



# Petrochemistry of Bhander Limestone (Upper Vindhyan) of Maihar, Satna District, Madhya Pradesh, India.

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**Abstract:** Bhander limestone (Late Neoproterozoic), in the Maihar area of Satna district, forms an outlier in the area of study (Fig.1). Petrographic study reveals that it consists majorly of calcite, aragonite and detrital minerals such as quartz. Geochemical data brings forth that the concentration of  $\Sigma$ REEs (La-Lu) ranges between 14.77 and 49.55 ppm., that of Eu and Ce anomaly (Normalized to PAAS) range between 0.53–0.69 and 0.57-1.07 respectively. The low values of  $\Sigma$ REEs, high values of Y/Ho and positive correlation between  $\Sigma$ REEs and elements such as Si, Al, Ti, V, Co, Ni and Nb and negative correlation between CaO and  $\Sigma$ REEs indicate that the Bhander limestone appear to have been precipitated in a basin where terrigenous material was being supplied intermittently. And it led to the admixture of detrital materials in the limestone, in question. Hence, the source of trace and REEs in the limestone of Maihar area seems to be the detrital material.

**Key words:** Petrochemistry, Rare Earth Elements, Bhander Limestone, Maihar.

## 1.Introduction

The study area falls on the survey of India Toposheet Numbers 63D/15, 63D/16 and it is limited by Longitude 80o21'14.983"E-80o57'33.309"E and Latitude 23o58'9.803"N-24o22'44.542"N (Fig.1). The Girgita mine is located 12km East of Maihar city of Satna district where the sample have been collected from.

The behavior and mode of distribution of rare earth elements (REEs) in carbonate rocks have extensively been investigated earlier by many researchers (Pandey and Kumar, 2013; Jyotiranjana S, Ray, 2006; Apurba Banerjee and Dhiraj Mohan Banerjee et al.,2011). Their studies showed that the important factors influencing enrichment and depletion of REEs in carbonate rocks are:(1) the lithology and diagenesis (Madhavaraju and Ramasamy,1999) (2) biogenic deposition from seawater (Murphy and Dymond, 1984) (3) scavenging processes related to depth, salinity, and oxygen level of seawater (Greaves et al., 1999) (4) the variation in oxygen level of seawater (Liu et al., 1988) (5) the amount of detrital material of terrigenous origin (Piper, 1974; McLennan,1989; Nagarajan et al., 2011) and (6) the variation in surface productivity. The results of recent investigations revealed that geochemical studies, on REEs in carbonate rocks, furnish a suitable basis for reconstruction of paleogeographic conditions, environment of deposition and source of sediments.

The stratigraphic succession of the Vindhyan Supergroup exposed in the Maihar area is given in Table 1 and the geological map of the study area is show in Fig.2.

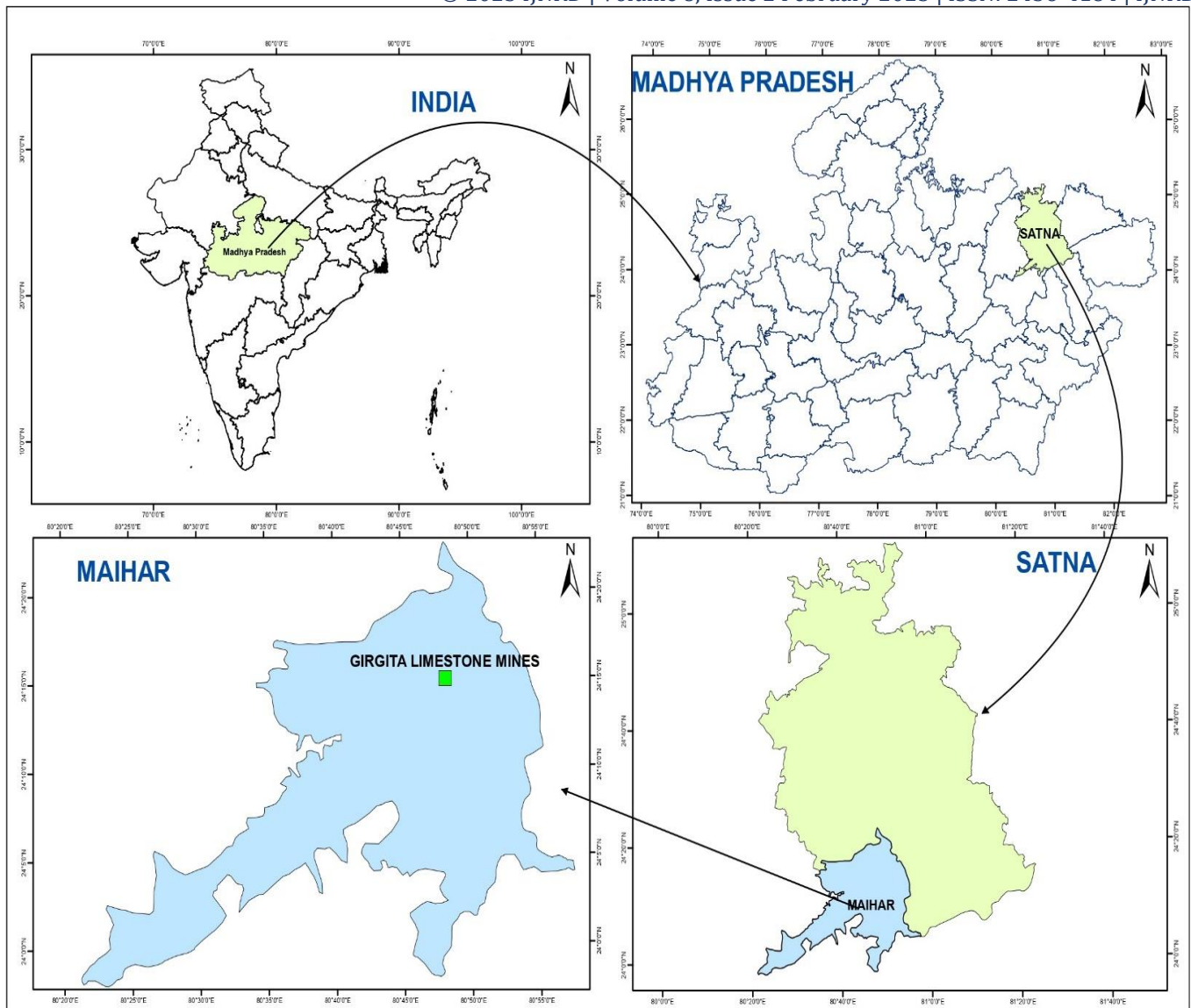


Fig.1. Location map of the study area.

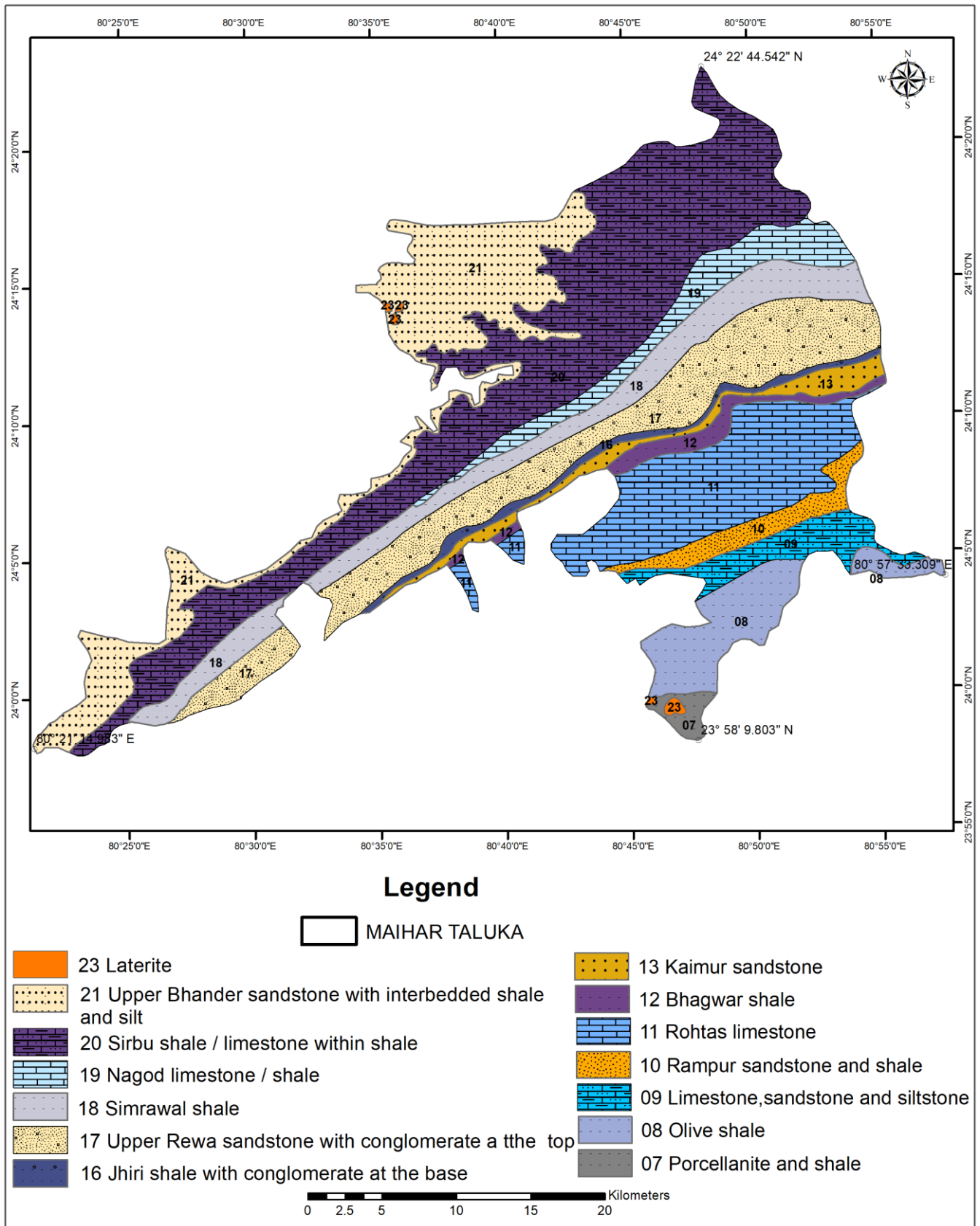
## 2. Geological setting

The Vindhyan basin is a sickle-shaped basin in the Bundelkhand-Aravalli Province which got stabilized prior to 2.5 Ga (Kumar,S and banerji,S.,2019). The Vindhyan Supergroup overlies a variety of precambrian basement rocks comprising Bundelkhand Granite, Mahakoshal Group, Bijawar Group, Gwalior Group, Banded Gneissic Complex (BGC) and Chhota Nagpur Gneissic Complex (CGC). The BGC separates the Vindhyan exposures of the Son Valley area from that of the Chambal Valley. The Bhandar limestone, exposed in the area of study i.e. Girgita mines, is fine grained, hard and compact, thinly bedded to massive and the other lithological unit is shale which is khaki green in color. The stratigraphy of Vindhyan supergroup is given below in the Table 1

Supergroup		Group	Stage		
V i n d h y a n  s u p e r g r o u p	Upper Vindhyan	Bhander	Upper Bhander Sandstone		
			Sirbu Shale		
			Lower Bhander Sandstone		
			<b>Bhander Limestone</b>		
			Ganurgarh Shale		
		-----Diamondiferous conglomerate-----			
		Rewa	Upper Rewa Sandstone		
			Jhiri Shale		
			Lower Rewa Sandstone		
			Panna Shale		
		-----Diamondiferous conglomerate-----			
		Kaimur	Upper Kaimur Sandstone		
			Kaimur Conglomerate		
			Bijaigarh Shale		
	Lower Kaimur Sandstone				
	Suket Shale				
	-----Unconformity-----				
	Lower Vindhyan	Semri	Rohtas Stage	Rohtas Limestone	
				Rampur shale	
			Khenjua Stage	Chorhat Sandstone	
				Koldaha shale	
			Porcellanite Stage		
			Basal Stage		

Table-1 Stratigraphic succession of Vindhyan Supergroup.





**Fig.2: Geological map of the study area.**

### 3. Methodology

Total twelve representative samples have been chosen for chemical analyses. The selected samples were first washed by distilled water to remove contamination and then were air-dried and ground to <2.60 mesh in a tungsten carbide mortar.

The powdered samples were analyzed at IIT, Kanpur using ICPMS for REEs and the X-Ray Fluorescence Spectroscopy (XRF), of the powdered sample, has been done at Savitribai Phule University, Pune for trace and major oxide concentration. Loss on Ignition (LOI) has been measured by the loss in weight. The results of the values of REEs have been normalized to PASS values using the following relation:

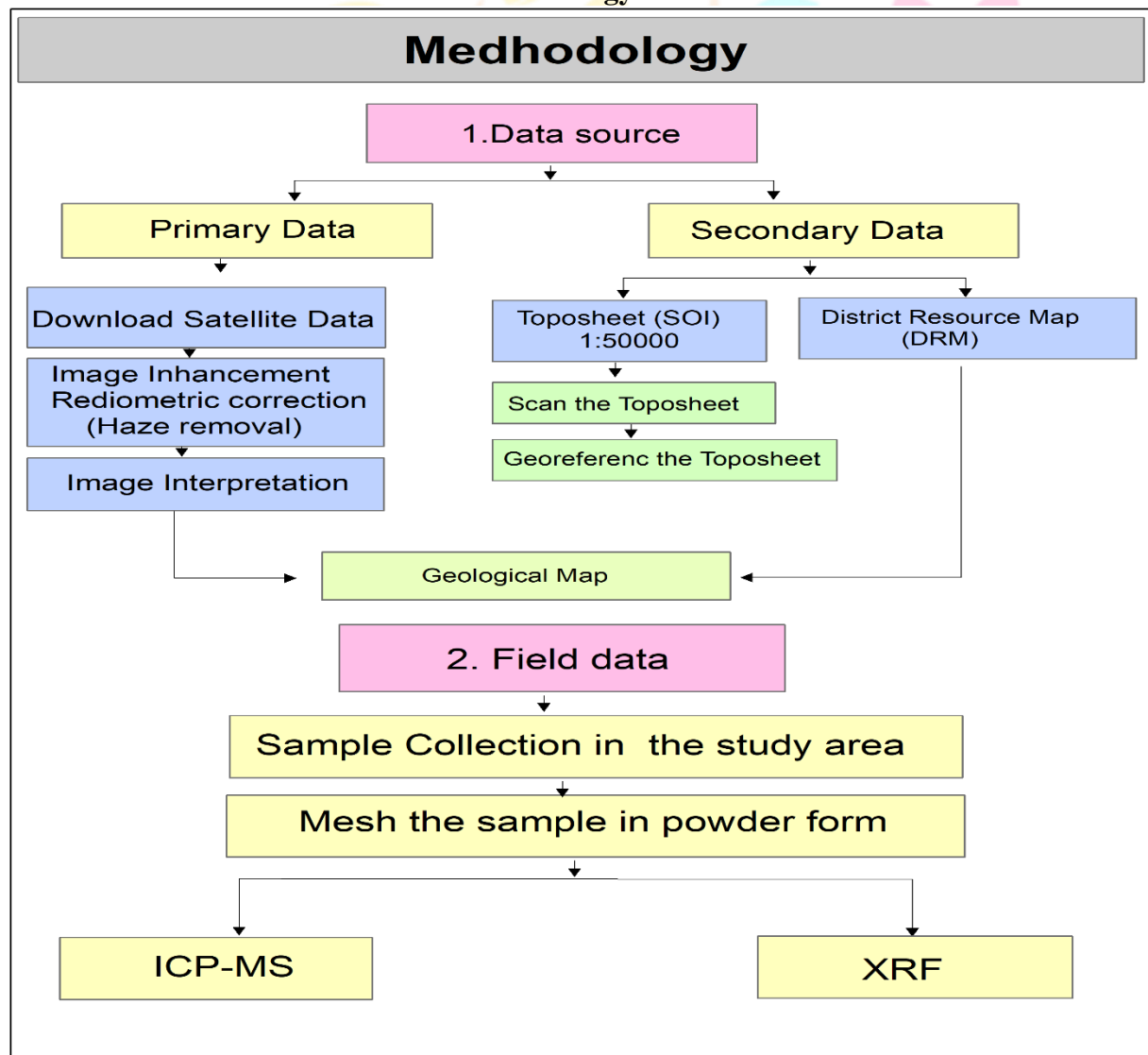
(Taylor and McLennan, 1985):

$$\text{Eu/Eu}^* = \text{EuN} / [(\text{SmN} \times \text{GdN})]^{1/2},$$

$$\text{Ce/Ce}^* = 2\text{CeN} / (\text{LaN} + \text{PrN}),$$

(Where N stands for the normalization of REEs to PAAS).

#### Methodology chart



#### 4. Results

The results of major, trace and rare earth elements (REEs) in samples of the limestone, in question, are given in Table 2

The bivariate plots between the pairs of major oxides show strong and positive correlation between  $Al_2O_3 - SiO_2$  ( $r = 0.70$ ; Fig.3a)  $Fe_2O_3 - SiO_2$  ( $r = 0.73$ ; 3b),  $Al_2O_3 - TiO_2$  ( $r = 0.93$ ; Fig.3e), The bivariate plots of major oxide that show weak and negative correlation include  $Al_2O_3 - CaO$  ( $r = -0.70$ ; Fig.3c),  $Fe_2O_3 - CaO$  ( $r = -0.58$ ; Fig.3d) and  $CaO - SiO_2$  ( $r = -0.88$ ; Fig.3f). What can be inferred from these plots is that CaO, compared with other constituent oxides, displays a different origin. The samples show strong depletion for elements such as V, Cr, Co, Ni, Cu, Rb, Y, Nb and Hf strong enrichment for element like Sr and rather notable enrichment for Ba and Zr (Fig.4). The  $\Sigma REE$  values for all the analyzed REEs have a range of 14.77 to 49.55 ppm. The distribution pattern of normalized REE concentrations shown graphically in Fig.5, reveals variation in concentrations with remarkably high concentration in Ce and Nd. The values of  $Eu/Eu^*$  and  $Ce/Ce^*$  vary between 0.53–0.69 and 0.57–1.07 respectively. The values of  $Er/Nd$  and  $Y/Ho$  are also within the range of 0.08–0.12 and 27.62–197.46 respectively.

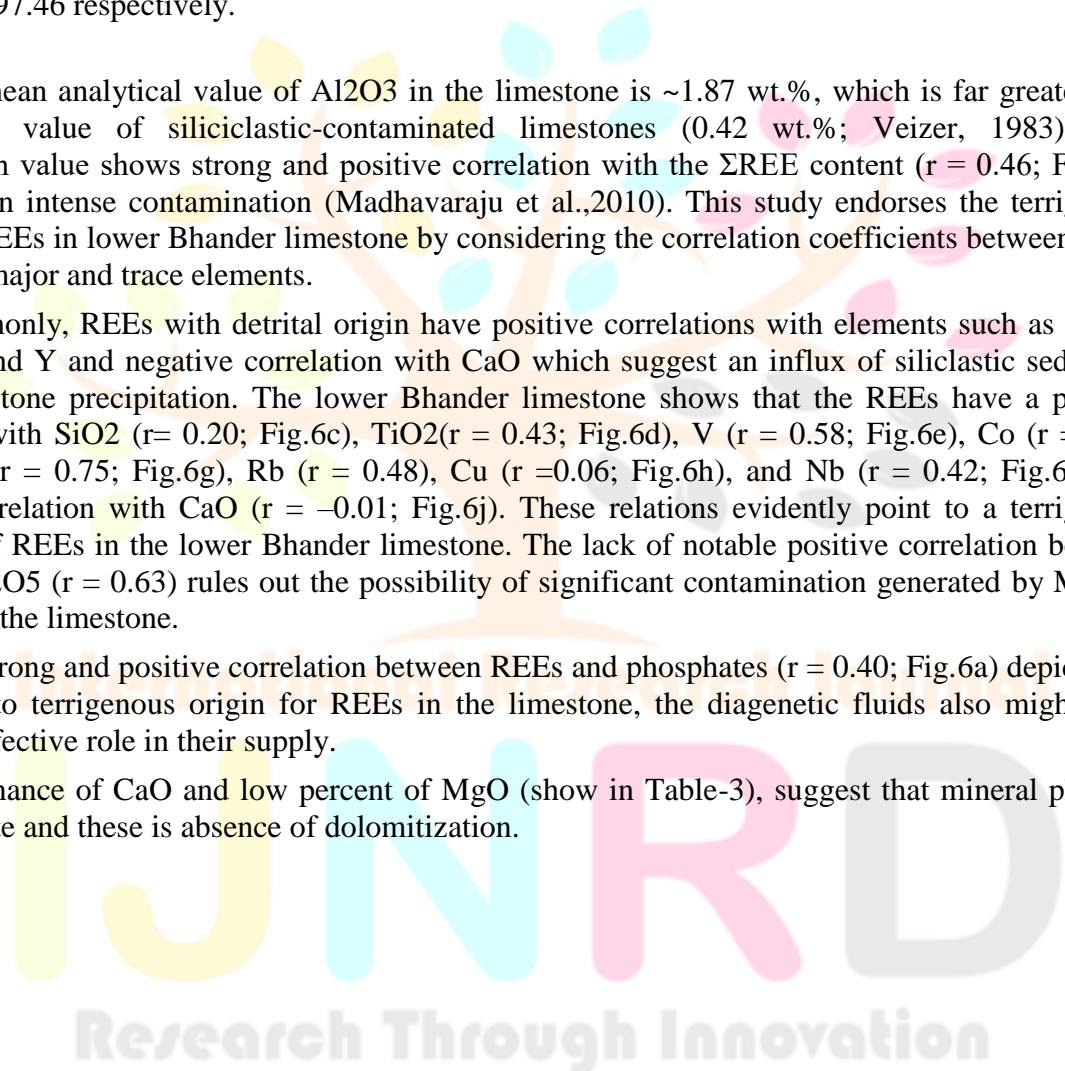
#### Discussion

The mean analytical value of  $Al_2O_3$  in the limestone is ~1.87 wt.%, which is far greater than the average value of siliciclastic-contaminated limestones (0.42 wt.%; Veizer, 1983). This concentration value shows strong and positive correlation with the  $\Sigma REE$  content ( $r = 0.46$ ; Fig.6b), suggesting an intense contamination (Madhavaraju et al.,2010). This study endorses the terrigenous source for REEs in lower Bhandar limestone by considering the correlation coefficients between REEs and certain major and trace elements.

Commonly, REEs with detrital origin have positive correlations with elements such as  $Al_2O_3$ ,  $Fe_2O_3$ , Ni and Y and negative correlation with CaO which suggest an influx of siliclastic sediments during limestone precipitation. The lower Bhandar limestone shows that the REEs have a positive correlation with  $SiO_2$  ( $r = 0.20$ ; Fig.6c),  $TiO_2$  ( $r = 0.43$ ; Fig.6d), V ( $r = 0.58$ ; Fig.6e), Co ( $r = 0.49$ ; Fig.6f), Ni ( $r = 0.75$ ; Fig.6g), Rb ( $r = 0.48$ ), Cu ( $r = 0.06$ ; Fig.6h), and Nb ( $r = 0.42$ ; Fig.6i), and negative correlation with CaO ( $r = -0.01$ ; Fig.6j). These relations evidently point to a terrigenous derivation of REEs in the lower Bhandar limestone. The lack of notable positive correlation between MnO and  $P_2O_5$  ( $r = 0.63$ ) rules out the possibility of significant contamination generated by Mn and Fe oxides in the limestone.

The strong and positive correlation between REEs and phosphates ( $r = 0.40$ ; Fig.6a) depicts that in addition to terrigenous origin for REEs in the limestone, the diagenetic fluids also might have played an effective role in their supply.

Dominance of CaO and low percent of MgO (shown in Table-3), suggest that mineral phase is mainly calcite and there is absence of dolomitization.



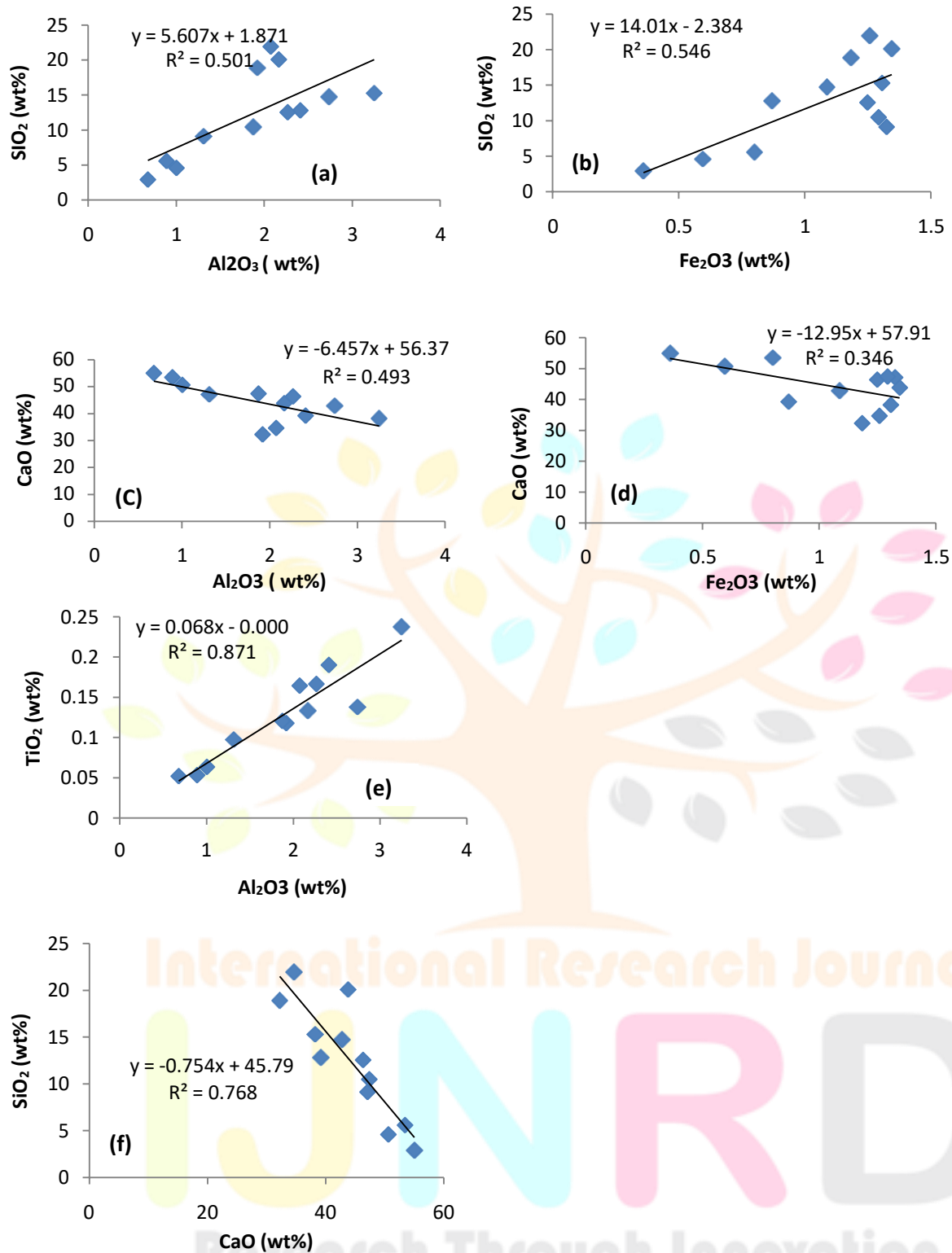
Sam. No.	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12
Li	9.8	36.1	46.5	35.3	22.4	26.4	37.8	16.5	38.0	15.3	30.3	29.9
Be	0.1	0.5	0.6	0.4	0.3	0.5	0.4	0.2	0.3	0.2	0.4	0.4
V	4.5	19.8	20.8	15.0	9.6	18.7	14.6	8.8	13.2	8.4	14.3	15.6
Cr	3.9	18.3	19.0	12.6	8.6	16.3	13.5	5.9	11.9	5.6	12.0	12.7
Mn	125.0	215.3	216.9	226.9	390.2	289.7	239.0	148.5	320.6	232.2	270.2	582.9
Co	1.3	3.0	3.2	2.6	3.0	3.2	1.9	1.8	2.5	1.9	2.7	4.9
Ni	6.4	9.1	11.3	8.9	8.3	13.6	7.6	6.8	7.3	7.9	11.8	14.2
Cu	1.5	4.4	6.5	4.4	3.2	4.9	16.2	2.3	4.6	2.6	3.7	5.4
Zn	-0.9	5.3	8.6	8.8	3.4	10.2	12.9	8.3	8.0	6.4	10.4	5.5
Ga	0.8	3.2	4.1	2.6	1.7	3.3	2.8	1.3	2.4	1.2	2.6	2.5
Ge	0.3	0.8	1.0	0.9	0.9	1.1	0.9	0.6	0.8	0.6	1.0	0.9
As	0.9	1.7	1.1	1.8	2.4	3.7	1.9	1.0	1.4	2.3	2.5	3.5
Se	1.0	2.9	0.6	2.0	1.0	1.0	1.2	1.1	0.5	1.4	0.7	1.5
Rb	6.1	25.8	33.1	20.7	11.2	25.1	21.2	9.9	19.3	8.2	20.1	17.0
Sr	441.1	316.6	252.4	253.0	155.4	272.3	231.0	246.0	242.3	241.0	170.8	209.1
Y	2.3	5.3	6.5	7.7	7.0	10.5	5.3	4.4	3.8	4.9	7.1	36.4
Zr	10.2	38.7	47.4	23.7	25.6	31.0	39.9	10.4	20.1	12.2	25.7	24.1
Nb	0.6	2.4	2.8	1.6	1.1	2.0	2.0	1.0	1.4	0.7	1.5	1.3
Mo	0.2	0.1	0.1	0.2	0.2	0.1	0.1	0.1	0.2	0.2	0.2	0.2
Cd	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.1	0.1
In	-0.9	-0.7	-0.4	-0.5	-0.4	0.0	-0.1	-0.7	0.3	-0.5	-0.3	-0.3
Sn	0.1	0.5	0.6	0.5	0.3	0.6	0.9	0.1	0.5	0.2	0.5	0.4
Sb	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.1	0.1	0.1	0.2	0.2
Ba	17.6	49.0	51.9	37.2	66.8	59.8	47.8	16.5	127.6	31.1	47.1	104.7
Hf	0.3	1.0	1.2	0.6	0.6	0.8	0.9	0.2	0.5	0.3	0.6	0.6
Ta	0.1	0.2	0.3	0.1	0.1	0.1	0.2	0.1	0.1	0.0	0.1	0.1
W	0.2	1.4	0.7	0.6	1.1	0.7	0.5	3.3	0.5	0.4	0.7	0.9
Tl	0.1	0.2	0.3	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Pb	1.9	5.2	5.6	3.8	3.5	5.4	5.6	3.2	2.7	4.6	3.3	4.5
Bi	0.0	0.1	0.1	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0
La	3.0	5.4	5.9	5.7	5.4	13.4	5.1	3.9	4.0	4.6	7.5	6.3
Ce	6.1	10.4	11.3	12.2	11.1	15.0	9.6	8.9	7.8	10.6	10.7	10.6
Pr	0.7	1.2	1.3	1.5	1.4	2.8	1.1	1.1	0.9	1.2	1.4	1.4
Nd	2.7	4.6	4.8	5.8	5.2	10.3	4.0	4.1	3.4	4.7	5.4	5.3
Sm	0.5	0.9	1.0	1.2	1.1	1.9	0.8	0.8	0.7	1.0	1.0	1.1
Eu	0.1	0.2	0.2	0.2	0.2	0.4	0.2	0.1	0.2	0.2	0.2	0.2
Gd	0.6	1.0	1.0	1.1	1.1	1.9	0.8	0.8	0.7	1.0	1.1	1.1
Tb	0.1	0.1	0.1	0.2	0.2	0.3	0.1	0.1	0.1	0.1	0.1	0.2
Dy	0.4	0.8	0.9	0.9	1.0	1.5	0.7	0.6	0.6	0.8	0.8	0.9
Ho	0.1	0.2	0.2	0.2	0.2	0.3	0.1	0.1	0.1	0.1	0.2	0.2
Er	0.2	0.5	0.6	0.6	0.6	0.8	0.4	0.3	0.3	0.4	0.5	0.5
Tm	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.1	0.1
Yb	0.2	0.5	0.6	0.5	0.5	0.8	0.4	0.3	0.3	0.3	0.4	0.5
Lu	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.1	0.1
REE	14.8	26.0	28.1	30.3	28.0	49.6	23.6	21.3	19.1	25.3	29.5	28.3
Eu/Eu*	0.5	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.7	0.6	0.6	0.6
Ce/Ce*	1.0	1.0	1.0	1.0	1.0	0.6	1.0	1.1	1.0	1.1	0.7	0.8
Er/Nd	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Y/Ho	27.6	30.3	34.9	40.0	37.8	35.6	36.6	36.3	33.6	34.1	43.8	197.5

Table 2. Results of chemical analysis (ICP-MS) of Lower Bhandar limestone.

**Table 3.** Normalized XRF data of the Lower Bhandar limestone in the area. BDL (Below dissolve level)

Sample No.	SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	K <sub>2</sub> O	CaO	TiO <sub>2</sub>	MgO	P <sub>2</sub> O <sub>5</sub>	MnO	Fe <sub>2</sub> O <sub>3</sub>
S1	2.918	0.6778	0.0735	55.01	0.0519	2.127	BDL	0.01842	0.361
S2	12.82	2.41	0.48	39.21	0.19	5.89	0.03	0.028	0.87
S3	15.3	3.248	0.6643	38.19	0.2376	8.452	0.0393	0.02947	1.307
S4	14.75	2.738	0.4997	42.81	0.1378	12.65	0.0333	0.03214	1.088
S5	9.121	1.311	0.1683	47.09	0.0972	6.869	0.0224	0.0552	1.325
S6	12.55	2.266	0.4907	46.34	0.1664	1.852	0.0295	0.0409	1.249
S7	21.95	2.074	0.4003	34.63	0.1643	8.414	0.0353	0.03172	1.258
S8	4.587	1.002	0.1544	50.62	0.0634	4.507	BDL	0.02006	0.5963
S9	18.89	1.919	0.3741	32.23	0.1178	11.85	0.0238	0.0421	1.184
S10	5.584	0.8898	0.1093	53.44	0.0531	1.541	BDL	0.03232	0.8012
S11	20.09	2.165	0.4138	43.78	0.1334	4.337	0.0254	0.03759	1.345
S12	10.48	1.873	0.2966	47.38	0.1204	2.972	BDL	0.0736	1.293





**Fig. 3:** Bivariate plots between  $\text{Al}_2\text{O}_3$ – $\text{SiO}_2$  (a),  $\text{Fe}_2\text{O}_3$  –  $\text{SiO}_2$  (b),  $\text{Al}_2\text{O}_3$  –  $\text{CaO}$ (c),  $\text{Fe}_2\text{O}_3$  –  $\text{CaO}$  (d),  $\text{Al}_2\text{O}_3$  –  $\text{TiO}_2$  (e),  $\text{Fe}_2\text{O}_3$  –  $\text{TiO}_2$  (f),  $\text{CaO}$  - $\text{SiO}_2$ (g), and  $\text{SiO}_2$  –  $\text{TiO}_2$ (h) for the limestone at Girgita Mines, Maihar area.

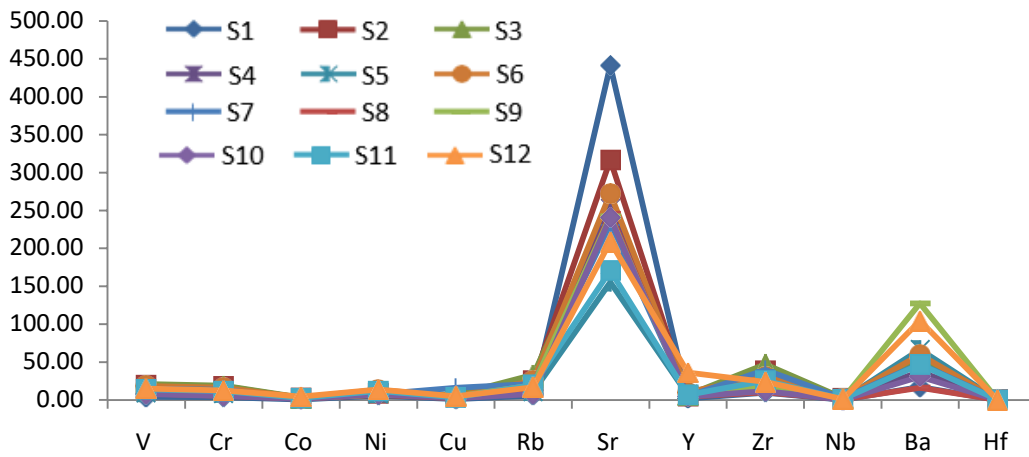


Fig. 4. Distribution patterns of trace elements (normalized) in the Bhandar limestone.

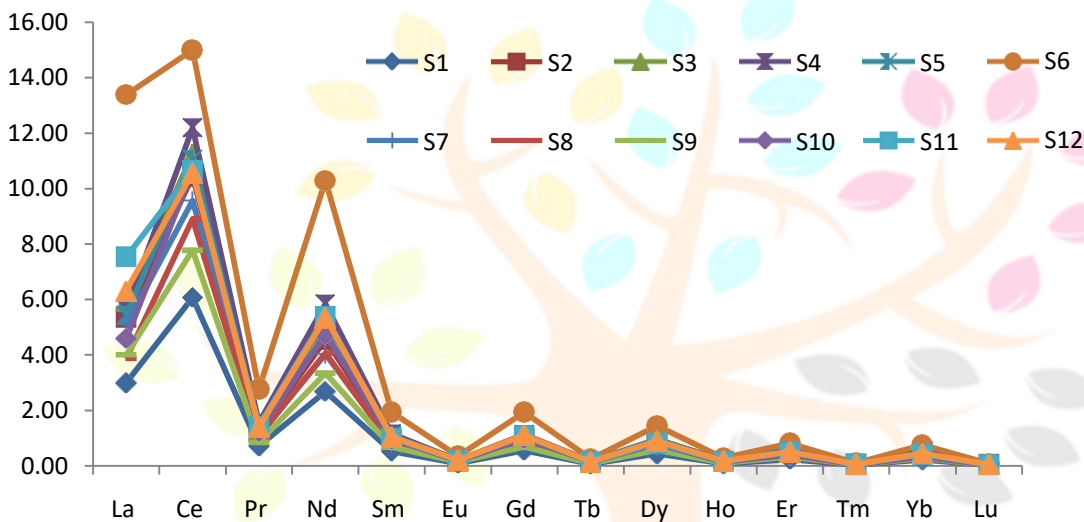
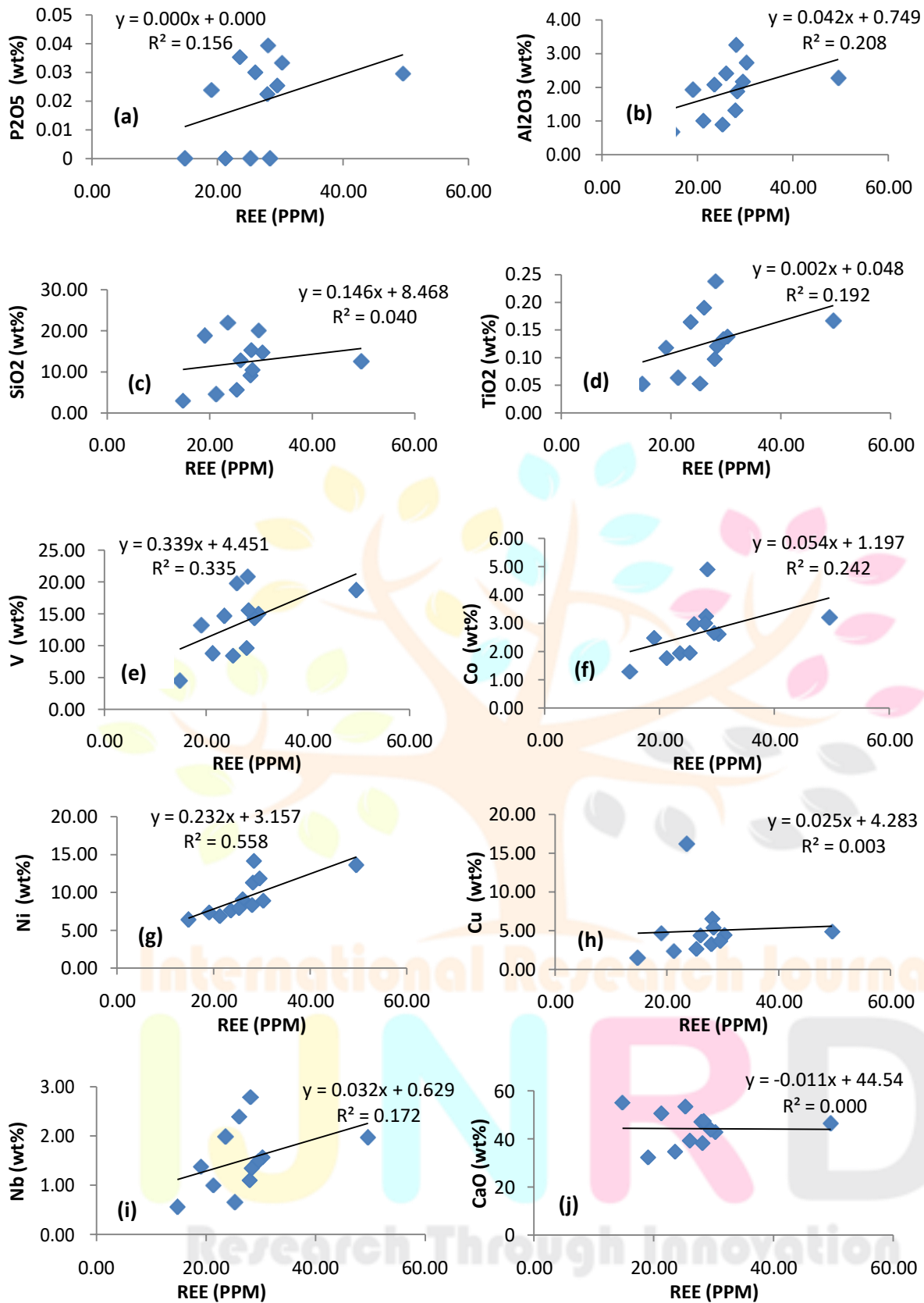


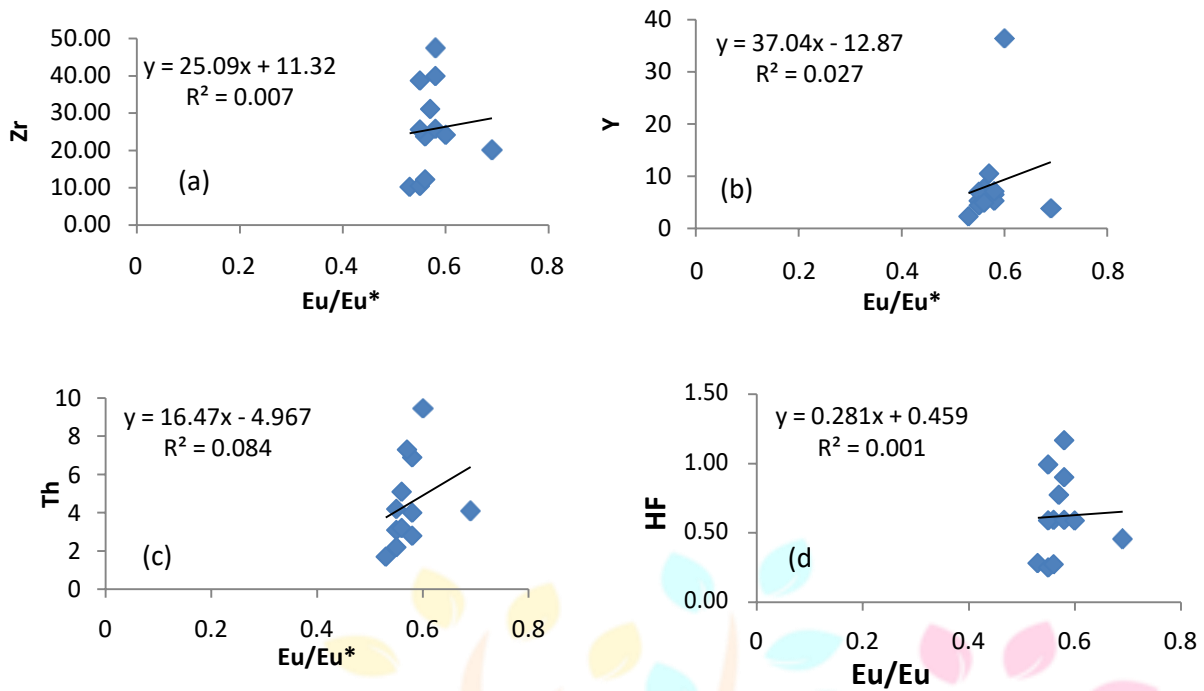
Fig. 5. Distribution patterns of REEs elements (normalized) in the Bhandar limestone.

### Eu anomaly

Eu anomaly values may be helpful in comprehending the physico-chemical conditions of various geochemical systems operating in the depositional environment of limestones (Derry and Jacobsen, 1990). The Eu anomalies, in the studied limestone, are negative ranging from 0.53 to 0.69, with a mean of 0.58. Commonly, positive Eu anomalies (normalized to PAAS) are observed in limestones influenced by hydrothermal processes whereas negative Eu anomaly is indicative of high decomposition of mineral and transportation of mineral containing Eu. the role of hydrothermal activities in the occurrence of positive Eu anomalies, in the limestone at Girgita mines, may be ruled out. The role of diagenetic processes can be postulated by positive correlations between  $\text{Eu}/\text{Eu}^*$  and by the concentration of certain immobile elements such as Zr, Y and Hf (Madhavaraju and Lee, 2009). The strong and positive correlations between  $\text{Eu}/\text{Eu}^* - \text{Zr}$  ( $r = 0.09$ ; Fig.7a),  $\text{Eu}/\text{Eu}^* - \text{Y}$  ( $r = 0.17$ ; Fig.7b),  $\text{Eu}/\text{Eu}^* - \text{Th}$  ( $r = 0.29$ ; Fig.7c) and  $\text{Eu}/\text{Eu}^* - \text{Hf}$  ( $r = 0.04$ ; Fig.7d) advocate the effective role of diagenesis in the occurrence of Eu anomalies in the Bhandar limestone.

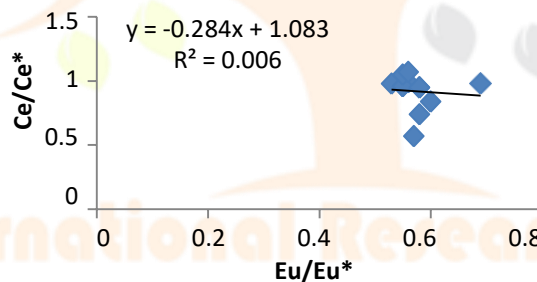


**Fig. 6.** Bivariate plots between REEs–P2O5 (a), REEs–Al2O3 (b), REEs–SiO2 (c), REEs–TiO2(d), REEs–V(e), REEs–Co (f), REEs–Ni (g), REEs–Cu(h), REEs–Nb (i), and REEs–CaO (j)



**Fig. 7.** Bivariate plots  $\text{Eu}/\text{Eu}^*$  –Zr (a),  $\text{Eu}/\text{Eu}^*$  – Y (b),  $\text{Eu}/\text{Eu}^*$  –Th (c), and  $\text{Eu}/\text{Eu}^*$  –Hf (d) in the Bhandar limestone

The controlling role of diagenetic processes in the distribution of REEs in limestone can be established by a poor and negative correlation between  $\text{Eu}/\text{Eu}^*$  and  $\text{Ce}/\text{Ce}^*$ . The existence of poor and negative correlation between  $\text{Eu}/\text{Eu}^*$  and  $\text{Ce}/\text{Ce}^*$  ( $r = 0.08$ ; Fig.8), in the limestone, demonstrates that the diagenesis happens to be a controlling factor in the distribution of REEs in this limestone.



**Fig.8.** A bivariate plot between  $\text{Eu}/\text{Eu}^*$  and  $\text{Ce}/\text{Ce}^*$  for the Bhandar limestone

## Ratios of Y/Ho and Er/Nd in the Bhander limestone

Yttrium(Y) is identical to Ho and Dy in terms of ionic charge and ionic radius. Therefore, in distribution pattern of REEs, it is inserted between Ho and Dy (Bau, 1996). Although Y and Ho have similar geochemical behavior, yet Ho can be removed from sea water twice as fast as Y. This phenomenon is related to the difference in degree of surface complex stabilities, which leads to a notable super chondritic marine ratio of Y/Ho (Bau, 1996; Nozaki et al., 1997). Terrigenous material and volcanic ash have constant chondritic values of Y/Ho (approximately 28). Seawaters have Y/Ho values greater than those of volcanic ash, ranging from 44 to 74 (Nozaki et al., 1997). In this study, the Bhander limestone has Y/Ho values varying noticeably from 27.62 to 197.46 (mean 49). These values indicate that the limestone is contaminated with terrigenous material. The value of Er/Nd, in normal seawater, is ~0.27. The Er/Nd value in limestone efficiently indicate the seawater signature. The Er/Nd values, in the studied limestone, display a narrow range of 0.08–0.12, which in turn, indicate the effective role of detrital material and diagenetic processes in the occurrence of Er and Nd in the Bhander limestone. The controlling role of diagenetic processes in the distribution of REEs in this limestone can be established by positive correlation between Eu/Eu\* and Ce/Ce\*. The positive correlation between Eu/Eu\* and Ce/Ce\* ( $r = 0.006$ ; Fig. 8) in the Bhander limestone endorses the role of diagenesis in the distribution of REEs.

## 5. Conclusions

Conclusions drawn from this study are:

Geochemical indicators such as low ratio of Y/Ho and high values of REEs show that the concentration of REEs in Bhander limestone is associated with the incorporation of terrigenous material. This can further be supported by strong positive correlation of REEs with elements such as Si, Al, Ti, V, Co, Ni, Rb, Cu and Nb and by negative correlation between REEs and CaO.

The positive correlation between Ce/Ce\* and elements like Si, Al, Zr, Hf, and Y along with negative correlation between Ce/Ce\* and certain components such as CaO, U, Fe<sub>2</sub>O<sub>3</sub> and MnO show that variation in the values of Ce anomaly in this limestone have substantially been controlled by fluvial detrital material. Besides, the negative correlation furnish strong evidence for deposition of this limestone in a shallow marine environment.

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## References

- Banerjee, A., Banerjee, D.M. (2011). Modal analysis and geochemistry of two sandstones of the Bhander Group (Late Neoproterozoic) in parts of the Central Indian Vindhyan basin and their bearing on the provenance and tectonics. *J. Earth Syst. Sci.* 119, No. 6, December 2010, pp. 825–839.
- Bau, M. (1996). Controls on the Fractionation of Isovalent Trace Elements in Magmatic and Aqueous Systems: Evidence from Y/Ho, Zr/Hf and Lanthanide Tetrad Effect. *Contributions to Mineralogy and Petrology*, 123: 323–333.
- Greaves, M., Elderfield, H., Sholkovitz, E.R. (1999). Aeolian sources of rare earth elements to the Western Pacific Ocean. *Mar Chem*68: 31–38.
- Ray, J. S. (2006). Age of the Vindhyan Supergroup: A review of recent findings. *Journal of Earth System Science*, volume 115, pp.149–160 (2006).
- Liu, Y.G., Miah, M.R.U., Schmitt, R.A. (1988). Cerium: a chemical tracer for paleoceanic redox conditions. *Geochimica Cosmochim Acta* 52: 1361–1371.
- Madhavaraju, J., Gonzalez-Leon, C.M., Lee YONG-II., Armstrong-Altrin, J.S., Reyes-Campero, L.M. (2010). Geochemistry of the Mural Formation (Aptian-Albian) of the Bisbee Group, Northern Sonora, Mexico. *Cretaceous Res*, 31: 400–414.

Madhavaraju, J., Lee, Y. (2009). Geochemistry of the Dalmiapuram Formation of the Uttatur Group (Early Cretaceous), Cauvery basin, southeastern India: implications on provenance and paleo-redox conditions. *Revista Mexicana de Ciencias Geologicas*, 26: 380–394.

Nagarajan, R., Madhavaraju, J., Armstrong-Altrin, J.S., Nagendra, R. (2011). Geochemistry of Neoproterozoic limestones of the Shahabad Formation, Bhima Basin, Karnataka, southern India. *Geosci. J.*, 15: 9–25.

Nozaki, Y., Zhang, J., Amakawa, H. (1997). The fractionation between Y and Ho in the marine environment. *Earth Planet Sci. Lett.*, 148: 329–340.

Piper, D.Z. (1974). Rare earth elements in the Sedimentary cycle: a summary. *Chem. Geol.*, 14: 285–304.

Madhavaraju, J., Ramasamy, S. (1999). Rare earth elements in limestones of Kallankurichchi Formation of Ariyalur Group, Tiruchirapalli Cretaceous, Tamil Nadu. *J Geol Soc India* 54: 291–301.

Murphy, K., Dymond, J. (1984). Rare Earth Element fluxes and geochemical budget in the eastern equatorial Pacific. *Nature* 307: 444–447.

Taylor, Y., McLennan, S.M. (1985). *The Continental Crust: Its Composition and Evolution*. 1st ed. Oxford, UK:

Veizer, J. (1983). Trace Elements and isotopes in Sedimentary carbonates. In: Reeder RJ, editor. *Carbonates: Mineralogy and Chemistry*, De Gruyter Vol. 11., From the book *Carbonates*. Pages: Front matter: 12, Main content: 399.

Pandey, S.K. and Kumar, S., (1913). Organic walled microbiota from the silicified algal clasts, Bhandar limestone, Satna area, Madhya Pradesh, *J Geol Soc India* 82, 499–508.

Kumar, S. and Banarji, S. *A Field Guide, A Synthesis of Depositional Sequence of the Proterozoic Vindhyan Supergroup in Son Valley*, Springer Singapore, 2019.

