Journal of Advances and Scholarly Researches in Allied Education
Vol. 13, Issue No. 1, April-2017, ISSN 2230-7540

Clay Mineral Assemblage of the Lower Siwalik Nahan Formation in the Type Area Nahan, Northwestern Himalaya

Rajesh Ranga*

Department of Geology, Kurukshetra University, Kurukshetra, Haryana

Abstract – The clay mineralogy of the Middle Miocene Nahan Formation of the type area, northwestern Himalaya, India has been investigated to understand the palaeoclimatic and palaeotectonic conditions in the frontal Himalayan terrain. The clay minerals were investigated by X-ray diffraction analysis. Study of the oriented aggregates of 35 representative clay samples of the Nahan Formation of the type area reveals that illite is the most dominant mineral followed by kaolinite, vermiculite and mixed layer clay minerals. The distribution of the clay minerals in the three measured sections of the Nahan Formation, namely the Shambhuwala – Nahan section, the Renuka – Nahan section and the Sataun – Rajban section is nearly uniform suggesting thereby the prevalence of similar sedimentation environments in the Himalayan foreland basin. The presence of illite and kaolinite suggests their derivation from crystalline rocks containing feldspar and mica as also from preexisting soils and sedimentary rocks. Further, the palaeoclimatic conditions were moderate. Vermiculite has been mainly formed by weathering and transformation of biotite. Warm and humid climatic conditions prevailed for a major part during the deposition of the detritus which favored weathering and transformation of minerals.

Key words – Clay minerals, Nahan Formation, Provenance

---------------------------------x---------------------------------

1. INTRODUCTION

Clay mineral suits incorporated in fluvial deposits are mostly detrital in nature and are a useful tool to understand the provenance of fine grained sediments, composition and climate of the source terrains (Chamley, 1989). The fine grained sediments are composed mainly of clay minerals and amorphous materials. The composition and relative abundance of the clay minerals are controlled by their source rocks and weathering conditions. Clay mineral assemblage of the Nahan Formation of the type area Nahan in northwestern Himalaya have the significant importance to understand the palaeoclimatic and palaeotectonic conditions , modes of sediment transport, sedimentation environments and post-depositional changes experienced by the sediments.

Clay minerals are hydrated aluminium silicates with very fine particle size, usually >2µm (Moore and Reynolds, 1989). Modern spectroscopic techniques can investigate the sediment surface on a molecular scale, but are not yet used routinely for sediment analysis (Linge, 2008). Mineralogical investigations were generally performed by using X-ray powder diffraction technique (Petschick et al., 1996; Preda and Cox, 2005), often in combination with other analytical techniques, like SEM, XRF. These techniques are accurate and have found widespread use.

In this paper we report clay mineral assemblage of selected represented samples from the measured three sections from the Lower Siwalik, Nahan Formation of the type area. Lithologically the Formation consists of alternating sequences of sandstone and clays. The sandstones are fine grained and show dominantly purple and grayish-purple colour in the lower part while in upper part grayish- purple colour is dominated. The clay are dominantly maroon in colour.

2. GEOLOGICAL SETTING

The Siwalik group of northwestern Himalaya in India is very well exposed in a linear fashion along the Himalayan foothills for a distance of about 2400 km from near Jammu in West to near Tripura in the East. It represents a huge thickness of sediments ranging from 3300m to 6300m which were deposited in a foredeep. The Siwalik group is further divided into three sub-groups, The Lower Siwalik (Middle Miocene), Middle Siwalik (Late Miocene- Early

Pliocene) and The Upper Siwalik (Late Pliocene- Early Pleistocene) (Kotlia et al., 2008).

The Lower Siwalik is also known as Nahan Formation. The age ranges from 13 Ma to 9.2 Ma. During the 9.2 Ma – 10.7 Ma the maximum erosion is takes place and from 11.5 Ma – 12.5 Ma upliftment takes place (Gautam and Wolfgang, 1999). The Middle Siwalik ranges from 9.2 Ma to 5 Ma and The Upper Siwalik ranges from 5 Ma to 0.8 Ma. Chaudhri (2000) observed that the Siwalik group of the western Himalaya is a product of two coarsening up mega cycle. The first mega cycle is represented by the Lower Siwalik / Nahan Formation which is characterized by a slow pace of erosion and sedimentation and stable palaeotectonic conditions. The second mega cycle comprising the Middle and Upper Siwalik Formation is marked by coarsening of the sediments which eventually indicates a fast rate of degradation process.

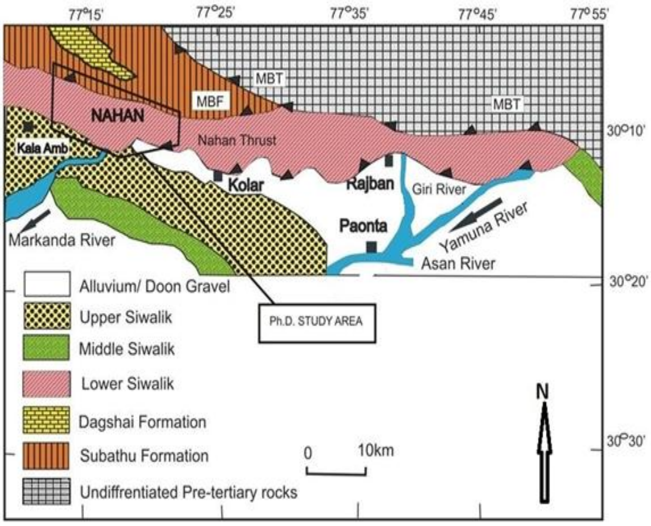

Fig. Geological map of Nahan and surrounding regions (*modified after Rohtash et al*., 2002)

3. MATERIALS AND METHODS

35 represented samples from the measured sections and random samples were identified for clay mineral analysis. Clay minerals require special techniques because of their extremely small size. These techniques are X- ray diffraction, infrared spectroscopy, differential thermal, thermo gravimetric; scanning electron microscope; neutron scattering, electron spin resonance, Mossbauer spectroscopy and ultraviolet and visible light spectroscopy. X- ray diffraction technique and Scanning Electron Microscope (SEM) has been used for analyzing the clays of the Nahan formation mainly because of availability and reliability of the technique. The area of investigation spreads over 504 sq. km in the frontal Himalayan terrain. Samples showing variations in grain size and colures are selected for this analysis.

The samples were first crushed to -250 mesh ASTM sieve size. About 100 gm of the sample powder was taken from each of the sample and the same was suspended in distilled water kept in 1000 ml measuring jar for about 24 hours and stirred with perforated stir and then allowed to settle down. The stirring was done after every 6 – 8 hour. After that the clear water was decanted off from the jar and fresh distilled water was added. The process was repeated till the suspension of clay particles appeared in the standing water column. 100 ml of suspension clays were separated out from a depth of 5 cm from the top of the standing water column with the help of pipette. The suspension so collected was put on glass slides of oriented aggregates of clay minerals. The incident X- ray beam from the X- ray machine can be directed down the Z axis of the flat lying plate- shaped phyllosilicate minerals in the oriented aggregates slides thus facilitating the recording of diagnostic basal diffractions. The Z axis depicts the intensity of d-spacing indicative of different clay minerals during glycolation and heating.

Sr. No.	Samples	Formation	Section	Location		Lithology
				Latitude	Longitude	
1	SNR-17	Lower Siwalik/ Nahan Formation	Shambhuwala – Nahan Section	30° 31.767’	77° 18.459’	Quartz wacke
2	SNR-22			30° 31.763’	77° 18.424’	Quartz wacke
3	SNR-35			30° 31.761’	77° 18.258’	Ferruginous cement
4	SNR-43			30° 31.796’	77° 18.135’	Arenite ferruginous cement
5	SNR-54			30° 31.937’	77° 17.914’	Quartz arenite
6	SNR-66			30° 31.909’	77° 17.893’	Lithic ferruginous cement
7	SNR-88			30° 31.982’	77° 17.819’	Quartz arenite
8	SNR-113			30° 31.083’	77° 17.723’	Quartz arenite
9	RNR-5		Renuka – Nahan Section	30° 34.342’	77° 17.628’	Mudstone
10	RNR-10			30° 34.301’	77° 17.567’	Arenite ferruginous cement
11	RNR-17			30° 34.262’	77° 17.583’	Mudstone
12	RNR-20			30° 34.231’	77° 17.544’	Quartz wacke
13	RNR-26			30° 34.122’	77° 17.446’	Arenite ferruginous cement
14	RNR-33			30° 34.089’	77° 17.483’	Purple clay
15	RNR-42			30° 34.020’	77° 17.805’	Wacke
16	SRR-7		Sataun – Rajban Section	30° 33.227’	77° 37.855’	Wacke
17	SRR-15			30° 33.194’	77° 37.989’	Quartz wacke
18	SRR-25			30° 33.020’	77° 38.100’	Siltstone
19	SRR-31			30° 32.991’	77° 38.139’	Greenish mud
20	SRR-40			30° 32.784’	77° 38.472’	Mudstone
21	SRR-61			30° 32.587’	77° 39.036’	Quartz wacke
22	SRR-125			30° 32.530’	77° 39.098’	Mudstone
23	SRR-131			30° 32.541’	77° 39.244’	Quartz wacke

Table 1 - Coordinates of sampling stations in the study areas

RESULT OF THE ANALYSIS

Knowing the clay minerals in sediments, X-Ray Diffraction was used. Identification of clay minerals was based on the position of the (001) series of basal reflections on the XRD diagrams. This evaluation was based on mineral standard data following the formula $n\lambda = 2d\sin\Phi$.

Table shows the result of minerals present in the study area. Result shows that through the bulk mineral analysis, we identified illite, vermiculite, kaolinite and mixed layers clay minerals. The mineral assemblage of the Shambhuwala – Nahan section, Renuka – Nahan section and Sataun – Rajban section are almost identical.

Rajesh Ranga*

Table 2. List of minerals identified by bulk mineralogical analyses with X-rd in Shambhuwala – Nahan section, Renuka – Nahan section and Sataun – Rajban section in Nahan Formation

Sr. No.	Minerals	Chemical Formula
1	Illite	(K,H3O) Al2Si4O10(OH)2
2	Kaolinite	$Al_2Si_2O_5(OH)_4$
3	Vermiculite	$(Mg,Fe,Al)_3((Al,Si)_4O_{10})(OH)_2.4H_2O$

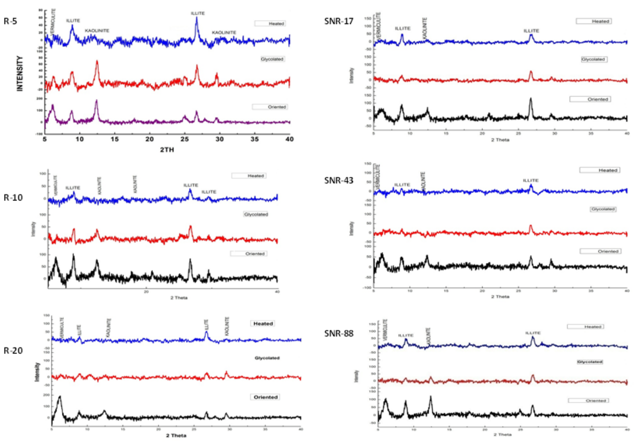

Fig. X- ray diffractograms of clay minerals of selected samples of Nahan Formation of Renuka Nahan section (RNR) and Shambhuwala Nahan section (SNR).

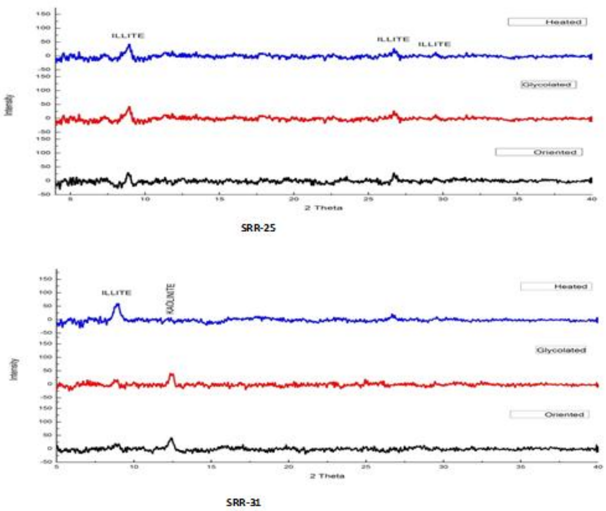

Fig. X- ray diffractograms of clay minerals of selected samples of Nahan Formation of Sataun – Rajban section (SRR).

Illite –

Illite (K1-1.5 Al4[Si7-6.5Al1-1.5O20](OH)8) is the most dominant clay mineral. The basal spacing at 10 Å shows the most dominant peak corresponding to basal reflection along (001) plane. Reflections at 4.98 Å corresponding to (002) are weaker than those at 3.32 Å. Illite contain little or no inter-layer water and therefore organic liquids do not have any effect on the mineral. Therefore it does not show any change on glycolation and remains unaffected on heating up to 500°C.

Kaolinite –

Kaolinite ($Al_2Si_2O_5(OH)_4$) is The reflection at (001) plane corresponding to 7.16 Å is more intense than those from (020) and (110) planes. The peak at 4.36 Å is stronger than the peak at 4.46 Å. The peaks of the dioctahedral kaolinite remain unaffected upon ethylene glycol treatment but get destroyed on heating above 450°C. Heat treatment helps in distinguishing kaolinite from chlorite which too has the basal reflection at 7.12 Å.

Vermiculite –

Vermiculite (Mg3(Si3Al)O10(OH)2Mg0.5(H2O4)4) forms about % of the total clay mineral assemblage. The peak at 14.4 Å corresponding to (002) plane is stronger than the peak corresponding to 2.39°. The reflection along the (021, 111) planes and along (060, 330, 332) planes are not distinct. The 14.4 Å peak of the trioctahedral vermiculite, containing strongly linked water molecule to the layer structure, expands to 15 Å - 16 Å on glycolation but collapses to 10 Å on heating up to 500°C.

Mixed- layer clay minerals –

Mixed-layer clay minerals formed as a consequence of regular, irregular or segregation of alternating packets which frequently occur in the sediments of the Nahan Formation. Irregular mixed-layers are generally more conspicuous than regular mixed-layers and are characterized by a series of non-linear reflections which result due to interference of very close diffracted rays.

4. MORPHOLOGICAL FEATURES

Based on the SEM result, the morphological character or microstructure of clay minerals in the sediment sample can be seen clearly. In figure- shows morphological features of clay minerals observed in the study area. Kaolinite normally formed in acidic environment like weathering of granitic rocks because it contains lot of feldspar that will turn into kaolinite after the weathering process.

Clay minerals that can be observed under SEM machine are illite, vermiculite and kaolinite.

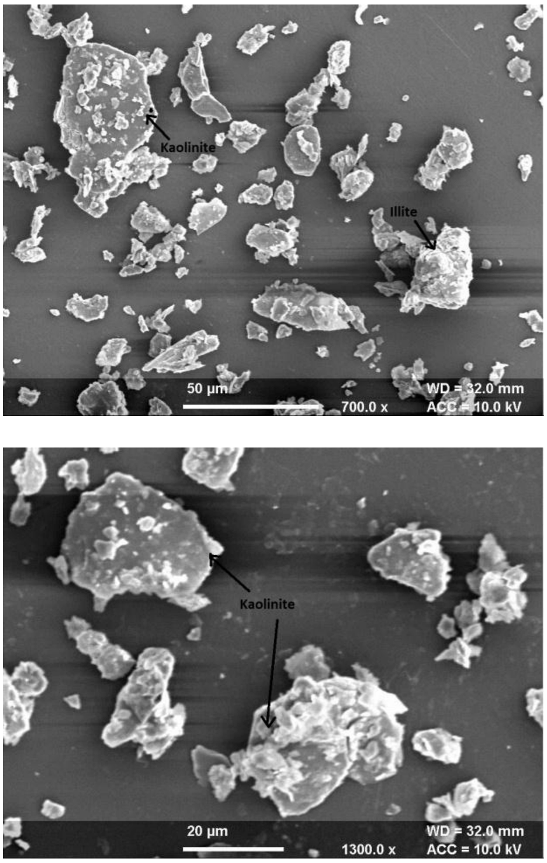

Fig. Clay mineral morphology observed under SEM in the study area

INTERPRETATION OF THE RESULT –

Clay minerals are the products of weathering and soil formation processes. The variation in the clay mineral assemblage is indicative of paleoclimatic changes, the cyclicity of tectonic activity and digenetic modifications experienced by the sedimentary horizon. Illite in Nahan Formation is primarily a product of detrital origin being derived from weathered crystalline rocks containing felspars and micas in the source areas and from soils and pre-existing sedimentary rocks in the drainage basin of fluvial channel(s) that deposited the sediments of the Nahan Formation.

Kaolinite is formed by weathering of igneous rocks which contain feldspar and mica that experienced weathering processes from the upstream and settle down in basin. The presence of kaolinite in the Nahan Formation is mainly attributed to the weathering and subsequent leaching of the mineral from these rocks in the source regions. Silicon and aluminum are the major chemical elements needed for kaolinite formation and these are derived by leaching of potassium felspars and micas present in the pre-existing rocks. The presence of kaolinite in the Nahan Formation indicates the prevalence of acidic conditions and presence of relict organic matter in the source areas and near neutral pH conditions in the basin of deposition.

Vermiculite forms as a result of selective fixation of potassium during diagenesis and as a consequence of alteration of fluorite and illite. An aggressive weathering regime following high precipitation and chemical weathering of feldspar and other intermediate weathering products has resulted in its development in the Nahan Formation.

Mixed layer clay minerals are present in the all the samples of the Pinjor Formation. In nature, clay minerals usually occur intermixed with each other. Environments rich in Na+ or K+ ions help in the formation of mica and hydrous aluminosilicate mixed layers.

Table 3 – Minerals present in sediment samples from three selected sections.

Sample No.	Lillie	kaolinite	Vermiculite
Shambhuwala – Nahan section			
SNR -17	++	+	+
SNR -22	+++	++	+
SNR -35	+++	++	+
SNR -43	++	+	+
SNR -54	+++	++	+
SNR -66	+++	++	+
SNR -88	++	+	+
Renuka – Nahan section			
RNR – 5	++	++	+
RNR -10	+++	++	+
RNR -17	+++	++	+
RNR -20	++	++	+
RNR -26	+++	++	+
RNR -33	+++	++	+
RNR -42	+++	++	+
Sataun – Rajban section			
SRR -7	+++	++	+
SRR -15	+++	++	+
SRR -25	+++	-	-
SRR -31	+	+	-
SRR -49	+++	++	+
SRR -65	+++	++	+
SRR -87	+++	++	+

Note: +++ dominant mineral (>50% observed), ++ frequent (21% - 50% observed), + few or less (< 21% observed), - none.

5. CONCLUSIONS

The Himalayan foreland basin has formed due to flexure of the Indian plate caused by the high mass of the evolving Himalayan mountain belt. Thrust tectonics, isostatic dynamics and load of overlain sediment have played a significant role in influencing the basin dynamics. The Siwalik sediments were deposited in a fore deep and represent the detrital products of the rather rapidly evolving Himalaya. The Himalayan tectonic activity reached its acme during the Quaternary period. During the period of deposition (Mid Miocene to Early Pleistocene) of the Siwalik sediments, the tectonic activity manifested itself in the formation of numerous fold and thrust structures by Chaudhri (2012), which intermittently increased the local relief triggering heightened erosion of the pre-existing rocks located adjacent to fore deep. The growth of the Himalaya also contributed significantly in altering the atmospheric circulation pattern and consequent climatic readjustments. The Indian Summer Monsoon (ISM) is perhaps the single most significant factor influencing the sediment supply of the foredeep sediments. Tectonic control of climate is best documented in the development of high relief intercontinental topographic barriers like the Himalayan mountain belt (Sakai et al., 2006). The rise of the Himalaya had a significant impact on the surface albedo and the atmospheric pressure regime which augmented the monsoon precipitation in the Himalayan terrain. Raymo et al., (1988) and Ruddiman (1997) suggested that the weathering processes acting in young orogenic belt consume carbon dioxide and drive global cooling. Deep sea sediment studies carried out in the Arabian Sea suggest that the ISM had established itself as a consequence of the Himalayan Mountain rise around 10 Ma and the monsoon intensity strengthened itself from about 8 Ma (Kroon et al., 1991 and Rea, 1992). Evidence from deep sea drilling in Bengal fan suggested an accelerated uplift of the Higher Himalaya around 10 Ma and subsequently after 0.9 Ma by Amano and Tyra (1992) and Derry and Lanord (1997). Studies from the Indus delta in the Arabian Sea carried out by Clift et al., (2008) suggest the intensification of the Indian summer monsoon after 14 ka.

Sediment supply in mountain regions is a complex interplay of tectonically related rock uplift and degradation processes influenced by precipitation. Hodges et al., (2004) and Wobus et al., (2005) favor precipitation as the primary controlling factor for sediment supply while Burbank et al., 2003 favor tectonic uplift. Clift et al., (2008) linked the volume and exhumation of the western Himalayan to the intensity of the summer monsoon.

In northwestern Himalaya rapid uplift of the Siwalik frontal range during Early Pleistocene to Middle Pleistocene has been reported by Burbank and Johnson (1983). Sakai et al., (2006) suggested that coeval uplift and consequent degradation of the frontal Lesser Himalaya since 1 Ma in Nepal had a perceptible influence on the composition of clay minerals observed in the deep sea Bengal Fan sediments.

The characteristic of clay minerals in terms of the mineral type and abundance is dependent upon three major factors viz, detrital inheritance, transformation and neo- formation. Clay minerals serve as reliable indicator of provenance and environments of sedimentation. Clay minerals are susceptible to alteration during transportation and accumulation in varying environments. The mineral illite is formed by weathering of felspathic and micaceous rock which is stable in moderate climatic conditions by M. L. Jacson (1959) and remains unaltered during transportation by fluvial agencies over a short distance of transport by Hurley et al (1961). A temperate environment and moderate weathering conditions have been recorded for the formation of Illite by Foth and Truck in 1973. Milne and Earley in 1958 suggested that illite is formed as a consequence of absorption of potassium from sea water by montmorrillonite. Digenetic origin of illite has been suggested by Chaudhri (1985, 1988), Chaudhri (1997), Velde (1983) and Shaw (1980). The clay mineral assemblage recorded from the Lower, Middle and Upper Siwalik subgroups in the northwestern Himalaya show variation in the mineralogy and abundance of different clay minerals given by Chaudhri (2000). In Lower Siwalik sediments, illite is the most dominant clay mineral followed by kaolinite, mixed layers and vermiculite. Chlorite and montmorillonite are nearly absent. In Middle Siwalik sediments a similar scenario persists with the difference that the abundance of vermiculite is severely reduced and montmorillonite is present in a few samples. In Upper Siwalik Pinjor Formation illite is the most dominant mineral followed by chlorite, kaolinite, vermiculite and mixed layer clay minerals. This variation in abundance of clay minerals reflects variation in source rocks, change in precipitation regime consequent to tectonism, variation in weathering pattern and distance of transport of the detritus and post depositional alterations/neoformation of the clay minerals. Siwalik sediments record reveals a slow pace of sedimentation for the Lower and Middle subgroups and a rather fast pace of sedimentation for the upper Siwalik subgroup. Degradation of the Himalayan hinterland during the deposition of this thick foreland stratigraphic unit resulted in successive unroofing of the evolving Himalaya and exposure of new hitherto buried lithologies to denudation processes. A variation in rates of tectonic uplift at local and regional scales as also uplift along thrusts and faults caused a change in precipitation levels and erosional patterns. The clay minerals/sediments of the Lower and the Middle Siwalik subgroups which were buried under the load of the overlying sediments underwent transformation/neoformation.

6. ACHKNOWLEDGEMENT

The author wish to record his sincere gratitude to Prof. Dr. A. R. Chaudhri for his constant support and guidance. The work was carried out at Department of Geology , Kurukshetra University, Kurukshetra.

REFERENCES

A. R. Chaudhri (1997). "Clay Mineralogy of the Nagthat Formation of the Chakrata Hills, Northwestern Himalaya," *Journal of Indian Association of Sedimentologist*, Vol. 12, No. 2, pp. 261-266.

A. R. Chaudhri (2012). "Tectonic Morphometric Studies as a Tool for Terrain Characterization in Himalayan Foothill Region—A Case Study," *Journal of Geological Society of India*, Vol. 79, No. 2, pp. 210-218.

A. R. Chaudhri, R. Ranga, M. Singh, V. Sharma and S. Mann (2016). "Heavy Mineral Assemblage of Lower Siwalik Nahan Formation, northwestern Himalaya and its significance in deciphering provenance."Journal of Geoscience Research, Vol. 1, No. 2, pp. 175-182.

A.R. Chaudhri and M. Singh (2012). "Clay Minerals as Climate Change Indicators—A Case Study" *American Journal of Climate Change,* 1, pp. 231-239.

B. Velde (1983). "Diagenetic Reactions in Clays," In: A. Parker and B. W. Sellwood, Eds., *Sediment Diagenesis*, D. Reidel Publication Company, Dordrecht, pp. 215-268.

C. Wobus, A. Heimsath, K. Whipple and K. Hodges (2005). "Active Out-Of-Sequence Thrust Faulting in the Central Nepalese Himalaya," *Nature*, Vol. 434, No. 7036, pp. 1008-1011.

D. K. Rea (1992). "Delivery of Himalayan Sediment to the Northern Indian Ocean and Its Relation to Global Climate, Sea Level, Uplift and Seawater Strontium," In: R. A. Duncan, D. K. Rea, R. B. Kidd, U. von Rad and J. K. Weise, Eds., *Synthesis of results from Scientific Drilling*, AGU, Washington, pp. 387-402.

D. Kroon, T. Steens and S. R. Troelstra (1991). "Onset of Monsoonal Related Upwelling in the Western Arabian Sea as Revealed by Planktonice Foraminifers," *Process Ocean Drilling Program Sciences Results*, Vol. 117, pp. 257-263.

D. W. Burbank and G. D. Johnson (1983). "The Late Cenozoic Chronology and Stratigraphic Development of the Kashmir Intermontane Basin, Northwestern Himalaya," *Pa-laeogeography, Palaeoclimatology, Palaeoecology*, Vol. 43, No. 3-4, pp. 205-235.

D. W. Burbank, A. E. Blythe, J. Putkonen, B. Pratt-Si-taula, E. Gabet, M. Oskins, A. Barros and T. P. Ojha (2003). "Decoupling of Erosion and Precipitation in the Himalayas," *Nature*, Vol. 426, No. 6967, pp. 652-655.

D. W. Burbank, L. A. Derry and C. France-Lanord, "Reduced Himalayan Sediments Production 8 Myr Ago despite an Intensified Monsoon," *Nature*, Vol. 364, No. 6432, 1993, pp. 48-50.

E. Raymo, W. F. Ruddiman and P. N. Froelich (1988). "Influence of Late Cenozoic Mountain Building on Ocean Geochemical Cycles," *Geology*, Vol. 16, No. 7, pp. 649-653.

H. Chamley (1989). "Clay Sedimentology," Springer-Verlag, Berlin.

H. D. Foth and L. M. Truck (1973). "Fundamentals of Soil Science," Wiley Eastern Pvt. Ltd., New Delhi, pp. 1-454.

H. F. Shaw (1980). "Clay Minerals in Sediments and Sedimentary Rocks," In: G. D. Hobson, Ed., *Developments in Petroleum Geology*, Allied Sciences Publication Ltd., London, pp. 53-85.

H. Milne and J. W. Earley (1958). "Effect of Source and Environment on Clay Minerals," *Bulletin of American Association of Petroleum Geology*, Vol. 42, No. 2, pp. 328-338.

H. Sakai, W. Yahagi, R. Fujii, T. Hayashi and B. N. Upreti (2006). "Pleistocene Rapid Uplift of the Himalayan Frontal Ranges Recorded in the Kathmandu and Siwalik Basins," *Palaeogeography*, *Palaeoclimatology*, *Palaeoeco- logy*, Vol. 241, No. 1, pp. 16-27.

J. J. Fripiat (1928). "Advanced Techniques for Clay Mineral Analysis," Elsevier Scientific Publication Company, Amsterdam, pp. 235.

K. Amano and A. Tyra (1992). "Two-Phase Uplift of Higher Himalayas since 17 Ma," *Geology*, Vol. 20, No. 5, pp. 391-394.

K. L. Linge (2008). Methods for Investigating Trace Elements Binding in sediments". Critical reviews in Enviornmental Science and Technology, Vol. 38, pp. 165-196.

K. V. Hodges, C. Wobus, K. Ruhl, T. Schildgen and K. Whipple (2004). "Quaternary Deformation, River Steepening, and Heavy Precipitation at the Front of the Higher Hima- layan Ranges," Earth and Planetary Science Letters, Vol. 220, No. 3-4, pp. 379-389.

L. A. Derry and C. F. Lanord (1997). "Himalayan Weathering and Erosion Fluxes; Climate and Tectonic Controls," In: W. F. Ruddiman, Ed., *Tectonic Uplift and Climate Change*, Plenum, New York, pp. 290-312.

M. L. Jackson (1959). "Frequency Distribution of Clay Minerals in Major Soil Groups as Related to Factors of Soil Formation," *Clays and Clay Minerals*, Vol. 6, pp. 133- 143.

M. Preda and M. E. Cox (2005). "Chemical and mineralogical composition of marine sediments and relation to their sources and transport, Gulf of Carpnetaria,Northern Australia". Journal of Marine systems,Vol. 53, pp. 169-186.

M. Singh (2009). "Sedimentology of the Pinjor Formation exposed in the type area Pinjore and surrounding regions" thesis, Kurukshetra University Kurukshetra, India.

M. Singh (2012). "Heavy Mineral Assemblage of the Pinjor Formation of the Northwestern Himalaya and its Significance in Deciphering the Provenance of the Sediments" Geosciences , 2(6): pp. 157-163.

N. A. Abdullah, L. I. Abdullah, N. A. Mohd. Shazili, and S. Sokiman (2015). "Clay Minerals on Recent Surface Estuarine Sediments from Selected Rivers of Terengganu, Malaysia", Journal of Earth Sciences ,Vol.1 , pp. 8-16

P. D. Clift, L. Giosan, J. Blusztajn, I. H. Campbell, C. Allen, M. Pringle, A. R. Tabrez, M. Danish, M. M. Rabbani, A. Alizai, A. Carter and A. Luckge (2008). "Holocene Erosion of Lesser Himalaya Triggered by Intensified Summer Monsoon," *Bulletin of Geological Society of America*, Vol. 36, No. 1, pp. 79-82.

P. Gautam and R. Wolfgang (1999). Depositional chronology and fabric of Siwalik group sediments in Central Nepal from magnetostratigraphy and magnetic anisotropy. Journal of Asian Earth Science, Vol. 17, pp. 659-682.

P. M. Hurley, D. G. Brookins, W. H. Pinson, S. R. Hearth and H. W. Fairbairn (1961). "K-Ar Age Studies of Mississippi and Other River Sediments," *Geological Society of America Bulletin*, Vol. 72, No. 12, pp. 1807-1816.

R. Petschick, G. Kuhn and F. Gingele (1996). "Clay mineral distribution in surface sediments of the South Atlantic: sources, transport and relationship to oceanography". Marine Geology, Vol.130, pp. 203-229.

R. S. Chaudhri (1971a) Petrogenesis of Cenozoic sediments of northwestern Himalaya. Geol. Mag. London, 108: pp. 143-148.

R. S. Chaudhri (1971a). "Petrogenesis of Cenozoic sediments of northwestern Himalayas", Geol. Mag., 108, pp. 43-48.

R. S. Chaudhri (1971b). Nahan- a problematic horizon of northwestern Himalaya. Jour. Geol. Soc. India, 12: pp. 373-377.

R. S. Chaudhri (1991). Sedimentology and genesis of the Cenozoic sediments of the Himalaya. Publ. Cent. Adv. Stdy. Geol.Pb. Univ.,4 (N.S.): pp. 1-32.

R. S. Chaudhri (2000). "Fifty Years of Research on Sustainable Resource Management in Siwaliks," In: S. P. Mittal, R. K. Aggarwal and J. S. Samra, Eds., *Geology of the Siwalik Group of Western and Central Himalaya*, Central Soil and Water Conservation Research and Training Institute, Research Centre, Chandigarh, pp. 3-18.

R. S. Chaudhri and C. K. Kalita (1985). "X-Ray Study of Clay Minerals of the Krol Formation of the Mussoorie Hills, Kumaon Himalaya," *Indian Journal of Earth Sciences*, Vol. 12, No. 4, , pp. 239-248.

R. S. Chaudhri and G. T. S. Gill (1983). "Clay Mineralogy of the Siwalik Group of the Simla Hills, Northwestern Himalaya," *Journal of Geological Society of India*, Vol. 24, pp. 159-165.

R. S. Chaudhri and H. S. Grewal (1988). "Clay Mineral Assemblage of the Jaunsar Group of Northwestern Himalaya," *Indian Journal of Earth Sciences*, Vol. 15, pp. 228- 233.

R. S. Chaudhri and N. Ramanujam (1985). "Clay Mineralogy of the Tal Formation of the Mussoorie Hills, Kumaon Himalaya," Publication Centre Advance Study of Geology, Panjab University, Chandigarh.

S. Ahmed and S. I. Hasnain (2007). "Textural, Mineralogical and Geochemical Characteristics of Sediment and Soil at High Altitude Catchment in the Garhwal Himalaya," *Geological Survey of India*, Vol. 69, pp. 291-294.

Suresh, N., Ghosh, S. K., Kumar, R. and Sangode, S. J. (2004). "Clay mineral distribution pattern in Late Neogene fluvial sediments of Subathu sub-basin, central sector of Himalayan foreland basin: Implication for provenance and climatic condition" Sed. Geol., 163, pp. 265-278.

T. N. Bagati and R. Kumar (1994). "Clay Mineralogy of Middle Siwalik Sequence in Mohand Area, Dehradun: Implication for Climate and Source Area," In: R. Kumar, S. K. Ghosh and N. R. Phadtare, Eds., *Siwalik Foreland Basin of Himalaya*, *Himalayan Geology*, Special Publication, pp. 219-228.

W. F. Ruddiman (1997). "Tectonic Uplift and Climate Change," Plenum Press, New York. 1997.

Z.F. LIU, Y.L. Zhao, C. Colin, F.P. Siringan, Q. WU (2009). "Chemical weathering in Luzon, Philippines from clay mineralogy and major-element geochemistry of river sediments", Applied Geochemistry 11 (24), pp. 2195-2205.

Corresponding Author

Rajesh Ranga*

Department of Geology, Kurukshetra University, Kurukshetra, Haryana

E-Mail –