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## RESEARCH ARTICLE

HEAVEY MINERALS ASSEMBLAGE OF QUATERNARY COLUMN OF HOMINID LOCALITY  
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*Abstract*

The Narmada river originates from Amarkantak plateau of Satpura Ranges in Rewa at an elevation of about 1057 m (220 40' -810 45'), it flows westerly course for about 1284 kms length across the middle of Indian subcontinent before entering Gulf of Cambay in the Arabian sea in Gujarat state. The Narmada River course conspicuously straight and is controlled by ENE\_WSW to E\_W lineament, is bounded by Vindhyan in the north and Satpura in the south. The Narmada valley has maximum length of about 1300 kms and has maximum width of about 32 kms. The Narmada Rift valley formed a linear trench in the middle of Indian subcontinent was an ideal loci for accumulation of sediments. The rift trench is intruded by the dolerite and other mafic and siliceous dykes and sills along lineaments in different phases of tectonic deformation. The Quaternary sedimentation incepting from glacial, followed by fluvio-glacial, lacustrine and fluvial activity. The platform of sedimentation had rinsing and sinking environment, block faulting, linear, displacement and dislocation, uplifting and isolated domal up- lift. The Neogene rifting and quaternary sedimentation, rift-bound Pliocene–Pleistocene rifting and volcanic activity specifically during glacial and fluvio-glacial phase are major component of the Quaternary period and tectonic processes of the Narmada Rift System which form the base of quaternary deposits.

The Narmada Valley in the Hathnora area is occupied by thick Quaternary sediments. These sediments are classified based on sedimentary depositional environments, sedimentological characters and correlation with depositional / erosional terraces. The lower most unit (Boulder conglomerate) is of glacio-fluvial origin (Khan *et al* 1991) whereas the rest of fluvial origin. The top four formations (Sohagpur, Shahganj, Hoshangabad and Janwasa) are classified based on morphostratigraphic status (NT<sub>0</sub>-NT<sub>3</sub>), degree of oxidation, calcification and compaction. The Janwasa formation comprises of sediments of active domain of Narmada whereas the three formations Sohagpur, Shahganj, Hoshangabad are related to older flood plains deposits of paleo-domain of Narmada and are grouped under older alluvium. Boulder conglomerate of fluvio-glacial origin is assigned an independent formational status based on distinct lithology and fossil assemblage. The sequence of Quaternary events and the history of sedimentation of Narmada indicate that the upper 70 m top 90 m of the Narmada, when dissection of the alluvium resulted two terraces (NT<sub>3</sub>-NT<sub>2</sub>). The sediments of this aggradations episode constitute three lithostratigraphy units viz. Boulder conglomerate,

Sohagpur and Shahganj formation. The sediments of the alluvial phase are underlain by a boulder bed of glacio-fluvial origin. Thus, the fossiliferous boulder conglomerate, the basal unit of alluvium marks a disconformity between the lower glacial-boulder layer and upper fluvial sediments. The fossiliferous basal boulder conglomerate is being of middle Pleistocene age (Khan 1992). The Quaternary sediments in Narmada represent three distinct group of deposits viz. glacial, fluvio- glacial and fluvial; which was deposited in distinct enviroment in Quaternary times.

The Hathnora Section \_I to IV ( $22^{\circ} 52''$  N;  $77^{\circ} 58''$  E) are located around village Hathnora between Sardarpur\_Hoshangabad along Narmada from where the 203 sediment samples are collected for heavy mineral studies. In river section 18 m scrap of quaternary sediments consisting of Boulder conglomerate and deposits of fluvial terraces are exposed in increasing antiquity. The Boulder bed is hidden and concealed in the area under younger deposits as such samples have been taken from ongoing bore hole drilling log between the depths of 90 to 201 m below the surface for heavy mineral study. The qualitative and quantitative studies of heavy minerals of Quaternary deposits of different domain revealed five prominent heavy mineral suites viz, opaque suite; amphibole-pyroxene suite, biotite-muscovite-chlorite suite, garnet, sillimanite, kyanite, staurolite suite and zircon, rutile, tourmaline suite. Among these the minerals of opaque suite, is the chief constituents of the heavy residue of sediments in Narmada, in varying frequencies from 10.50 to 39.50 and on average it contributess about 34.30,41.4 0 of total heavy fraction in the entire area of study. The higher frequency of these minerals towards the younger terraces in Narmada is most conspicuous. The minerals of amphibole and pyroxene on the other hand exhibit uniform frequencies; an increase in frequency is noticed towards the terraces of fluvial domain. It is attributed to the exposure of these mineral bearing rocks, such as basics, ultramafic, and volcanic to denudation towards the later phases of sedimentation (Khan et al, in press). The mica group of minerals include muscovite, biotite and chlorite, the over all frequencies of these minerals in the entire quaternary varies from 4.50 to 23.50, muscovite 5.00 to 16.50 and chlorite 2.50 to 7.50 and average frequencies are 18.80, 13.85, 11.75 respectively . These minerals exhibit increasing contribution towards Boulder conglomerate and fluvial terrace depositsof paleodomain The shape,size and their diagnostic physical characters in these deposit implies the extensive erosion of mica-bearing rocks, such as muscovite, biotite schist, gneiss, granite and pegmatite rocks in the headwards ends of Narmada during the early phases of sedimentation. The minerals of high metamorphic suite includes garnet, sillimanite and kyanite the over all frequencies varies from 3.50 to 9.25, 3.50 to 8.50, 9.50 to 7.00 and 3.50 to 6.50 and average frequency is 8.58, 7.75, 5.5 and 5.00. The affinity of higher frequencies of these minerals towards older deposits viz. glacial and fluvio-glacial appears to be due to ready availability of these minerals bearing rocks to erosion. The mineral of stable group viz. rutile, zircon and tourmaline show uniform distribution in the entire domain of terraces in the area of study.The zircon rutile, tourmaline and sphene are highly stable minerals though their abundance is common in quaternary deposit, howeverthey are considered to be very significant as they bear imprints of tectonics, neotectonics and environment of sedimentation . The grain morphology and imprints of sedimentation these mineral bear are of immense significance in understanding the source of sediment, its nature of transportation, mode of transport, kinetics of medium and sedimentation. Their relative frequency in critical column bear significance as regard to tectonic set up of various rock

units in the watershed. The contrasting grain morphology of these heavies in the various

domains of quaternary deposits are useful in tracing the environments of their deposition. The amphibole and pyroxene minerals with low stability such as hornblende, hypersthene, are more significant as regards to the correlation and chronological status of quaternary deposit. These minerals show variable degree of stability and morphological characteristics, hence these parameters have been taken into account in deciphering the mode of environment of sedimentation and correlation of quaternary deposits in Narmada Valley.

The zircon rutile tourmaline and sphene minerals occur as accessories mineral, mostly released from rock fabrics comprising boulder bed and were subjected to different degree of wear and tear and physical condition of weathering transport and deposition, the micro imprints acquired by different condition of sedimentation revealed the intense grinding and bed traction of sediments from the source. The striations on these minerals indicate intense glacial activity in the initial stage of sedimentation. These are generally angular to highly angular in shape and show very poor indices of sphericity and roundness typical of glacial environments.

The study revealed that sediments were primarily derived from metamorphic source comprising of kyanite-paragonite, muscovite schist, gneiss, garnet mica schist, and para-amphibolite metasedimentaries and meta-volcanic. Apart minerals were also reworked from older Quaternary deposits from Boulder bed (glacial deposit), Boulder conglomerate of (fluvio-glacial deposit) and older terraces of fluvial domain. These heavies were basically transported from the sources area by glacial fluvio-glacial and fluvial agencies to the present site of their occurrence. The mode of transportation, environment of deposition and energy system of transporting media has greatly affected the frequency and concentration of heavies, their grain morphology and stability in that particular domain. These minerals, mostly released from rock fragments and other fabrics comprising boulder bed, subjected to intensive wear and tear and physio-chemical environment of weathering transport and deposition. The micro imprints acquired by different phases of sedimentation revealed the intense grinding and bed traction of sediments from the source. The striations on these minerals indicate glacial activity in the initial stage of sedimentation. These suites of minerals are stable as compared to the other suite of these deposits; although these mineral are associated with all domain of quaternary deposits but show different frequency of their occurrence and physical characters, shape size sphericity and roundness and bear the micro imprints related with tectonics and environment. The striations on these minerals indicate glacial activity in the initial stage of sedimentation. The configuration of minerals, rock clastic, ground mass, imprints and impact of tectonics revealed the anisometric environments of sedimentation in Narmada valley.

The study of heavy mineral suites of Quaternary deposits indicate that the sediments are derived from mixed sediments source comprising of Lower protozoic and middle protozoic rocks consisting of gneisses granite metabasic, amphibolites, meta-sedimentaries, high grade biotite gneisses, muscovite gneisses, kyanite, paragonite, muscovite – schist, gneiss, garnet-mica schist, para amphibolite, tourmaline garnet, meta – sedimentaries and meta -volcanics and Gondwana rocks.

## Introduction:-

The Narmada river originates from Amarkantak plateau of Satpura Ranges in Rewa at an elevation of about 1057 m (220 40' -810 45'), it flows westerly course for about 1284 kms length across the middle of Indian subcontinent before entering Gulf of Cambay in the Arabian sea in Gujarat state. Plate No\_1

The Narmada River course conspicuously straight it is controlled by ENE\_WSW to E\_W lineament, bounded by Vindhyan in the north and Satpura in the south. The Narmada valley has maximum length of about 1300 kms and has maximum width of about 32 kms.

The Narmada Rift valley formed a linear trench in the middle of Indian subcontinent was an ideal loci for accumulation of sediments. The rift trench is intruded by the dolerite and other mafic and siliceous dykes and sills along lineaments in different phases of tectonic deformation. The Quaternary sedimentation incepting from glacial activity, followed by fluvio-glacial, lacustrine and fluvial phase within the rifting and sinking environment, block faulting, linear displacement, differential dislocation, uplifting and isolated domal up- lift, Neogene rifting Quaternary sedimentation and rift-bound Pliocene–Pleistocene volcanic activity specifically during glacial and fluvio-glacial phase are major component of the Quaternary period of Narmada Rift System which form the base of quaternary deposits.

The Narmada rift system basin platform provided a unique setting for dynamic ecosystem that was characterized by rift-related subsidence and coeval sedimentation which has also created an ideal loci of Quaternary sedimentation and environment for the accumulation of sediments, burial of organic remains, diagenesis, and preservation. The rift formed after widespread Quaternary sedimentation and accumulation of voluminous sediments in the rift basins by glacial activity consequential upon the lowering of temperature and climatic changes.

The principal tributaries of Narmada river are Sher Sakkar Dudhi Tawa and Ganjal, Hiran & Gaur Man, Karjan, Madhumati, Heran and Orsang, Amravati are the other tributaries of Narmada valley. They all originate from the Satpura and Vindhyan hills from south and north of the trunk channel. The only important tributary on the north is Hiran River, which emanates from the Vindhyan hills around Jabalpur.

The catchment area of the river, bordered by the Satpura and Vindhya mountain ranges, stretches over a territory of 98,796 km<sup>2</sup> (38,145.3 sq mi). It is situated between longitudes 72°32' and 81°45' east and latitudes 21°20' to 23°45' north, on the northern edge of the Deccan Plateau. The catchment area encompasses important regions in Madhya Pradesh, Gujarat, and Maharashtra.

The Quaternary tract of Narmada basin covers an area of about 17950 sq. km starting from west of Jabalpur (23°07' 79 05 30) to east of Harda (22° 29'; 76° 58'), and Gureshwar and Bharouche section in Gujarat state for a distance of about 1320 km. It is found to be ideal locus of Quaternary sedimentation in Central India as witness by multi-cyclic sequence of Quaternary terraces in the valley. The general elevation of Narmada alluvial plain varies between 265.7 and 274.3 m above the sea level. The general gradient of this plain in this stretch is about 1m /Km towards West. (Plate No \_1 to \_3)

## Quaternary deposits of hominid locality hathnora & Narmada man:-

The Hathnora has received attention of scientist after the recovery of Human Skull Sonakia (1984). The Quaternary deposits of the Narmada valley represent the thickest quaternary deposits in peninsular India. They contain the richest vertebrate fossil assemblage including only known Hominid fossil from the Indian sub-continent (Sonakia 1984). The boulder conglomerate which yielded Hominid fossil reported for the first time to be of glacial & fluvial origin (Khan & Sonakia 1992). Beside occurrences and association of ash beds with fossiliferous boulder conglomerate (Khan & Rahate 1991) indicates some of the volcanic source. It appears that close to the completion of cycle of deposition of the boulder bed there was violent volcanic eruption and subsequent settling of the ash. The occurrences of association of two well marked horizons at different levels further reveal the cyclic eruption and settling of volcanic matrix during sedimentation. The Boulder conglomerate which is of glacio-fluvial origin Khan and Sonakia (1992) which represents arid and humid cycles of climate is also associated with volcanic ash. The morpho and lithostratigraphy of Narmada valley has described of the area by Khan (1984), Khan & Benarjee (1984), Khan & Rahate (1990-91), Khan & Sonakia (1992), Khan *et al* (1991), Rahate & Khan (1985), Khan (1991), Khan & Sonakia (1992), Yadav & Khan (1996).

The Narmada valley forms an ENE-WSW lineament and Quaternary deposits are confined in trough like basin, with profound asymmetry in northern and southern valley walls. The Narmada valley in Peninsular India forms a prominent lineament with profound geomorphologic and geological asymmetry between the northern and southern valley walls, giving it a tectonic significance. The alluvial deposits of the Narmada valley represent the thickest Quaternary deposits in peninsular India. Beside the association of fossils and tool and stone implements of these deposits are well described. The quarries on various aspects on geology geomorphology, sedimentology, provenance of sediments, stream kinetics, stratigraphy, chronology, tectonics, neotectonic, subsurface geometry, and overall model of Quaternary sedimentation of Narmada in faulted and sinking platform under structural riparian rift trench are unquantified as such hidden miseries needs attention.

The complete account of Quaternary lithostratigraphy has been up dated in the Narmada valley (Khan 1984, Khan & Benarjee 1984, Khan & Rahate 1990-91-90 Khan & Sonakia 1992, Khan *et al* 1991, Rahate & Khan 1985, Khan *et al.* 1991, Khan 1991, Khan *et al.* 1992, Yadav & Khan 1996. The Narmada valley embodies almost complete sequence of the Quaternary deposits in time span from the lower Pleistocene to Holocene (Khan & Sonakia (1992). Khan (1912), Khan (2012), Khan (in press), Khan (in press). The results of sedimentological studies Khan (2015), quartz grain morphology, Khan (2014), quartz grain morphology, Palesole Quaternary column section in Hominid locality in central sector of Narmada revealed the presence of complete sequence of quaternary sediments in Narmada rock basin consisting of glacial, fluvio-glacial and fluvial domain; whereas the boulder conglomerate which has yielded human skull is of fluvio-glacial origin Khan & Sonakia (1991).

The results of analysis of sedimentary structures Khan (in Press), Quartz grain morphology of sediment column, Khan (2014) Quartz grain morphology of different paleo- sole, Khan (2014), Ash bed Khan & Maria (2012) tephrostratigraphy, Khan *et al* (1991) Khan & Maria (1912) Ash fall and its impacts (2015) magnetostratigraphy, and bio-stratigraphy and correlation of sediment columns intra valley wise, inter valley wise and on unified Quaternary Platform Khan *et al* (2012) focusing on hominid localities of China, where the data has enlightened about the age of the Narmada *Homo erectus*.

In the present work an attempt has been made for the first time to conduct detailed sedimentological and heavy mineral studies with an objective to build-up and conceive the Quaternary sedimentological model with environment of sedimentation of the Hominid locality Hathnora in Narmada valley. About 150 sediment samples were collected from surface and subsurface quaternary deposits and from ongoing drilling logs up to 180 m below the ground surface and carried out detailed statistical analysis in the laboratory which is presented. (Plate No \_1 to \_3)

The skull cap of Narmada man *Homo erectus* Narmadanesis was found in near village Hathnora (22° 52' N; 77° 52' E) in fossiliferous boulder conglomerate, (Sonakia, 1984) at an elevation of about 268 m above the m.s.l. and at the depth of about 83 m in Central Narmada Valley. These deposits are underlain by fluvio-glacial deposits and overlain by fluvial deposits of palaeo-domain of Narmada. The Quaternary sequence of Hathnora is described by Khan & Sonakia (1992).

The skull cap of *Homo erectus* "Narmada Man" is recovered from the vom of basal unit of boulder conglomerate at the depth of 83 m. (278 m. above m.s.l.) is estimated to be 1.20 (+) m.y.r. old. Table No QGT 99\_101

The statistical analysis of sediments from these different domain in vertical column has been attempted Khan & Maria (2015) revealed that Narmada Rift Valley forms the linear trench and Sonata Lineament where the inception of quaternary sedimentation occurred by glacial activity. The tectonic trench which is the mega structural disconformity and had unstable platform still possess intact quaternary deposits. The heavy mineral and sedimentological studies have assisted to ascertain and trace the breaks in environment of sedimentation and climate (Khan *et al.* in press).

On critical analysis of data heavy mineral study, it has been conceived for the first time Khan *et al* (2013) that the stratigraphic columns of associated hominid fossils of Narmada valley (325 m) India and that of Luochuan sequence, (90-120 m) Chenjiawo (50m) and Congwanling sequence (36 m) of China on unified Quaternary platform tied up and developed at mean sea level revealed that the depth of occurrence of Narmada skull cap on unified Quaternary platform is about (83 m) as compared to with that of Chenjiawo and Gongwangling of China which occur at very shallow depth of 38 and 26 m respectively. On the merits of collective sedimentological study



Khan & Maria (2015) and heavy mineral analysis across entire thickness of sediments, correlation of stratigraphic columns, accumulation of sediment, rate of sedimentation, palaeo- environments, lithostratigraphy and biostratigraphic position of boulder conglomerate on unified Quaternary Platform, author considers that Narmada Man is one of the earliest and oldest *Homo erectus* in Asia. Khan et.al (2013).

The skull cap of Narmada man *Homo erectus* was found in near village Hathnora (22 ° 52" N; 77 ° 52" E) in fossiliferous boulder conglomerate, (Sonakia, 1984) at an elevation of about 268m above the m.s.l. and at the depth of about 83m in synchronized stratigraphic column in Central Narmada Valley. These deposits are underlain by glacial deposits and overlain by fluvial deposits of palaeo-domain of Narmada. The Quaternary sequence of Hathnora is described by Khan & Sonakia (1992).

In Homonid locality in Hathnora section I to IV 203 sediment samples were precisely taken from four crucial and critical section, representative stratigraphic columns of complete sequence of quaternary deposits (320 m), i.e. Boulder bed, Boulder conglomerate and Fluvial deposit in increasing antiquity. The objective of study to understand the assemblage heavy minerals their distribution trends, breaks in environment of sedimentation in tectonic and turmoil trench basin dynamics in increasing antiquity and provenances in Narmada valley. The results of study are illustrated in Table No HM-.1 to 4

### **Analytical techniques:-**

The representative samples were taken for heavy mineral analysis from the Boulder bed, Boulder conglomerate Fluvio-glacial & Fluvial deposit. The bulk samples were reduced to appropriate size by conning quartering and about 100 gram samples were analyzed using the different sieves. The size grades of 2.00 and 3.25 were taken for heavy mineral separation, clay fraction was removed by repeated decantation and sized detrital grains were cleaned with acetic samples having thick coating of ferruginous matter were treated with dilute solution of hydrochloric acid and stannous chloride. The cleaned samples were washed with distilled water and dried in oven at low temperature. The Heavy mineral separation was carried out by Bromoform of sp.g 2.89. The heavy mineral thus obtained was mounted on the slides and studies both quantitatively and qualitatively under microscope. The percentage and frequency of various minerals is given in Table No HM-.1 to 4 & represented graphically.

### **Mineralogy:-**

The heavy mineral assemblage of different domain of Quaternary deposit of Narmada and its tributaries consist of opaque and non-opaque groups. The mineral assemblage is more or less similar in these sediments, nevertheless, a great deal of variation noticed in their abundance (Khan et. al; in press). These minerals exhibit distinguished morphological characteristics and significant variation in their physio-chemical stability the results of model analysis are portrayed in Table No. HT\_1 to 4

### **Physio-chemical stability:-**

The composition and abundance of the heavy minerals is exclusively dependant on their stability against wear and tear in course of transportation and the physio-chemical parameters of the environments of deposition.

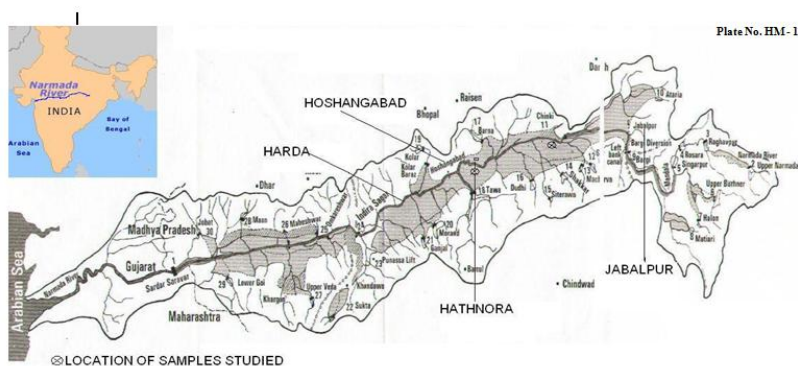
The samples of Narmada and its tributaries the minerals with high stability are zircon and rutile. They are ubiquitous in all the samples and hence are not considered to be very significant. Their relative frequency augments in critical column bear significance as regard to erosion pattern and tectonic set up of various rock units in the watershed regions of Narmada. The contrasting grain morphology of heavies in the various regimes of terraces is useful in making out the environments of their deposition. Minerals with low stability such as hornblende, hypersthene, and biotite are more significant as regards to the correlation and chronological status of terrace deposit. These minerals show variable degrees of stability and morphological characters, hence, these parameters have been taken into account as it is deciphering the mode of environment of deposition, sedimentation and correlation of terraces in Narmada Valley. The mineral assemblage is more or less similar in these sediments, nevertheless, a great deal of variation noticed in their abundance, frequency, shape size shape and size and grain morphology (Khan et.al; in press) These minerals exhibit distinguished morphological characteristics and significant variation in their physio-chemical stability. The composition and abundance of the heavy minerals is exclusively dependant on their stability against wear and tear in course of transportation and the physio-chemical parameters of the environments of deposition.

### Hathnora section \_I :-

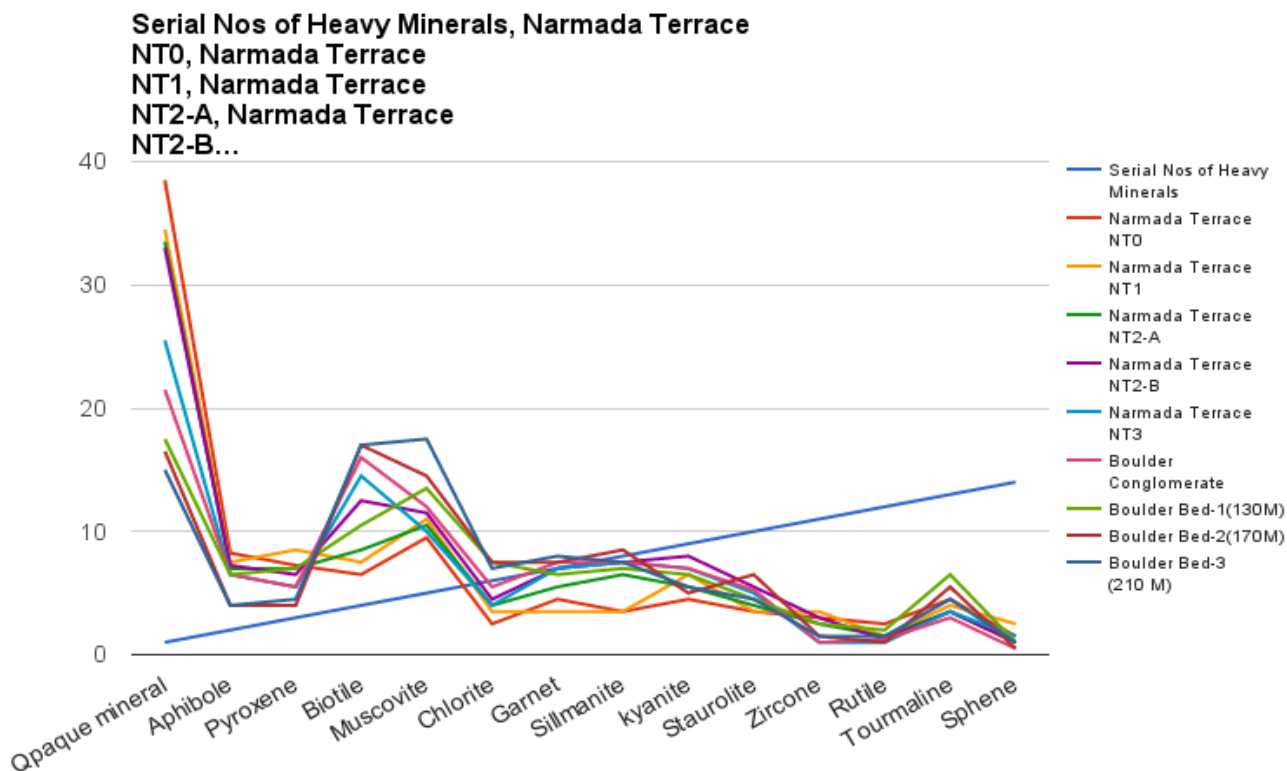
(22° 52' N; 77° 52' E)

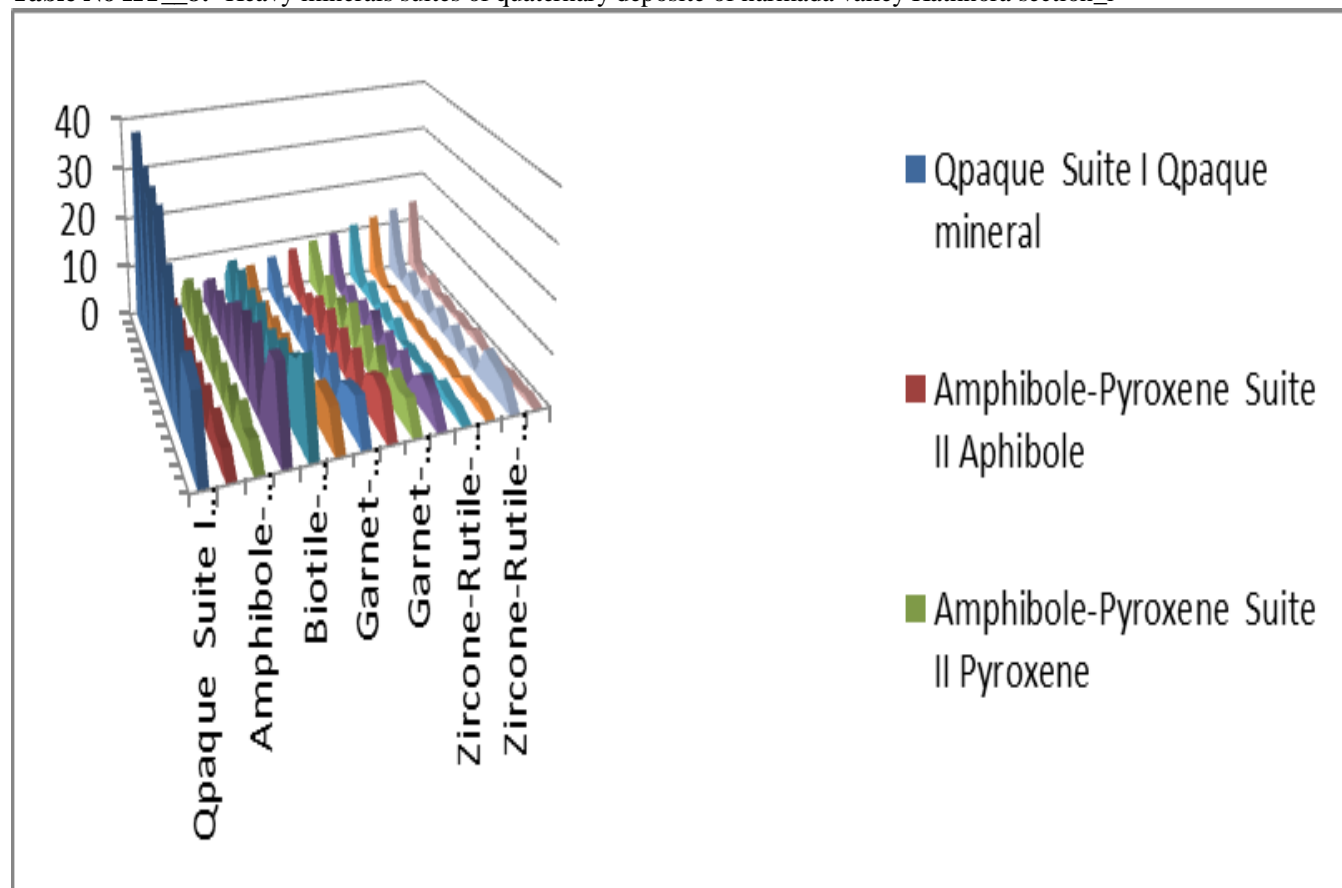
The Hathnora Section \_I is located at village Hathnora the sediment samples have been collected from the exposed section of Quaternary deposits. In river section 18 m scrap of sediments of Boulder conglomerate and fluvial terraces is exposed in increasing antiquity. The underlying sediments of Boulder bed are concealed under boulder conglomerate as such samples have been collected from ongoing bore hole logs between the depth of 90 to 210 m below the surface.

The study of sediment samples revealed the presence of five suites of heavy mineral assemblages in the quaternary deposits of Hominid locality are i) Opaque Suite ii) Amphibole-Pyroxene Suite iii) Biotite-Muscovite-Chlorite Suite iv) Garnet Sillimanite-Kyanite Staurolite Suite v) Zircon-Rutile-Tourmaline and Sphene Suite. (Table No HM\_1,) Plate No HM\_4 & 8.

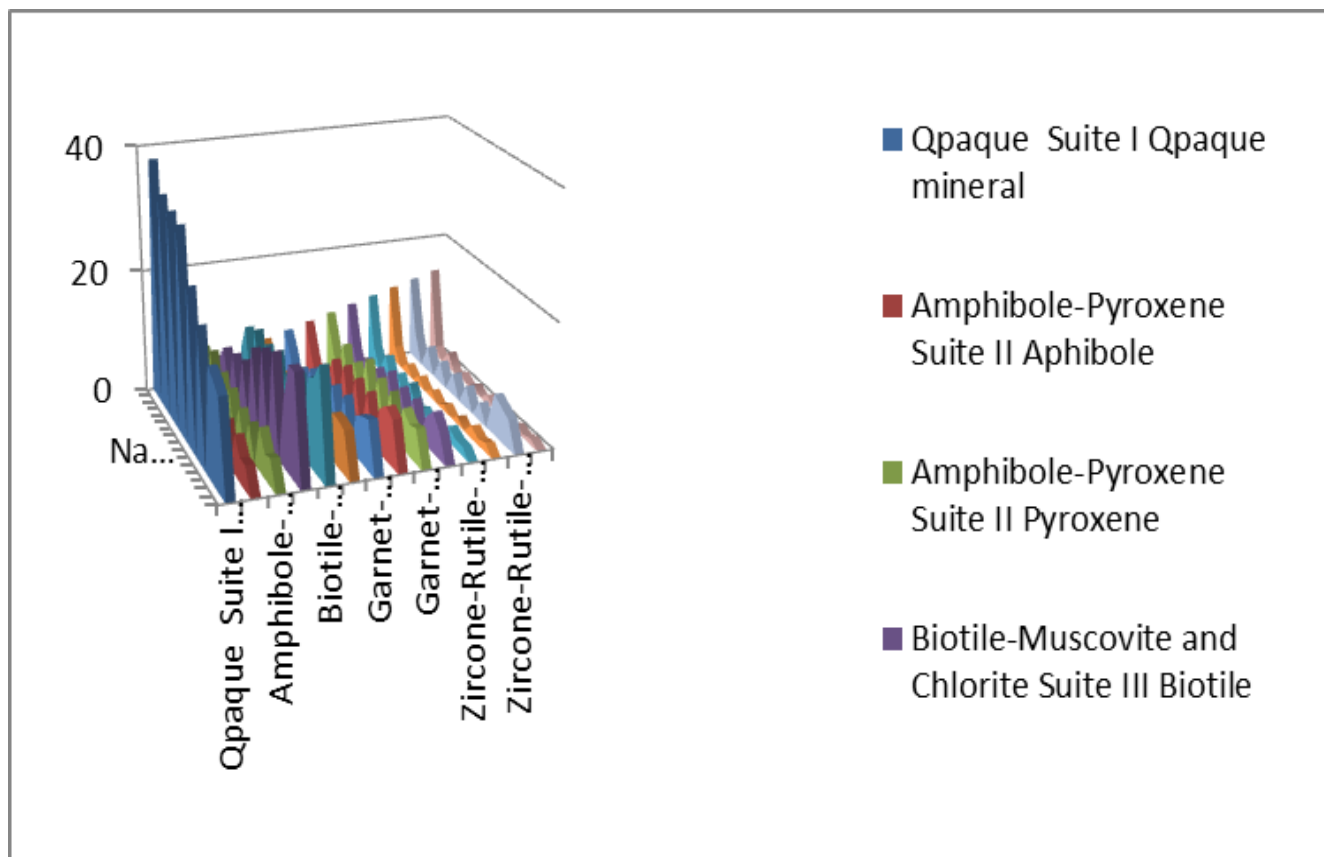


Heavy minerals suites of quaternary deposit of Narmada valley Hathnora section\_i  
Plate No. HM-5



**Table No HT\_\_8:-** Heavy minerals suites of quaternary depostite of narmada valley Hathnora section\_i



**Plate No HT\_\_9:-** Heavy minerals suites of quaternary deposit of narmada valley Hathnora section\_ii

**Table No HM\_ 1:-** Heavy minerals suites of quaternary deposite of Narmada alley Hathnora section\_I

Hathnora Section_I Quaternary deposits of Glacial Fluvio-galcial & Fluvial domain of Narmada	Qpaque Suite	Amphibole- Pyroxene Suite		Biotile-Muscovite and Chlorite Suite			Garnet-Sillmanite- KyaniteStaurolite Suite				Zircone-Rutile-Tourmaline- Sphene Suite			
	I	II		III			IV				V			
	Qpaque mineral	Aphibo le	Pyroxe ne	Biotit e	Musco vite	Chlo rite	Gar net	Sillma nite	kyani te	Staurol ite	Zirco ne	Rutil e	Tourmal ine	Sphene
Serial Nos of Heavy Minerals	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Narmada Terrace NT <sub>0</sub>	38.50	8.25	7.25	6.50	9.50	2.50	4.50	3.50	4.50	3.50	3.00	2.50	4.50	1.50
Narmada Terrace NT <sub>1</sub>	34.50	7.50	8.50	7.50	11.00	3.50	3.50	3.50	6.50	3.50	3.50	1.50	4.00	2.50
Narmada Terrace NT <sub>2</sub> -A	33.50	7.00	7.00	8.50	10.50	4.00	5.50	6.50	5.50	4.00	2.50	1.50	3.50	1.00
Narmada Terrace NT <sub>2</sub> -B	33.00	7.25	6.50	12.50	11.50	4.50	7.00	7.50	8.00	5.50	3.00	1.25	3.50	1.00
Narmada Terrace NT <sub>3</sub>	25.50	6.50	5.50	14.50	10.00	4.00	7.00	7.50	7.00	5.00	1.00	1.00	3.50	1.50
Boulder Conglomerate	21.50	6.50	5.50	16.00	12.00	5.50	7.50	7.50	7.00	5.25	1.00	1.25	3.00	0.50
Boulder Bed- 1(130M)	17.50	6.50	7.00	10.50	13.50	7.50	6.50	7.00	6.50	4.50	2.50	2.00	6.50	1.00
Boulder Bed- 2(170M)	16.50	4.00	4.00	17.00	14.50	7.50	7.50	8.50	5.00	6.50	1.50	1.00	5.50	0.50
Boulder Bed-3 (210 M)	15.00	4.00	4.50	17.00	17.50	7.00	8.00	7.50	5.50	4.50	1.50	1.50	4.50	1.00

**Opaque Suite:-**

This suite of mineral in the sediment of Boulder bed is characterized by the minerals like hematite, magnetite and ilmenite. These minerals show variation in their distribution & frequency. The relative frequency of these sediments in these deposits is 12.50, 16.00 and 18.50 respectively. The grains of minerals are mostly angular to highly angular in shape and show very poor degree of roundness typical of glacial environments.

The sediments of Boulder conglomerate of Fluvio-glacial deposit consist of predominantly hematite, magnetite and ilmenite which contribute about 18.45 percent of total heavies. These minerals are generally sub-angular to angular and sub-rounded in shape and show improvement in roundness over the opaque suite of minerals of sediments of glacial origin.

The opaque minerals of fluvial deposit chiefly consist of magnetite, hematite and ilmenite. These minerals show variable frequency in this deposit of Narmada. The frequencies of these mineral viz, magnetite varies from 18.50 to 36.50 whereas the relative frequency in NT-0 NT2 is 36.50, 35.50, 33.50, 32.00 26.50 and 21.50 respectively. The average frequency of opaque suite of minerals in fluvial regime is 32.20. where as the Boulder Bed-1, 2, & 3, indicate individual frequency of 12.50, 16.50, 18.00. The relative frequency of opaque suite increases in increasing antiquity. These minerals are sub-rounded to well round in shape and exhibit higher order of sphericity and roundness in contrast to the glacial and fluvio-glacial and typical of fluvial environments.

**Amphibole-Pyroxene Suite –**

Boulder bed contains amphibole Boulder bed \_1 to Boulder bed \_4.00, 4.00, 6.50 5.50 respectively, the average frequency is 5.25, where as frequency of pyroxene is 5.50, 7.00, 4.00, 4.50 and average is 5.00. The relative frequency of these minerals increases in increasing antiquity. These minerals are predominantly sub-hedral and anhedral in shape the wear and tearing of these minerals increases in increasing antiquity in sedimentary columns in the valley. The relative roundness of these minerals among the fluvial terraces significantly shows improvement towards younger deposits, which revealed the cyclic and repeated reworking of these minerals in the valley from glacial front. The increasing frequencies of these minerals from Boulder bed \_1 to Boulder bed \_3 towards upper deposits indicate extensive erosion of these mineral bearing rocks towards later phases of sedimentation.

This suite in the sediment of Boulder bed and Boulder conglomerate is characterized by association of highly altered hornblende and hypersthene minerals. The frequency of these minerals viz. hornblende and hypersthene varies from 4.00 to 9.25; the relative frequencies are 4.50, to 9.254. The average frequencies are 6.33, 6.50. The older sediments of Boulder bed at the depth of 190-210 m below the surface exhibit low frequencies of these minerals, which indicate selective erosion of mother rocks of these minerals in early phases of sedimentation in the valley.

These minerals are predominantly sub-hedral and occasional anhedral in shape and show higher degree of alteration as compared to sediments of fluvial and fluvio-glacial origin. The Boulder conglomerate contributes about 4.00 each of amphibole and pyroxene of total heavies in the valley. The majority of grains of these minerals are sub-hedral and anhedral in shape and show moderate degree of sphericity and roundness and as compared to the heavies of other group of sediments. This mineral show moderate to high degree of alteration, it is more pronounced along the cleavages and outer edges of these minerals.

This suite of minerals in the sediments of fluvial deposit is characterized by hornblende and hypersthene, which varies in range viz. hornblende 6.50 to 8.35, hypersthene 5.50 to 7.50, whereas the individual frequencies in NT-0 NT1 NT-2A, NT-2B, NT-2C, NT-3 of hornblende is 9.25, 7.50, 7.00, 7.25, 6.55, 7.25.

**Biotite-Muscovite-Chlorite Suite:-**

This suite consists of flaky minerals viz. biotite, muscovite and chlorite. The frequency of these minerals in Boulder bed viz. biotite varies from 6.50 to 17.50, muscovite 10.50 to 17.50, chlorite 2.50 to 7.50, relative frequencies for biotite are 10.50 to 17.00, & 17.00, for muscovite 13.50, 14.50 17.50, chlorite 7.00, 7.50, 7.50 and average frequencies are 34.50, 11.50 and 7.50 respectively at in between the depth of 130 to 210 m below the surface. The relative frequency of these minerals generally decreases upward. These minerals are generally sub-hedral and anhedral in shape and exhibit poor degree of roundness and sphericity typical of glacial environment. In general these minerals show high degree of alteration. The biotite often possesses quartz as inclusive mineral. The muscovite show highest degree of alteration among this suite of minerals.

The Boulder conglomerate mainly consists of, biotite muscovite with subordinate amount of chlorite. The frequency of these minerals are biotite 16.00, 12.00, 5.50, respectively these minerals are generally sub-hedral and anhedral in shape and depict moderate indices of sphericity and roundness, alteration along the cleavages and outer edges of these minerals is very prominent in these sediments. The majorities of muscovite grains are anhedral in shape and show highest order of alteration, followed by biotite and chlorite respectively.

The zircon and quartz are identified as accessories minerals with this suite which generally occur as inclusive minerals. The sediments of paleo- domain of Narmada consist of biotite as prominent mineral of this suite, followed by muscovite and chlorite. The frequency of biotite in this regime of terraces varies from 6.50 to 14.50, muscovite 10.00 to 11.50 and chlorite 2.50 to 4.00. The relative frequencies of these minerals of terraces NT-0 NT1 NT-2A, NT-2B, NT-2C, NT-viz. biotite is 6.50, 7.50, 8.50, 12.50, 14.50, muscovite 10.50, 11.50, 10.50, 11.00, 10.00 and of chlorite is 2.50, 3.50, 4.00, 4.50, 4, and average frequencies are 11.20, 11.20, 3.50 respectively.

These minerals are generally euhedral and sub-hedral in shape typical of fluvial environment. These minerals show variable degree of alteration increases from biotite to chlorite, where biotite show little alteration followed by muscovite which is moderately altered and chlorite exhibit highest degree of alteration. In this suite of quartz and zircon occur as accessories inclusive minerals pre-dominantly with biotite. These minerals are generally sub-rounded to rounded and show strong pleochroism.

The abundance frequencies of these minerals generally increase towards older terraces indicates significant erosion of these mineral bearing rocks towards early stages of sedimentation in the valley.

#### **Garnet – Sillimenite-KyaniteStaurolite Suite:-**

This suite consist of garnet, sillimanite, Kyanite as essential minerals and zircon, rutile and biotite as accessories minerals.

The Boulder bed<sub>1</sub> to 3 is characterized by pre-dominant association of garnet, sillimanite, kyanite and staurolite. The abundance of these minerals at the depth 130-210 m below the surface viz. garnet varies from 6.50 to 8.00, sillimanite 7.00 to 8.50 and kyanite is 6.50, 7.50, 8.00 6.50, staurolite 4.50 to 6.50, whereas the relative frequencies of these minerals is 7.50, 9.00, 9.25, sillimenite 7.00, 8.50, 7.50, kyanite 6.50, 5.00 and 5.00 staurolite, 4.50, 6.50 4.50 and average frequency is 8.58, 6.50, 7.3, 5.00 respectively. These minerals are pre-dominantly sub-hedral and occasionally anhedral in shape and show little alteration. These minerals show increasing abundance towards the top sedimentary column in the valley.

The Boulder conglomerate comprised of garnet 7.50 sillimenite 7.50 kyanite 6.50 and staurolite 4.50. These are mostly sub-hedral and anhedral in shape and show variable degree of alteration typical of fluvio-glacial environments.

The sediments terraces NT-0 NT1 NT-2A, NT-2B, NT-2C, and NT-3 display varied frequency of this suite of minerals. The garnet varies from 3.50 to 7.50, sillimanite 3.50 to 7.50, kyanite 4.50 to 8.00 and staurolite 3.50 to 5.50. The relative frequencies of Garnet is 4.50, 3.50, 5.50, 7.00, 7.00, 7.00, sillimenite 3.50, 4.50, 5.00, 6.50, 7.50, 7.50 and staurolite 3.50, 3.50, 4.00, 5.50, 5.00 and 5.25, whereas the average frequencies of these minerals in NT0 to NT3 is 5.83, 5.75, 6.25, 4.46 respectively.

These minerals are generally sub-hedral and anhedral in shape and show insignificant alteration as compared to the mineral of same suite of minerals of glacial and Fluvio-glacial terraces.

Except staurolite the minerals of this suite show higher frequencies towards older terraces, which suggest the extensive erosion of these mineral bearing rocks during early stages of sedimentation.

#### **Zircon-Rutile-Tourmaline and Sphene Suite:-**

In Boulder bed B-1, B-2, B-3 consist of zircon rutile, sphene & tourmaline the frequency of zircon, varies from 1.00 to 2.50, rutile 1.00 to 2.00 tourmaline 4.50 to 6.50, Sphene 0.50 to 1.00, the relative frequencies are 1.50, 1.50, 1.00, 1.00, 1.50, 1.00, 5.50, 4.50, 4.00; 0.50, 1.00, 1.00 and average frequencies are 1.333, 1.666, 4.66, 0.833 at the depth of 130 to 210 m below ground surface respectively.

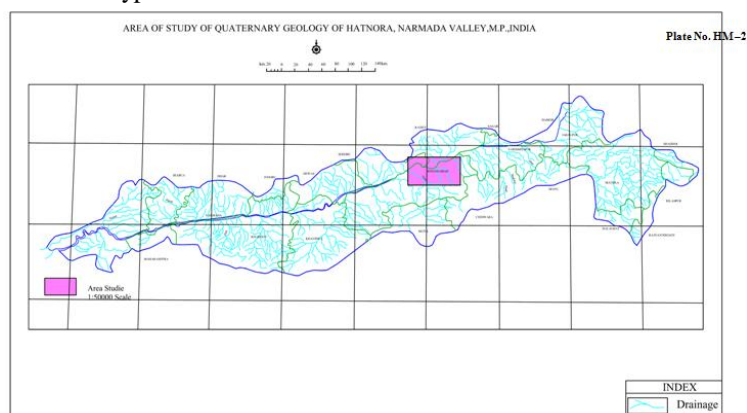
This suite comprises stable mineral like zircon, rutile, tourmaline and sphene. These mineral although are associated with all domain of quaternary deposits but show different frequency of their occurrence and physical characters, shapsize shpericity and roundness.

These minerals occur as accessories mineral, mostly released from rock fabrics comprising boulder bed and were subjected to different degree of wear and tear and physical stress of weathering transport and deposition, the micro imprints acquired by different condition of sedimentation revealed the intense grounding and bed traction of sediments from the source. The striations on these minerals indicate intense glacial activity in the initial stage of sedimentation. These are generally angular to highly angular in shape and show very poor indices of sphericity and roundness typical of glacial environments.

The Boulder conglomerate consists of zircon 2.50 rutile 2.00, tourmaline 6.50, and sphene 1.00 percent. These minerals are generally sub-angular to sub-rounded and exhibit moderate degree of sphericity and roundness in contrast to the sediment of glacial origin.

In fluvial terraces the frequency of zircon varies from 1.00 to 4.00, Rutile 1.00 to 1.50, tourmaline 3.00 to 4.50, sphene 0.50 to 1.50, whereas the relative frequencies in terraces NT-0 NT1 NT-2A, NT-2B, NT-2C, NT-3 viz. of zircon is 4.00, 3.50, 2.50, 2.00, 1.00, 1.00; rutile 1.50, 1.50, 1.50, 1.25, 1.00 and 1.25; tourmaline 4.50, 4.00, 3.50, 3.50, 3.50 and 3.00 sphene 1.50, 1.50, 1.00, 1.00, 0.50 and the average frequencies are 2.333, 1.333, 3.666, 1.00 respectively. Among this suite of minerals tourmaline shows highest frequencies, followed by zircon, rutile and sphene respectively.

These minerals are mostly anhedral in shape, sub-rounded to well rounded and show higher indices of sphericity and roundness typical of fluvial environments. Table No HM-.1



### Hathnora section II:-

(22 ° 52" N; 77 ° 58" E)

The Hathnora Section \_II is located at between villages Hathnora-Nathankheri-Sardarpur in upstream of Hathnora, samples has been collected from exposed section of quaternary deposits. In river section about 16 m scrap of sediments of Boulder conglomerate and a fluvial terrace is exposed in increasing antiquity. The Boulder bed is concealed not exposed in the section samples have been taken from on gonging bore hole drilling logs between the depths of 95 to 190 m below the surface.

**Table No HM\_2:-** Heavy minerals suites of quaternary deposit of Narmada valley Hathnora section\_II.

HathnoraSection n_II Quaternary deposits of Glacial Fluvio-galcial & Fluvial domain of Narmada	Qpaq ue Suite	Amphibole- Pyroxene Suite		Biotile-Muscovite and Chlorite Suite			Garnet-Sillmanite- KyaniteStaurolite Suite				Zircone-Rutile-Tourmaline- Sphe ne Suite			
	I	II		III			IV				V			
	Qpaq ue miner al	Aphibo le	Pyrox e	Bioti le	Muscovi te	Chlori te	Garn et	Sillmani te	kyani te	Staurol ite	Zirco ne	Rutil e	Tourmali ne	Sphe ne
Serial Nos of Heavy Minerals	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Narmada Terrace NT <sub>0</sub>	35.50	9.25	6.25	6.50	12.50	3.50	3.50	3.50	5.50	3.50	4.00	1.50	5.50	1.50
Narmada Terrace NT <sub>1</sub>	33.50	8.50	6.50	7.50	9.00	4.50	3.50	5.50	5.50	4.50	3.50	1.50	4.00	1.50
Narmada Terrace NT <sub>2</sub> -A	32.50	7.00	8.00	9.50	10.50	3.00	5.50	6.50	6.00	4.00	2.50	1.50	3.50	1.50
Narmada Terrace NT <sub>2</sub> -B	30.00	7.25	6.50	13.50	13.50	4.50	7.00	7.50	7.00	5.50	2.00	1.25	3.50	1.00
Narmada Terrace NT <sub>3</sub>	23.50	6.50	5.50	15.50	12.00	4.00	7.00	8.50	7.00	5.00	1.00	1.00	3.50	0.50
Boulder Conglomerate	21.50	6.50	5.50	16.00	12.00	5.50	7.50	7.50	7.00	5.00	1.50	1.25	3.00	0.50
Boulder Bed- 1(130M)	20.50	6.50	7.00	10.50	12.50	6.50	7.50	7.00	5.50	4.50	2.50	2.00	6.50	1.00
Boulder Bed- 2(170M)	18.50	4.00	4.00	13.00	13.50	8.50	9.50	7.50	6.00	6.50	1.50	1.00	5.50	0.50
Boulder Bed-3 (210 M)	14.00	3.00	5.50	19.00	17.50	7.00	8.00	7.50	5.50	4.50	1.50	1.50	4.50	1.00



The study of sediment samples of revealed the five suites of heavy mineral assemblages in the quaternary deposits of Hominid locality i) Opaque Suite ii) Amphibole-Pyroxene Suite iii) Biotite-Muscovite-Chlorite Suite iv) Garnet Sillimenite-KyaniteStaurolite Suite . (Table No HMT\_ 2, 5 & 9) Plate No HM\_2 & 9

#### **Opaque Suite:-**

The Boulder bed consists of opaque suite of mineral which is characterized by the minerals like hematite, magnetite and ilmenite. These minerals show variation in their distribution and abundance in different sediment domain. The relative frequency of these minerals in different unit Boulder bed\_1 to 3 of these deposits is 14.00, 18.50, and 20.50 respectively. The grains of minerals are mostly angular to highly angular in shape and show very poor degree of roundness typical of glacial environments.

The sediments of Boulder conglomerate contain of this suite of minerals which is about 21.50 percent of total heavies. These minerals are generally are sub-angular to angular in shape and suffered heavy wear and tear due to sudden transportation of sediments from glacial front.

The opaque minerals of fluvial deposit are magnetite, hematite and ilmenite. These minerals display variable frequency in this deposit of Narmada. The frequencies of these mineral in NT0-NT3 are 36.50, 34.50, 32.50, 30.00 23.50. The average frequency of opaque suite of minerals in fluvial regime is 32.20.

These minerals are generally sub-hedral and anhedral in shape and show insignificant alteration in contrast to the mineral of other suite. The relative occurrence and abundance of these minerals towards older terraces revealed exposure of these mineral bearing rocks specially, volcanic meta- basics, basaltic and gneisses during early middle Pleistocene time. These rocks constitute tectonic wedge and are embedded with tectonic rock sequence unstable platform of rift valley.

#### **Amphibole-Pyroxene Suite -**

This suite of minerals in the sediment of Boulder bed B-1 to B-3 display frequency of these minerals which varies from 14.00 to 20.50, the relative frequencies 14.00, 18.50, 20.50, whereas the average frequencies are 18.50. It is characterized by association of highly altered hornblende and hypersthene minerals. The Boulder conglomerate possess average amphibole and pyroxene 6.50, & 5.50 average at the depth of 130-210 m below the surface, which indicate preferential and selective erosion of granite and genesis the mother rocks of these minerals in early phases of sedimentation in the valley.

These minerals are mostly sub-hedral to anhedral in shape and show higher degree of alteration as compared to sediments of other domain. The Boulder conglomerate contributes average about 21.50 amphibole and pyroxene of total heavies in the valley. The majority of grains of these minerals is sub-hedral and anhedral in shape and identified as moderate to highly altered mineral in these deposits.

This suite of minerals in the sediments of fluvial deposit viz NT-0 NT1 NT-2A, NT-2B, NT-2C, NT-3 occurred as amphibole 8.25, 7.50, 7.00, 9.25, 6.50 percent pyroxene 7.25, 6.50, 8.00, 6.50, and average frequency 7.50 and 7.50 respectively. The relative frequency of these minerals increases towards younger deposits which perhaps revealed repeated reworking of these minerals both from source rock as well as from older Quaternary deposits.

#### **Biotite-Muscovite-Chlorite Suite:-**

In Boulder Bed this suite consists of flaky minerals viz. biotite, muscovite and chlorite. The frequency of these minerals in Boulder Bed\_1 to 3 viz. biotite varies from 10.50 to 20.00, muscovite 13.50 to 17.50, chlorite 6.50 to 7.00, relative frequencies for biotite are 6.50, 7.00, 9.50, 13.50, 15.50, 16.00, 10.50, 17.00, 20.00 Muscovite 11.50, 10.00, 10.50, 13.50, 12.00, 13.50, 14.50, 17.50 chlorite 3.50, 3.50, 3.00, 4.50, 4.00 and average frequencies are 9.00, 18.50, 3.50 respectively. The relative frequency of these minerals generally decreases upward. These minerals are generally sub-hedral and an-hedral in shape and exhibit poor degree of roundness and sphericity typical of un-orientated & un-organized sedimentation. In general these minerals show high alteration. The biotite often possesses quartz as inclusive mineral. These flaky mineral are subhedral and anhedral and are mostly uncomposed and altered. The relative degree of alteration decreases up ward in the stratigraphic column.

The Boulder conglomerate mainly comprised of biotite muscovite with subordinate amount of chlorite. The frequency of these minerals are biotite 16.00, 12.00, 5.50 respectively, these minerals are generally sub-hedral and anhedral in shape and depict moderate intensity of alteration along the cleavages and outer edges of these minerals the degree of alteration in these minerals increases from biotite, muscovite to chlorite.

The zircon and quartz are identified as accessories with this suite which generally occur as inclusive minerals.

The sediments of paleodomain of Narmada consist of biotite as prominent mineral of this suite, followed by Muscovite and chlorite. The frequency of biotite in this regime of terraces varies from 6.50 to 14.50, muscovite 10.00 to 11.50 and chlorite 2.50 to 4.00. The relative frequencies of these minerals of terraces NT-0 NT1 NT-2A, NT-2B, NT-2C, NT-viz. Biotite is 6.50, 7.50, 8.50, 12.50, 14.50, muscovite 10.50, 11.50, 10.50, 11.00, 10.00 and of chlorite is 2.50, 3.50, 4.00, 4.50, 4, and average frequencies are 11.20, 11.20, 3.50 respectively.

These minerals are generally euhedral and sub-hedral in shape and show alteration along the cleavages and grain profile the degree of alteration increases to the older terraces appears to be due to sudden change in temperature and climatic condition.

In this suite of minerals quartz and zircon occur as inclusive minerals associated with biotite. These minerals are generally sub-rounded to rounded and show strong pleochroism.

The abundance frequencies of these minerals generally increase towards older terraces indicates significant and selective exposure of these mineral bearing rocks and erosion due to uplift towards Middle Pleistocene times.

#### **Garnet – Sillimanite-KyaniteStauroliteSuite:-**

This suite consist of garnet, sillimanite, Kyanite as essential minerals and zircon, rutile and biotite as accessories minerals.

The Boulder bed<sub>1</sub> to 3, contain garnet, sillimanite, kyanite and staurolite. The frequencies of these minerals viz. garnet varies from 7.50 to 8.50, sillimanite 5.00 to 7.00 and kyanite is 5.50 to 6.50 staurolite 4.50 to 6.50, whereas the relative frequencies of these minerals is 9.00, 9.75, 7.50, sillimanite 7.00, 8.50, 7.00, kyanite 5.50, 5.00, 6.50 staurolite, 4.50, 6.50 4.50 and average frequencies are 8.25, 7.25, 5.250, respectively. These minerals are sub-hedral and occasionally anhedral in shape and show little alteration. The abundance of these minerals show towards the top sedimentary columns in the valley which revealed that the high grade metamorphic rocks bearing these minerals are schist, gneiss, granitoid, syenite & and intrusive granites.

The Boulder conglomerate comprised of garnet 7.50 sillimanite 7.50 kyanite 7.00 and staurolite 5.00. These minerals are generally sub-hedral and anhedral in shape show little alteration. These minerals suffered moderate wear & tear and appears to have been transported by flushing stream typical of fluvio-glacial environments.

The sediments of fluvial domain and terraces NT-0 NT1 NT-2A, NT-2B, NT-2C, NT-3 contain these mineral in different abundance. The garnet varies from 3.50 to 9.00, sillimanite 3.50 to 8.50, kyanite 5.50 to 7.00 and staurolite 3.50 to 5.50. The relative frequencies of garnet is 4.50, 3.50, 5.50, 7.00, 7.00, 7.00, sillimanite 3.50, 4.50, 5.00, 6.50, 7.50, 7.50 and staurolite 3.50, 3.50, 4.00, 5.50, 5.00 and 5.25, whereas the average frequencies of these minerals in NT0 to NT3 is 5.83, 5.75, 6.25, 4.46 respectively.

These minerals are generally sub-hedral and anhedral in shape and show insignificant alteration as compared to the mineral of same suite of minerals of glacial and fluvio-glacial terraces.

Except staurolite the minerals of this suite show higher frequencies towards older terraces, which suggest the extensive erosion of these mineral bearing rocks during early stages of sedimentation.

#### **Zircon-Rutile-Tourmaline and Sphene Suite:-**

In Boulder bed<sub>1</sub> to 3 consist of zircon, rutile, sphene & tourmaline, the frequency of these minerals viz zircon, varies from 1.00 to 2.50, Rutile 1.00 to 4.00 tourmaline 1.00 to 1.50, sphene 0.50 to 1.50, the relative frequencies are 1.50, 1.50, 1.00, 1.00, 1.50, 1.00, 5.50, 4.50, 4.00; 0.50, 1.00, 1.00 and average frequencies are 1.333, 1.566, 4.66, 0.833 at the depth of 130 to 210 m below ground surface respectively.

These suites of minerals are stable as compared to the other suite of minerals of these deposits although these minerals are associated with all domain of quaternary deposits but show different frequencies of their occurrence and physical characters, shape size sphericity and roundness.

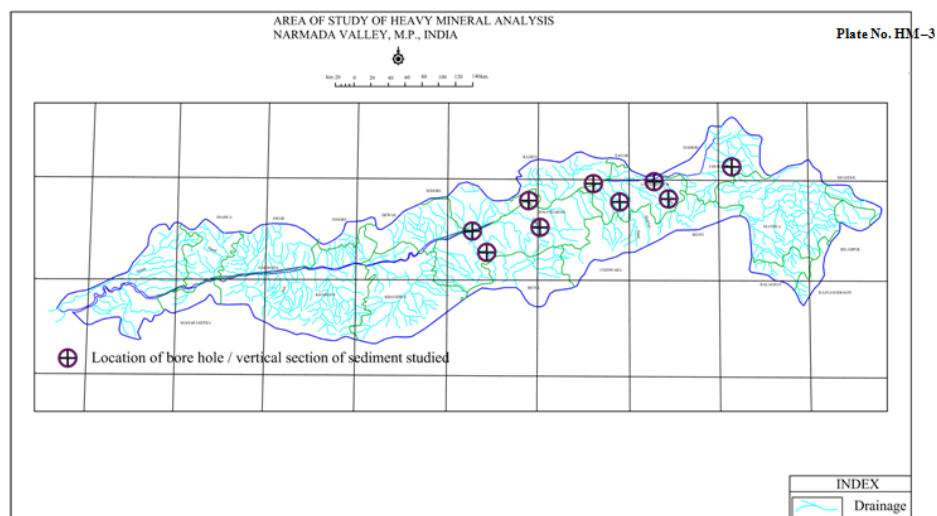
These minerals occur as accessories mineral, mostly released from rock fragments and other fabrics comprising boulder bed, subjected to intensive wear and tear and physio-chemical environment of weathering transport and deposition, the micro imprints acquired by different condition of sedimentation revealed intense grinding and bed traction of sediments from the source. The polishing and striations on these minerals indicate glacial activity in the initial stage of sedimentation. These are generally angular to highly angular in shape and show very poor indices of sphericity and roundness typical of glacial environments.

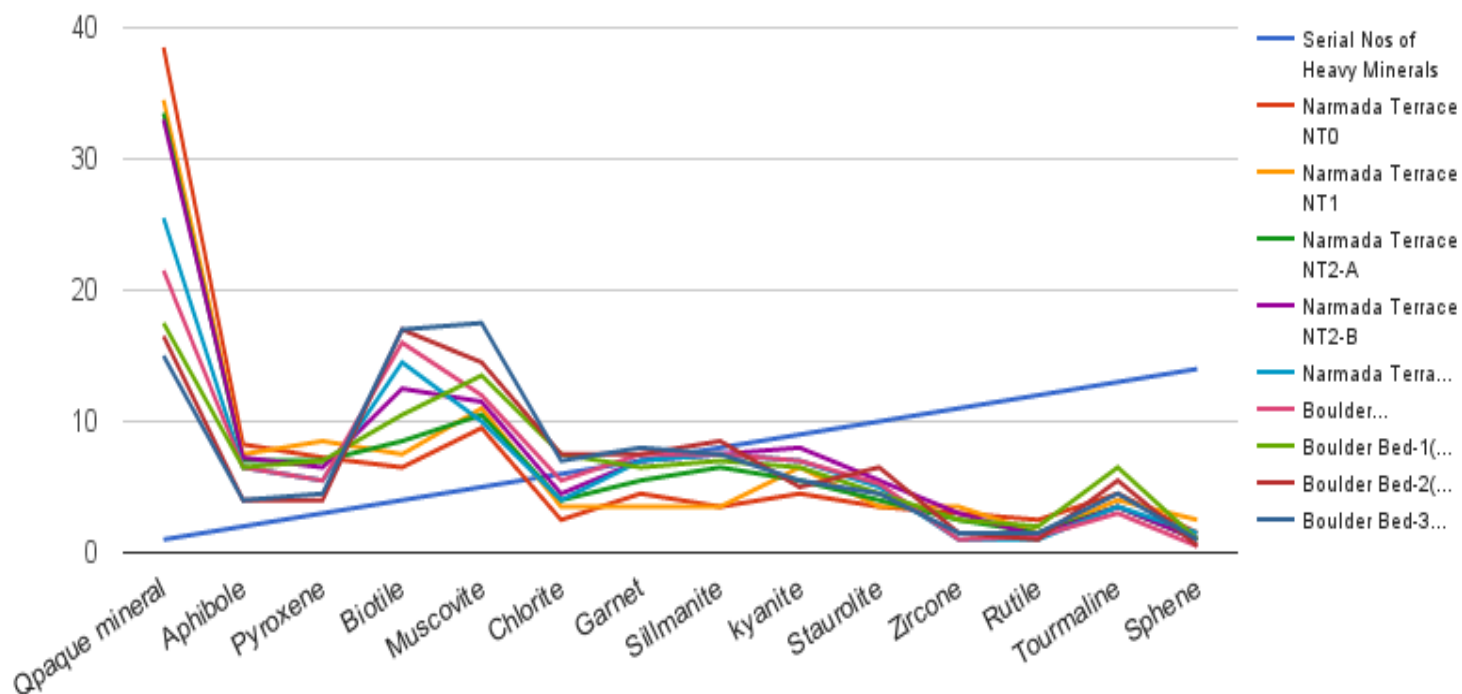
The Boulder conglomerate consists of zircon 1.00, rutile 1.25 tourmaline 3.00 sphene 0.50 which are generally sub-angular to sub-rounded and exhibit moderate degree of sphericity and roundness in contrast to the sediment of other domain. These minerals bear relicts of imprints of sudden transportation of sediment under turmoil and oscillating energy condition both by traction and suspension load.

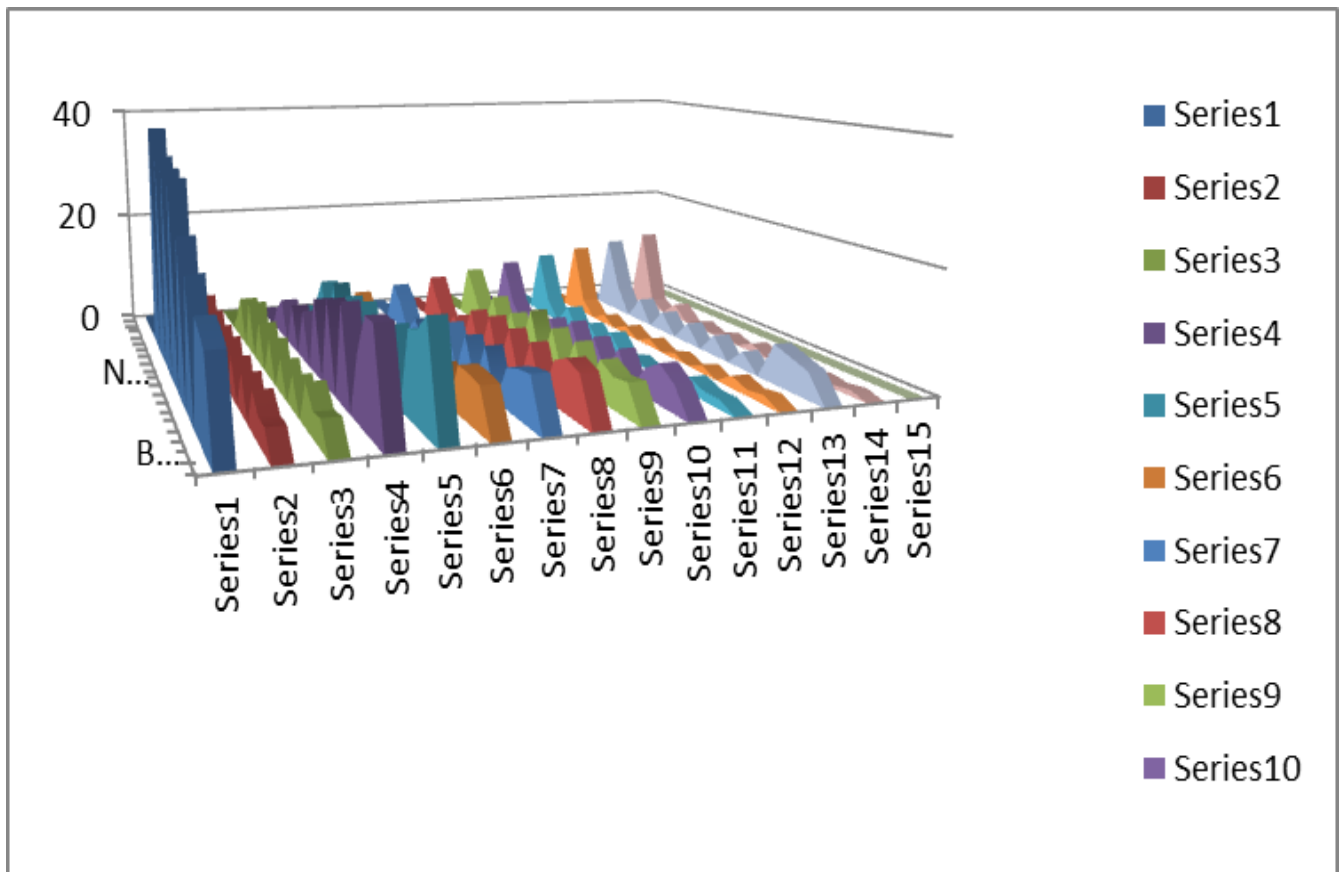
The fluvial deposits consist zircon varies in frequency from 1.50 to 4.00 rutile 1.25 to 1.50, tourmaline 3.00 to 5.50, and sphene 0.50 to 1.00, whereas the relative frequencies in terraces NT-0 NT1 NT-2A, NT-2B, NT-2C, NT-3 of these minerals is 4.00, 3.50, 2.50, 2.00, 1.00, 1.00; rutile 1.50, 1.50, 1.50, 1.25, 1.00 and 1.25; tourmaline 4.50, 4.00, 3.50, 3.50 and 3.00 sphene 1.50, 1.50, 1.00, 1.00, 0.50 and the average frequencies are 2.333, 1.333, 3.666, 1.00 respectively. Among this suite of minerals tourmaline shows highest frequencies, followed by zircon, rutile and sphene.

These minerals are mostly anhedral in shape, sub-rounded to well rounded and show higher indices of sphericity and roundness in contrast to the sediment of other domain which indicate repeated reworking of these minerals typical of fluvial environments.

### Hathnora section\_III:- (22° 52' N; 77° 45' E)



**Heavy minerals suites of quaternary deposit of Narmada valley Hathnora section\_ii****Plate No. HM – 6****Serial Nos of Heavy Minerals, Narmada Terrace NT0, Narmada Terrace NT1, Narmada Terrace NT2-A, Narmada Terrace NT2-B...**

**Plate No HT\_\_10:-** Heavy minerals suites of quaternary deposite of narmada valley Hathnora section\_iii

**Table No HM \_3:-** Heavy minerals suites of quaternary deposite of narmada valley Hathnora section\_III

HathnoraSection _III Quaternary deposits of Glacial Fluvio- galcial & Fluvial domain of Narmada	Qpaq ue Suite	Amphibole- Pyroxene Suite		Biotile-Muscovite and Chlorite Suite			Garnet-Sillmanite- KyaniteStaurolite Suite				Zircon-Rutile-Tourmaline- Sphe ne Suite			
	I	II		III			IV				V			
	Qpaq ue miner al	Aphibo le	Pyrox e	Bioti le	Muscovi te	Chlori te	Garn et	Sillmani te	kyani te	Staurol ite	Zirco ne	Rutil e	Tourmali ne	Sphe ne
Serial Nos of Heavy Minerals	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Narmada Terrace NT <sub>0</sub>	36.00	8.75	7.25	6.50	10.50	2.50	4.50	3.50	5.50	3.50	4.00	1.50	4.50	1.50
Narmada Terrace NT <sub>1</sub>	34.50	7.50	7.50	7.50	10.00	3.50	3.50	4.50	6.50	3.50	3.50	1.50	4.00	2.50
Narmada Terrace NT <sub>2</sub> -A	32.50	8.00	7.00	9.50	11.50	3.00	5.50	5.50	5.50	3.00	2.50	1.50	3.50	2.00
Narmada Terrace NT <sub>2</sub> -B	33.00	7.25	6.50	12.50	12.50	4.50	6.00	6.50	7.00	5.50	2.00	1.25	3.50	2.00
Narmada Terrace NT <sub>3</sub>	22.50	6.50	6.50	12.50	12.00	5.50	8.00	7.00	7.00	5.00	2.00	1.00	3.50	0.50
Boulder Conglomerate	21.50	6.50	5.50	13.00	13.00	6.50	7.50	8.50	7.00	5.25	1.00	1.25	3.00	0.50
Boulder Bed- 1(130M)	19.50	6.50	7.00	10.50	13.50	6.50	8.50	7.00	6.50	4.50	2.00	2.50	6.50	1.00
Boulder Bed- 2(170M)	19.50	4.00	4.00	16.00	13.50	7.50	7.50	7.00	5.50	6.50	2.50	2.00	3.50	0.50
Boulder Bed-3 (210 M)	13.00	4.00	4.50	19.00	16.50	7.00	9.00	8.50	5.50	4.50	1.50	1.50	4.50	1.00



**Opaque suite:-**

The Boulder bed<sub>1</sub> to<sub>3</sub> consists of minerals opaque like hematite, magnetite and ilmenite. These minerals contribute 12.00, 16.50, 18.50 sedimentary column. The grains of these minerals are mostly sub-angular to angular in shape and possess imprints of intensive wear and tear by traction in un-oriented and oscillating energy condition on uneven platform of sedimentation.

The Boulder conglomerate sediments contain opaque suite of minerals which are mostly hematite, magnetite and ilmenite which contribute about 21.50 percent of the total heavies. These minerals are generally sub-angular to sub-rounded and show little alteration. The grain morphology and micro imprints of these minerals revealed unorganized deposition of sediments. The sediments were deposited by sudden gushing and flushing stream system from the source under highly oscillating energy condition on unstable linear platform.

The sediments of fluvial domain and fluvial terraces contain opaque suite of minerals which includes hematite, magnetite and ilmenite. This suite of minerals exhibit different frequency of distribution across the column of fluvial deposits. The relative percentage of these mineral in NT<sub>0</sub>, NT<sub>1</sub>, NT<sub>2</sub>, NT<sub>3</sub> 36.50, 35.50, 33.50, 32.50, and 26.50 respectively. The average frequency of opaque minerals in the fluvial terraces is 32.45. The occurrences of opaque minerals increases towards younger terraces indicate that these mineral bearing rocks become vulnerable to erosion towards the later part of erosion.

The high indices of sphericity and roundness of these minerals revealed cyclic and repeated reworking of sediments from source rocks and older quaternary deposits.

**Amphibole and Pyroxene Suite:-**

The Boulder bed<sub>1</sub> to<sub>3</sub> contains amphibole and pyroxene the relative distribution is 12.00, 16.50, & 18.50 in increasing antiquity. The average occurrence is 17.50. This suite of minerals are relatively stable as compared to the other suite of minerals in the different domain of sediments. These minerals are generally sub-hedral, elongated in shape show perceptible alteration along the cleavage and outer edges. The grains of these minerals possess traction marks and bear imprints of grounding during the sedimentation on rinsing and sinking platform revealing influence of structural dislocation and impact of tectonics during sedimentation.

The Boulder conglomerate contributes about 4.50 percent of amphibole and 4.50 percent pyroxene minerals. These minerals are generally sub-hedral and anhedral in shape and show high degree of alteration being the unstable minerals. The grain morphology and micro features indicate impact of tectonism on sedimentation.

The Fluvial sediments comprising of terraces NT<sub>0</sub> to NT<sub>3</sub> consist of amphibole and pyroxene, the abundance and occurrence of these minerals ranges from 6.50 to 8.25; pyroxene 6.50 to 7.25, whereas the relative frequency of amphibole is 8.25, 7.50, 7.00, 7.25, 6.50, 5.50 and pyroxene 7.25, 7.50, 7.00, 6.50, 6.50, from NT<sub>0</sub> to NT<sub>3</sub> including NT<sub>2A</sub>, NT<sub>2B</sub> & NT<sub>2C</sub> and the average frequencies of these group of minerals is 6.50 and 9.70 respectively. The relative distribution of these minerals consistently increases upward in stratigraphic section towards younger deposits which may be attributed to repeated and cyclic reworking of sediments together with extensive erosion of these mineral bearing rocks throughout the sedimentation.

**Biotite-Muscovite-Chlorite Suite:-**

The Boulder bed<sub>1</sub> to<sub>3</sub> B<sub>1</sub>, B<sub>2</sub> contain this suite of mineral comprising of biotite, muscovite and chlorite minerals. The relative frequency of biotite is 20.00, 17.00, 10.50, muscovite 17.50, 14.50, 13.50 chlorite 7.00, 7.50, 6.50 respectively. The relative occurrence of these minerals persistently increases in increasing antiquity of sedimentary sequence. These minerals are highly variable in shape and size and are altered along the cleavage and outer boundary. The assemblage of minerals with configuration with ground matrix is erratic and anisotropic as most of the mineral decomposed in static position on unstable platform. The hybrid, diverse and extremely unsorted nature of sediments with association of this mineral revealed stagnant and close trough like sedimentation impounded by valley walls and rock blocks bounded by structural elements. This suite of also bear impact of tectonics on sedimentation.

The Boulder conglomerate contains 16.50, 12.00 and 5.00 biotite muscovite and chlorite respectively, whereas the average occurrence is 10.20, these minerals are generally sub-hedral and anhedral in shape and exhibit alteration along cleavages and outer profile of minerals. The mineral assemblage with ground matrix is un-oriented and

embodies the relicts of insequential erratic transport system of channel with oscillating energy condition from single source.

The fluvial sediments and terraces NT0-NT3 display occurrence of biotite, 6.50, 7.50, 9.50, 13.50, 14.00, muscovite 11.50, 18.00, 11.50, 12.50, 10.00 and chlorite, 2.50, 3.50, 3.00, 4.50, 5.50; the average percentage of these minerals is 10.50, 10.50, 3.50 respectively. These minerals exhibit decreasing abundance towards the younger deposits by cyclic reworking and frequent change in energy system of transporting medium towards the later phases of sedimentation.

These are generally associated sub-hedral and anhedral in shape identified to be highly altered and decomposed along the cleavage and outer profile of mineral grain.

#### **Garnet – Sillimanite – Kyanite Suite:-**

This suite is characterized by high grade metamorphic minerals such as garnet, sillimanite and kyanite.

The Boulder Bed 1 to 3 consist of Garnet 9.00, 7.50, 8.50 sillimanite 8.00, 7.00, 7.00 kyanite 5.50, 5.50, 6.50 and staurolite of concealed strata at the depth of 150-210 m below ground level respectively. The average frequencies of these minerals at these levels 8.50, 7.50, 5.50 and 5.50. The average combined association of these minerals is 7.58.

The minerals of this suite are subhedral and anhedral showing alteration along cleavages and outer margins of grain profile. The mosaic of minerals with association of ground matrix indicate impact of mass grounding of sediments on uneven and irregular platform under stress with slow movement in close environment impounded in trench strongly influence by cyclic structural dislocation.

The Boulder conglomerate consists of garnet 7.50 percent sillimanite 8.50 kyanite 7.00 staurolite 5.25. These minerals are mostly are, sub-angular to angular in shape and show little alteration along the cleavage, cracks and outer edges. The kyanite and sillimanite show pleochroism where the staurolite exhibits sieve structure due to inclusions of quartz, zircon and other accessories. The minerals of this suite are associated with unsorted hybrid sediments which are suddenly dumped by flashing stream incepting by sudden change of climate and temperature in the system of sedimentation.

The fluvial terraces NT0 to NT3 including NT2-A, NT2-B, NT2-C display distribution of garnet 4.50, 3.50, 5.50, 7.7.00, sillimanite 3.50, 4.50, 5.50, 6.50, 7.00, kyanite 5.50, 6.60, 5.50, 7.00, 7.00; staurolite 3.50, 3.50, 3.00, 5.50, 5.00. The percentage of garnet varies from 4.50 to 7.00, sillimanite 3.50 to 7.00, kyanite 5.50 to 7.00, staurolite 3.50 to 5.50 respectively. The average association of these minerals is 7.40, 6.61, 5.00, and 4.30. The relative occurrence and close associations of these minerals decrease in decreasing antiquity towards younger deposits, it suggests the less exposure of these mineral bearing rocks towards the later phases of sedimentation in the valley.

#### **Zircon-Rutile-Tourmaline and Sphene Suite:-**

The Boulder Bed consist of Zircon 1.50, 2.50, 2.00, rutile 1.50, 2.50, 2.50, Tourmaline 4.50, 3.50, 6.50 Sphene 1.00, 0.50, 1.00 and average percentage of these minerals are 2.00, 3.25, 4.25, 1.25 respectively the minerals of this suite although associated with the sediments of all domain of Quaternary deposits, but they are ultra stable show variable frequency and impound diagnostic features of sedimentation and environment. This is the group of minerals consist of zircon, rutile, tourmaline and sphene.

These minerals occur as accessories mineral released from parent rock fragments comprising of boulder bed, subjected to intensive wear and tear and static physio-chemical environment of weathering, transport and deposition under close system of sedimentation. The configuration of minerals, rock clastic, ground mass, imprints and impact of tectonics revealed the intense grounding of sediments from the source to site of sedimentation.

The Boulder Conglomerate comprised of zircon rutile, tourmaline and sphene which are viz zircon 1.00, 1.25, 3.00, and 0.50. These minerals as compared to the other suite are stable and best indicator of sedimentary history. The occurrence and abundance of these mineral is not in conformity of rock clastic ground matrix and site of

impounding of sediments in the tectonic trench of turmoil nature. These minerals bear imprints of hostility of erosion of source, transportation and deposition.

The fluvial sediments and terraces NTo-NT3 of display occurrence and distribution of these minerals viz zircon varies from 1.00 to 2.50, rutile 1.00 to 1.75, tourmaline 3.25 to 4.50 sphene 0.50 to 1.50. The average association of these minerals in these terraces is 1.50, 1.35, 4.40, and 0.75 respectively. The relative abundance of zircon and sphene increase towards upper column of quaternary deposits whereas tourmaline and rutile show higher frequency revealed reworking of sediments both from source rock and older deposits in the valley.

These minerals are generally sub-rounded to well rounded in shape, their indices of sphericity increases towards younger deposits, it revealed that the sediment were repeatedly subjected to reworking towards the later phases of sedimentation in the valley.

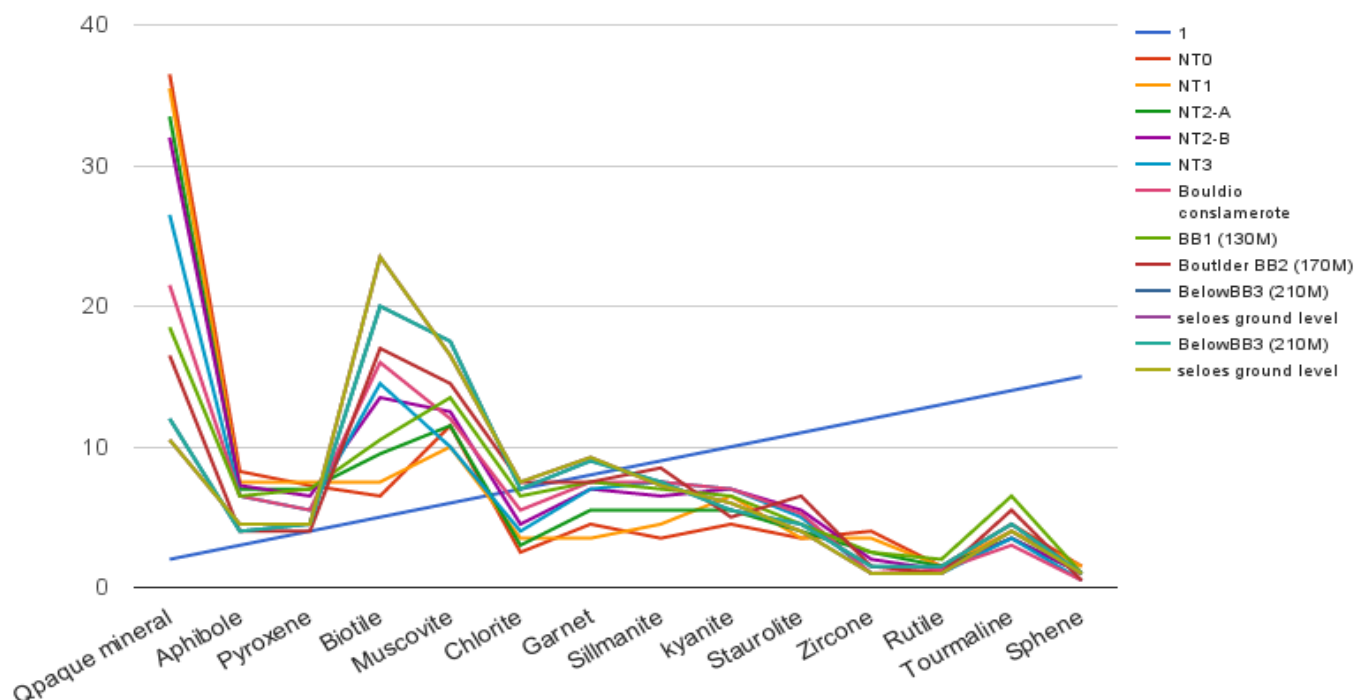
#### Hathnora section\_IV:-

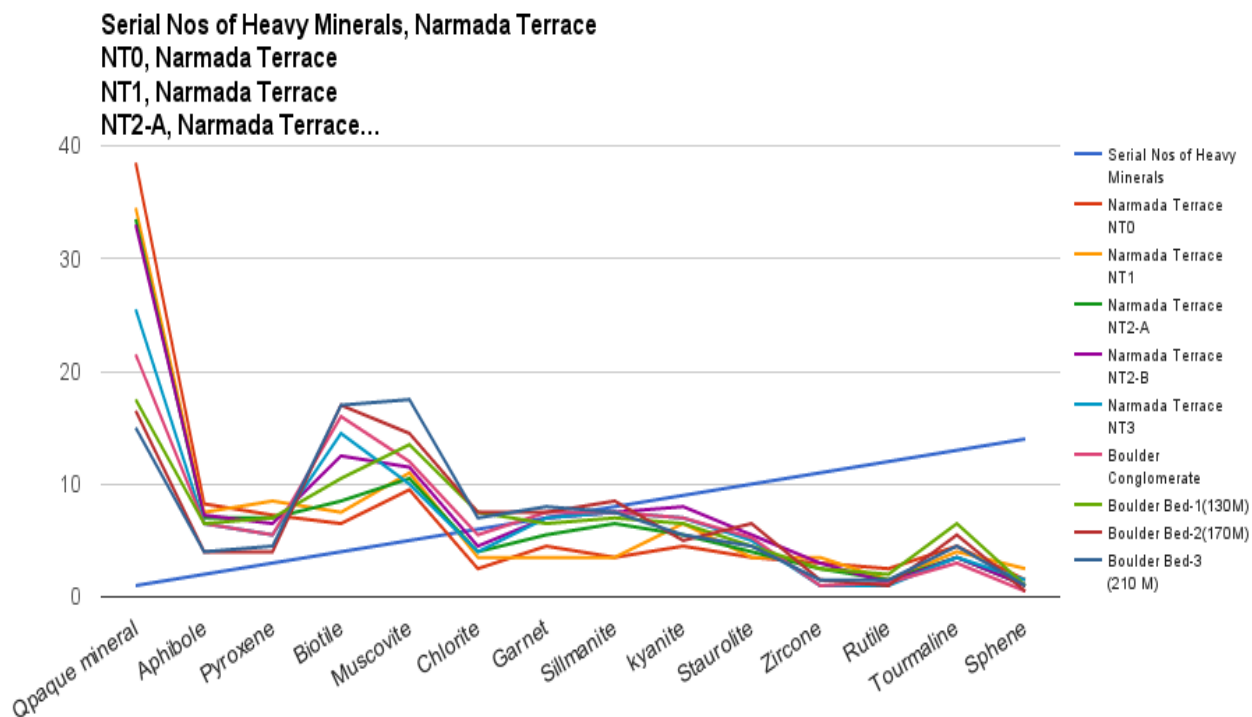
(22° 52' N; 77° 40' E)

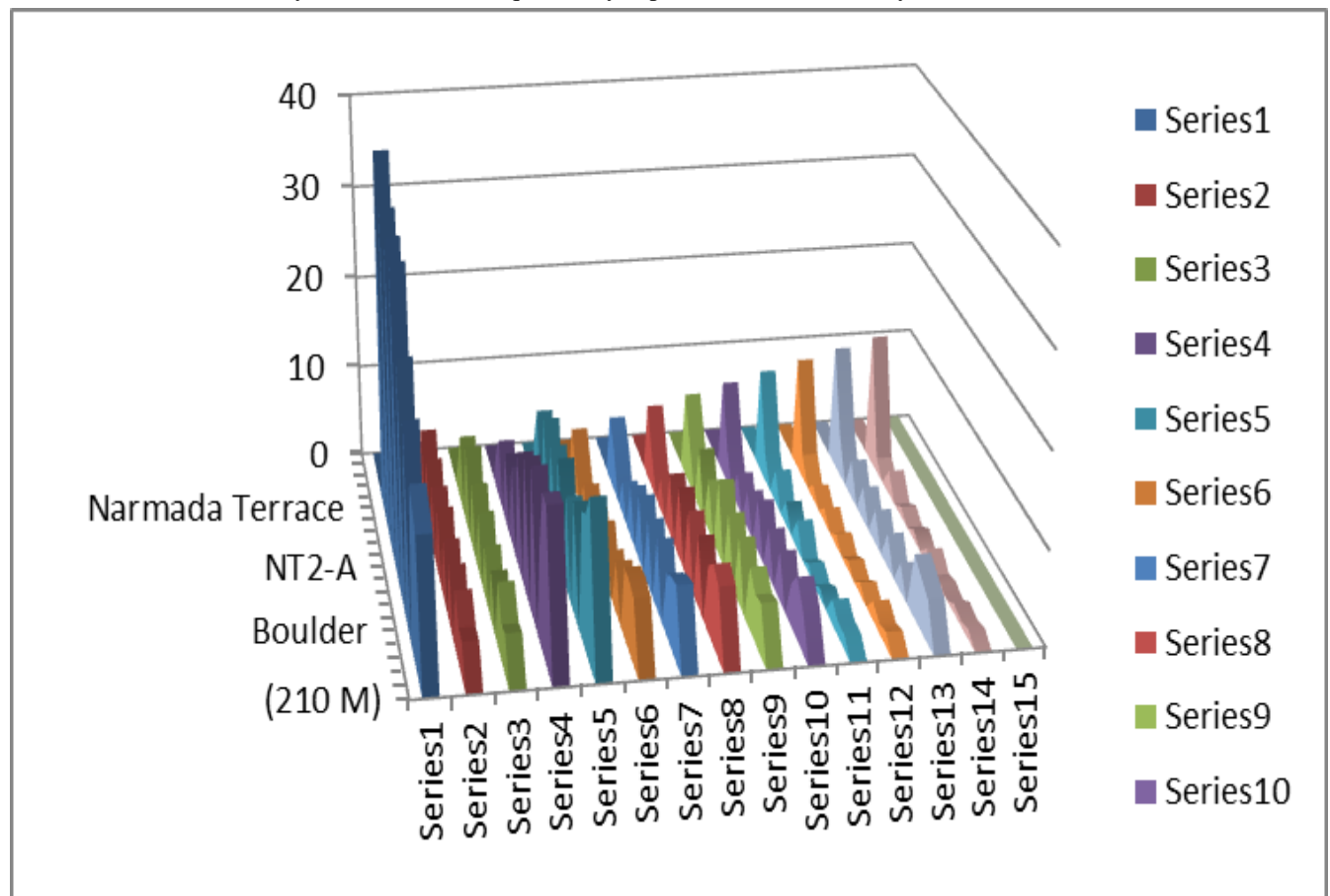
The Hathnora Section \_IV is located at between villages Hathnora-Shahganj-Hoshangabad section in down stream of Hominid locality, the samples have been taken from exposed section of Quaternary deposits. In river section about 20 m scrap of sediments of Boulder conglomerate and fluvial terraces are exposed in increasing antiquity. The Boulder bed is not exposed in the section as such to establish the chronology of sediments the samples of underlying Boulder bed have been taken from on going bore hole drilling log between the depths of 80 to 170 m below the surface. Table No. HT\_4, 7, 11)

#### Heavy minerals suites of quaternary deposits of narmada valley Jabalpur – bharouche section Plate No. HM –4

1, NT0, NT1, NT2-A, NT2-B...



**Heavy minerals suites of quaternary deposit of narmada valley Hathnora section\_iii****Plate No. HM – 7**

**Plate No HT\_\_11:-** Heavy minerals suites of quaternary deposit of narmada valley Hathnora section\_iv

**Table No HM \_4:-** Heavy minerals suites of quaternary deposite of narmada valley Hathnora section\_IV

Hathnora Section IV Quaternary deposits of Glacial Fluvio- glacial & Fluvial domainof Narmada	Qpaque Suite	Amphibole- Pyroxene Suite		Biotile-Muscovite and Chlorite Suite			Garnet-Sillmanite-KyaniteStaurolite Suite				Zircone-Rutile-Tourmaline- Sphene Suite			
	I	II		III			IV				V			
	Qpaque mineral	Aphibol e	Pyroxen e	Biotile	Muscovi te	Chlor ite	Garne t	Sillman ite	kyanit e	Staurol ite	Zirco ne	Rutil e	Tourmali ne	Sphene
Serial Nos of Heavy Minerals	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Narmada Terrace NT <sub>0</sub>	37.50	7.25	8.25	6.50	11.50	2.50	4.50	3.50	4.50	3.50	3.00	1.50	4.50	1.50
Narmada Terrace NT <sub>1</sub>	36.50	6.50	7.50	7.50	10.00	3.50	3.50	4.50	6.50	3.50	3.50	1.50	4.00	1.50
Narmada Terrace NT <sub>2</sub> -A	33.50	6.00	7.50	8.50	11.50	3.00	5.50	5.50	5.50	5.00	3.50	1.50	3.50	1.00
Narmada Terrace NT <sub>2</sub> -B	32.00	7.25	6.50	14.50	12.50	4.50	7.00	6.50	6.00	5.50	2.00	1.25	3.50	1.00
Narmada Terrace NT <sub>3</sub>	27.50	6.50	5.50	14.50	10.00	3.00	7.00	7.50	7.00	4.00	1.00	1.00	3.50	0.50
Boulder Conglomerate	20.50	6.50	5.50	15.00	13.00	5.50	7.50	7.50	8.00	5.25	1.00	1.25	3.00	0.50
Boulder Bed- 1(130M)	18.50	6.50	5.00	13.50	12.50	6.50	8.50	7.00	6.50	4.50	2.50	2.00	5.50	1.00
Boulder Bed- 2(170M)	17.50	4.00	4.00	17.00	13.50	7.50	7.50	8.50	5.00	6.50	1.502	1.00	5.50	0.50
Boulder Bed-3 (210 M)	13.00	4.00	4.50	19.00	15.50	7.00	9.00	7.50	5.50	5.50	2.50	1.50	4.50	1.00



The sediment samples of Quaternary deposit revealed the five suites of heavy mineral assemblages in the quaternary deposits of Hominid locality i) Opaque Suite ii) Amphibole-Pyroxene Suite iii) Biotite-Muscovite-Chlorite Suite iv) Garnet Sillimanite-Kyanite-Staurolite Suite v) Zircon-Rutile-Tourmaline and Sphene Suite. Table No HMT\_4 Plate No HM\_\_7 & 11

#### **Opaque Suite:-**

The Boulder bed consists of opaque suite of mineral which is characterized which includes minerals hematite, magnetite and ilmenite the relative percentage of these minerals is variable in the quaternary deposits of different domain in stratigraphic sequence. The distribution of minerals of in Boulder bed \_1, Boulder bed \_2, and Boulder bed \_3 is 12.00, 16.50, and 18.50 respectively. The grains morphology of these minerals is erratic and variable they are mostly angular to highly angular in shape and show very poor degree of roundness typical of glacial environments.

The sediments of Boulder conglomerate consist of this suite of minerals which is about 21.50 of total heavies. These minerals are generally are sub-angular to angular in shape and suffered heavy wear and tear in different stages of sedimentation.

The opaque minerals of fluvial deposit chiefly consist of magnetite, hematite and ilmenite, show variable frequency shape and size in association. The frequencies of these mineral in NT0-NT3 are 36.50, 35.50, 33.50, 32.00 26.50. The average frequency of opaque suite of minerals in fluvial regime is 32.20.

#### **Amphibole-Pyroxene Suite:-**

The Amphibole and Pyroxene in Boulder Bed Boulder Bed \_1, Boulder Bed \_2, Boulder Bed \_3 is characterized by association of highly altered hornblende and hypersthene minerals. The relative percentage 4.50, 4.00 7.00; 4.00, 4.00 and 5.00 respectively; whereas the average frequencies is 3.50 5.00. The sediments of Boulder conglomerate of concealed strata exhibit low frequencies which indicate selective and intensive erosion of mother rocks of these minerals in early phases of sedimentation in the valley.

These minerals are mostly sub-hedral to anhedral in shape and show higher degree of alteration as compared to sediments of other domain. The Boulder Conglomerate contributes average about 21.50 amphibole and pyroxene of total heavies in the valley. The majority of grains of these minerals are sub-hedral and anhedral in shape which show moderate to high degree of alteration.

The fluvial domain of deposits of Narmada NT-0 NT1 NT-2A, NT-2B, NT-2C, NT-3 contain 8.25, 7.50, 7.00, 7.25, 6.50 7.25, 7.50, 7.00, 6.50, 6.50, Pyroxene 7.25, 7.50, 7.00, 6.50, 6.50 s respectively where average value is 7.50 and 7.50. The relative abundance of these minerals increases in increasing antiquity towards younger deposits.

#### **Biotite-Muscovite-Chlorite Suite:-**

In Boulder bed this suite consists of flaky minerals viz. biotite, muscovite and chlorite. The frequency of these minerals in Boulder bed viz. biotite varies from 10.50 to 20.50, muscovite 13.50 to 17.50, chlorite 6.50 to 7.50, and average frequencies are 18.50, 14.50, 3.00 respectively. The relative frequency of these minerals generally decreases upward. These minerals are generally sub-hedral and anhedral in shape and exhibit poor degree of roundness and sphericity typical of unorganized sedimentation. In general these minerals show high degree of alteration. The biotite often possesses quartz as inclusive mineral.

The Boulder conglomerate mainly consists of, biotite muscovite with subordinate amount of chlorite. The frequency of these minerals are biotite 16.00, 12.00, 5.50 respectively, these minerals are generally sub-hedral and anhedral in shape and depict moderate indices of sphericity and roundness, alteration along the cleavages and outer edges of these minerals is very prominent in these sediments. The majority of muscovite grains are anhedral in shape and show highest order of alteration, followed by biotite and chlorite respectively.

The zircon and quartz are identified as accessories with this suite which generally occur as inclusive minerals.

The sediments of paleodomin of Narmada consist of biotite as prominent mineral of this suite, followed by muscovite and chlorite. The frequency of biotite in the terraces varies from 6.50 to 14.50, muscovite 10.00 to 11.50

and chlorite 2.50 to 4.00. The relative frequencies of these minerals for terraces NT-0 NT1 NT-2A, NT-2B, NT-2C, NT-viz. biotite is 6.50, 7.50, 8.50, 12.50, 14.50, muscovite 10.50, 11.50, 10.50, 11.00, 10.00 and of chlorite is 2.50, 3.50, 4.00, 4.50, 4, and average frequencies are 11.20, 11.20, 3.50 respectively.

These minerals are generally euhedral and sub-hedral in shape and show fairly good degree of roundness typical of fluvial environment. These minerals show variable degree of alteration increases from biotite to chlorite, where biotite show little alteration followed by muscovite which is moderately altered and chlorite exhibit highest degree of alteration.

In this suite of minerals quartz and zircon occur as accessories inclusive minerals pre-dominantly with biotite. These minerals are generally sub-rounded to rounded and show strong pleochroism.

The abundance frequencies of these minerals generally increase towards older terraces indicates significant erosion of these mineral bearing rocks towards early stages of sedimentation in the valley.

#### **Garnet – Sillimanite- Kyanite Staurolite Suite:-**

This suite consist of garnet, sillimanite, kyanite as essential minerals and zircon, rutile and biotite as accessories minerals.

The Boulder Bed B-1, B-2, B-3, are characterized by pre-dominant association of garnet, sillimanite, kyanite and staurolite. The frequency viz. garnet varies from 7.50 to 7.50, sillimanite 7.00 to 8.50 and kyanite is 5.00 to 6.50, staurolite 4.50 to 6.50, whereas the relative frequencies of these minerals viz garnet is 4.50, 3.50, 5.50, 7.00, 7.00, 7.50, 9.00, 9.25, sillimanite 3.50, 4.50, 5.50, 6.50 and 7.50 kyanite 4.50, 6.50, 5.00, 6.00 and 7.00, staurolite, 3.50, 3.50 5.00, 5.50 and 4.00 and average frequencies are 7.25, 7.25, 6.25 5.00, respectively. These minerals are pre-dominantly sub-hedral and occasionally anhedral in shape and show little alteration. These minerals show increasing abundance towards the top sedimentary columns in the valley.

The Boulder conglomerate comprised of garnet 7.50 sillimanite 7.50 kyanite 8.00 and staurolite 5.20. These minerals are mostly sub-hedral and anhedral in shape and show variable degree of alteration typical of Fluvio-glacial environments.

The sediments terraces NT-0 NT1 NT-2A, NT-2B, NT-2C, and NT-3 show varied frequencies of this suite of minerals. The garnet varies from 3.50 to 9.00, sillimanite 3.50 to 8.50, kyanite 5.50 to 7.00 and staurolite 3.50 to 5.50. The relative frequencies of Garnet is 4.50, 3.50, 5.50, 7.00, 7.00, 7.00, sillimanite 3.50, 4.50, 5.00, 6.50, 7.50, 7.50 and staurolite 3.50, 3.50, 4.00, 5.50, 5.00 and 5.25, whereas the average frequencies of these minerals in NT0 to NT3 is 5.83, 5.75, 6.25, 4.46 respectively.

These minerals are generally sub-hedral and anhedral in shape and show insignificant alteration as compared to the mineral of same suite of minerals of glacial and fluvio-glacial deposits.

Except staurolite the minerals of this suite show higher frequencies towards older terraces, indicating the extensive erosion of these mineral bearing rocks during early stages of sedimentation

#### **Zircon rutile, shene& tourmaline suite:-**

In Boulder bed 1 to 3 consist of zircon rutile, shene& tourmaline, the frequency of these minerals viz zircon, varies from 1.00 to 2.50, Rutile 1.00 to 2.00 tourmaline 4.00 to 6.50, sphene 0.50 to 1.50, the relative frequencies are 1.50, 1.50, 2.50, 1.00, 1.50, 1.00, 2.00, 4.50, 5.50; 6.50, 1.00, 0.50 and average frequencies are 1.333, 1.566, 4.66, 0.833 at the depth of 130 to 210 m below ground surface respectively.

These suites of minerals are stable as compared to the other suite of minerals of these deposits although these mineral are associated with all domain of quaternary deposits but show different frequencies of their occurrence and physical characters, shape size sphericity and roundness.

These minerals occur as accessories mineral, mostly released from rock fragments and other fabrics comprising boulder bed, subjected to intensive wear and tear and physio-chemical environment of weathering transport and

deposition, the micro imprints acquired by different condition of sedimentation revealed the intense grounding and bed traction of sediments from the source. The striations on these minerals indicate glacial activity in the initial stage of sedimentation. These are generally angular to highly angular in shape and show very poor indices of sphericity and roundness typical of glacial environments.

The Boulder conglomerate consists of zircon which is generally sub-angular to sub-rounded and exhibit moderate degree of sphericity and roundness in contrast to the sediment of other domain. These minerals have imprints of sudden transportation of sediment under turmoil energy condition both by traction and suspension load.

The fluvial deposits consist zircon, varies in frequency from 1.50 to 4.00 rutile 1.25 to 1.50, tourmaline 3.00 to 5.50, and sphene 0.50 to 1.00, where as the relative frequencies in terraces NT-0 NT1 NT-2A, NT-2B, NT-2C, NT-3 of these minerals is 4.00, 3.50, 2.50, 2.00, 1.00, 1.00; rutile 1.50, 1.50, 1.50, 1.25, 1.00 and 1.25; tourmaline 4.50, 4.00, 3.50, 3.50, 3.50 and 3.00 sphene 1.50, 1.50, 1.00, 1.00, 0.50 and the average frequencies are 2.333, 1.333, 3.666, 1.00 respectively. Among this suite of minerals tourmaline shows highest frequencies, followed by zircon, rutile and sphene. These minerals display increasing frequency in decreasing antiquity.

These minerals are mostly anhedral in shape, sub-rounded to well rounded and show higher indices of sphericity and roundness in contrast to the sediment of other domain which indicate repeated reworking of these minerals typical of fluvial environments.

### **Summary & conclusion:-**

The qualitative and quantitative studies of heavy minerals of sediment samples of Narmada and revealed five prominent heavy mineral suites viz, opaque suite; amphibole-pyroxene suite, biotite-muscovite-chlorite suite, garnet, sillimanite, kyanite, staurolite suite and zircon, rutile, tourmaline suite. Among these the minerals of opaque suite, are the chief constituents of the heavy residue of recent sediments in Narmada and its tributaries, varying in frequencies from 10.50 to 39.50 and on average these minerals contribute about 34.00 34.14 of total heavy fraction in the entire area of study. The higher frequency of these minerals towards the younger terraces in Narmada is most conspicuous. The minerals of amphibole and pyroxene exhibit uniform frequency; an increase in frequency is noticed towards the terraces of fluvial domain. It is attributed to the exposure of these mineral bearing rocks, such as basics, untramafics, and volcanic to denudation towards the later phases of sedimentation (Khan et al, in press). The mica group of minerals include muscovite, biotite and chlorite, the over all frequencies of these minerals in the entire quaternary deposits varies biotite 4.50 to 23.50, muscovite 5.00 to 16.50 and chlorite 2.50 to 7.50 and average frequencies are 18.80, 13.85, 11.75 respectively. These minerals exhibit increasing contribution of these minerals in Boulder conglomerate and fluvial deposits and their diagnostic physical characters in these deposit implies the extensive erosion of mica-bearing rocks, such as muscovite, biotite schist, gneiss, granite and pegmatite rocks in the headwards ends of Narmada and its tributaries during the early phases of sedimentation. The minerals of high metamorphic suite of minerals includes garnet, sillimanite and kyanite the over all frequencies varies from 3.50 to 9.25, 3.50 to 8.50, 9.50 to 7.00 and 3.50 to 6.50 and average frequency is 8.58, 7.75, 5.5 and 5.00. The affinity of higher frequencies of these minerals towards older terrace viz. glacial and fluvio- glacial appears to be due to ready availability of these minerals bearing rocks to erosion. The mineral of stable group viz. rutile, zircon and tourmaline show uniform distribution in the entire domain of terraces in the area of study.

The heavy minerals of Quaternary deposits were primarily derived from metamorphic source comprising of kyanite-paragonite, muscovite schist, gneiss, garnet mica schist, para-amphibolite tourmaline garnet metasedimentaries and meta-volcanic belonging. Apart from this heavy of younger Quaternary terrace were also re-worked and derived from Boulder bed i.e glacial deposit, Boulder conglomerate of fluvio-glacial deposit and fluvial deposits and higher and other older terraces of fluvial domain. These heavies were basically transported from the sources area by glacial fluvio-glacial and fluvial agencies to the present site of their occurrence. The mode of transportation, environment of deposition and energy system of transporting media has greatly affected the frequency of concentration of heavies, their grain morphology and stability in that particular domain of deposit.

In the Quaternary terraces of Narmada and the heavies of various suites show variable degree of stability, the most stable minerals are of zircon, rutile, and tourmaline, followed by garnet, muscovite, biotite, ilmenite magnetite, staurolite, kyanite sillimanite hornblende and hypersthene. The heavy minerals derived from source rock and reworked from older Quaternary deposits display significant variation in stability and grain morphology, Vau Andel (1959) has discussed four processes capable of altering original heavy mineral suites. These are (i) weathering (ii)

abrasion (iii) selective sorting (iv) intrastratal solution. Dryden and Dryden (1946) and Sindowaski have suggested the possibilities of removal of less stable heavy minerals by weathering under stable conditions, however, the order of their stability has been questioned (Perrijhon 1957). Prolong weathering of a broad low relief region in the source area under stable tectonic condition can effectively alter less stable heavy mineral zircon, tourmaline and rutile association (VauAndel 1959). The mineralogical maturity of heavy minerals in Quaternary terraces and concentration of ultra-stable zircon, tourmaline, and rutile is suggestive of such weathering condition in the source area in which less stable heavy mineral species were removed before transportation of detritus. Experimental work in mechanical abrasion of heavy minerals has revealed that these minerals show variable resistance of weathering processes (PetiJhon 1957). It seems plausible that prolonged quiescence and reworking of detritus from the old moraines and pre-existing other Quaternary deposit may result destruction of mechanically less stable species.

In the Rhina Delta (Van Andel 1950) has shown effectiveness of selective sorting in the modification of heavy minerals assemblage. However, a similar work in Alpine flysh has demonstrated insignificance of such process. The study of zircon and tourmaline in Quaternary terraces of Narmada rift complex has also indicated that process of selective sorting was not strong in removing tourmaline from zircon so as to develop two separate associations in these deposits.

The intrastate solution has a very little role in alteration of heavy minerals of Quaternary terraces. It seems that stability of source and depositional area might have ultimately controlled the distribution of ultra basic heavy minerals rather than the stability of minerals and action of intra stratal solution as suggested by Krynine (1942), VauAndel (1959), Chanda (1960), and Gozi (1965).

To summarize prolong weathering and abrasion of detritus in source area under stable tectonic conditions appears to have greatly altered on originally less stable heavy mineral suite to an improvised restricted ultra stable assemblage of zircon with tourmaline and rutile.

The study of heavy mineral suites of Quaternary deposits in the area is suggestive of Narmada Boulder bed, Boulder conglomerate and fluvial terraces measuring 325 m thickness has mixed sediments source comprising of Lower protozoic and middle Protozoic rocks consisting of gneisses granite metabasics, amphibolites, meta-sedimentary, high grade biotite gneisses, muscovite gneisses, kyanite, paragonite, muscovite – schist, gneiss, garnet-mica schist, para amphibolite, tourmaline garnet, meta – sedimentaries and meta – volcanics and Gondwana rocks.

The Narmada Rift valley formed a linear trench in the middle of Indian subcontinent was an ideal loci for accumulation of sediments. The rift trench is intruded by the dolerite and other mafic and siliceous dykes and sills along lineaments in different phases of tectonic deformation. The Quaternary sedimentation incepting from glacial activity, followed by fluvio-glacial, lacustrine and fluvial phase within the rinsing and sinking environment, block faulting and segmental and linear displacement and dislocation, uplifting and isolated domal up- lift, Neogene rifting and Quaternary sedimentation and rift-bound Pliocene–Pleistocene rifting and volcanic activity specifically during glacial and fluvio-glacial phase are major component of the Quaternary period and tectonic processes of the Narmada Rift System which form the base of quaternary deposits.

The Narmada rift system basin platform provided a unique setting for dynamic ecosystems that were characterized by Rift-related subsidence and coeval sedimentation also created an ideal loci of Quaternary sedimentation and environment for the accumulation of sediments volcanic fabrics sediments, burial, diagenesis, and preservation of organic remains. Because rifts formed after widespread Quaternary sedimentation occurred and voluminous sediments in the rift basins were accumulated by glacial activity consequential upon the lowering of temperature and climatic changes in the region.

The skull cap of *Homo erectus* “Narmada Man” is recovered from the vom of basal unit of boulder conglomerate at the depth of 83 m. (278 m. above m.s.l.) is estimated to be 1.20 (+) m.y.r. old. . Table No QGT 99\_101

The composition and abundance of the heavy minerals is exclusively dependant on their stability against wear and tear in course of transportation and the physico-chemical parameters of the environments of deposition.

The Boulder conglomerate consists of zircon 2.50 rutile 2.00, tourmaline 6.50, and sphene 1.00 percent. These minerals are generally sub-angular to sub-rounded and exhibit moderate degree of sphericity and roundness in

contrast to the sediment of glacial origin. The grains of these minerals are generally sub-angular to sub-rounded and exhibit moderate degree of sphericity and roundness in contrast to the sediment of other domain. These minerals bear relicts of imprints of sudden transportation of sediment under turmoil and oscillating energy condition both by traction and suspension load.

These minerals occur as accessories mineral, mostly released from rock fragments and other fabrics comprising boulder bed, subjected to intensive wear and tear and physio-chemical environment of weathering transport and deposition, the micro imprints acquired by different condition of sedimentation revealed the intense grinding and bed traction of sediments from the source. The striations on these minerals indicate glacial activity in the initial stage of sedimentation. These are generally angular to highly angular in shape and show very poor indices of sterility and roundness typical of glacial environment.

These minerals occur as accessories mineral, mostly released from rock fragments and other fabrics comprising boulder bed, subjected to intensive wear and tear and physio-chemical environment of weathering transport and deposition, the micro imprints acquired by different condition of sedimentation revealed the intense grinding and bed traction of sediments from the source. The polishing striations on these minerals indicate glacial activity in the initial stage of sedimentation. These are generally angular to highly angular in shape and show very poor indices of sphericity and roundness typical of glacial environments.

The Boulder conglomerate sediments are generally sub-angular to sub-round, exhibit moderate degree of sphericity and roundness in contrast to the sediment of other domain. These minerals bear relicts of imprints of sudden transportation of sediment under turmoil and oscillating energy condition both by traction and suspension load.

These suites of minerals are stable as compared to the other suites although these mineral are associated with all domain of quaternary deposits but show different frequencies of their occurrence and physical characters, shape size sphericity and roundness.

These minerals also occur as accessories mineral released from parent rock fragments comprising of boulder bed, subjected to intensive wear and tear and static physio-chemical environment of weathering, transport and deposition under close system of sedimentation. The configuration of minerals, rock clastic, ground mass, imprints and impact tectonics revealed the intense grinding and bed traction of sediments in turmoil transporting system from the source to site of sedimentation.

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