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Research Article

ISSN : 2455-1953

JGSR

Journal of Geosciences Research

Vol. 11, No.1, January, 2026, pp. 01-12

Redox Series Assessment of Proterozoic Granite Gneiss and Cambrian Granite Plutons from Meghalaya Plateau, Northeast India: Insights from Field Relations and Magnetic Susceptibility Mapping

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Abstract

The Meghalaya Plateau including the Mikir Hills mainly comprises the Proterozoic granite gneiss, migmatites, metasediments, Cambrian granite plutons, and Mesozoic-Tertiary cover rocks. Field relationships and magnetic susceptibility (MS) mapping of granite gneisses, granites and related rocks of Meghalaya Plateau have been conducted in order to assess the redox series (magnetite, oxidized vs. ilmenite, reduced) nature of granites. The observed MS values of Proterozoic granite gneisses and Cambrian granites largely correspond to magnetite (>3.0×10^{-3} SI unit) series (oxidized type) and a few to ilmenite (<3.0×10^{-3} SI unit) series (reduced type) granites. The Cambrian granite plutons are dominated by magnetite series (>3.0×10^{-3} SI unit) series granites, which appear to have inherited primarily from the infracrustal (igneous) sources. However, the observed highly oxidizing (magnetite series) condition of granites from these plutons were most likely achieved during synchronous mixing and fractionation in open magma chamber, as evident from the presence of mafic to hybrid microgranular enclaves, and accumulation of ferromagnesian minerals. Fine to medium grained leucocratic granites measure low MS values (<3.0×10^{-3} SI unit) corresponding to ilmenite (reduced) series granite because of their evolved nature as being depleted in ferromagnesian (magnetic) minerals. At places, a few Cambrian granites hosting the pyrite and chalcopyrite measure a relatively higher MS values as compared to the unmineralized granites. Magnetite series granites are found to be reduced as ilmenite series close to its intrusive contacts with metasedimentary country-rocks.

Keywords: Magnetic Susceptibility, Redox Series Granites, Meghalaya Plateau, NE India

Introduction

Granites (*sensu lato*) are formed in varied tectonomagmatic environments ranging from Archean to Phanerozoic and essentially constitute an integral part of the continental crust. Granites are commonly bimodal in nature, and in terms of alumina saturation index (Shand, 1948) can be classified as metaluminous (I-type) and peraluminous (S-type) granites derived from partial melting of older igneous (infracrustal) and sedimentary source rocks respectively (Chappell and White, 1974, 2001). Magnetic susceptibility (MS) is a measure of magnetic properties of rock as magnetic or ferromagnetic and weakly magnetic or paramagnetic (Gregorová *et al.*, 2003). The MS value of granites is used to develop magnetite series (>3.0×10^{-3} SI unit) and ilmenite series (<3.0×10^{-3} SI) granites (Ishihara, 1977; Ishihara *et al.,* 2002) corresponding to oxidized-type and reduced-type granites respectively (Takagi and Tsukimura, 1997). The MS values primarily indicate redox conditions (oxygen fugacity) of felsic melts commonly inherited from source regions (Ishihara, 1979). In principle, magnetite and ilmenite series granites should be parallel to the I-type and S-type granites respectively, however, S-type magnetite series and I-type ilmenite series granites may also occur (Takahashi *et al.*, 1980). The alteration from magnetite series to ilmenite series of granites or vice-versa may be because of changing physico-chemical condition of magma chamber (Czamanske *et al.*, 1981, Carmichael, 1991), degassing or assimilation of wall-rocks *in situ* (Takagi, 2004), enroute or deeper-derived lithological assimilation, mafic-felsic magma mixing, and/or later tectonic processes acted upon them (Kumar *et al.*, 2005, 2006; Singh and Kumar, 2005; Kumar and Rino, 2007; Kumar and Singh, 2008, Kumar and Pathak, 2009, Kumar, 2010a-b; Kumar *et al.*, 2010; Anetsungla *et al.*, 2018; Panwar and Kumar, 2022). The MS value is therefore considered most powerful first-order discriminating parameter and can be potentially used to evaluate relative redox (magnetite *vs.* ilmenite series) conditions of granites and their likely association with mineralization, if any.

The Meghalaya Plateau including the upland of Mikir Hills is dominantly composed of Proterozoic granite gneiss (*ca.* 1900-1100 Ma), migmatites, granulites, metasediments, Cambrian granite

(Received : 01 March 2025 ; Revised Form Accepted : 13 November 2025)

https://doi.org/10.56153/g19088-025-0250-90

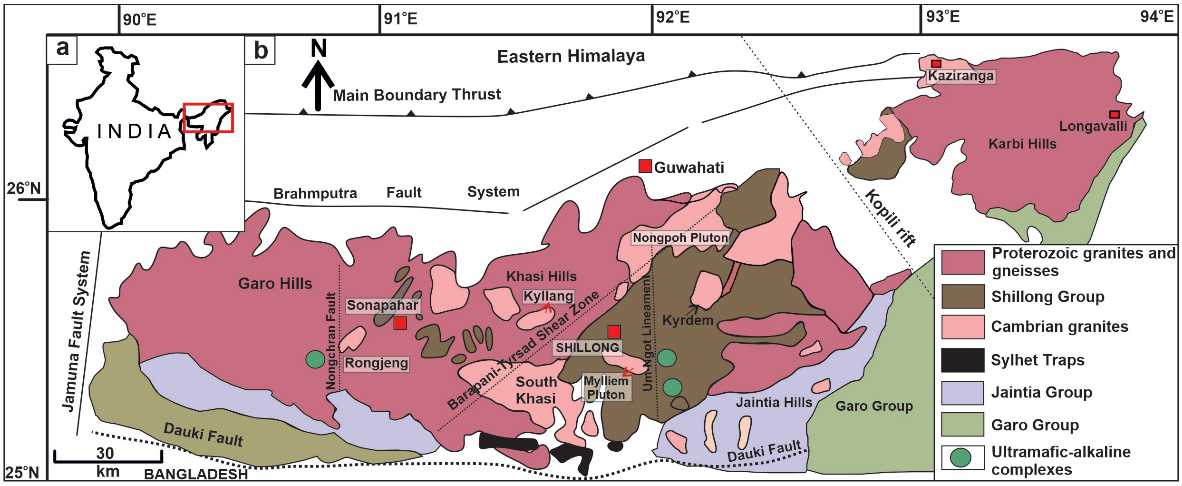

Fig.1. (a) Location of study area (Meghalaya Plateau) in the NE India. (b) Geological map of Meghalaya Plateau including the Mikir Hills (Mazumder, 1976; Ghosh *et al.*, 1991).

plutons (*ca.* 560-475 Ma), and rocks of Mesozoic-Tertiary Groups (Bidyananda and Deomurari, 2007; Chatterjee *et al*., 2007; Yin *et al.*, 2010; Majumdar and Dutta, 2016; Kumar *et al.*, 2017a, b). Cambrian granite plutons intrude the Proterozoic basement granite gneisses and Shillong Group of rocks. Proterozoic granite gneisses and Cambrian granites are texturally distinct. However, they exhibit nearly identical mineral assemblages and geochemical features showing strongly metaluminous to moderate peraluminous, magnesian to ferroan, alkali-calcic to calc-alkaline, and transitional I-A-type characters similar to the oxidized granites formed in a post-collision tectonic environment (Kumar *et al.*, 2022). The redox series of the south Khasi pluton (Kumar *et al.,* 2005), Kyrdem pluton (Kumar and Singh, 2008) and Karbi Anglong Hills (Anettsungla *et al.,* 2018) has been assessed earlier based on magnetic susceptibility measurements. In the present study, we established the field relationships between the granites and associated lithological units and conducted the MS mapping of representative granite gneiss and granite outcrops covering a vast area from the Meghalaya Plateau to evaluate the redox conditions of granites. This analysis also aims to shed light on the magmatic and tectonic processes that may have influenced the MS (redox state) of the granites. Furthermore, we attempted to explore the mineralization potential associated with granite magmatism based on the observed MS values.

Geology, Geochronology and Petrology

The Precambrian cratonic block of the NE India forms an integral deep-level crystalline complex of the Meghalaya Plateau (erstwhile Shillong Plateau or Assam-Meghalaya Plateau) including the Mikir Hills, which is tectonically separated from the rest of the Indian Peninsula by a large-scale Garo-Rajmahal depression (Evans, 1964). The Meghalaya Plateau forms a part of the NE extremity of the Indian peninsular shield and is considered to be an extension of discontinuous part of Central Indian Tectonic Zone (CITZ), extended through Chotanagpur Gneissic Complex (Evans, 1964; Desikachar, 1974; Crawford, 1974). It is dominantly made up of Basement Gneissic Complex and the overlying Proterozoic metasediments of the Shillong Group. Cambrian granite magmatism in the form of number of plutons and stocks intrudes the Proterozoic metasedimentary sequences belonging to Shillong Group and Basement Gneissic Complex of Meghalaya Plateau (Mazumder, 1976). Mazumder (1976, 1986) provided a detailed geological map of Neoproterozoic to Early Palaeozoic granite plutons. Maximum exposures of the granite plutons occur towards the central and north eastern part of the plateau (Fig. 1a-b). Of these, the Mylliem pluton is intrusive into the Shillong Group, the Nongpoh, Rongjeng and Kyrdem plutons intrude within the Basement Gneissic Complex, and the South Khasi pluton intrudes both the Basement Gneissic Complex and Shillong Group.

The geochronological records of granites and granite gneisses in the Meghalaya Plateau have been compiled by Kumar *et al.* (2017a-b, 2022). Some granite plutons (*ca.* 1150-500 Ma) of Meghalaya plateau (Ghosh *et al.*, 1991, 1994) appear gradually younging in age from southwest to northeast and emplaced as diapirs at different crustal depths (3-5 kbar), probably reactivating the Tyrsad-Barapani lineament as a result of mantle upwelling (Kumar, 1998). Rb-Sr dating of Basement Gneissic Complex (Ghosh *et al.*, 2005) and Pb-Pb detrital zircon dating of Shillong Group of rocks suggested ages of 1530-1550 Ma (Mitra, 1988). The majority of granite plutons belong to Early Palaeozoic to Late Palaeozoic thermal events as have been documented based on whole-rock Rb-Sr and K-Ar dating from Kyrdem, Nongpoh, South Khasi, East Garo Hills, and Goalpara regions (Crawford, 1969; Chimote *et al.,* 1988; Van Breemen *et al.,* 1989; Kumar, 1990; Ghosh *et al.*, 1991). Proterozoic magmatic pulses are typically formed during *ca.* 1780-1600 Ma (Kumar *et al.,* 2017a-b), 1860–1400 Ma (Bidyananda and Deomurari, 2007), and 1630–1110 Ma (Yin *et al.*, 2010) based on U-Pb zircon ages. Proterozoic granite gneiss and granites resulted from the recycling of older Neoarchean crust (2630–2560 Ma), as evident from the inherited zircon, during the assembly and breakup of the Columbia supercontinent (Bidyananda and Deomurari, 2007; Kumar *et al.*, 2017b; Gogoi *et al.*, 2019). Neoproterozoic granites dated *ca.* 880-600 Ma and Cambrian granites formed during 580-480 Ma, commonly intrude the Paleoproterozoic basement gneissic complex (Ghosh *et al.*, 1991, 1994, 2005). However, the U-Pb zircon ages from granite plutons suggest a relatively narrow timeframe for the Cambrian plutonism *ca.* 535–506 Ma (Kumar *et al.*, 2017a, b) and 520–430 Ma (Yin *et al.*, 2010). There is a need for more chronological records to provide meaningful insights into the duration of Cambrian plutonism. The Cambrian plutons are derived from recycling of Neoarchean (*ca.* 2560 Ma) and Proterozoic (*ca.*

1750–1610 Ma) crustal sources during the assembly and growth of the Gondwana supercontinent (Kumar *et al.*, 2017a, b). Younger granite plutons in the Meghalaya Plateau have been thought to have formed during the Neoproterozoic-Cambrian period based on whole-rock Rb-Sr isochron ages (Ghosh *et al.*, 1994). However, most of them belong to the Cambrian period (500–535 Ma), as indicated by U-Pb zircon SHRIMP (Kumar *et al.,* 2017a, b) and LA-ICP-MS (Sadiq *et al.,* 2018; Majumdar and Dutta, 2016) dating methods. The age variation of the younger plutons may arise from differences between the whole-rock isochron and U-Pb zircon dating methods.

Proterozoic and Cambrian granites exhibit similar mineral assemblages (biotite ± amphibole - plagioclase - potassium feldspar - quartz - zircon - magnetite - titanite - apatite ± ilmenite), but they are texturally distinct. Microgranular enclaves are commonly found in Cambrian plutons, whereas they are either absent or rare in Proterozoic granites. Cambrian granites are medium- to coarse-grained, inequigranular, hypidiomorphic, and frequently porphyritic, and can range from undeformed to mildly deformed. Proterozoic granites are also medium- to coarse-grained but are less frequently porphyritic and can be mild to strongly deformed (Kumar *et al.*, 2022). Geochemically, the Proterozoic granites have a molar Al_2O_3/CaO+Na_2O+K_2O ratio (A/CNK) of 0.86–1.15 and a FeO^t/(FeO^t+MgO) ratio of 0.60–0.93. On the other hand, the Cambrian granites have a A/CNK ratio of 0.77–1.20 and a FeO^t/FeO^t+MgO ratio of 0.56–0.90. Both types of granites are classified as high-K, calc-alkaline to alkali-calcic, and largely metaluminous, formed mainly in a post-collisional tectonic environment.

Analytical Method

A portable hand-held magnetic susceptibility (MS) meter model SM-20 (Geofyzika, Brno), which operates at a frequency of 10 KHz and sensitivity of 1×10^{-6} SI unit, was used to obtain MS values of granites directly from fresh rock outcrops. The MS meter works within a temperature range of 10 to 60ºC, and the measuring time for each reading is less than three seconds per sample, commonly performed in two steps. Firstly, the MS meter is placed on a smooth rock surface larger than 60×60 mm, and the measure button is pressed shortly. Secondly, the MS meter is taken at least 30 cm in the open air away from the rock surface and magnetic objects, and then the measure button is again pressed shortly. The actual MS value ($\times10^{-3}$ SI unit) is displayed. Thirty MS measurements saved in the memory, manually noted or transferred on a laptop. The obtained MS values were corrected using recommended factors for the degree of rock surface unevenness: 1mm = 1.07, 2mm = 1.15, 3mm = 1.23, 4mm = 1.32, 5mm = 1.41, 6mm = 1.51, 7mm = 1.61, 8mm = 1.72, 9mm = 1.84, 10mm = 1.96 (as given in the manual of SM-20 MS Meter). In the present investigation, however, average surface unevenness was noted at about 1.15 mm, and accordingly, measured MS values were corrected and processed.

Results and Discussion

The subsequent section examines the field relations and recorded magnetic MS values of the granite gneisses and granites in the Meghalaya Plateau, including the Mikir Hills. Table 1 summarizes the average MS values ($\times10^{-3}$ SI) observed across various outcrops, along with the inferred magnetite and ilmenite granite series granites.

Nongpoh Granite Pluton

The Nongpoh granites are biotite-rich porphyritic (K-feldspar megacrysts) and medium to coarse-grained (Fig. 2a), which intrude the Shillong Group of rocks as evident from the presence of quartzite xenoliths near the marginal parts of the pluton. These quartzites are partially melted in some places to produce a flowage texture. A relatively homogenous medium to coarse-grained and phenocryst-free granites measures very low MS values, which commonly range between 0.34-0.64x10^{-3} SI unit. Biotites in granitoids are segregated and appear as autolith. Quartzofeldspathic veins of 2-3 cm wide cross-cut the granites and bear folded ductile fabric of alternate bands of light and dark colour flowage structures, giving rise to a paragneiss appearance (Fig.2b). The granites are locally charged with pyrite and chalcopyrite mineralization. They are intruded by cm-thick pegmatite veins having crystals of tourmalines. Near the contact with pelitic country rocks, pegmatites contain large crystals of biotite and garnet similar to those found in pelitic country rocks. Approaching the basement granite gneiss of the Guwahati region, the non-porphyritic variety of Nongpoh granites is extensively intruded by tourmaline-bearing pegmatitic veins, whereas porphyritic granites contain less frequent pegmatitic veins. The MS value of porphyritic coarse-grained variety ranges from 17.12 to 68.37$\times10^{-3}$ SI unit, with an average MS value of 39.01$\times10^{-3}$ SI unit (n=34) which belong to highly oxidized, magnetite series granites (Table 1; Fig. 2c-d).

Although Nongpoh granites intrude the metasediments (quartzite), they do not exhibit reduced MS value because of the fact that quartzite is mainly comprised of quartz grains and partially recrystallized silica, which will absolutely not affect the MS value. However, in a few places, Nongpoh granites are relatively homogenous, fine to medium-grained equigranular, and poor in ferromagnesian minerals, which have shown highly reduced MS values corresponding to the ilmenite series. These may represent more evolved fraction (residual) of the Nongpoh granites and hence measure low MS values (0.34-0.64$\times10^{-3}$ SI unit) being depleting in ferromagnesian (orthomagnetic) minerals.

Mylliem Granite Pluton

Mylliem pluton is a relatively small-sized granite pluton compared to other Cambrian plutons, which is well exposed in and around Mylliem village, referred herewith Mylliem granites. Mylliem pluton is primarily composed of grey to pink, medium to coarse grained porphyritic granites with ubiquitous K-feldspar megacrysts or variable sizes. Although K-feldspar megacrysts are common to almost in all young granite plutons, Mylliem pluton contains uniformly and randomly oriented K-feldspar megacrysts which are at places moderately to highly affected by potash metasomatic fluids. Mylliem granites contain small to large sized rounded, subrounded to ellipsoidal mafic to hybrid (K-feldspar xenocrysts bearing) microgranular enclaves (Fig. 3a). Even some small cm-sized hybrid microgranular enclaves contain mafic microgranular enclaves giving rise to a feature of double or composite enclaves. Locally crystals of K-feldspar and biotites are segregated in such a manner that they together exhibit cumulate-like texture. K-feldspar megacrysts of enclaves are morpho-logically very identical to those present in the host granites but some megacrysts have rounded to subrounded crystal outlines. Occasionally, large grains of quartz ocelli can also be observed in

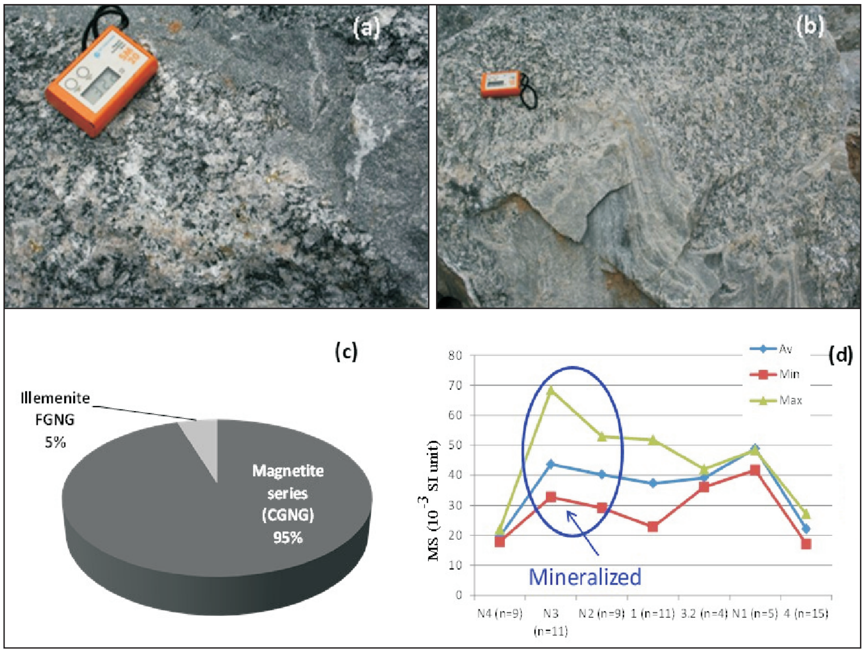

Fig.2. (a) Porphyritic coarse-grained granites of Nongpoh showing high MS value with spotted sulphide mineralization. (b) Intrusive contact of Nongpoh granites with quartzite country-rocks which get partially assimilated due to high-temperature intrusion. (c) Relative proportion of coarse-grained magnetite series granites (95%) and fine-grained ilmenite series (5%) granites is shown as wheel diagram. (d) Mineralized parts of granites record relatively higher MS values as compared to unmineralized parts.

the enclaves that are indeed partly dissolved, along with K-feldspar megacrysts showing rounded crystal outlines, under high temperature environment of hybrid melt, and hence are xenocrysts (Kumar, 1995, 2010b, 2020). Both the enclaves and host granites have pyrite and chalcopyrite mineralization (Fig 3b), similar to as commonly found in the sulphide mineralization of porphyry origin.

Mylliem granites are also intruded by number of tourmaline-bearing pegmatitic veins. The MS value of granites varies from 6.38 to 15.30 $\times 10^{-3}$ SI unit, which correspond to magnetite series granites (Table 1; Fig. 3 c-d). The observed large variations in the MS value of Mylliem granites may be due to the large modal variations of ferromagnesian minerals. For instant, biotite rich granites have

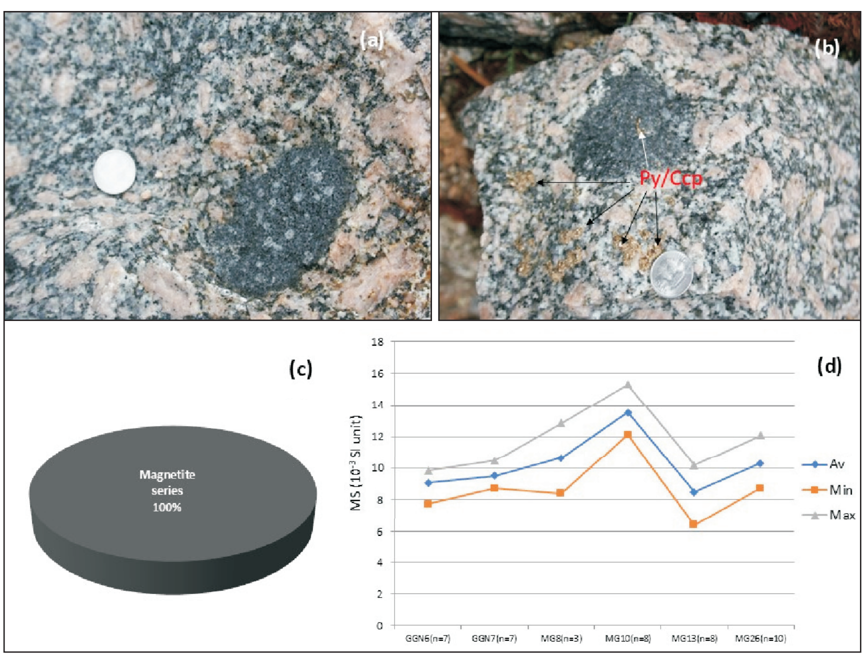

Fig.3. (a) Porphyritic (hybrid, xenocryst-bearing) microgranular enclave hosted in the K-feldspar megacryst bearing porphyritic Mylliem granites (pink colour). Please note the ubiquitous rounded to subrounded K-feldspar megacrysts armouring the enclave along its contact outline, mainly by the K-feldspar megacrysts. (b) Localized pyrite (Py) and chalcopyrite (Ccp), shown by arrows, both in host granites and microgranular enclave. Note the fine-grained mafic nature of enclave with partially diffused boundary apparently penetrated by the K-feldspar megacrysts. (c) All measured MS values correspond to magnetite series granites. (d) MS values of Mylliem granites (MG) are also compared with those of associated country-rock basement granite gneiss (GGn). Note that a small MS difference has been observed between the MG and GGn.

Table 1: Magnetic susceptibility (MS) values (in × 10^{-3} SI unit) of Proterozoic granite gneiss and Cambrian granite plutons of the Meghalaya plateau including the Mikir Hills, northeast India

Granite plutons/ Granite Gneisses	Location	Textural types of granites	Measured MS values (×10^{-3}SI unit)	Corrected MS values (×10^{-3}SI unit)	Average MS and range of MS value (×10^{-3}SI unit)	Inferred granite series(magnetite *vs.* ilmenite series)
Nongpoh	N25°50'63" E91°52'49.7"	Coarse grained porphyritic granites	41.3, 39.0, 45.2, 40.3, 39.1	44.19, 41.73, 48.36, 43.83	43.85 (n=5) 39.0-45.2	Magnetite series
	N25°55'42.7" E91°52'38.2"	Coarse grained porphyritic granites	40.1, 33.1, 39.2, 40.8, 46.4, 43.3, 32.2, 27.2, 32.7	42.91, 35.42, 41.94, 43.65, 49.65, 46.33, 34.45, 29.10, 34.99	39.83 (n=9) 29.10-49.65	Magnetite series
	N25°57'17.2" E91°51'40.2"	Coarse grained porphyritic granites	32.2, 31.3,37.5, 31.3, 49.2, 40.1, 57.2, 63.9, 34.0, 40.6, 30.6	34.45, 33.49, 40.13, 33.49, 52.64, 42.91, 61.20, 68.37, 36.38, 43.44, 32.74	43.57 (n=11) 32.74-68.37	Magnetite series
	N25°52'07.4" E91°52'59.6"	Medium grained equigranular granites	29.5, 42.1, 43.3, 21.3, 32.7, 35.8, 26.2, 39.4, 26.5, 37.8, 48.4	31.57, 45.05, 46.33, 22.79, 34.99, 38.31, 28.03, 42.16, 28.36, 40.45, 51.79	37.26 (n=11) 22.79-51.79	Magnetite series
		Homogeneous, pheno-cryst free granites	0.60, 0.07, 0.32	0.64, 0.07, 0.34	0.35 (n=3) 0.34-0.64	Ilmenite series
	N25°51'15.5" E91°52'57.3"	Coarse grained porphyritic granites	37.9, 33.7, 35.3, 39.3	40.55, 36.06, 37.77, 42.05	39.11 (n=5) 36.06-42.05	Magnetite series
	N25°49'56.6" E91°52'44.8"	Coarse grained porphyritic granites	18.1, 20.2, 25.3, 23.1, 24.6, 18.8, 22.9, 20.2, 18.4, 23.5, 19.6, 20.6, 20.6, 16.0, 17.3	19.37, 21.61, 27.07, 24.71, 26.32, 20.12, 24.50, 21.61, 19.69, 25.15, 20.97, 22.04, 22.04, 17.12, 18.15	22.06 (n=15) 17.12-27.07	Magnetite series
Rongjeng Basement Granite Gneiss	N25°17'59.0" E91°55'59.8"	Coarse grained equigranular granites	8.10, 8.58, 9.19, 7.22, 8.461, 9.175, 8.54	8.67, 9.18, 9.83, 7.72, 9.05, 9.82, 9.14	9.06 (n=7) 7.72-9.83	Magnetite series
	N25°18'01.1" E91°56'00.1"	Coarse grained equigranular granites	9.76, 8.42, 9.79, 8.15, 8.86, 8.25, 8.89	10.44, 9.01, 10.48, 8.72, 9.48, 8.83, 9.5	19.50 (n=7) 8.72-10.48	Magnetite series
Mylliem	N25°18'45.28" E91°55'14.5"	Coarse grained porphyritic granites	10, 7.84, 12.0	10.7, 8.39, 12.84	10.64 (n=3) 8.39-12.84	Magnetite series
	N25°27'04.4" E91°50'34.1"	Porphyritic (Biotite rich) granites	14.3, 12.6, 12.36, 12.1, 13.2, 11.7, 12.5, 12.6	15.30, 13.48, 13.22, 12.95, 14.12, 12.12, 13.38, 13.48	13.51(n=8) 12.12-15.30	Magnetite series
	N25°29'15.7" E91°49'23.4"	Porphyritic (Biotite rich) granites	9.50, 8.74, 9.49, 7.88, 5.89, 6.60, 7.48, 7.66	10.17, 9.35, 10.15, 8.43 6.38, 7.06, 8.00, 8.20	8.47(n=8) 6.38-10.17	Magnetite series
	N25°27'38.8" E91°49'48.3"	Porphyritic granites (K-feldspar rich megacryst)	8.14, 9.23, 9.31, 10.1, 9.26, 11.1, 8.90, 11.3, 9.86, 9.09	8.71, 9.88, 9.96, 10.81, 9.91, 11.88, 9.52, 12.09, 10.55, 9.73	10.30 (n=10) 8.71-12.09	Magnetite series
Kylong	N25°37'48.3" E91°37'33.9"	Equigranular granitess (garnet-bearing)	48.5, 44.7, 47.1, 47.4, 52.8, 55.1, 58.2, 45.5, 43.4, 53.2, 52.9, 49.8, 44.8, 50, 41.4, 49.2, 47.8, 49.5	51.90, 47.83, 50.40, 50.72, 56.50, 58.96, 62.27, 48.69, 46.44, 56.92, 56.60, 53.29, 47.94, 53.50, 44.30, 52.64, 51.15, 52.97	52.39 (n=18) 44.30-62.27	Magnetite series
	N25°42'00.1" E91°36'04.1"	Equigranular granites (garnet-bearing)	35.5, 29.5, 31.7, 28.5, 39.3, 31.7, 31.5	37.99, 31.57, 33.92, 30.50, 42.05, 33.92, 33.71	34.81 (n=7) 30.50-42.05	Magnetite series
	N25°40'52.1" E91°38'23.8"	Equigranular granites	24.2, 25.5, 27.4, 25.8, 25.5, 25.7	28.89, 27.28, 29.32, 27.61, 27.29, 27.50	27.48 (n=6) 27.28-29.32	Magnetite series
	N25°39'44.7" E91°38'21.9"	Equigranular granites	28.6, 33.9, 31.7, 28.5, 31.9, 32.8, 33.5, 23.9	30.60, 36.27, 33.92, 30.50, 34.13, 35.09, 35.85, 25.57	32.74 (n=8) 25.57-36.27	Magnetite series
	N25°38'12.6" E91°37'48.9"	Equigranular granites	41.0, 25.0, 48.3, 46.8, 37.8, 31.5, 32.6, 44.4, 50.6, 42.4, 56.3	43.87, 26.75, 51.68, 50.08, 40.45, 33.71, 34.88, 47.51, 54.14, 45.37, 60.24	44.43 (n=10) 26.75-60.24	Magnetite series
Mowdoh	N25°39'11.4" E91°38'07.9"	Porphyritic granites (leucocratic)	7.0, 7.98, 7.63, 6.31, 7.98, 6.94, 7.22, 8.12, 7.64, 8.04	7.49, 8.54, 8.16, 6.75, 8.54, 7.43, 7.73, 8.69, 8.17, 8.60	8.01 (n=10) 6.75-8.69	Magnetite series
	N25°41'44.1" E91°36'09.6"	Porphyritic granites (melanocratic)	10.0, 12.1, 10.4, 12.2, 10.5, 15.2, 13.8, 13.2, 9.20, 8.77(xenolith)	10.70, 12.95, 11.13, 13.05, 11.23, 16.26, 14.77, 14.12, 9.84	12.67 (n=9) 9.84-16.26	Magnetite series
	N25°41'37.0" E91°36'25.6"	Porphyritic granites (melanocratic)	14.6, 12.5, 11.1, 14.4, 12.2, 9.64, 11.8, 14.2, 14.9	15.62, 13.38, 11.88, 15.41, 13.05, 10.31, 12.63, 15.19, 15.94	13.71 (n=9) 10.31-15.94	Magnetite series
	N25°41'24.4" E91°36'34.7"	Equigranular granites	1.08, 0.192, 2.58, 4.41, 2.66, 0.743, 1.25, 1.67, 1.66	1.16, 0.21, 2.76, 4.72, 2.85, 0.79, 1.34, 1.79, 1.78	1.93 (n=9) 0.21-4.72	Illmenite - Magnetite series
	N25°41'06.6" E91°37'02.3"	Porphyritic granites (mesocratic)	10.8, 10.0, 22.0, 10.5, 8.42, 12.3, 20.6, 18.5, 9.04, 11.7, 18.4, 8.88, 15.4, 11.1, 11.8	11.56, 10.7, 23.54, 11.24, 9.00, 13.16, 22.04, 19.79, 9.67, 12.52, 19.69, 9.50, 16.48, 11.88, 12.63	14.23 (n=15) 9.00-22.04	Magnetite series
Sindhuli	N25°58'49.3" E91°14'48.9"	Porphyritic granites	15.2, 15.0, 16.3, 14.2, 14.4, 16.2	16.26, 16.05, 17.44, 15.19, 15.41, 17.33	16.28 (n=6) 15.19-17.44	Magnetite series

Contd. ....

Table contd. ....

Granite plutons/ Granite Gneisses	Location	Textural types of granites	Measured MS values ($\times10^{-3}$SI unit)	Corrected MS values ($\times10^{-3}$SI unit)	Average MS and range of MS value	Inferred granite series(magnetite *vs.* ilmenite
Guwahati granite gneiss	N25°50'07.2" E91°14'59.0"	Coarse grained grey granites (slightly	54.1, 64.0, 52.0, 56.5, 52.4, 59.7, 55.6, 52.5	57.89, 68.48, 55.64, 60.46, 56.07, 63.88, 59.49, 56.18	59.76 (n=8) 55.64-68.48	Magnetite series
	N25°58'49.3" E91°14'48.9"	Coarse grained grey granites (slightly foliated)	46.2, 45.8, 46.3, 38.9, 41.6, 37.0, 36.2, 50.3	49.43, 49.01, 49.54, 41.62, 44.51, 39.59, 38.73, 53.82	45.78 (n=8) 38.73-53.82	Magnetite series
	N26°09'19.2" E91°40'43.8"	Coarse grained grey granites (slightly foliated)	19.2, 16.4, 15.8, 19.5, 18.0	20.54, 17.55, 16.91, 20.87, 19.26	19.03 (n=5) 16.91-20.87	Magnetite series
Rongjeng	N25°39'34.5" E90°49'11.0"	Coarse grained porphyritic granites	13.16, 18.39, 10.14, 11.62, 15.20, 9.86, 13.36, 13.11	14.08, 19.68, 10.85, 12.43, 16.26, 10.55, 14.29, 14.03	14.02 (n=8) 10.55-19.68	Magnetite series
	N25°39'28.9" E90°49'04.4"	Coarse grained porphyritic granites	15.07, 12.27, 8.47, 10.92, 18.46, 11.74, 16.20, 18.92, 18.79, 17.49, 10.68, 9.148	16.12, 13.13, 9.07, 11.68, 19.75, 12.56, 17.33, 20.24, 20.11, 18.71, 11.43, 9.79	14.99 (n=12) 9.07-20.24	Magnetite series
	N25°39'23.3" E90°48'55.7"	Coarse grained porphyritic granites	16.26, 16.03, 13.74, 14.14, 12.23, 14.85, 16.19, 13.92, 14.74, 18.94, 14.76, 16.77, 13.93	17.39, 17.15, 14.70, 15.13, 13.09, 15.89, 17.32, 14.89, 15.77, 20.27, 15.79, 17.94, 14.91	16.17 (n=13) 13.09-20.27	Magnetite series
	N25°39'15.8" E90°48'51.3"	Coarse grained porphyritic granites	10.89, 9.662, 13.36, 19.47, 9.60, 8.85, 13.38, 12.06, 16.45, 10.09	11.65, 10.34, 14.29, 20.83, 10.28, 9.47, 14.32, 12.90, 17.60, 10.79	13.25 (n=10) 9.47-20.83	Magnetite series
	N25°38'19.3" E90°48'30.8"	Coarse grained porphyritic granites	10.35, 3.02, 8.20, 7.85, 6.12	11.07, 3.23, 8.78, 8.39, 6.55	7.60 (n=5) 3.23-11.07	Magnetite series
	N25°37'55.9" E90°47'59.0"	Medium grained, grey; gneissic	11.79, 5.11, 1.385, 4.23	12.62, 5.47, 1.45, 4.53	6.12 (n=4) 1.45-12.62	Ilmenite – Magnetite series
	N25°36'35.0" E90°45'00.7"	Medium grained, pink granites	4.11, 8.34, 11.41, 3.31, 5.79, 3.59, 5.35, 3.31, 11.68, 19.41, 7.71, 5.41, 5.85	4.40, 8.93, 12.21, 3.55, 6.19, 3.84, 5.72, 3.54, 12.49, 20.77, 8.25, 5.79, 6.26	7.84 (n=13) 3.54-20.77	Magnetite series
	N25°36'34.0" E90°45'59.6"	Medium grained, grey granites	7.390, 4.925, 17.19, 14.65, 15.84, 11.33, 8.34, 15.14, 16.97	7.90, 5.27, 18.39, 15.68, 16.95, 12.12, 8.92, 16.19, 18.16	13.29 (n=9) 5.27-18.39	Magnetite series
Songsak	N25°39'15.0" E90°36'46.4"	Medium grained, pink granites	2.77, 3.48, 2.25, 1.85, 3.35 4.07, 2.63, 3.70	2.96, 3.72, 2.41, 1.98, 3.58, 4.36, 2.81, 3.95	3.22 (n=8) 1.98-4.36	Ilmenite - Magnetite series
	N25°38'57.5" E90°36'07.4"	Medium grained, pink granites	1.866, 0.595, 1.366, 0.794, 0.734, 1.579, 2.568	1.99, 0.64, 1.46, 0.85, 0.79, 1.69, 2.75	1.45 (n=7) 0.79-2.75	Ilmenite series
	N25°38'40.3" E90°35'38.9"	Medium grained, pink granites	2.006, 1.669, 3.40, 2.93	2.15, 1.79, 3.64, 3.14	2.68 (n=4) 1.79-3.64	Ilmenite series
	N25°37'41.4" E90°36'22.4"	Medium grained, pink granites	3.083, 3.331, 2.260	3.29, 3.56, 2.42	3.09 (n=3) 2.42-3.56	Ilmenite - Magnetite series
	N25°32'40.3" E90°42'52.1"	Medium grained, grey granites	5.41, 4.63, 4.32, 4.81, 4.94, 4.15, 2.02	5.79, 4.95, 4.62, 5.15, 5.29, 4.44	5.04 (n=6) 4.44-5.79	Magnetite series
	N25°33'19.8" E90°43'03.1"	Medium grained, grey granites	15.58, 6.13, 4.77, 5.94, 5.90, 5.27	6.56, 5.10, 6.35, 6.31, 5.63	5.99 (n=5) 5.63-6.56	Magnetite series

MS values ≤ 3.0×10^{-3} SI units: Ilmenite series; MS values ≥ 3.0×10^{-3} SI units: Magnetite series (*After* Ishihara, 1990; Ishihara *et al.*, 2002)

recorded relatively higher MS value ranging from 10.17 to 15.30×10^{-3} SI units than those of K-feldspar megacrysts bearing granitoids which recorded MS values in the range of 8.71-12.09 × 10^{-3} SI units. The presence of mafic to hybrid microgranular enclaves in the granites also enhances the oxidation state of magma chamber thereby increasing the MS value more akin to an open system and dominance of ferromagnesian (orthomagnetic) minerals and Fe-Ti oxides (Kumar 2010a; Kumar *et al.*, 2006).

Rongjeng Basement Granite Gneiss

The basement granite gneiss is exposed mainly to and around the Mawparan and Myllat localities. It is overlain by a conglomerate horizon (Fig. 4a) and then followed by homogenous massive quartzites. Porphyritic Mylliem granites intrude the quartzite. Granite gneiss is medium-grained, equigranular and records a relatively narrow range of MS values ranging from 7.72 to 10.48×10^{-3} SI units with an average MS value of 9.28×10^{-3} SI unit (n=14). Granite gneiss of the Rongjeng area measured substantially lower MS values compared to the granite gneiss exposed in and around the Guwahati area; however, for both MS values correspond to magnetite series granites (Fig.4b).

Kylong Granite Pluton

Granites of Kylong pluton are medium to coarse-grained, equigranular garnet-bearing granites (Fig.5a). A very few platy, angular xenoliths of amphibolite hosted in granites can be observed (Fig. 5b), which have reduced the MS values of granites close to its contact outline of host granites. Kylong granites are associated with

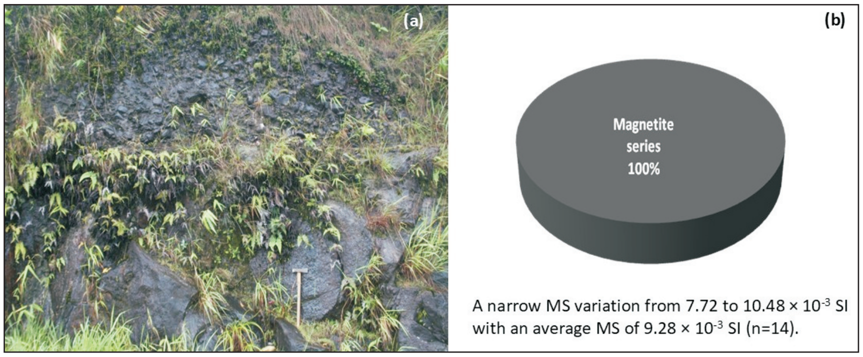

Fig.4. (a) Medium-grained pink coloured Proterozoic basement granite gneiss overlain by the conglomerate horizon. (b) The MS values of granite gneiss correspond to magnetite series granites. Note a very narrow range of variation in the MS values for the granite gneisses.

granulites, which are sometimes mineralized. The MS value of granites ranges from 25.57 to 62.27 × 10^{-3} SI units, with an average MS value of 38.37 (n=50), corresponding to magnetite series granites. Mineralized parts of the granites observed at two outcrops measure substantially high MS values ranging from 44.30 to 62.27 ×10^{-3} SI unit with an average MS value of 52.39×10-3 (n=18) and from 30.50 to 42.05×10-3 SI unit with average MS value of 34.81× 10^{-3} (n=07), which are highly oxidized as compared to rest of the granite outcrops (Fig. 5 c-d). The medium-grained granites are more mafic and mineralized than the coarse-grained Kylong granites and, therefore, measure anomalously high MS values. The reduction of Kylong granites close to the contact with amphibolitic xenoliths could be due to the marginal reaction between them that lowered the MS values.

Mowdow Granite Pluton

Granites forming the Mowdow pluton are well exposed between the Sindhuli and the Kylong localities. Mowdow granites are melanocratic to leucocratic, medium to coarse-grained and porphyritic. Elongated porphyritic (felsic phenocrysts or xenocrysts bearing) microgranular enclave can be observed in the porphyritic Mowdow granites, which appeared to follow the magmatic flowage as exhibited by crudely aligned phenocrysts of host and enclave in the direction of enclave elongation (Fig. 6a), which indicate coeval nature of enclave and host magma (Vernon *et al.,* 1988; Kumar, 2010b). Mowdow granites intrude the arkosic sandstone country rocks. As a result, potash-rich devolatised fluids metasomatized and stained the granites as pink (Fig.6b). Mesocratic coarse-grained porphyritic variety of granites contains xenoliths of amphibolites, granulites and a few porphyritic (hybrid) microgranular enclaves (Fig. 6b). MS value ranges from 9.00 to 22.04 × 10^{-3} SI units belonging to magnetite series granites (81%). MS value of granites has reduced to a larger degree near the intrusive contacts with country rocks (Fig. 6c-d), which reduced and correspond to ilmenite series granites (19%) where granites become pinkish evolving a hydrothermal system and form the tourmaline-bearing pegmatite system. Almost uniform MS values

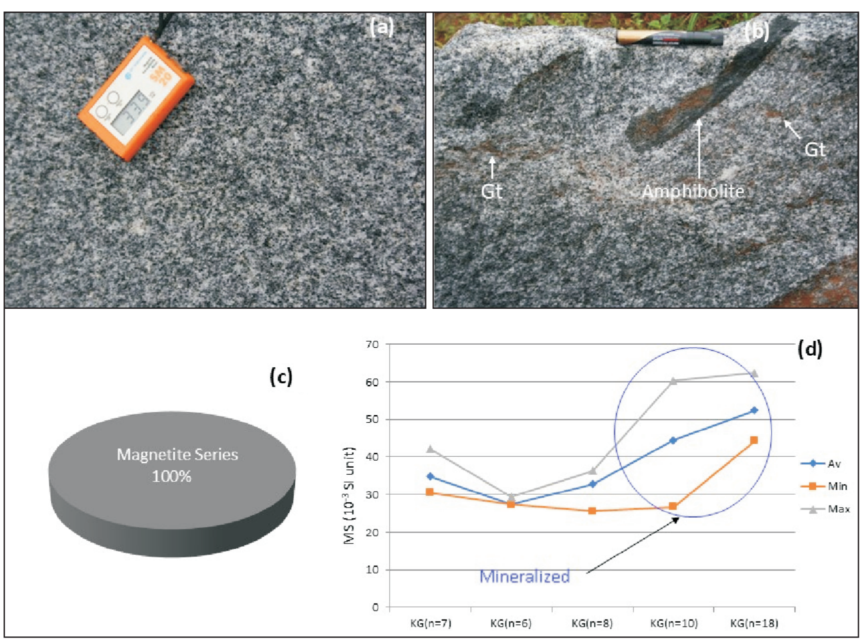

Fig.5. (a) Coarse-grained equigranular, mafic-rich Kylong granites measuring substantially high MS values as compared to other studied granite plutons, (b) Platy xenolith of amphibolite hosted in the Kylong granites, and the reduction of MS values of host granite has been noted close to the contact with the xenolith. Note the garnet grains (Gt) in the Kylong granites. (c) The Kylong granites correspond to highly oxidized magnetite series granites, (d) Mineralized zone of Kylong granites records substantially high MS value.

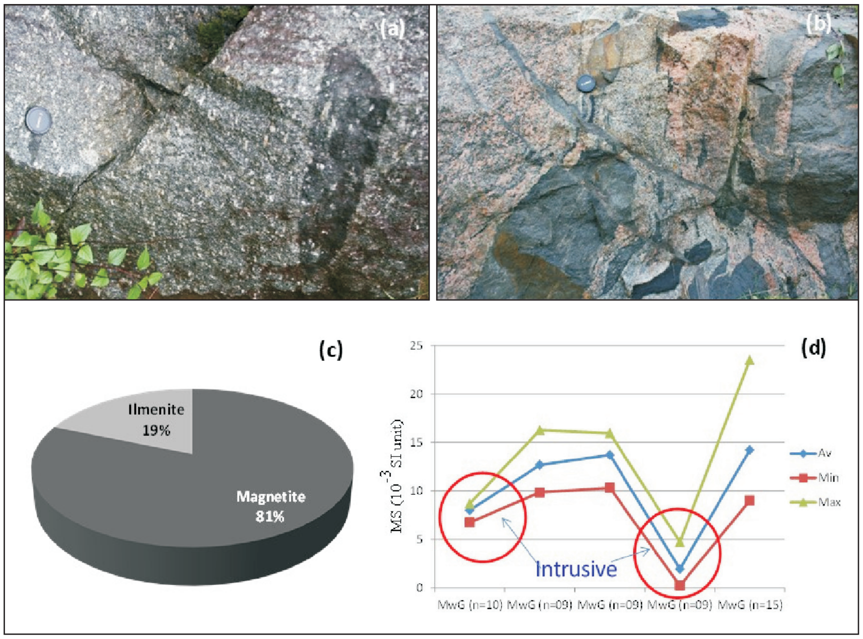

Fig.6. (a) Dark coloured, elongated, porphyritic microgranular enclaves hosted in the porphyritic (K-feldspar bearing) Mowdow granites. (b) Mowdow granites intrude the arkosic sandstone country rocks. (c) Magnetite series granites are 81% whereas ilmenite series granites are 19% together forming the whole of the Mowdow granite (MwG) pluton. (d) Mineralized zone records highest MS value whereas granites near the intrusive contacts are highly reduced to ilmenite series.

for the granites were recorded in the central part of the pluton. Moving towards the southwest, close to the Kylong pluton, the MS value increased gradually.

The dominance of fine grains of mafic minerals towards the pluton margin is primarily due to the rapid cooling at an early stage of fractional crystallization. This process significantly influences the mineral composition, leading to the increasing content of mafic minerals near the margin and hence records higher MS values. As magma crystallizes, a thermal gradient is established from the margin to the core of the pluton. This results in a finer-grained margin that transitions into a coarser-grained core. During magma differentiation, the minerals that crystallize early in the sequence render the margin rich in mafic minerals. At the same time, more siliceous residuals become depleted in mafic components in the core of the pluton.

The leucocratic variety of Mowdow granites can be classified into porphyritic and non-porphyritic types. The porphyritic leuco-granites are free from the country-rock xenoliths and exhibit lower magnetic susceptibility (MS) values, ranging from 6.75 to 8.69×10^{-3} SI units. In contrast, the non-porphyritic pink Mowdow granites, which intrude into the arkosic quartzite, show highly reduced MS values that range from 0.21 to 4.72×10^{-3} SI units, with an average of 1.93×10^{-3} SI units (n=9). For the melanocratic porphy-ritic Mowdow granites with K-feldspar megacrysts, moderate MS values were recorded, ranging from 9.84 to 16.26×10^{-3} SI units, with an average MS value of 12.67×10^{-3} SI units (n=18).

Sindhuli Granite Pluton Associated with Guwahati Granite Gneiss

Sindhuli granites are primarily found in the Boko and Patherkhanang localities. However, most parts of these regions are covered with dense vegetation (forest), which makes the access for the MS measurements difficult. The Sindhuli granites intrude the Guwahati granite gneiss, characterized as grey, coarse-grained, equigranular, and foliated moderately. The pink variety of Sindhuli granites is notably coarse-grained and porphyritic, characterized by K-feldspar megacrysts. It contains a few cognates and cumulates of early-formed mafic minerals, which may be present in the form of mafic schlierens (Fig. 7a, b). However, these cognates appear to be dismembered lithological blocks from the early mafic crust by the intruding granites.

The magnetic susceptibility (MS) values of the granites range from 15.19 to 17.44×10^{-3} SI units, with an average MS value of 16.28×10^{-3} SI units (n=6). The Sindhuli granites exhibit textural features similar to those of the Mylliem granites, although they lack the mafic to hybrid microgranular enclaves found in the latter. The MS values of the Sindhuli granites correspond to the oxidized-type magnetite granites, consistent with those recorded for other Cambrian granites in the Meghalaya Plateau.

Guwahati Granite Gneiss

Granite gneiss exposed in and around Guwahati is equigranular, grey, and moderately foliated, which is intruded by coarse-grained porphyritic variety of Sindhuli granites. At places, granite gneiss consists of a few cm-sized microgranular enclaves (Fig. 8a), and the MS value ranges from 38.73 to 68.48×10^{-3} SI (n=16; Table 1) which exclusively correspond to magnetite series granites (Fig. 8b). However, at some outcrops exposed in the Guwahati region, relatively lower MS values of granite gneiss were recorded, which range from 16.91 to 20.87×10^{-3} SI unit (Fig. 7d).

The recorded high MS value near the Boko area might have become elevated because of the mingling and mixing of mafic and felsic magmas, which is evident by the occurrence of hybrid microgranular enclaves. However, a low MS value was observed close to the Guwahati region, where the granitic gneiss is cross-cut by a number of pegmatitic and aplitic veins. Although there is a high fluctuation in the MS values, they still belong to magnetite series granites (Fig. 7c).

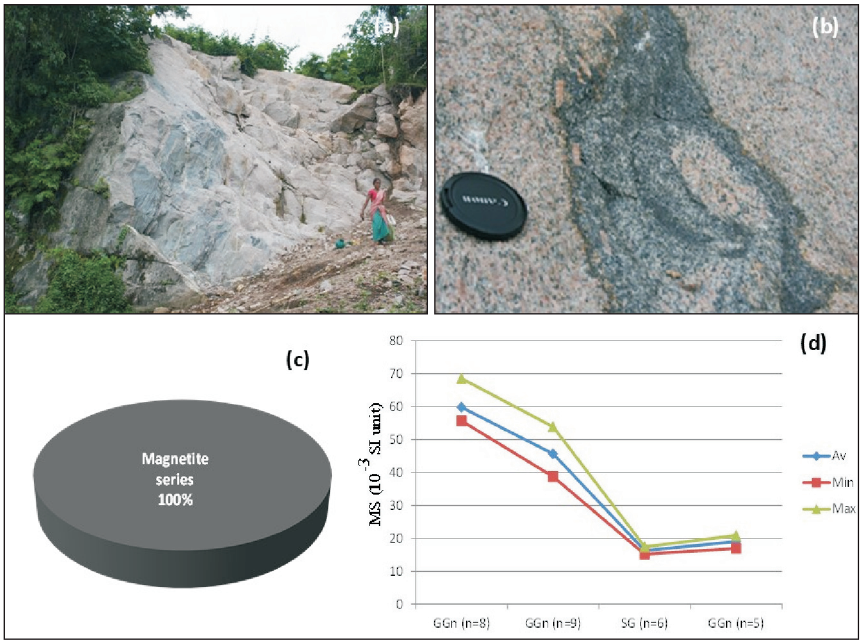

Fig.7. (a) Mafic schlierens and mafic aggregates of early crystallized mafic minerals, forming the cognate or autolith, hosted in the porphyritic (K-feldspar bearing) Sindhuli granites, (b) Sindhuli granites contain the mafic schlierens showing magmatic flowage, (c) Sindhuli granites exclusively belong to magnetite series granites, and (d) Granitic gneiss (GGn) measures substantially higher MS values as compared to the Sindhuli granites (SG).

Granites of East Garo Hills

In the East Garo Hills, the Rongjeng and Songsak granite plutons are intrusive into the Meghalaya Gneissic Complex (MGC). The MGC comprised the granite gneiss, migmatites, augen gneiss, biotite gneiss, granulites, and mafic-ultramafic rocks. Banded Magnetite Quartzite (BMQ) also occurs near the Dobu area. The Rongjeng granites occur as sporadic outcrops exposed from the Rongjeng village to the Darugiri transect in the south. The granites exposed around Rongjeng village are composed of grey to pink, coarse-grained porphyritic granites with ubiquitous anhedral to subhedral K-feldspar megacrysts (Fig. 9a). The K-feldspar megacrysts are randomly oriented and at places moderately affected by potash metasomatic fluids giving rise to a pinkish hue. Locally, the K-feldspar and biotite crystals crudely define the gneissosity (Fig. 9b). The MS value of coarse-grained porphyritic variety ranges from 3.23 to 20.83×10^{-3}SI unit, which corresponds to magnetite series granites (Fig. 9c-d) with an average value of 13.21 ×10^{-3}SI unit (n=48). In contrast, the MS value of medium-grained grey to pink granites varies from 1.45 to 20.77×10^{-3}SI unit with an average MS value of 9.08 ×10^{-3} SI unit (n=26). About 3% of medium-grained granite gneiss yielded the MS values corresponding to ilmenite series (reduced type) granites.

In the Songsak area, the granites are represented by grey to pink, medium to coarse-grained granites (Fig. 10a), which are occasionally cut across by the pink-coloured quartzofeldspathic veins (Fig. 10b). The abundant K-feldspar crystals impart pink to the granites because of a high degree of potash metasomatism. Measured MS values are comparatively lower for the pink-coloured granites ranging from 0.79 to 4.36 ×10^{-3}SI unit with an average MS value of 2.61×10^{-3}SI unit (n=22) corresponding mostly to ilmenite series granites (Table 1). While for the grey variety, the MS value ranges from 4.44 to 6.56×10^{-3} SI unit with an average MS value of 5.52×10^{-3}SI unit (n=11) corresponding to magnetite series granites (Table 1). Overall, the Songsak granites correspond to ilmenite (19%) and magnetite (81%) granite series granites (Fig. 10c-d), which are reduced-type and oxidized-type granites, respectively. Low MS values were noted for the intensely pink-coloured granites and still lowered MS values were observed for the granites adjacent to the pegmatitic veins. The observed reduction in the MS values is caused by the potash metasomatism, which eroded out the magnetic properties of the granites.

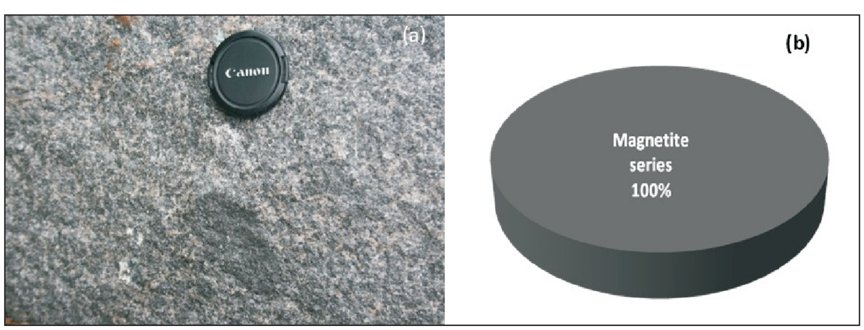

Fig.8. (a) Guwahati granite gneiss is medium-grained equigranular consists of cm-sized micrograndular enclave. (b) The MS values of Guwahati granite gneiss exclusively correspond to magnetite series granites. See text for detailed explanation.

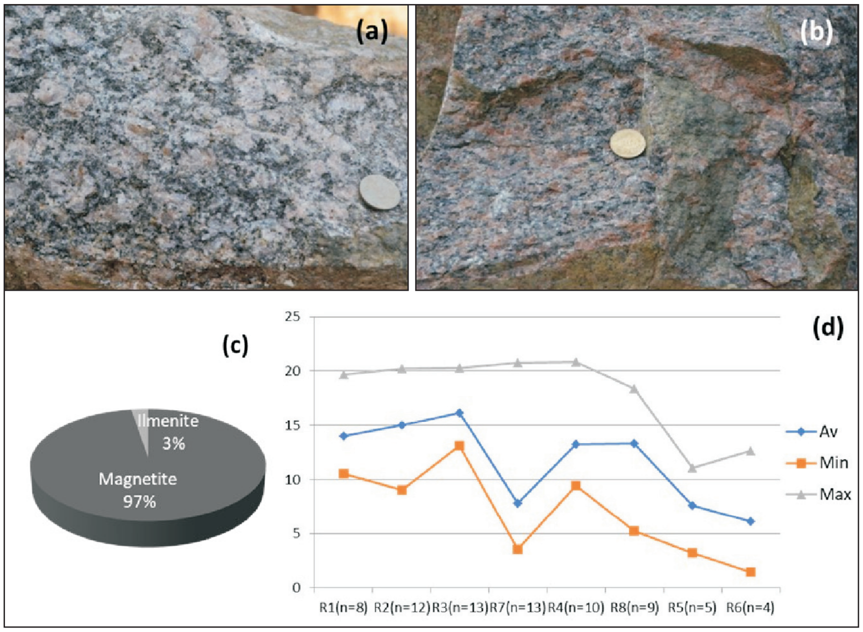

Fig.9. (a): Coarse-grained porphyritic Rongjeng granites containing pink-coloured anhedral to subhedral K-feldspar megacrysts. (b): Pink Rongjeng granites exhibit gneissic character. (c) Relative proportion of magnetite series granites (97%) to ilmenite series granites (3%). (d) Medium-grained Rongjeng granite gneiss (R1 to R6) recorded the high to low MS values.

Conclusions

In the Meghalaya Plateau, the Cambrian granite plutons of variable dimensions intrude the Basement granite gneisses and Shillong Group of rocks. Mafic microgranular enclaves hosted in some Cambrian granite plutons indicate the involvement of mafic-felsic magma mixing in the crustal growth of Meghalaya plateau. These granite bodies probably represent fracture-controlled diapiric plutons formed by a protracted thermal event related to mantle upwelling during Pan-African orogeny. Based on available age data of the granitoid pluton of Meghalaya by various authors, the granitic magma emplacement might have occurred at several stages, leading to varied degrees of crustal-mantle interaction, assimilation, and metasomatism. This is very well reflected in the oxidised magnetite series and reduced ilmenite series nature of granites and granite gneisses.

Most of the Meghalaya plateau granite plutons and basement granite gneiss belong to magnetite series (oxidised type) granites. Substantially high MS values have been recorded for the Nongpoh and Kylong granites and basement granite gneiss of the Guwahati region. However, 5%, 19%, 3% and 19% of MS values were measured for the Nongpoh, Mowdow, Rongjeng and Songsak

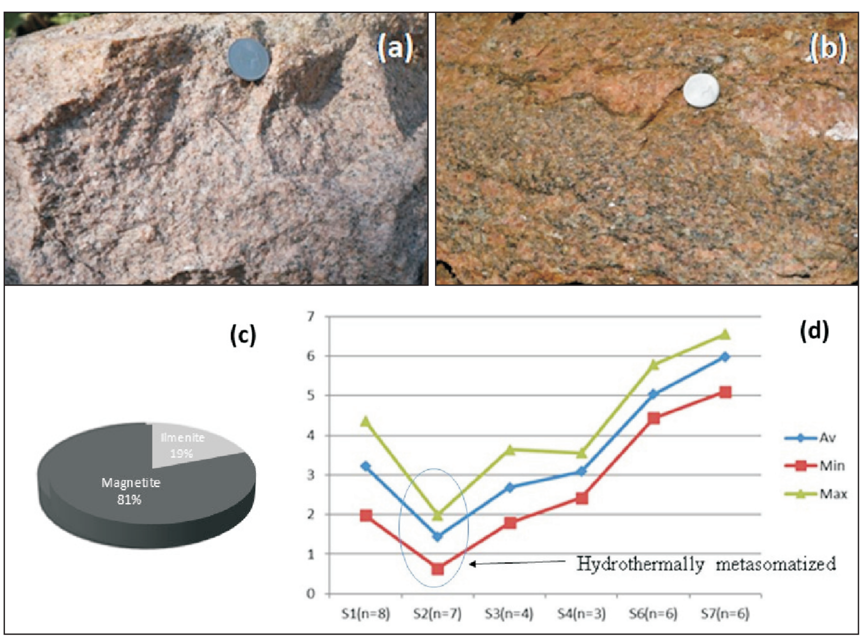

Fig.10. (a) Medium-grained grey to pink Songsak granites. (b) Medium-grained intensely pink Songsak granites cut across by the pink coloured pegmatitic vein. (c) Relative proportion of magnetite series (81%) to ilmenite series (19%) granites. (d) Hydrothermally metasomatized Songsak granites yielded low MS values.

plutons belonging to the ilmenite series (reduced type) granites. Although Nongpoh granites intrude the metasediments (quartzite), they do not exhibit a noticeable reduction in MS value because quartzite mainly comprises quartz grains, and partially assimilated silica did not reduce the MS value. However, in a few places, Nongpoh granites are relatively fine to medium-grained equigranular in texture, showing highly reduced MS values corresponding to the ilmenite (reduced type) granite series. These may represent evolved (residual) parts of the Nongpoh granites and hence measured the low MS values (0.059-0.071×10-3 SI unit) being depleting in ferromagnesian minerals.

Most of the reduced (ilmenite series) MS values of studied granites have been observed either close to the intrusive contacts with country rocks or where hydrothermal or potash metasomatic fluids have significantly affected the granites. In relatively fresh granite outcrops, the variations in MS values are governed mainly by the modal mineral variations of orthomagnetic (magnetite) and ferromagnesian (amphibole and biotite) minerals. Mineralised and mafic-felsic magma mixing (hybridizing) systems have been recognized in some granites of the Meghalaya Plateau because of the prevailing oxidising environment, which is more akin to an open system. The occurrence of microgranular enclaves in granites suggests the mingling of mafic to hybrid magma in the relatively cooler host granite melts. Zones of hybridisation and mineralisation in granites have recorded higher MS values than the enclave-free and unmineralized granites of the Meghalaya Plateau.

Authors' Contributions

SB: Conceptualization, Investigation, Writing-Original Draft, Analysis. **VR**: Conceptualization, Investigation, Writing-Eiting, Analysis. **HJ:** Investigation, Writing-editing, Analysis. **MSR:** Investigation, Writing-Editing, Analysis. **SK**: Conceptualization Investigation, Writing-Reviewing and Editing, Analysis, Supervision, Principal Investigator

Conflict of Interests

Authors declare no conflict of interests.

Acknowledgments

This paper stands as a heartfelt tribute to the memory of Manohar S. Rawat, a valued co-author who has sadly passed away. His contributions and legacy will always be remembered and honoured through this work. S. K. and VR acknowledge grants (DST/SR/S4/ES-546/2010(1)/2012) received from Science and Engineering Research Board (SERB), Department of Science and Technology, Government of India. S. B. acknowledges receiving a Senior Research Fellowship (SRF) for the same project. This work utilizes the infrastructure developed in the Department of Geology at Kumaun University, funded by the UGC-CAS Phase I and II programs and DST-Level I and II programs. S. Rahman, D. K. Paul, S. Sinha Roy, M. Mohanty, R. K. Mahajan, Umesh K. Sharma, Rajwant and Prahlad Ram are thanked for their continuous support and encouragement throughout the research work. We thank Ajay V. Kulkarni and the Handling Editor, Sumedh Humane, for their generous scientific comments, which significantly improved the earlier version of the manuscript.

References

Anettsungla, Rino, V. and Kumar, S. (2018). Redox condition, nature and tectono-magmatic environment of granitoids and granite gneisses from the Karbi Anglong Hills, Northeast India: Constraints from magnetic susceptibility and biotite geochemistry. Jour. Geol. Soc. India, v. 91, pp. 601–612.

Bidyananda, M. and Deomurari, M.P. (2007). Geochronological constraints on the evolution of Meghalaya Massif, northeastern India: An ion microprobe study. Curr. Sci., v.93, pp. 1620–1623.

Carmichael, I.S.E. (1991). The redox states of basic and silicic magmas -a reflection of their source regions. Contrib. Mineral. Petrol. v.106, pp.129–141.

Chappell, B.W. and White, A.J.R. (1974). Two contrasting granite types. Pacif. Geol., v.8, pp.173–174.

Chappell, B.W. and White, A.J.R. (2001). Two contrasting granite types: 25 years later. Jour. Geol. Soc. Australia, v. 48, pp. 489-499.

Chatterjee, N., Mazumdar, A.C., Bhattacharya, A., Saikia, R.R. (2007). Mesoproterozoic granulites of the Shillong–Meghalaya Plateau: evidence of westward continuation of the Prydz Bay Pan-African suture into Northeastern India. Precamb. Res., v. 152, pp. 1-26.

Chimote, J.S., Pandey B.K., Bagchi, A.K., Basu, A.N., Gupta, J.N. and Saraswati, A.C. (1988). Rb-Sr whole rock isochron age for the Mylliem granite, east Khasi Hills, Meghalaya. IV National Symposium in Mass Spectromentry, Bangalore.

Crawford, A.R. (1969). India, Ceylon and Pakistan: New age data and comparison with Australia. Nature, v.223, pp.80-84.

Crawford, A.R. (1974). The Indus Suture line, the Himalayas, Tibet and Gondwana land. Geol. Mag., v. 111, pp. 369-480.

Czamanske, G.K., Ishihara, S. and Atkin, S.A. (1981). Chemistry of rock forming minerals of the Cretaceous–Paleocene batholith in southwestern Japan and implications for magma genesis. Jour. Geophys. Res.: Sol. Earth, v.86, pp. 10431-10469.

Desikachar, S.V. (1974). A review of the tectonic and geological history of eastern India in terms of plate tectonics theory. Jour. Geol. Soc. India, v.15, pp.137–149.

Evans, P. (1964). The tectonic framework of Assam. Jour. Geol. Soc. India, v.5, pp.80–96.

Ghosh, S., Bhalla, J.K., Paul, D.K., Sarkar, A., Bishul, P.K., Gupta, S.N. and Chakraborty, S. (1991). Geochronology and geochemistry of granite plutons from East Khasi Hills, Meghalaya. Jour. Geol. Soc. India, v.37, pp.331–342.

Ghosh, S., Paul, D.K., Bhalla, J.K., Bishui, P.K., Gupta, S.N. and Chakraborty, S. (1994). New Rb-Sr isotopic ages and geochemistry of granitoids from Meghalaya and their significance in middle-to late Proterozoic crustal evolution. Indian Miner., v. 48, pp.33–34.

Ghosh, S., Fallick, A.E., Paul, D.K. and Potts, P.J. (2005). Geochemistry and origin of Neoproterozoic granitoids of Meghalaya, northeast India: Implications for linkage with amalgamation of Gondwana Supercontinent. Gond. Res., v.8, pp.421–432.

Gogoi, A., Majumdar, D., Cottle, J. and Dutta, P. (2019). Geochronology and geochemistry of Mesoproterozoic porphyry granitoids in the northern Karbi Hills, NE India: Implications for early tectonic evolution of the Karbi Massif. Jour. Asian Earth Sci., v.179, pp. 65–79.

Gregorová, D., Hrouda, F., and Kohút, M. (2003). Magnetic susceptibility and geochemistry of Variscan west Carpathian granites: Implications for tectonic setting. Phys. Chem. Earth, v. 28, pp.729–734.

Ishihara, S. (1977). The magnetite-series and ilmenite-series granitic rocks. Mining Geology, v. 27, pp.293–305.

Ishihara, S. (1979). Lateral variation of magnetic susceptibility of the Japanese granitoids. Jour. Geol. Soc. Japan, v.85, pp.509–523.

Ishihara, S., Robb, L.J., Anhaeusser, C.R. and Imai, A. (2002). Granitoid series in terms of magnetic susceptibility: a case study from the Barberton region, South Africa. Gond. Res., v. 5, pp. 581-589.

Kumar, S. (1990). Petrochemistry and geochronology of pink granite from Songsak, east Garo Hills, Meghalaya. Jour. Geol. Soc. India, v. 35, pp. 39-45.

Kumar, S. (1995). Microstructural evidence of magma quenching inferred from microgranular enclave hosted in Hodruša granodiorite. western Carpathians. Geolog. Carpath., v. 46, pp 379-382.

Kumar, S. (1998). Granitoids and their enclaves from East Khasi Hills of Meghalaya: Petrogenetic and geochemical reappraisal. Geodynamics of Northeast India, Dibrugarh, pp 17-18.

Kumar, S. (2010a). Magnetite- and ilmenite-series granites of Ladakh batholith, Northwest Indian Himalaya: Implications on redox conditions of subduction zone magmatism. Curr. Sci., v. 99, pp. 1260-1264.

Kumar, S. (2010b). Mafic to hybrid microgranular enclaves in the granitoids of Ladakh batholith, Northwest Higher Himalaya: implications on calc-alkaline magma chamber processes. Jour. Geol. Soc. India, v. 76, pp. 5-25.

Kumar, S. (2020). Schedule of mafic to hybrid magma injections into crystallizing felsic magma chambers and resultant geometry of enclaves in granites: New field and petrographic observations from Ladakh Batholith, Trans-Himalaya, India. Front. Earth Sci., v. 8, 551097. doi: 10.3389/feart.2020.551097.

Kumar, S. and Pathak M. (2009). Magnetic susceptibility and geochemistry of Felsic Igneous rocks from western Arunachal Himalya: Implication on granite series evaluation in orogenic belt. Magmatism, Tectonism and Mineralization, Macmillan Publishers, pp 74-91.

Kumar S., Raju, S., Pathak, M. and Pandey, A. (2010). Magnetic susceptibility mapping of felsic magmatic lithounits in the central part of Bundelkhand massif, central India. Jour. Geol. Soc. India, v.75, pp.539-548.

Kumar, S. and Rino V. (2007). Redox series evaluation of Cu(±Mo±Au) hosting Paleoproterozoic Malanjkhand granitoids and enclaves, central India: evidence from magnetic susceptibility, phase petrology and geochemistry. Jour. Econ. Geol. Resour. Manag., v.4, pp. 105-127.

Kumar, S. and Singh, Kh.M. (2008) Granite series evaluation of Early Ordovician Kyrdem granitoids and enclaves, Meghalaya plateau, northeast India: implication on oxidation condition of interacting mafic-felsic magma system. E-Jour. Earth Sci. India, v.1, pp. 204-219.

Kumar. S., Pieru, T. and Rino, V. (2005): Evaluation of granitoid-series of and magmatic oxidation of Neoproterozoic south Khasi granitoids and their microgranular enclaves, Meghalaya: Constrains from magnetic susceptibility and biotite composition. Jour. Appl. Geochem., v.7, pp. 175-194.

Kumar, S., Pieru, T., Rino, V. and Hayasaka, Y. (2017a). Geochemistry and U–Pb SHRIMP zircon geochronology of microgranular enclaves and host granitoids from South Khasi Hills of the Meghalaya Plateau, NE India: evidence of synchronous mafic–felsic magma mixing–fractionation and diffusion in a post-collision tectonic environment during the Pan-African orogenic cycle. Geol. Soc., London, Spec. Publ., 457, pp. 1-37.

Kumar, S., Rino, V., Hayasaka, Y., Kimura, K., Raju, S., Terada, K. and Pathak, M. (2017b). Contribution of Columbia and Gondwana Supercontinent assembly- and growth-related magmatism in the evolution of the Meghalaya Plateau and the Mikir Hills, Northeast India: Constraints from U-Pb SHRIMP zircon geochronology and geochemistry. Lithos, v. 277, pp. 356-375.

Kumar, S., Pundir, S., Rino, V., Bora, S., Pathak, M., Anettsungla, Joshi, H., Rawat, M.S., Pieru, T. and Singh, K.M. (2022). Geochemistry of Proterozoic and Cambrian granites from Meghalaya Plateau, north-east India: Implication on petrogenesis of post-collisional, transitional from I-type to A-type felsic magmatism. Geol. Jour., v.4351, pp.1–35.

Kumar, S., Singh B., Joshi C.C. and Pandey A. (2006). Magnetic susceptibility and biotite composition of granitoids of Amritpur region, Kumaun Lesser Himalaya: Implications on granite series evaluation and nature of felsic magma. Jour. Geol. Soc. India. V.68, pp.666-674.

Majumdar, D. and Dutta, P. (2016). Geodynamic evolution of a Pan-African granitoid of extended Dizo valley in Karbi Hills, NE India: Evidence from geochemistry and isotope geology. Jour. Asian Earth Sci., v.117, pp. 256-268.

Mazumder, S.K. (1976). A summary of the Precambrian geology of the Khasi Hills, Meghalaya. Geol. Surv. India Misc. Publ., v. 23, pp. 311-334.

Mazumder, S.K. (1986). The Precambrian framework of the Khasi Hills, Meghalaya, Rec. Geol. Surv. India, v. 117(2), pp. 1-52.

Mitra, S. K. (1998). Structure, sulphide mineralisation and age of the Shillong Group of rocks, Meghalaya. S.K. Krishnan Centenary Commemorative National Seminar. 1 – 2 November, Calcutta, pp.118 – 119.

Panwar, K.S. and Kumar, S. (2022). Granite series assessment, nature and crystallization condition of Paleoproterozoic granite gneisses from Askot and Chiplakot klippe, Kumaun Lesser Himalaya, India. Jour. Earth Syst. Sci., v. 131, pp.173

Sadiq, M., Umrao, R.K., Sharma, B.B., Chakraborti, S., Bhattacharyya, S. and Kundu, A. (2018). Mineralogy, geochemistry and geochronology of mafic magmatic enclaves and their significance in evolution of Nongpoh granitoids, Meghalaya, NE India. Geol. Soc., London, Spec. Publ., v. 463, pp. 171–198.

Shand, S.J. (1948). The eruptive rocks. 3rd Ed., New York: John Wiley, 444p.

Singh B. and Kumar, S. (2005). Petrogenetic appraisal of Early Palaeozoic granitoids of Kinnaur district, Higher Himachal Himalaya, India. Gond. Res., v. 8, pp 67-76.

Takagi, T. (2004). Origin of magnetite- and ilmenite-series granitic rocks in the Japan arc. Amer. Jour. Science, v. 304, pp. 169–202.

Takagi, T. and Tsukimura, K. (1997). Genesis of oxidized- and reduced-type granites. Econ. Geol., v. 92, pp. 81-86.

Takahashi, M., Aramaki, S. and Ishihara, S. (1980). Magnetite-series/Ilmenite-series vs. I-type/S-type granitoids. Mining Geol. Spec. Issue, No. 8, pp. 13-28.

Van Breemen, O., Bowes, D.R., Bhattacharjee, C.C., Chowdhary, P.K. (1989). Late Proterozoic-Early Paleozoic Rb–Sr whole rock and mineral ages for granite and pegmatite, Goalpara, Assam, India. Jour. Geol. Soc. India, v. 34, pp. 89–92.

Vernon, R.H., Etheridge, M.A. and Wall, V.J. (1988). Shape and microstructures of microgranitoid enclaves: Indicators of magma mingling and flow. Lithos, v.22, pp. 1-11.

Yin, A., Dubey, C.S., Webb, A.A.G., Kelty, T.K., Grove, M., Gehrels, G.E. and Burgess, W.P. (2010). Geologic correlation of the Himalayan orogeny and Indian Craton: Part 1. Structural geology, U-Pb zircon geochronology, and tectonic evolution of the Shillong Plateau and its neighbouring regions in NE India. Bull. Geol. Soc. Amer., v.122, pp.336–359.