himalaya, Lesser Himalaya and Outer Himalaya. In Gaumukh area, the Bhagirathi River and the Alaknanda River form broad Ushaped valley in their upper reaches. While flowing downstream through Greater and Lesser Himalayan terrain they cut deep V-shaped gorges.

There are two seismic block in this area namely The Lesser Himalayan Seismic Block and the Frontal Hill Seismic Block. The Lesser Himalayan Seismic Block lying between the Main Boundary Thrust (MBT) in the south and Main Central Thrust (MCT) in the north. It has highest seismicity level with a source thrust fault trending parallel to Himalayan trend. There is an epicentral location close to Main Central Thrust (MCT). The Frontal Hill Seismic Block is in the south of Main Boundary Thrust (MBT) upto Himalayan Frontal Thrust (HFT) and beyond. All these fault surfaces are neotectonically active.

The landforms in the area are glacial, structural, fluvial, and denudation in origin. In the north, inversion of relied in highly metamorphosed rocks, reflects the impact of high rate of erosion process on long-term scale of millions of years in the area. Rapid tectonic uplift, intense fluvialand glacial incision produce long steep slopes (Shrader and Bishop, 1998). The common geomorphic features found in this area are the rocky slopes, cliffs major and minor ridges, waterfalls and Quaternary deposits along the hill. Highly dissected denudation hills, moderately and low dissected denudation hills, river terraces, and various fluvial geomorphic features like point bar, meandering scars, natural levees, terraces are also the main features (Chakraborty, 2007).

In my study area, the main geomorphic features are high to medium dissected hills, talus and scree deposits, river terraces and fluvio-glacial material. The paleo and present glacial events are the main factors for producing such landforms. Due to the consecutive geomorphic processes, many features incised during palaeoglacial, either destroyed or buried. Some glacial and periglacial landforms present in the study area are shown in the table below.

Table 3: Glacial and periglacial landforms in the study area (Naiwal*et al*., 2007).

Process	Landforms
Glacial	Moraines, proglacial lakes, avalanche chute and fans, ice caves, aretes horns, cirques, hanging and U-shaped valleys.
Periglacial	Outwash plains, moraines terraces, patterned ground, proglacial relict lake deposits, drumlins, talus cone, alluvial fan, solifluction lobes, debris cone and talus fans.

3.5: Climate

In the Alaknanda river basin,the Monsoon climate is prominent with rainstorms ranging between 200 to 1000mm/hour. In this area, there is a variation in rainfall from place to place depends on the windward and leeward side of high ridges. Approximately 50% annual rainfall in Alaknanda valley receives rainfall in monsoon months of June and mid-September.

3.6: Vegetation

In Alaknandavalley,farmers prefer farming mostly in the terrace deposits. Themain grown crops in this area are potatoes, pulses and barley. The vegetation density of Alaknanda valley varies from low to moderate. The slopes at high altitudes are unproductive containing lichens, shrubs, mosses, rhododendrons and some windflowers.

CHAPTER-4

4.1: Materials and Methods

The materials, methods and techniques used during the dissertation work are described below.

4.1 Sampling

During the fieldwork by my seniors,14 samples were collected from five different locations in the Alaknanda valley of Uttarkhand and studied the morphology and sediment size fractionation. The samples collected from different layers based on field observations and physical appearance. Samples labeled with BM-1, BM-2 and BM-3 are taken from Bamini village, RC-1, RC-2, 5A-1 to 3 and 7E-old were collected from Ranrang Chatti and HC-1 to 5 are collected from Hanuman Chatti and it is more likely to be glacio-fluvial origin which is reported to be a medial moraine (Nainwal et al. 2007 & 2009) . The location and sample name with proper symbols shown in table-4.

Table-4: Samples Name and Symbols With location

SERIAL NO.	SAMPLES NAME	LATITTUDE	LONGITUDE	ALTITUDE IN METERS
1	HC-1	$30^0$51′ 43"	79^0 43′ 17"	2544
2	HC-2	30^0 51′ 43"	79^0 43′ 17"	2544
3	HC-3	30^0 51′ 43"	79^0 43′ 17"	2544
4	HC-4	30^0 51′ 43"	79^0 43′ 17"	2544
5	HC-5	30^0 51′ 43"	79^0 43′ 17"	2544
6	BM-1	$30^0$51′ 56"	79^0 37 55"	3108
7	BM-2	30^0 51′ 56"	79^0 37 55"	3108
8	BM-3	30^0 51′ 56"	79^0 37 55"	3108
9	RC-1	30^0 53′ 7"	79^0 41′ 27"	2909
10	RC-2	30^0 53′ 7"	79^0 41′ 27"	2909
11	5A-1	30^0 43′ 14"	79^0 29′ 45"	2970
12	5A-2	30^0 43′ 14"	79^0 29′ 45"	2970
13	5A-3	30^0 43′ 14"	79^0 29′ 45"	2970
14	7E-OLD	30^0 49′ 6"	79^0 29′ 45"	2902

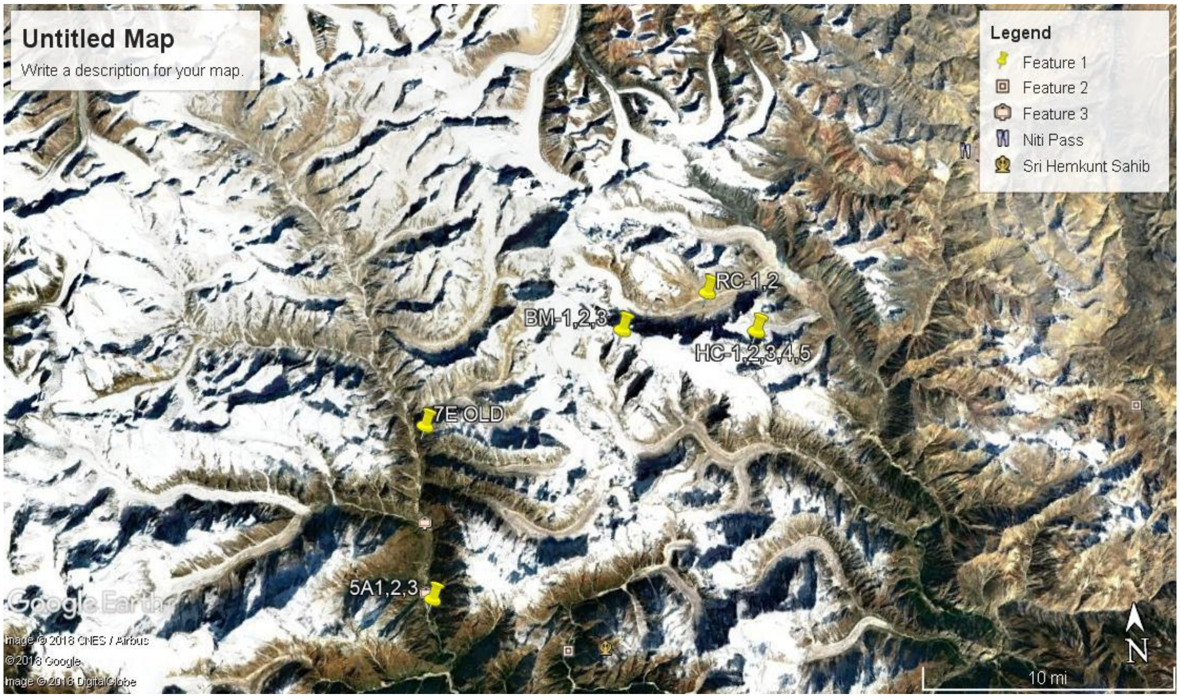
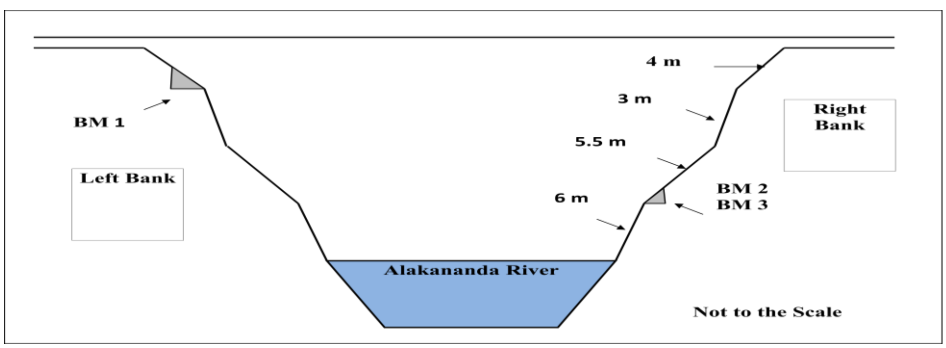


Fig. 3: showing sample location in Google Earth.



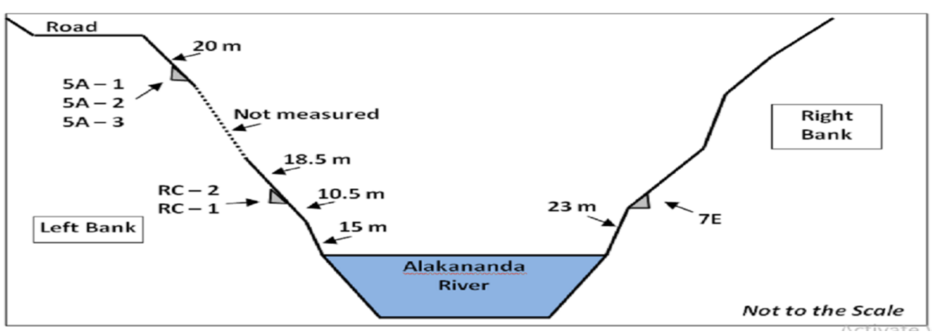
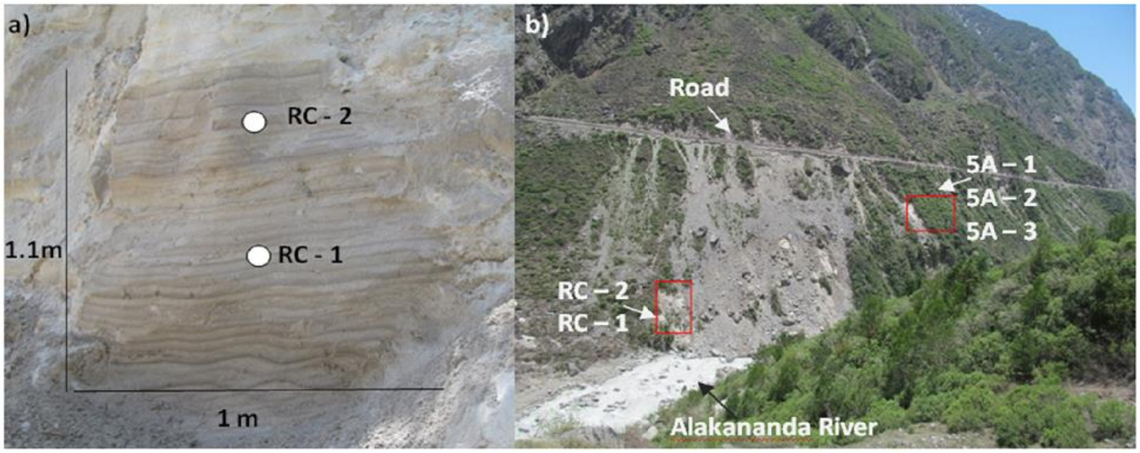
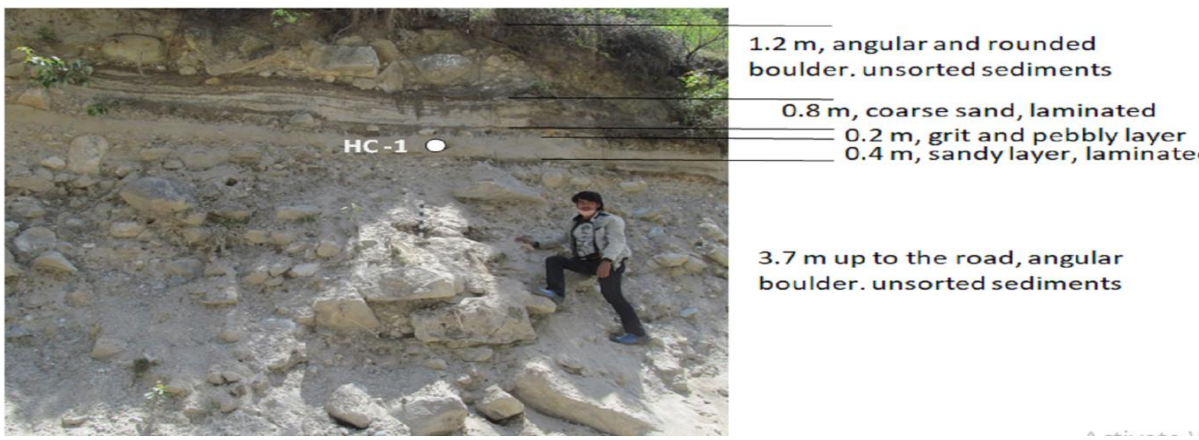


Fig. 4: Figure showing locations of sample at the left and right bank of Alaknanda River. (Source: Dissertation paper of Neeraj, June, 2017).





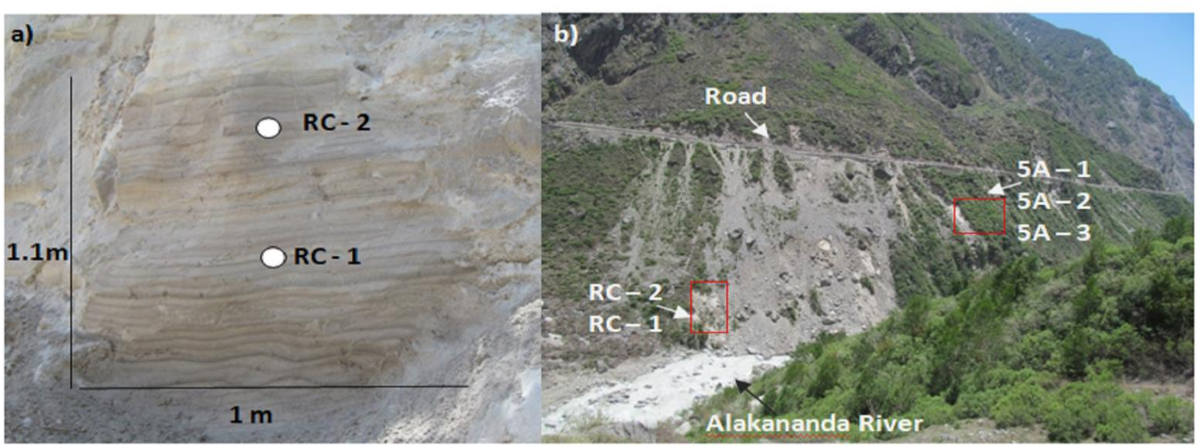


Fig.5: Photograph of sample location

4.2: Sample Processing Methods

I. There are 14 samples collected from five locations in my study area and dried up. About 80 grams of each samples are taken and homogenized to 20 gram by cone and quartering method.
II. Each samples are firstly grinded in steel motor for about 4 hours and than in agate motors for about 6 hours with proper cleaning the surrounding for avoiding contamination each time.
III. The steel motor and agate motor washed each time when new samples have to grind. The motors are firstly washed by tap water and then with soap solution. After that, the motors are rinse with Milli-Q water and dried up. The motors cleaned by ethanol before using each time.
IV. Out of 20 grams samples, 10 grams of each samples are packed for XRF analysis in a butter sheet paper with proper labeling on the zip log.
V. The remaining samples kept for further use.

4.3: Clay Separation Method

I. Out of 14 samples, two samples of size < 38 microns taken for clay separation using gravity settling method. The samples are BM-2 and BM-3.
II. After two times cone and quartering 10 grams of samples are taken.
III. Apparatus required are 1000 ml columns, 500 ml beakers and 250 ml suction pipette.
IV. The apparatus washed firstly by tap water, then by a soap solution and at last rinse by Milli Q.
V. The samples added carefully in the respective labeled column and added Milli-Q upto the desired label.
VI. The samples mixed thoroughly by shaking for about 2 minutes and putted on a safe place by noting the starting time and end time in a diary, and set a stopwatch for reminding.

VII. After completing the fixed time take the saturated solution sample with a pipette to a depth of 5 cm for less than 4 micrometers and 10 cm for 4-16 micrometer size and put in a 1000 ml beaker with proper labeling.

VIII. Label the column with Milli-Q again and repeat steps VI and VII.

IX. Repeat the steps VI, VII and VIII until the upper-labeled 5 cm and 10 cm water become clear for size less than 4-micrometers and 4-16 micrometers respectively.

X. Repeat the whole process for other samples but noting the initial time and final time clearly with proper labeling the column for respective time.

XI. After that, we centrifuged all the samples at 4000 rpm for 20 minutes at 25^{o}C, poured water without disturbing the clay samples, and preserved the samples for slide making.

<u>STOKE'S LAW FORMULA</u>

$$V = \frac{g\left(\rho_1/\rho - 1\right)d^2}{18\vartheta}$$

➢

where V= settling velocity of the solid

g= acceleration due to gravity

ρ_1= mass density of the solid

ρ =mass density of the fluid

D= diameter of the solid (assuming spherical)

ϑ = kinematic viscosity of the fluid

4.4: Oriented Clay Slide Preparation Method

I. First one mole solution of KCl and $CaCl_2$ are prepared.

II. The maximum water of the clay samples were poured out after centrifuge and maked a slury on vertex shaker.

III. Two 50 ml testtubes are taken and labeled K and Ca.

IV. Three-pipette tube of 1 ml taken to put the samples and solutions in the test tube and marked each pipette tube with the respective solutions/samples name.

V. For making k-saturation samples, 3 ml of slurry sample and 3 ml of 1 mole solution of KCl taken in a K labeled 50 ml test tube.

VI. For making Ca saturation sample, 3 ml of slurry sample and 3 ml of 1 mole Ca solution taken in a 50 ml Ca labeled test tube.

VII. The saturated K and Ca samples are shaked on vertex shaker for few minutes and left aside for 5 minutes.

VIII. After that, we centrifuged the samples for 10 minutes at 7000 rpm, poured out the water, and again repeated the same process.

IX. After centrifuge, the remaining residue saturated with 1 ml Milli-Q and 1 ml ethanol for both K, Ca and original sample and left aside for 5 minutes after shaking on vertex shaker.

X. After that, we again centrifuged the sample at 7000 rpm for 10 minutes and poured out the water.

XI. Now we treated the samples with 1 ml ethanol and shaked the sample on vertex shaker again and repeated step X.

XII. At last, we treated the sample with Milli-Q and repeated step X again.

XIII. Now the sample slurry is ready for making slide

XIV. The slides cleaned with Milli-Q properly and labeled on bottom side with proper sample name.

XV. The slurry being taken by respective labeled pipette tube and then poured on the middle of the slide.

XVI. The slides are now prepared and kept for dry on a safe place.

4.5: X-RAY DIFFRATION Method

The x-ray powder diffraction (XRD) is an analytical technique, whichis used for determining the atomic and molecular structure of a crystal and can give information about the unit cell dimension. Bragg's law used to explain the interference pattern.

According to Bragg's law when a beam of X-rays of wavelength λ enters a crystal, the maximum intensity of the reflected ray occurs when sin θ = nλ/2d, where θ is the angle of incidence, n is a whole number, and d is the space lattice.

The crystals mounted on a goniometerand bombarded with X-Ray while rotating. Diffraction patterns of regularly spaced spots will produce. The 2-D images taken at different rotationconverted to 3-D models of the electron density map by the method of Fourier Transform.

It is a non-destructive technique. It is uses to determine the structural properties such as lattice parameters (10-4 A^0), strain, grain size arrangement, to measure the thickness of the thin films and multi layers.

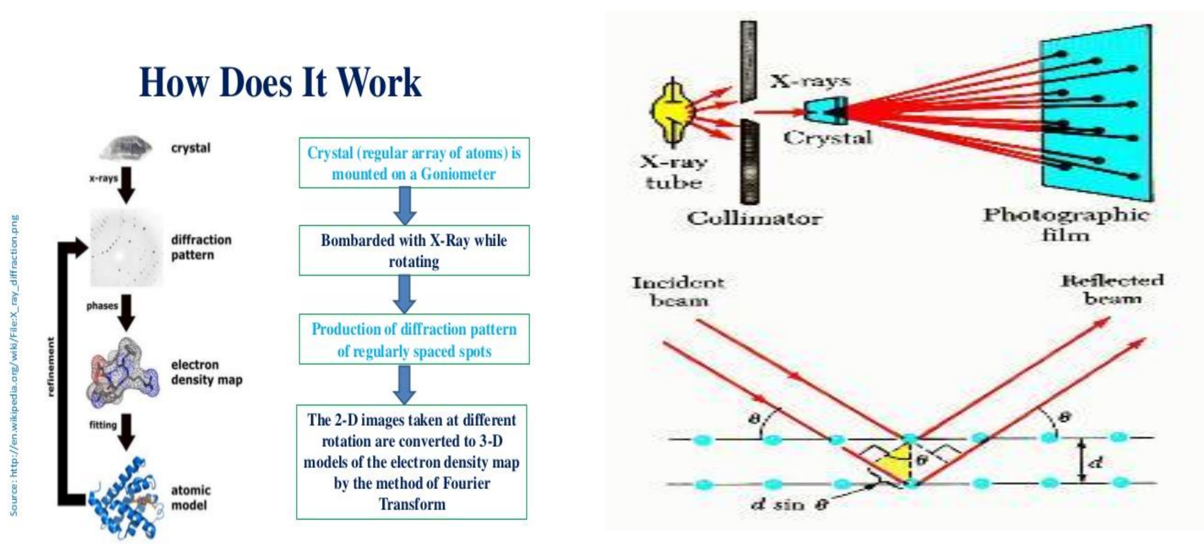


Fig. 6: Image of XRD principle (Source-http://www.xraydiffrac.com/xraydiff.html)

Powdered sediment samples were analysed at Inter University Accelerator Centre (IUAC), New Delhi using Panalytical XRD instrument. The starting and ending position of goniometer which represent by (2θ) value was set between 2° and 70°.

The step size set (2θ) in the instrument is 0.0080° and scan set time set to be 9.2550. XRD analysis was carried out in continuous scan type and at room temperature 25°c. The Cu-anode source with k_α value of 1.54060 was used for the experiment. The current and voltage was set at 40mA and 45kV respectively for the source.

The Raw data received from the IUAC wasin the format of .xrdmlThis data is analysed using X'Pert High score software to identify the clay minerals and their semi-quantification. The 14, 10 and 7 angstrom (A^0) peaks are mainly focused and calculated the semi-quantification valuemanually. The intensity of the mineral with highest matching score was selected. After mineral identification its abundance (Semi-quantifications) was estimated manually taking the respective score from the peak list.

4.6: X-Ray Fluorescence

An x-ay fluorescence spectrometer is an x-ray instrument used for routine relatively non-destructive chemical analysis of rocks, minerals, sediments and fluids. It is typically used for bulk analysis of larger fractions of geological materials. It is one of the most widely used methods due to its relative ease, low cost of sample preparation and the use of x-ray spectrometer. It is also one of the best analytical techniques to perform element analysis in all kinds of samples either it may liquid, solid or loose material.

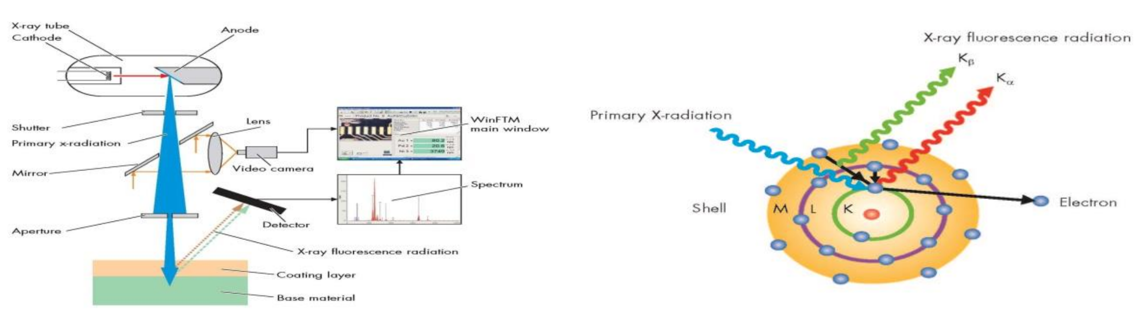


Fig.7: Left side functional principle X-Ray Fluorescence Spectroscopy (XRF) Instrument and right side the Principle of the X-Ray Fluorescence Spectroscopy (XRF).(Source-https//www.xrf-spectroscopy.com).

It works on methods involving interaction between electron beams and x-ray with samples. This made possible by the behavior of atoms when they interact with radiation. When materials are excited with high energy short wavelength radiations (e.g. x-ray), become ionized. If the energy of the radiation is sufficient to dislodge a tightly held inner electron, the atoms become unstable and outer electron replaces the missing inner electron. When this happens, energy released due to the decreased binding energy of the inner electron orbital compared with the outer one. The emitted radiation is of lower energy than the primary incident x-rays and is termed fluorescence radiation. Because the energy of the emitted photon is characteristics of a transition between specific electron orbital in a particular element, the resulting fluorescent x-ray can be used to detect the abundance of elements that are present in the sample.

4.7: Wentworth Grain Size Scale

Table 5: Udden-Wentworth grain-size scale for siliciclastic sedim. (Wentworth, 1922).

Millimeters		µm	Phi (φ)	Wentworth size class	
			-20		
	4096		-12	Boulder (-8 to -12φ)	
	1024		-10		
	256		-8		
	64		-6	Pebble (-6 to -8φ)	
	16		-4	Pebble (-2 to -6φ)	Gravel
	4		-2		
	3.36		-1.75		
	2.83		-1.50	Gravel	
	2.38		-1.25		
	2.00		-1.00		
	1.68		-0.75		
	1.41		-0.50	Very coarse sand	
	1.19		-0.25		
	1.00		-0.00		
	0.84		0.25		
	0.71		0.50	Coarse sand	
	0.59		0.75		
1/2	0.50	500	1.00		
	0.42	420	1.25		
	0.35	350	1.50	Medium sand	Sand
	0.30	300	1.75		
1/4	0.25	250	2.00		
	0.210	210	2.25		
	0.177	177	2.50	Fine sand	
	0.149	149	2.75		
1/8	0.125	125	3.00		
	0.105	105	3.25		
	0.088	88	3.50	Very fine sand	
	0.074	74	3.75		
1/16	0.0625	63	4.00		
	0.0530	53	4.25		
	0.0440	44	4.50	Coarse silt	
	0.0370	37	4.75		
1/32	0.0310	31	5	Medium silt	
1/64	0.0156	15.6	6	Fine silt	
1/128	0.0078	7.8	7	Very fine silt	
1/256	0.0039	3.9	8		Mud
	0.0020	2.0	9		
	0.00098	0.98	10		
	0.00049	0.49	11	Clay	
	0.00024	0.24	12		
	0.00012	0.12	13		
	0.00006	0.06	14		

CHAPTER-5

RESULT AND DISCUSSION

5.1: Grain Distribution in Silt and Clay

To find the respective percentage of clay and silt we separated the clay and silt. The clay and silt particles are separatedby the gravity settling method. A sample of 10 gram of less than 38 micron size are taken. The less than 2 micro-meter clay is separated at 3 hour 36 minutes, 2 to 4 micron size clay at 54 minute 2 seconds, 4 to 8 micron silt at 27 minute and 8 to 15.6 micron size silt at 6 minute 45 seconds. We dried the sample and weigh it to know the weight percent ratio of different size fraction, which is tabled below.

Percentage Calculated in Excel sheet.

s/no.	Sample S	Initial Weigh in mg	3 h 36 min in mg	54 min 2 sec in mg	27 min 1 sec in mg	6 min 45 sec in mg	Residue Weigh in mg	Total
1	BM-2	10223	11.2	19.17	27.37	165.07	10000.19	10223
2	BM-3	11079	47.02	97.37	292.37	642.17	10000.07	11079

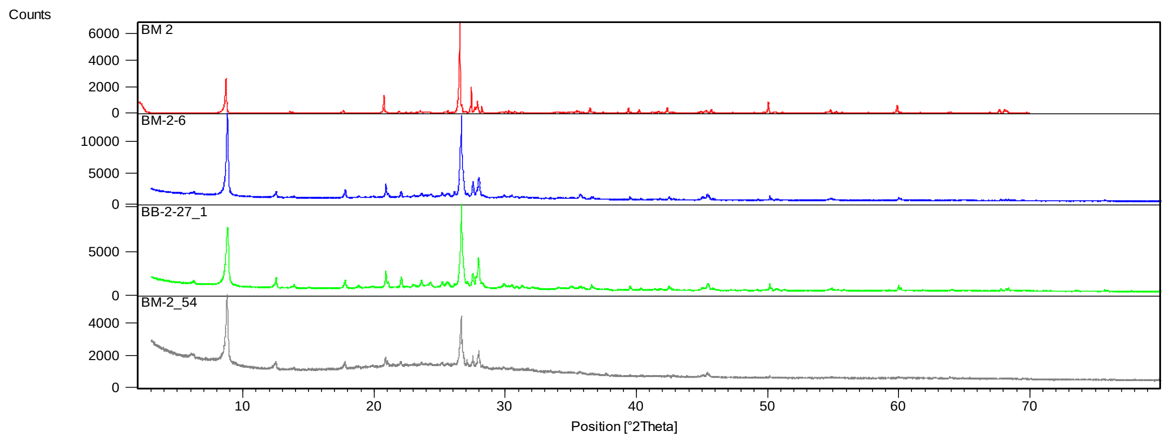
Table 6: Weight percent calculation of clay and silt by gravity settling method.

Samples	3 h 36 m %	54 m 2 sec %	27 m 1 sec%	6 m 45 sec %	residue %
BM-2	0.109557	0.187518	0.26773	1.614692	97.820503
BM-3	0.424407	0.87887	2.63896	5.796281	90.261486

The clay samples proportion i.e less than 4 micron size are very much less as compare to the silt fractions between 4 to 38 micron size as one can compare in the table above. It conforms that the clay percentage in the sample is very much less as compare to the silt. From this we can evaluate that the sample is not far travelled from the provenance and also the chemical weathering is not occurred much.

5.2 : Comparison between bulk sample and different size fraction

BM-2



BM-3

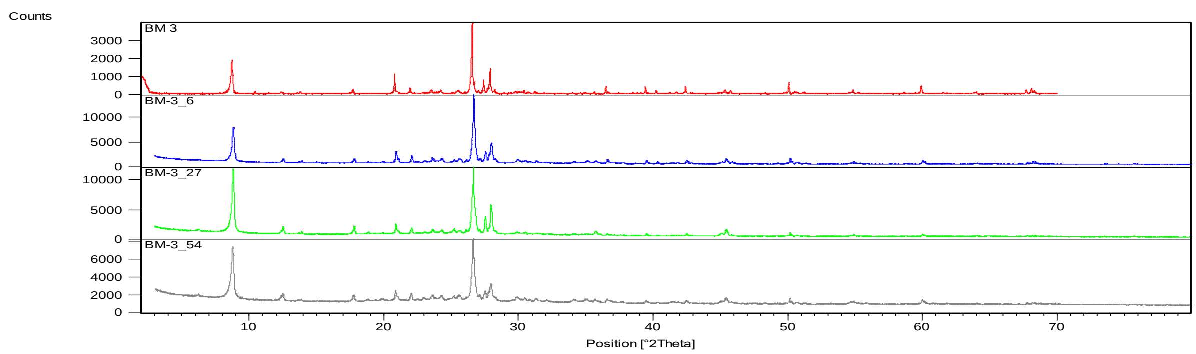
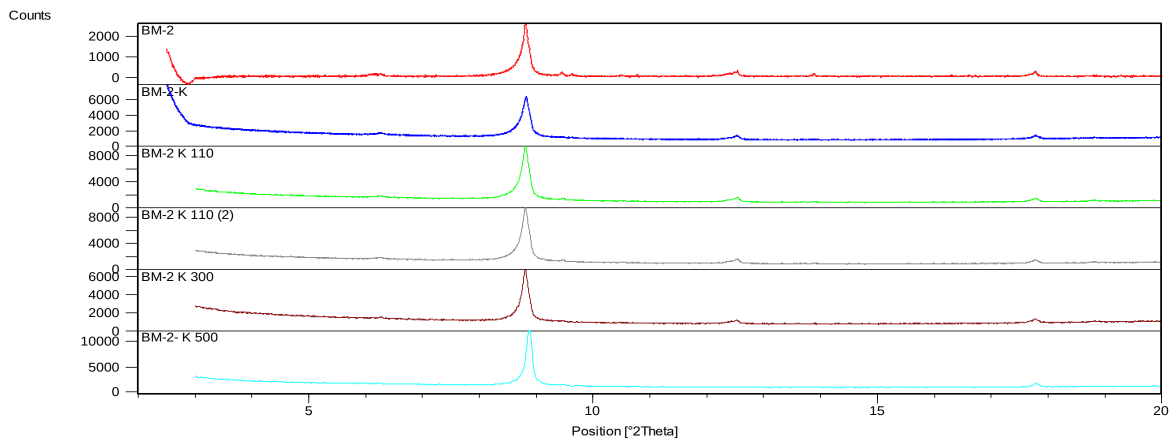


Fig.8: Comparison of BM-2 and BM-3 bulk sample with different size fraction.

On comparison of different size fraction with the bulk sample, we inferred that as the sample size increases the intensity of clay minerals decreases and the intensity of other minerals decreases and vice-versa.

5.3: Identification of clay

BM-2



BM-3

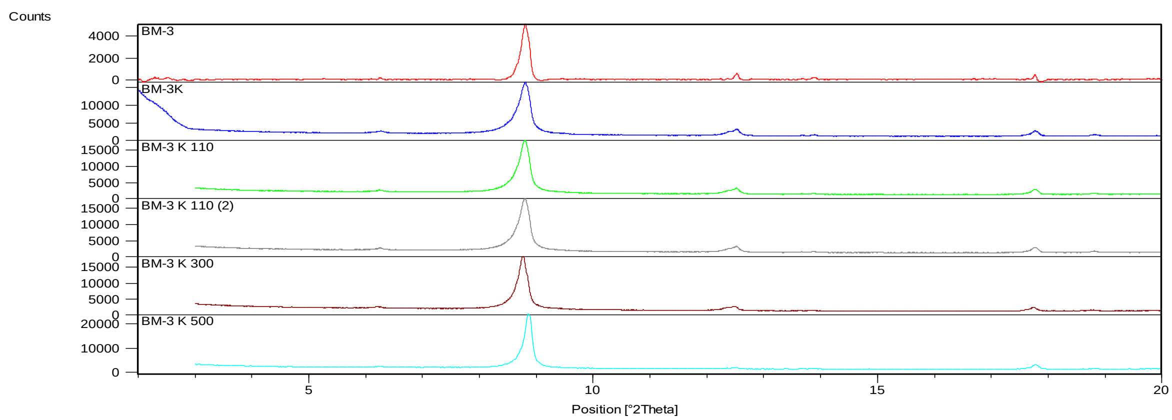


Fig.9: Graph for clay identification of sample BM-2 and BM-3 by treating with K and thermal treatment at different temperature.

Clay identification is not easy as some clays shows almost same d spacing value. The clay samples are treated with KCl and $CaCl_2$, and K saturated sample were heated at 110 deg., 330 deg. and 550 deg. centigrade. As kaolinite and chloriteboth shows 7-angstrompeak, illite and hydrated halloysite shows 10 angstrom peak.The hydrated halloysite readily dehydrate at 100 ^{0}C to a spacing of 7.2 to 7.4 A^0 while illite shows not much change. On thermal treatment at 110, 300 and 550 ^{0}C, the d spacing is showing no much change, which confirms the presence of illite. On thermal treatment at 110, 300 and 500 ^{0}C the 7 A^{0}angstrom peak is slowly diminishing which conforms the presence of kaolinite. The 14 A^{0} peak is conformed as montmorillonite.

5.4: Quantification of Clay

The quantification of clay is done manually by using the formula [Illite + Montmorillonite +(kaolinite/2.5)]. The percentage kaolinite, illite and montmorillonite are tabled below

Table 7: Quantification of clay table.

BM-2							
7 Å	**10 Å**	**14 Å**	**7 Å /2.5**	**Total**	**Kaolinite%**	**Illite%**	**Chlorit%**
216	**2636**	**77**	**86.4**	**2799**	**3.0863757**	**94.163**	**3.0864**
BM-3							
7 Å	**10 Å**	**14 Å**	**7 Å /2.5**	**Total**	**Kaolinite %**	**Illite %**	**Chlorite**
509	**5021**	**117**	**203.6**	**5341**	**3.81159**	**93.998**	**2.1904**

The quantification of illite as compare to kaolinite and montmorillonite is very much. As from the quantification the illite mineral is dominant in my study as compare to other clay minerals like kaolinite and montmorillonite.Comparing soils along a gradient towards progressively cooler or drier climate, the proportion of kaolinite decreases , while the proportion of other clay minerals such as illite (in cooler climate) or smectite in (drier climate) increases.Thus it shows a cold paleo-climate of the study area as the quantification of illite is much more greater than kaolinite.

5.5: Hydrated XRF data in weight percent.

Table 8: Hydrated XRF data in weight percent.

Sam. Name	Al2O3 (%)	CaO (%)	Fe2O3 (%)	K2O (%)	MgO (%)	Na2O (%)	SiO2 (%)	MnO (%)	Total
HC 5	9.926	1.092	2.102	2.643	0.152	2.175	73.338	0.01	91.438
HC 4	14.193	1.191	5.661	4.521	3.774	1.466	58.048	0.05	88.904
HC 3	8.307	0.976	2.472	2.455	0.282	1.48	71.044	0.02	87.036
HC 2	11.898	0.818	2.121	3.436	0.19	2.636	68.942	0.01	90.051
HC 1	9.506	1.203	2.504	2.339	0.915	1.766	73.201	0.01	91.444

5.6: CIA Calculation in in mole

Table 9: CIA value calculation in excel sheet

Sam. Name	Al2O3 (%)	CaO(%)	Fe2O3 (%)	K2O (%)	MgO (%)	Na2O (%)	SiO2 (%)	MnO (%)	CIA(%)
HC 5	0.09735	0.019473	0.01316	0.02806	0.0038	0.03509	1.22067	0.00014	54.0918
HC 4	0.13920	0.021239	0.03545	0.04799	0.0936	0.02365	0.96618	0.00070	59.9781
HC 3	0.08147	0.017405	0.01548	0.02606	0.0070	0.02388	1.18249	0.00028	54.7466
HC 2	0.11669	0.014587	0.01328	0.03648	0.0047	0.04253	1.14750	0.00014	55.4923
HC 1	0.09323	0.021452	0.01568	0.02483	0.0227	0.02849	1.21839	0.00014	55.4926

Chemical index of alteration (CIA) , which is $[Al_2O_3/(Al_2O_3+CaO+Na_2O+K_2O)]*100$ in molecular proportions is a parameter to determine the intensity of weathering (Nesbitt and Young, 1982).The A-CN-K plot is an important plot for determining fresh rock composition and finding their weathering trends asunweathered primary igneous rocks have CIA values close to 50 (Fedo et al., 1995). The CIA value of the 5 samples are in between 54 to 59. From this, we can infer that there is low chemical weathering in the source area and also the sediments are not travelled far from the provenance.

5.7: Comparison between Fe/Si and Al/Si

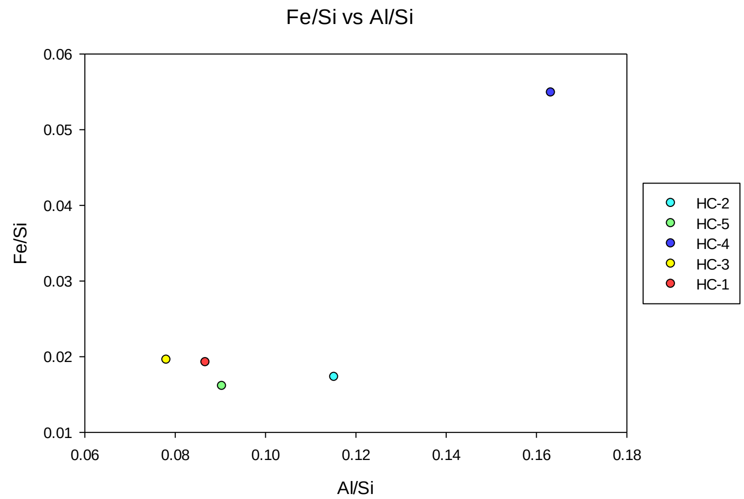


Fig.10: Diagram showing Fe/Si vs Al/Si

In Fig.10 Fe/Si vs Al/Si plot the samples are plotted near to coarse quartz field and only one sample i.e HC-4 plotted near the clay field. From the plot it is inferred that the clay percentage is very much low except HC-4, we can say that there is low chemical weathering in the provenance and also the samples are not far travelled from the provenance.

5.8: A-CN-K and A-CNK-FM diagram

In the A-CN-K and A-CNK-FM diagram the samples are plotted to the site of felsic rock as our source rock is felsic in nature. All the samples are plotted near the plagioclase feldspar line. Apex ‘A’ represents kaolinite, gibbsite clay minerals, and 50 % A-CN and A-K tie line represent plagioclase and K-feldspar. It helps to evaluate the sediments that do not undergo chemical weathering as the samples are plotted near Feldspar line. As these sediments are collected form upper reach and transported shorter distance percentage of clay compare to other minerals is much less.

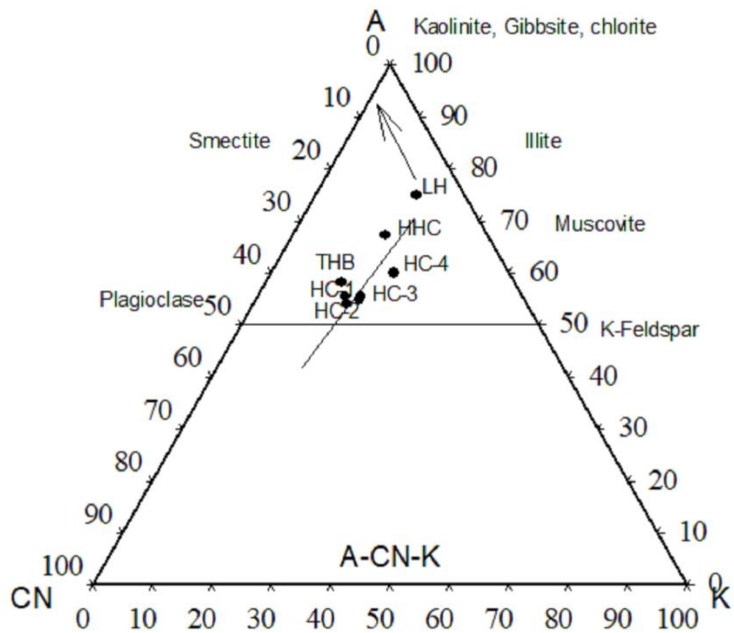


Fig.11: A-CN-K Diagram

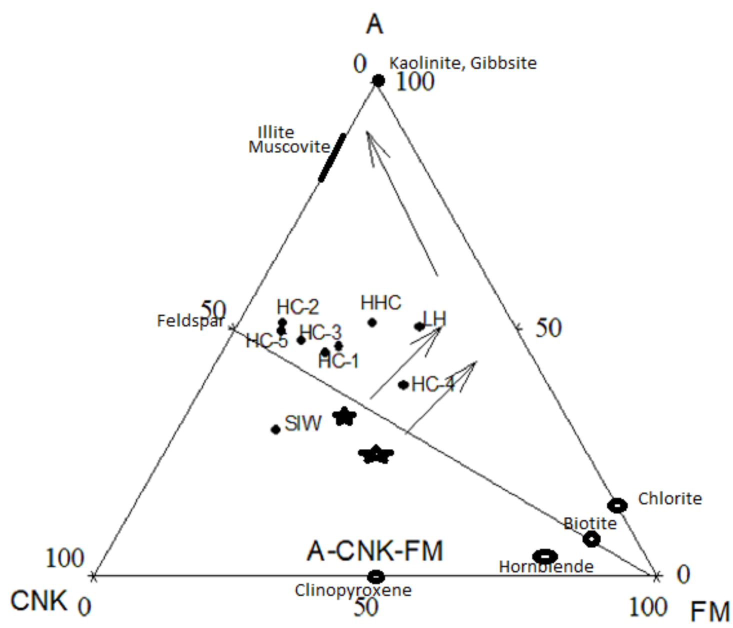


Fig.12: A-CNK-FM Diagram

CHAPTER-6

CONCLUSION

From this studyfollowing conclusions are drawn.

I. From the grain size distribution analysis it is concluded that the clay size fractions are less as compare to silt size fraction which conforms that the sediments are not far travelled from the provenance.

II. From the comparison between different size fractions with bulk sample, it indicates clay fraction shows negative correlation with coarser grain size.

III. Quartz, plagioclase feldspars, K- feldspar and muscovite are major minerals present in the sediments. The percentage of feldspars and muscovite are varying in some samples as compare to others.

IV. Clay minerals such as Illite, kaolinite and montmorillonite are dominating in the sediments.

V. The clay mineral quantification indicates that illite is dominantin the sediment, whichconformed that the sediments were deposited in a colder climatic condition. Hence, pro-glacial lake deposits are formed during glacial periods.

VI. CIA values, A-CN-K and A-CNK-FM ternary plot of the sediment indicate lower chemical weathering in the catchment area.

VII. Fe/Si vs Al/Si plot shows sediments are not travelled far distance from the source and also there were less chemical alteration during the deposition of the sediments in the pro-glacial lake deposit.

Future Work: Detailed geochemical analysis is required for provenance study.

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