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# Geochemistry of Mesoproterozoic metadolerite dykes and sills of Shillong basin, Meghalaya, NE India

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***Abstract*** *The Shillong Basin is the only Proterozoic (Purana) basin of NE India and is an intracratonic sag basin in nature. The basin is dominantly exposed in Meghalaya and partly in Karbi Anglong district of Assam and confined in the central and eastern parts of the Shillong plateau. This Proterozoic basin was developed during early Mesoproterozoic time. The metasedimentary rock associations of this basin are classified under Lower Metapelitic and Upper Quartzitic Formations closely associated with mafic magmatism in the form of mafic sills and dykes (metadolerite, locally named as Khasi greenstone). They are metamorphosed under greenschist – amphibolite transitional facies. The present study aims at generating geochemical characteristics of the metadolerites of the basin. Mafic dykes and sills of the basement of the Shillong plateau is of Cretaceous age and excluded from the present study. Geochemically, metadolerites are subalkaline and tholeiitic in nature and emplaced in continental setting. Geochemical data, mantle normalized spidergram and chondrite normalized REE patterns suggest that they are genetically related and probably derived from the same parental source magma undergoing shallow level fractionation.*

**Keywords**: Shillong Plateau, Shillong basin, Dolerite dykes and sills, Geochemistry.

## Introduction

Mafic dykes and sills occur in a wide variety of geological tectonic settings and their study provides insights into geological events and continental breakups which ultimately help in reconstruction of continents. Petrology and geochemistry of mafic magmatic bodies document origin, emplacement and growth of continental crust and provide vital evidences for distinct episodes of crust generation. The chemical composition of mafic dykes and sills provides clues to their crustal emplacement conditions that maybe related to the prevalent tectonic stress regimes. The Shillong plateau has played a vital role in the Precambrian history of the Indian plate and in particular northeast Indian region. The magmatic history and mafic emplacements of

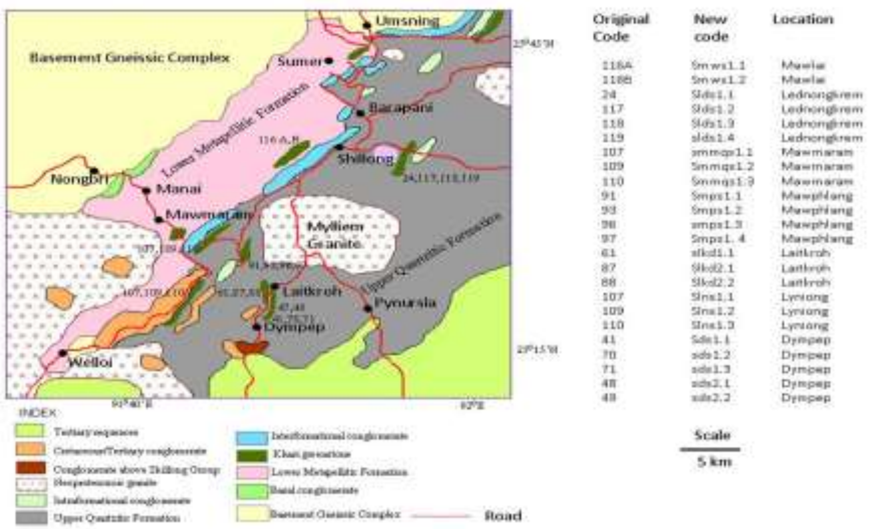



Fig.1 Generalised geological map of Shillong basin showing the location of metadolerites

the Shillong plateau are important as the plateau forms the northeastern margin of Indian Peninsula and records evidence of the evolving plate boundary. The mafic dykes and sills in Shillong basin, an intracratonic rift related sag basin of Mesoproterozoic age, are metadolerites (named as Khasi greenstone by Medlicott, 1869). They are metamorphosed along with arenaceous and argillaceous sediments under greenschist – amphibolite transitional facies (Turner, 1968). These dykes were not given much attention as compared to other mafic dykes of Indian subcontinent. Some sporadic works on geochemistry and palaeomagnetism have been done by Hazara et al. (2008), Mallikharjuna Rao et al. (2009), Ray et al. (2013), Sarma et al. (2014). But the present study aims at generating geochemical data, petrographic information and interpretation of origin of these Proterozoic Metadolerite dykes and sills of the Shillong Basin which is an intracratonic Purana basin of the Shillong plateau and to demonstrate important features of their emplacement history and source material.

**Regional geological setting**

Shillong plateau represents a detached part of the Indian sub continental craton. The E-W trending Shillong plateau is an elevated block about 600-800m above Bangladesh plain and geomorphologically appears as an inverted spoon shaped structure (Duarah and Phukon, 2011). The uplift is related to collision of Indian and Tibetan plates during Cenozoic time (Johnson and Alam, 1991; Nandi, 2000 and Bilham and England, 2001). The plateau is bounded to the north by Brahamaputra lineament, to the south by Dauki fault, Indo Myanmar Mobile Belt (IMMB) to the east and Dhubri – Yamuna lineament to the west and is tectonically separated by Garo-Rajmahal graben from Peninsular India (Eremenco et al., 1969). It constitutes the leading edge of the Indian plate during its oblique collision with the Australo-Antarctic plate at ca. 500-650 Ma (Chatterjee et al., 2006). The plateau is criss crossed by numerous lineaments in NE-SW, N-S and EW sdirections (Chattopdhyaya and Hashmi, 1984). Further, a NW-SE tectonic Kopili lineament dissects the plateau into two blocks namely Meghalaya massif and Mikir massif (renamed as Karbi Anglong massif by Sarma and Dey, 1996).

The Shillong plateau portrays a classic example of basement – cover relationship where Shillong Group (SG) acts as cover and basement by Basement Gneissic Group (BGG). The BGG comprises of metamorphites including quartzofeldspathic gneisses, migmatites, amphibolites, calc-granulites, calc-silicate rocks, high grade schist, basic and acid intrusives andpegmatites. They are metamorphosed under granulite - amphibolite transitional facies. The granite gneiss of BGG from Patharkhang area of West Khasi Hills district of Meghalaya, is dated as Paleoproterozoic age (Hazara et al., 2008; Ghosh et al., 1994). Yin *et al*. (2010) have established three episodes of igneous activity at 1600 Ma, 1100 Ma and 500 Ma witnessed in the rocks of the Shillong plateau. The first episode of igneous activity at 1600 Ma is related to the collision of two proto India continents and the ductile phase that took place at 1100 Ma under contractional mechanism induced by assembly of Rodinia and Eastern Gondwana. This finding is correlatable with the findings of Chatterjee et al. (2006) who have presented monazite date from Goalpara and Sonapahar area as 1596±15 Ma and 570± 14 Ma. Bidyananda and Deomurari (2007) have given 1.5 to 2.6 Ga dates from basement gneisses. However, Chatterjee et al. (op. cit) have arguably claimed that there is no Archean rock in the Shillong plateau.

The lithoassociations of the Shillong basin constituting Shillong group (earlier Shillong series of Medlicott, 1869), is classified under two formations, namely Lower Metapelitic Formation (LMF) and Upper Quartzitic Formation (UQF). The UQF was named as “Mawphlang Formation” or Shillong Formation (Ahmed, 1981; Barooah and Goswami, 1972), whereas LMF is known as Manai Formation by Bhattacharjee and Rahman, (1985) or Tyrsad Formation by Barooah and Goswami (1972), Barapani Formation by (Ahmed, 1981). The LMF are marked by quartz – mica schist, quartz– sericite schist, biotite- sericite schist and biotite schist. The UQF representing the upper sequence of the Shillong basin are of massive to more micaceous types showing primary cross stratifications and ripple marks. They are often intercalated with thinly bedded metapelites and at the contact of Neoproterozoic granite, contact metamorphic rocks (hornfelse) are observed with well developed andalusite crystals.

Metadolerites (Khasi greenstone of Medlicott, 1869) occur as green coloured dykes, sills or isolated linear to curvilinear bodies.They often occur as angular rafts, fragments and subrounded xenolithic bodies within the younger granites. They are compact, medium grained and rarely coarse grained and it exhibits spheroidal blocks due to weathering. Two types of mafic bodies – massive and foliated, from type area Leitkroh in East Khasi Hills district are found (Hazara et al., 2008). Both the types are essentially enclosed within Upper Quartzitic Formation of Shillong Group. But a notable factor is observed that the foliated type is essentially enclosed within the lower metapelitic formation and massive type is confined within upper quartzitic formation, the latter is marginally altered and affected by low grade metamorphism, central part being still massive.

The Shillong Group of metasediments has been dated as 1530 – 1550 Ma (Mitra, 1998) and 1.4 to 1.9 Ga (zircon dates of metasedimentary quartzites by Bidyananda and Deomurari, 2007). Neoproterozoic granites were intruded into the Shillong basin (e.g. Mylliem pluton, Kyrdem pluton and South Khasi pluton), which have been dated as

607±10 Ma (Crawford, 1969); 885 – 80 Ma (Ghosh et al., 1991, 1994 and Bhattacharyya and Ray Barman, 1998) andthey form another Formation named as “Mylliem Formation” (GSI, 1972). Recently Sarma (2014) has attempted reclassification of Shillong Group and their underlying basement gneisses and proposed Shillong Supergroup in the light of lithostratigraphic nomenclature. Conglomerates of the Shillong Group separating underlying BGG and overlying Mesozoic – Tertiary sequences are delineated in detail by Devi and Sarma (2006, 2010) and their strain history is established. Besides, there are number of conglomerates, of interformational and intrafoemational types within Shillong basin. Cretaceous and Tertiary rocks are extensively exposed in southern part of the plateau. Thus the plateau witnessed bsic, acidic and The occurrence and distribution of the metadolerites of the Shillong basin are shown in Figure 1.

**Petrography**

Metadolerite are light green to greenish black in colour and are coarse to medium grained rocks. They are essentially composed of augite, plagioclase, opaques and rarely olivine in addition to secondary hornblende, actinolite, chlorite, epidote and biotite. The field association and their megascopic appearance clearly indicate that there are two types of mafic bodies such as foliated and massive types and it is supported by petrographic features. The massive type shows ophitic textures without alteration effects (Fig.2A) and partly altered type shows alteration and recrystallization of plagioclase and clinopyroxene with relict ophitic texture (Fig. 2B). Plagioclases are bytwonite (An71) in composition and show compositional zoning and effects of clouding in the central part while outer rim is more sodic which indicate that they are partially affected bu low grade metamorphism. The plagioclases are most abundant and often accompanied by augite (Fig.2C). The clinopyroxenes are augite and zoning is observed from rim to cores. Olivine grains when alter to augite, form rims around olivines (Fig. 2D). Extensive development of with variable amounts interstitial magnetite is seen (Fig.2E). Quartz and biotite occurs in minor amount. Clusters of plagioclase form relict glomeroporphyritic texture. Granoblastic texture is seen in the massive types (Fig.2F). Magnetite, ilmenite, apatite and rutile are present as accessories. Presenece of relict ophitic to subophitic texture along with skeletal habit of pyroxene are seen which indicate their basic igneous parentage

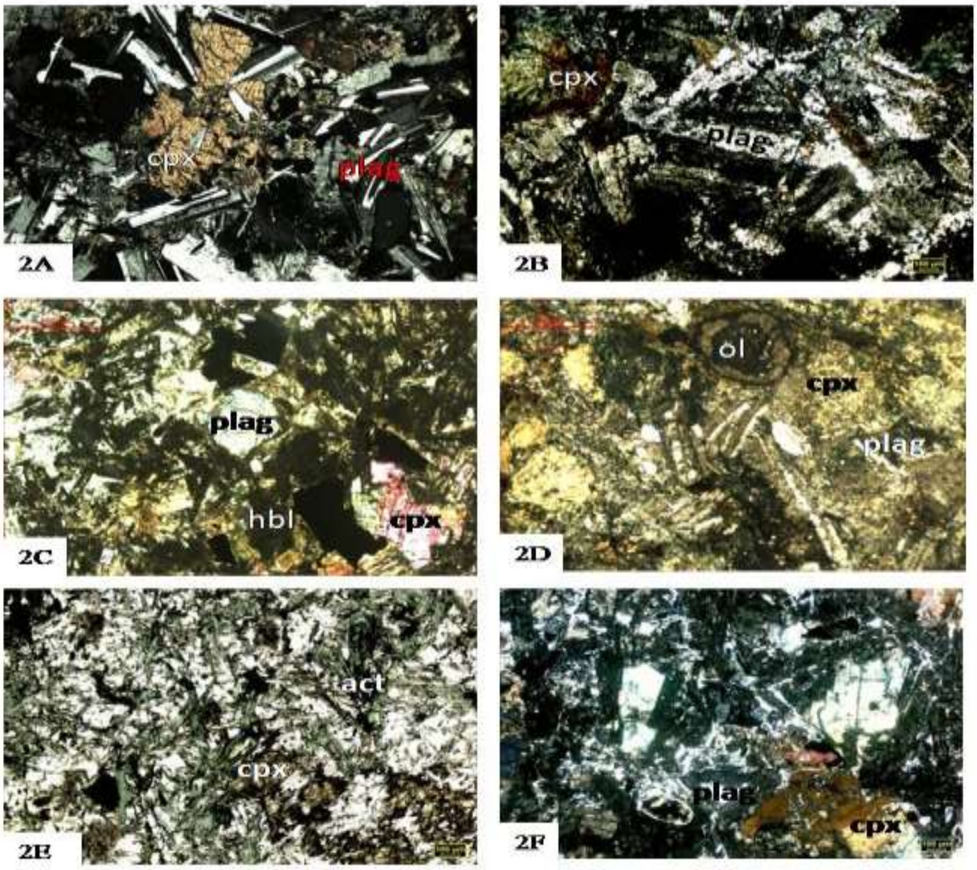



**Fig. 2. Photomicrographs of Khasi greenstone samples. A. Fresh massive dyke showing ophitic texture. B. Partly altered dyke shows relict ophitic texture and marginal granulation effect. C. Development of hornblende and presence of plagioclase and augite microphenocrysts. D. Clinopyroxene rims around olivine grains. E. Secondary actinolite development and variable amounts of interstitial magnetite. F. Partly recrystallized and altered dyke samples from central part of the dykes**

**Geochemistry**

After careful petrographic studies, 15 representative samples of dykes nd sills were analysed for major, trace and rare earth elements. Whole rock major oxides were analysed by automated sequential spectrometer X-ray fluorescence (XRF) and trace and REE element analyses were done by ICP-MS technique at NGRI Geochemical Laburatory, Hyderabad, following the procedures described by Balaram (2005). The geochemical data of the samples are presented in Table 1. The geochemical data reveals variation in their geochemical characters and indicate that the mafic magma source has differentiated at mantle depths. All metadolerites show $SiO_2$ (53.07-58.92 wt %), total iron as $Fe_2O_3$ varies between 10 -17 wt%. The rocks are relatively high in $TiO_2$ content (0.8 to 3.54 wt %) and such high content may be due to crustal contamination. Alumina exhibits a wide variation ranging from 11.22 to 15.86 wt% and the variation is mainly attributed to the fractionation. Iron and magnesia show variation from 10.99 to 16.74wt% and 2.40 to 5.97 wt%, respectively. The moderate Mg # 23-47 suggests that this variation is not only controlled by the fractionation of ferromagnesian silicates but also by iron oxides. The rocks have moderate calcium content of 3.23 to 7.71 wt% and the $Na_2O$ (0.83 to2.07 wt %) appears to be low. $K_2O$ content varies from 0.15 to 1.96 wt%.

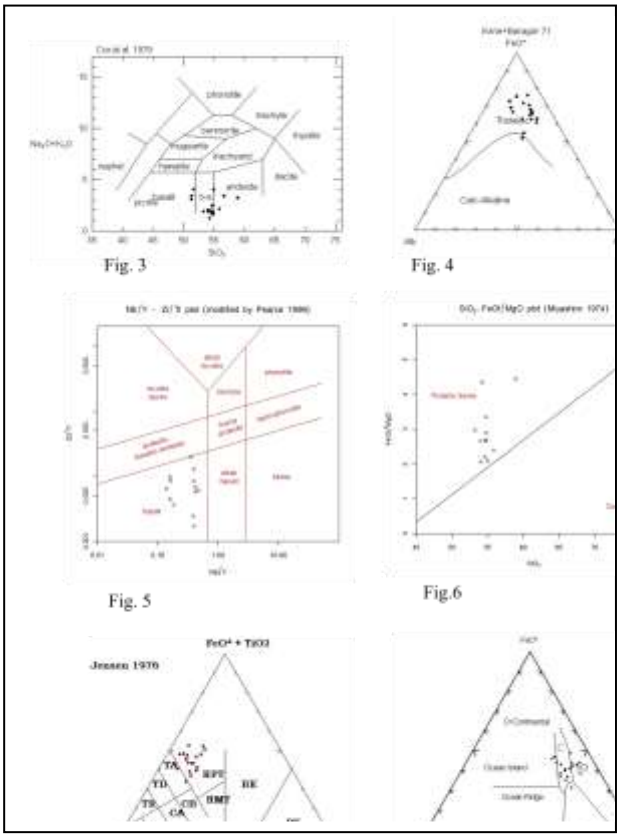


Fig. 3 Fig. 4 Fig. 5 Fig.6

Several variation diagrams were used to know the classification of geochemical characteristics and their tectonic emplacement. $SiO_2$ when plotted against TiO2 (wt%) it is observed that $SiO_2$ decreases with increasing $TiO_2$ and negative correlation is indicative of crystal fractionation. Similar negative correlation is shown by $Fe_2O_3$, CaO, MgO against $SiO_2$while positive correlation is shown by $Al_2O_3$, MnO, $Na_2O$, $P_2O_5$ (Fig. 10a). In the total alkali vs $SiO_2$ (TAS diagram after Cox et al. 1979;, metadolerites are plotted in the fields of basalt and basaltic andesite excepting three sample confined to andesite and all plots are characteristically fall in the field of sub alkaline (Fig. 3). All the metadolerites show enrichment of iron during their evolution and showing tholeiitic trend (Fig. 4). Binary variation Nb/Y- Zr/Ti plot shows sub alkaline basaltic composition in the Pearce (1996) diagram (Fig. 5). The tholeiitic character is obviously displayed by plots of FeO(t) /MgO vs $SiO_2$ in the Miyashiro's (1974) diagram (Fig. 6). It is supported by another ternary plot of Jensen (1976) MgO-$Al_2O_3$- FeO+$TiO_2$ which shows that all the samples have high iron rich tholeiitic characteristics (Fig. 7). Plots of Zr / $TiO_2$ vs Nb / Y for mafic dykes and sills also categorically fall in the sub alkaline field. All the dolerites show quartz normative (q= 19.4-33) and are tholeiitic in composition. Many mafic bodies show corundum in their norms (0.4- 6.0%). $SiO_2$ when plotted against $TiO_2$ (wt %) it is observed that $SiO_2$ decreases with the increased $TiO_2$ and such negative anomaly is another subscribing evidence of crystal fractionation. Ternary plots of $TiO_2$ – $P_2O_5$ – $K_2O$ and FeO – MgO – $Al_2O_3$ clearly indicate that the mafic dykes and sills are of continental tholeiitic type (Figs. 8, 9).

The LILE (large ion lithophile elements) such as Ba (110-540 ppm), Rb (5-109 ppm), Sr (122- 486 ppm) show higher concentration. Tectonic discriminatory ternary diagrams like FeO* - MgO – $Al_2O_3$ and $TiO_2$ – $K_2O$ – $P_2O_5$ are self explanatory that they belong to continental setting. Tectonic diagrams are used only as part of a framework that is also based on other evidences. Different major oxides and trace elements plot against $SiO_2$ show systematic variations and supports fractional crystallization from the source magma (Fig. 11a, b).

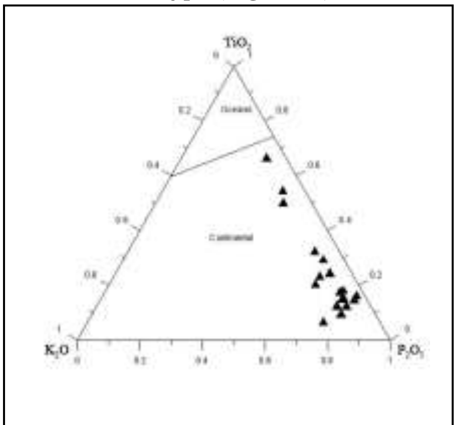


Fig. 9

The HFSE (High Field Strength Elements) such as Sc (25-58 ppm), Y (24-83 except one sample 252 ppm), Th (2-10 ppm), U (up to 3 ppm), Pb (14- 53 ppm), Zr (25- 287 ppm), Hf (1- 27 ppm), Nb 4-30 ppm) and Ta are found to be moderate in these metadolerite dykes and sills. Zr / Nb ratio ranges from 2.2-15, Zr / Hf ratio of 25-71, Zr / Nb ratios of 2.1- 15 indicates strongly enriched character. REE in the metadolerites varies from 56 to 281 ppm, and show fractionation trends $(La/Yb)_N$= 4.1- 9.8. Most of the samples enriched in LREE ($La_N/Sm_N$ =1.8-2.5) and relatively similar enriched HREE ($Gd_N/Yb_N$ = 1.9-3.3) trends. The Europium anomaly in these samples is nearer to one indicating that the plagioclase feldspar has not played significant role. Eu/Eu* varies between 0.8-1.1 and our earlier reported results are also support similar geochemical characters (Mallikharjuna Rao et al., 2009). La/SmN vary between 1.56 to 2.29. The REE pattern is relatively flat and coherent and negative minor Eu anomaly is observed (Fig. 10a). La/Nb, Th/La, Hf/Sm ratios are useful indicators of crustal contamination and those ratio ranges from La/Nb 1.3 to 3.6, Hf / Sm=0.15-2.16, Th/La range from 0.29 to 0.15. Th/La (upto 0.33) indicates effect of crustal contamination. In multielemental spidergram negative troughs of Sr and Eu also suggest the plagioclase fractionation. In both the spidergram moderate negative peaks is indicated by Nb, Sr, Zr, P, Ta and Ti suggesting that crustal contamination affected the samples chemistry and often strongly positive Pb peaks (Fig.10a, b) are the typical of continental crust. All the diagrams referred to above suggest that the mafic dykes and sills are the products of fractional crystallization, partly contaminated and mantle derived partial melting products.

Chemical composition show high silica, high alumina nature, and quartz hypersthenes normative which signify that the rocks are quartz tholeites (Thompson, 1984). $SiO_2$-Zr/$TiO_2$ classification diagram (Winchester and Floyed, 1977) shows sub alkaline character (figure not shown). (La/Lu)N ratio is more than 5, which indicates that the studied samples are genetically related to each other. These mafic rock samples exhibit REE patterns and do not show significant Eu anomaly. It is important to note that HFSE and REE pattern do not show any significant contamination signatures because contaminated samples should exhibit inconsistent pattern. Samples contaminated by crust should exhibit steeper slope for LREE than HREE as crustal material are enriched in LREE.

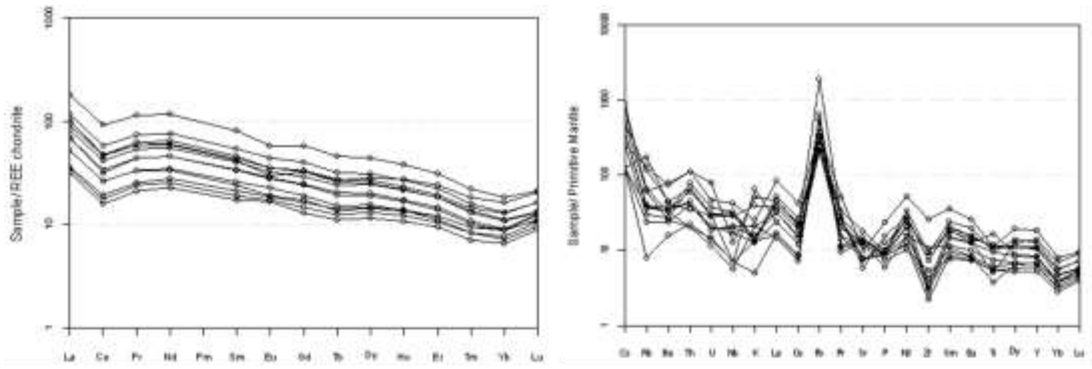
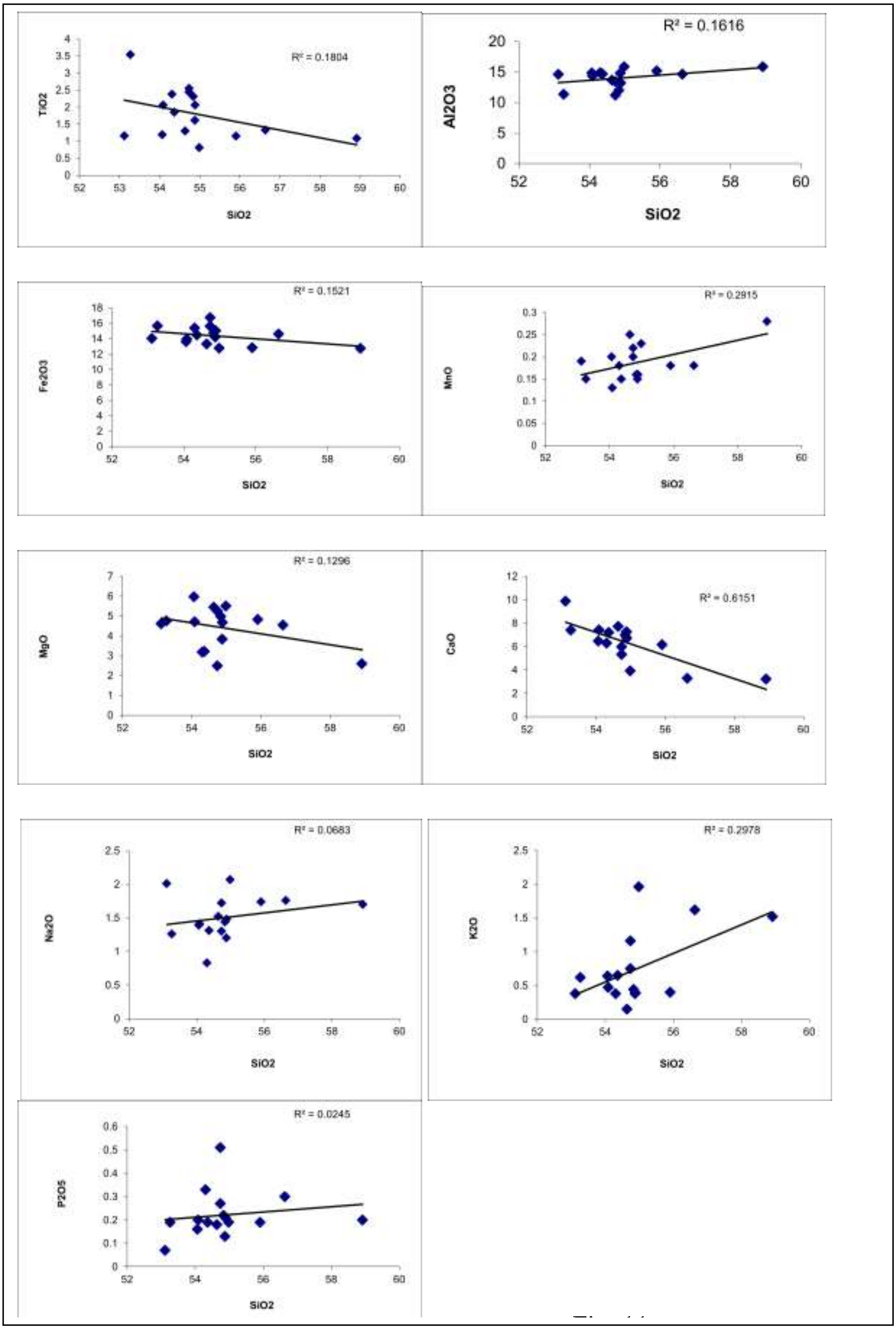


Fig. 10a Fig. 10b

In this case (La/Eu)N should be higher than (Eu/ Lu)N but it is not. Average Nb / La is 0.5 which is close to Primordial mantle (1.01) (McDonough, et al., 1992), whereas it is 0.23 for Lower crust (Weaver and Tarney, 1984). High Ba / Ta ratios observed suggest involvement of crust. Ray et al. (2013) have noted two types of metadolerite-foliated and massive-and based on isotopic signatures, it was opined that partial melting of a subduction modified, metasomatized, enriched lithospheric mantle wedge of spinel-peridotite is the parent magma source for metadolerites. It is seen that the studied samples are probably derivedfrom a magma contaminated with a minor amount of crustal material, but it requires further chemical data, particularly isotopic data are necessary to establish this.

**Discussion**

Stratigraphically, the BGG of amphibolite – granulite transitional facies is regarded as the basement of Palaeoproterozoic age above which, Shillong Group of rocks of Mesoproterozoic age acts as cover rock in the Shillong basin. Two sets of mafic dykes and sills are found to occur both in the basin as well as underlying basement. Partially metamorphosed mafic dykes and sills of Mesoproterozoic age is confined only within the Shillong basin and not in the basement gneisses. In the basement gneiss, unmetamorphosed basic dykes and sills of Cretaceous age (both dolerite and basalt) are seen in the western part of the Shillong plateau (East and West Garo Hills districts of Meghalya) and they are equivalent to Sylhet trap. The geochemical and plaeomagnetic characteristics of the two sets are distinctly different. The metamorphic events in the Shillong plateau are wide spread between 1500-1600 Ma which is the tentative emplacement period of the older group of Mesoproterozoic metadolerite dykes and sills. The plot of Y/Nb and Zr/Nb to show the relationship between Plume related MORB and normal MORB for the metadolerite, the data sets are plotted towards Zr/Nb side of the mixing line between Y/Nb- Zr/Nb which indicate that mantle plume or hot spot may be the supplying source of influx (Mallikharjuna Rao et.al., 2009). The Khasi greenstone dykes and basalts that show continental flood basaltic nature and low Mg# suggest that they were not equlibrated with the mantle rock mineralogies. From the chondrite normalized REE pattern, an overall poor fractionation of REE with no significant Eu anomaly is observed which probably indicate that the rocks have been derived from a melt undergoing shallow level fractionation. Nb/Y vs Rb/Y plot (Fig. 12a) clearly define two groups of samples present, in one group plots are closely spaced andin another group wide spread scatter field for samples. The Ba/Nb vs Sm/Nd ratio are plotted and these ratios also define two similar groups. Most of the plots of metadolerite dykes and sills are close to average lower crust and average Indian amphibolites (Fig. 12b).



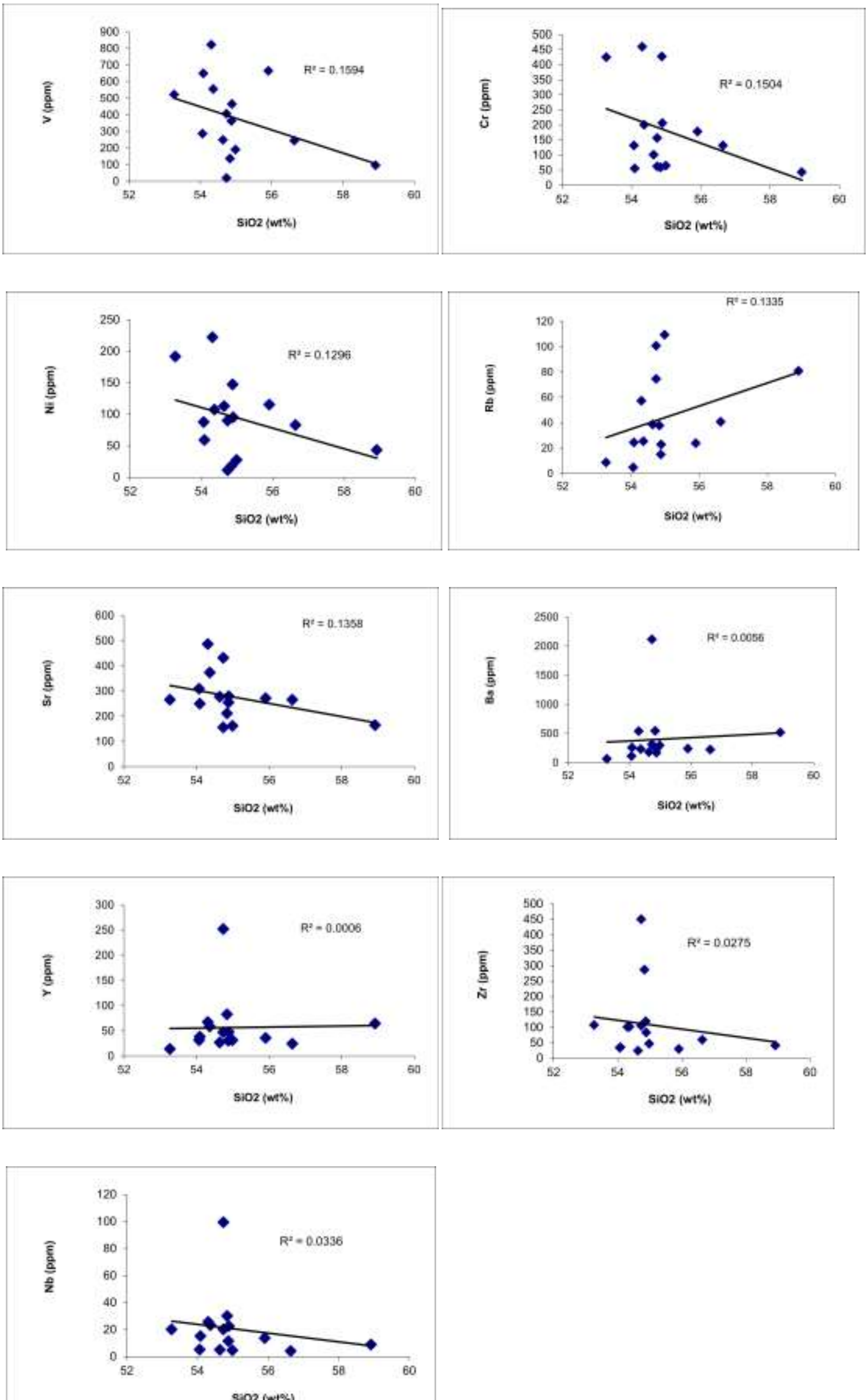

V (ppm)
SiO2 (wt%)
R² = 0.1594
Cr (ppm)
SiO2 (wt%)
R² = 0.1504
Ni (ppm)
SiO2 (wt%)
R² = 0.1296
Rb (ppm)
SiO2 (wt%)
R² = 0.1335
Sr (ppm)
SiO2 (wt%)
R² = 0.1358
Ba (ppm)
SiO2 (wt%)
R² = 0.0056
Y (ppm)
SiO2 (wt%)
R² = 0.0006
Zr (ppm)
SiO2 (wt%)
R² = 0.0275
Nb (ppm)
SiO2 (wt%)
R² = 0.0336

Fig. 11b

## Conclusions

The petrological and geochemical signatures of the metadolerites of the Shillong basin of Meghalaya lead to the following conclusion. The metadoleites of the Shillong plateau are restricted only in the intracratonic Shillong basin and intruded into the metasedimentary metavolcanic sequences of Shillong Group metamorphosed under of green schist – amphibolite transitional facies . A large numbers of mafic dykes and sills of Cretaceous age are present in the basement gneisses in the western Garo hills of the plateau as well as in the southern border of the basin as Sylhet trap. Since the metadolerite dykes and sills confined to Proterozoic Shillong basin and are older than the other Cretaceous group of dolerite dykes and sills emplaced only into the basement, they are not correlatable under one tectonic setting.

The dolerites have low $SiO_2$ (53.0 – 58.9%) suggesting derivation from a ultramafic mantle source rather than from crust or partial melting of crustal rocks. Plots within calcalkaline and continental basaltic fields probably indicate that the low grade metamorphic effect resulting subsequent alteration might have not influenced much in the composition of the major oxides The most contaminated samples tend to be the least differentiated. Enriched LREE, LILE and similar concentrations of HREE distinguished by negative Eu, Nb, P, Ta in mantle normalised spidergrams suggests that they are derived by relatively low degree partial melting. The absence of carbonate rock in the Shillong basin probably indicate unstable depositional environment during Mesoproterozoic time. The geochemical signature as well as low grade metamorphism and polydeformation history of the Shillong basin may suggest to the fact that the singularly defined Intracratonic Shillong Basin of NE India reaches its highest intensity during Neoproterozoic period with the influx of felsic magmatism in the form of various granite plutons. Plots suggest that the mafic dykes are genetically related to WPB (Within Plate Basalt) and such type of continental basalt were emplaced in a rift related tectonic setting.

These mafic metadolerite dykes do not constitute a greenstone belt of the Shillong plateau although some speculations are made by few workers. They are significantly different from MORB or arc trench basalt collisional mechanism is not reflected by geochemical signatures. Continued rifting within the Shillong plateau in a post – Precambrian time, led to the formation of subsequent deposition of younger sediments during Mesozoic time. Such extensional tectonism assists for emplacement of mafic dykes and sills in Shillong Basin. Hussain *et al.* (2004) also advocated similar type of setting from central Indian shield. However, more work is due to elucidate two sets of emplacement of mafic bodies separated in time and space and detailed palaeomagnetic analysis on this aspect is in the process.

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**Table 1**: Major oxides (wt%) and trace element (ppm) abundances of representative samples of metadolerites of Shillong basin

| Sample | SRS1 | SMWS1 | SSUS1 | SLDS1 | SLKD1 | SLKD2 | SLKD3 | SDS2 | SDS1 | SMPS2 | SMPS1 | SLNS1 | SLNS2 | SMMQS1 | SMMLS1 | ssus(gh) | SNaS | SUbS | average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SiO2 | 58.92 | 54.88 | 54.99 | 54.74 | 55.91 | 54.64 | 54.07 | 56.64 | 54.74 | 54.84 | 54.89 | 53.27 | 54.37 | 54.09 | 54.31 | 51.65 | 51.3 | 51.35 | 54.42 |
| TiO2 | 1.08 | 1.61 | 0.81 | 2.55 | 1.15 | 1.3 | 1.19 | 1.33 | 2.44 | 2.31 | 2.06 | 3.54 | 1.85 | 2.06 | 2.38 | 1.24 | 2.24 | 2.99 | 1.9 |
| Al2O3 | 15.86 | 14.82 | 15.86 | 11.22 | 15.19 | 13.67 | 14.84 | 14.66 | 13.44 | 12.01 | 13.22 | 11.37 | 14.72 | 14.36 | 14.88 | 16.74 | 14.74 | 14.63 | 14.24 |
| Fe2O3 | 12.75 | 14.2 | 12.76 | 15.61 | 12.83 | 13.3 | 13.6 | 14.61 | 16.74 | 14.79 | 15.03 | 15.65 | 14.47 | 13.94 | 15.38 | 10.99 | 14.36 | 14.22 | 14.18 |
| MnO | 0.28 | 0.15 | 0.23 | 0.22 | 0.18 | 0.25 | 0.2 | 0.18 | 0.2 | 0.16 | 0.16 | 0.15 | 0.15 | 0.13 | 0.18 | 0.29 | 0.29 | 0.22 | 0.2 |
| MgO | 2.59 | 3.83 | 5.5 | 5.24 | 4.83 | 5.44 | 5.97 | 4.55 | 2.49 | 4.98 | 4.67 | 4.75 | 3.21 | 4.71 | 3.18 | 5.16 | 1.83 | 2.4 | 4.19 |
| CaO | 3.23 | 7.27 | 3.92 | 5.98 | 6.15 | 7.71 | 6.48 | 3.28 | 5.33 | 6.99 | 6.71 | 7.41 | 7.2 | 7.42 | 6.29 | 6.57 | 9.84 | 9.1 | 6.49 |
| Na2O | 1.7 | 1.2 | 2.07 | 1.3 | 1.74 | 1.52 | 1.39 | 1.76 | 1.72 | 1.44 | 1.48 | 1.26 | 1.31 | 1.41 | 0.83 | 3.86 | 2.86 | 2.81 | 1.76 |
| K2O | 1.52 | 0.38 | 1.96 | 1.16 | 0.4 | 0.15 | 0.64 | 1.62 | 0.75 | 0.44 | 0.39 | 0.62 | 0.65 | 0.47 | 0.38 | 0.19 | 0.19 | 0.59 | 0.7 |
| P2O5 | 0.2 | 0.13 | 0.19 | 0.27 | 0.19 | 0.18 | 0.16 | 0.3 | 0.51 | 0.22 | 0.21 | 0.19 | 0.19 | 0.2 | 0.33 | 0.12 | 0.54 | 0.1 | 0.24 |
| Total | 98.13 | 98.47 | 98.29 | 98.29 | 98.57 | 98.16 | 98.54 | 98.93 | 98.36 | 98.18 | 98.82 | 98.21 | 98.12 | 98.79 | 98.14 | 96.81 | 98.19 | 98.41 | 98.32 |

Trace element (ppm)

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SC | 28 | 34 | 25 | 33 | 26 | 36 | 30 | 40 | 29 | 37 | 39 | 42 | 58 | 35 | 38 |
| V | 95 | 362 | 191 | 406 | 248 | 286 | 244 | 18 | 136 | 465 | 555 | 649 | 821 | 664 | 417 |
| Cr | 43 | 428 | 65 | 157 | 101 | 132 | 132 | 62 | 59 | 206 | 201 | 56 | 460 | 178 | 208 |
| Co | 28 | 65 | 34 | 302 | 56 | 80 | 46 | 45 | 52 | 59 | 83 | 78 | 130 | 57 | 68 |
| Ni | 43 | 147 | 27 | 90 | 113 | 88 | 83 | 11 | 18 | 95 | 107 | 59 | 222 | 115 | 105 |
| Cu | 33 | 140 | 14 | 221 | 56 | 87 | 67 | 158 | 291 | 290 | 240 | 188 | 326 | 146 | 473 |
| Zn | 161 | 115 | 146 | 147 | 87 | 115 | 91 | 299 | 158 | 176 | 164 | 180 | 217 | 128 | 163 |
| Ga | 17 | 20 | 18 | 23 | 18 | 19 | 16 | 67 | 27 | 25 | 32 | 23 | 43 | 24 | 25 |
| Rb | 81 | 15 | 109 | 75 | 38 | 5 | 41 | 101 | 38 | 23 | 25 | 24 | 57 | 24 | 19 |
| Sr | 165 | 254 | 161 | 155 | 277 | 309 | 266 | 432 | 210 | 279 | 373 | 249 | 486 | 271 | 122 |
| Y | 64 | 30 | 31 | 47 | 27 | 31 | 24 | 252 | 83 | 48 | 58 | 38 | 67 | 36 | 50 |
| Zr | 41 | 120 | 47 | 105 | 25 | 34 | 60 | 450 | 287 | 83 | 102 | 36 | 102 | 30 | 82 |
| Nb | 9 | 12 | 5 | 20 | 5 | 5 | 4 | 99 | 30 | 23 | 23 | 15 | 26 | 14 | 21 |
| Cs | 2 | 1 | 1 | 4 | 4 | 1 | 6 | 5 | 7 | 3 | 3 | 1 | 11 | 1 | 2 |
| Ba | 516 | 165 | 295 | 310 | 176 | 110 | 221 | 2113 | 541 | 232 | 228 | 257 | 540 | 237 | 187 |
| Hf | 1 | 3 | 1 | 3 | 1 | 1 | 1 | 11 | 4 | 2 | 3 | 1 | 27 | 1 | 2 |
| Ta | 0 | 1 | 0 | 1 | 1 | 1 | 0 | 4 | 2 | 2 | 2 | 1 | 20 | 1 | 0 |
| Pb | 130 | 15 | 27 | 23 | 25 | 46 | 38 | 53 | 24 | 17 | 20 | 15 | 14 | 15 | 20 |
| Th | 10 | 3 | 3 | 6 | 2 | 2 | 2 | 36 | 10 | 5 | 7 | 4 | 7 | 4 | 6 |
| U | 2 | 0 | 1 | 1 | 0 | 0 | 0 | 3 | 1 | 1 | 1 | 0 | 1 | 0 | 1 |
| La | 32 | 16 | 16 | 26 | 11 | 11 | 10 | 192 | 56 | 29 | 36 | 21 | 42 | 22 | 31 |
| Ce | 39 | 21 | 21 | 34 | 14 | 16 | 13 | 237 | 75 | 38 | 47 | 28 | 54 | 26 | 39 |
| Pr | 7 | 4 | 4 | 7 | 3 | 3 | 3 | 44 | 14 | 7 | 9 | 5 | 10 | 5 | 8 |
| Nd | 36 | 21 | 20 | 33 | 15 | 17 | 14 | 216 | 70 | 36 | 46 | 27 | 53 | 28 | 39 |
| Sm | 8 | 5 | 5 | 8 | 4 | 4 | 3 | 48 | 16 | 8 | 11 | 7 | 12 | 7 | 9 |
| Eu | 2 | 2 | 1 | 2 | 1 | 1 | 1 | 12 | 4 | 3 | 3 | 2 | 4 | 2 | 3 |
| Gd | 8 | 5 | 4 | 8 | 4 | 4 | 3 | 47 | 15 | 8 | 10 | 6 | 78 | 6 | 9 |
| Tb | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 7 | 2 | 1 | 2 | 1 | 72 | 1 | 1 |
| Dy | 9 | 5 | 5 | 8 | 4 | 5 | 4 | 44 | 14 | 8 | 10 | 6 | 65 | 6 | 9 |
| Ho | 2 | 1 | 1 | 2 | 1 | 1 | 1 | 9 | 3 | 2 | 2 | 1 | 59 | 1 | 2 |
| Er | 5 | 2 | 3 | 4 | 2 | 3 | 2 | 21 | 7 | 4 | 5 | 3 | 53 | 3 | 4 |
| Tm | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 1 | 0 | 1 | 0 | 46 | 0 | 0 |
| Yb | 3 | 2 | 2 | 2 | 2 | 2 | 1 | 11 | 4 | 2 | 3 | 2 | 40 | 2 | 3 |
| Lu | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 1 | 0 | 1 | 0 | 33 | 0 | 1 |