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Characteristics of Mesoproterozoic felsic meta-volcanics from the Shillong Group of rocks, Meghalaya, North East India

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Shillong Group comprises a thick meta-volcano-sedimentary sequence forming a part of Shillong Plateau and Mikir Hills. The litho variants of felsic meta-volcanics are characterized in detail based on their constituent material, textural variation, depositional feature and mode of eruption. Lava flows are characterized as porphyritic, spherulitic and aphyric type whereas pyroclastic deposits are classified as tuff breccia, lapilli tuff, tuff and ignimbrite. Fractured crystal and brecciated lithic fragments in tuff; fiamme and eutaxitic texture of ignimbrite suggest for sub-aerial eruption. The felsic meta-volcanics are rhyolitic to dacitic in composition and interbedded with tuffaceous phyllite, phyllite and quartzite.

Keywords: Felsic volcanics, ignimbrite, lava flow, tuff, Shillong Group, subaerial.

THE Mesoproterozoic Shillong basin comprises a thick pile of meta-sedimentary sequence known as Shillong Group of rocks. It occupies the eastern central part of the Assam Meghalaya Gneissic Complex (AMGC) that forms part of the Shillong Plateau (Figure 1). The meta-sediments of Shillong Group are deposited unconformably over Umsning Schist Belt (USB)[1]. Sills and dykes of Khasi metabasics, Neoproterozoic granitoids of Pan-African origin (Mylliem Granite (607 ± 13 Ma), South Khasi Granite (690 ± 19 Ma) and Kyrdem Granite (479 ± 26 Ma)) and late cretaceous mafic dykes and sills intrude the Shillong Group of rocks[2–5]. The Pan-African granitic plutons (South Khasi batholith) limit the upper age of Shillong Group to ~700 Ma and detrital zircon dates from quartzite of Shillong Group restricts the lower age limit to 1100 Ma (ref. 6). It has undergone polyphase deformation and metamorphosed under the green schist–amphibolite transional facies[7].

Felsic meta-volcanics in the form of meta-acid volcanic and tuff have been reported from Shillong Group as thin band of dark grey, fine-grained, intensely sheared and profusely impregnated with quartz veins occurring within phyllite[1,8]. Phenocryst of feldspar is strewn in the devitrified fine-grained groundmass. Volcanic tuff of Kerguelen hotspot-related volcanism exposed in Smit area is of Cretaceous age[9]. The felsic meta-volcanics of Shillong basin exposed in Meghalaya as well as in Mikir hills of Assam was least studied till date. Textural differences in the felsic lava flows from the Shillong basin exposed in Meghalaya part are reported here. The volcanic features of lava flows and pyroclastic deposits are reported here based on their constituent material, depositional feature and mode of eruption. Further, the nature of eruption and deposition of felsic meta-volcanics are also highlighted here.

The NE–SW trending meta-volcano-sedimentary sequences of the Shillong basin have regional dip towards SE. It covers approximately 2500 sq. km area of Shillong plateau. The litho sequence of Shillong Group was divided into three formations as Lower Mawlyndep, Middle Umiam and Upper Nongpiur formations (Table 1)[1]. The Lower Mawlyndep Formation comprises quartzite with subordinate quartz mica schist, phyllite and basal conglomerate at base. The Middle Umiam Formation dominantly comprises tuffaceous phyllite and felsic meta-volcanics with subordinate amount of phyllite,

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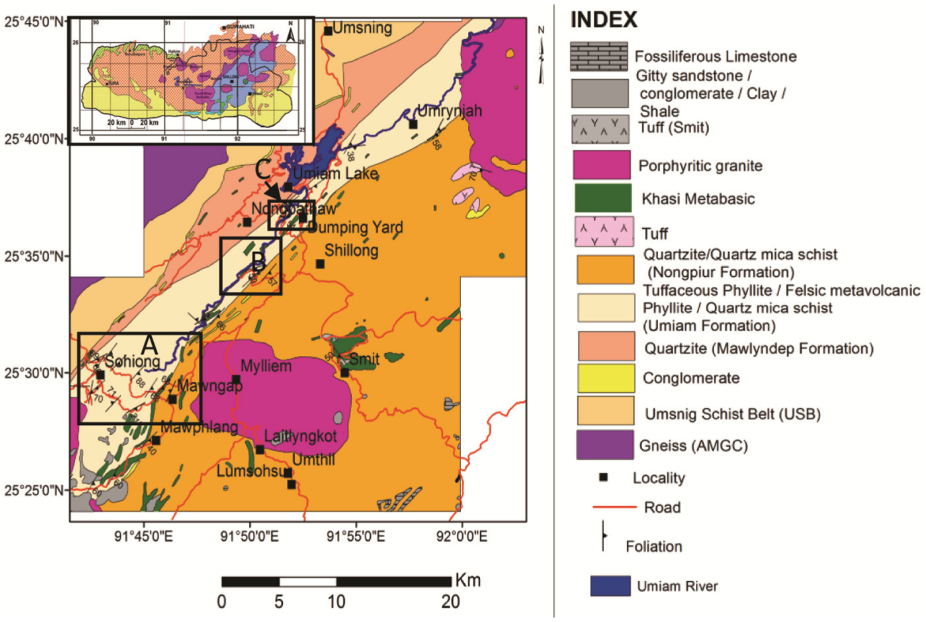

Figure 1. Geological map of south-western part of the Shillong Basin modified after Khonglah[1] and Mero[8].

Table 1. Stratigraphy of the Shillong Plateau in Shillong and nearby areas[1]

Khasi Group Cretaceous	Mahadek Formation bottom coglomerate	Sandstone, Conglomerate	
Late Proterozoic to Ordovician	Kyrdem Plutons Nongpoh Mylliem South Khasi	Porphyritic granite	
Late Proterozoic	Basic intrusives	Meta gabbro/dolerite	
Shillong (Late Proterozoic) (1100 to 700 Ma) (based on detrital zircon and age of intrusive granitic pluton)	Nongpiur Formation Umiam Formation Mawlyndep Formation	Arkosic quartzite, conglomerate Phyllite with thin quartzite intercalations and quartzo Feldspathic meta-volcanics Bedded white quartzite, basal polymictic conglomerate	
Umsning Schist Belt (Early to Middle Proterozoic) (1550 Ma, Pb–Pb dating of galena)	Quartz muscovite schist, carbonaceous phyllite, micaceous quartzite, quartz feldspathic mica schist, quartz hornblende biotite schist, quartz biotite schist, quartz sericite sillimanite schist	Gneissic complex (1150 + 26 and 1714 + 44 Ma) (intrusive into the Umsning Schist Belt)	Granite gneiss, migmatites with enclaves of biotite schist, quartz hornblende – biotite schist, sillimanite schist
Basement Gneissic Complex			

carbonaceous shale/slate and thin bands of quartzite and quartz mica schists. The Upper Nongpiur Formation dominantly comprises thick quartzite, thin phyllite bands and subordinate amount of lithic quartzite, conglomerate and felsic meta-volcanics. The Nongpiur Formation is separated from Umiam Formation by a polymictic, clast supported conglomerate horizon exposed at the North Eastern Hill University (NEHU) bypass. The felsic meta-volcanics are exposed in the SW part of the basin around Sohiong (Figure 2 *a*) and along the Umiam River section in the central part of the present day basin configuration (Figure 2 *b* and *c*) in Meghalaya as well as in parts of Mikir Hills in Assam.

The felsic meta-volcanics include variable proportions of several lithotypes that are characterized by distinct textural styles. It occurs as interbedded sequence with phyllite and tuffaceous phyllite of Middle Umiam Formation and quartzite of Upper Nongpiur Formation. It can be traced for about 40 km from SW (Sohiong area) to NE (Sonidan) part of the basin in Meghalaya but are not compositionally and petrographically similar. The volcanics are crystal rich in central and NE part compared to

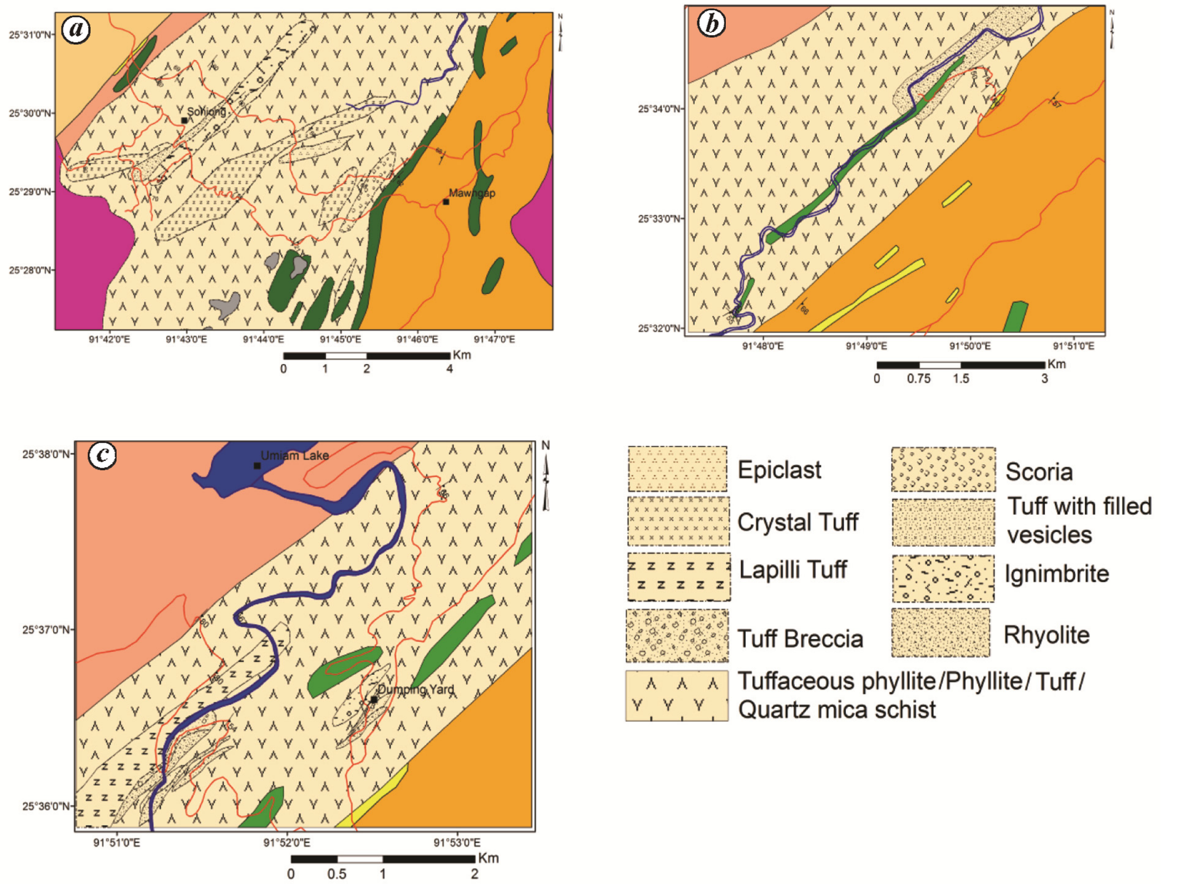

Figure 2. ***a***, Variants of felsic metavolcanics in south–western part of the basin around Sohiong area; ***b*** and ***c***, Variants of felsic metavolcanics in central part of the basin along Umiam River.

SW part of the basin. These felsic meta-volcanics are exposed along the Umiam River section, Sohiong and NEHU bypass and are regionally metamorphosed to green schist facies, up to amphibolites facies near to Khasi metabasic along the Tyrsad road and are mylonytized as proximity to Barapani Tyrsad Shear Zone.

The felsic meta-volcanics of Shillong Group are broadly grouped into two, effusive phase as coherent lava flow and explosive phase as pyroclastic deposits. Further, the coherent lava flows are characterized as porphyritic, spherulitic, glassy and scoriaceous whereas the pyroclastic deposits are grouped as tuff breccia, lapilli tuff, tuff and ignimbrite based on their structures and textures, clast types and sizes, presence of phenocrysts and their relationship with the groundmasses. The porphyritic texture is one of the most important criteria for distinguishing coherent lava flow facies from explosive pyroclastic facies in the field[10].

The coherent lava flows are dark grey to pink, massive to flow banded, aphyric to quartz–feldspar and feldspar–phyric, locally glassy and vesicular. It is exposed in NE, central and SW parts of the basin. The porphyritic lava flow shows flow banding of grey and light pink colour indicating compositional variation (Figure 3 *a*). In thin section, the lava flows are observed to be aphanitic to porphyritic and spherulitic with devitrified groundmass. The quartz–feldspar phyric porphyritic rhyolites have phenocryst of quartz and albitic plagioclase. The euhedral phenocrysts vary in size and abundance within the individual flow units but rarely exceed 3 mm in size and 20% to 30% by volume. The phenocrysts are embedded within the devitrified groundmass. The groundmass mainly comprises quartz, feldspar, mica and opaque. Zircon, monazite, apatite and tourmaline present as accessory phase. The groundmass is rich in potash feldspar than sodic feldspar. Zircons are well developed and euhedral in shape. Quartz are of bipyramidal habit and show effect of round resorption (Figure 3 *b*). They are embayed and partly rounded. The feldspar phenocrysts are rounded, show resorption and sieve texture. The feldspar–phyric rhyolites have phenocryst of albite to olgoclase plagioclase and show glomeroporphyritic texture typical of coherent facies. The aphanitic varieties are glassy in nature, individual minerals are identified through Back Scattered Electron (BSE) image. The BSE image (Figure 3 *c*) reveals that, it comprises more than 60% quartz, more than 20% feldspar and the rest mica, opaque, other accessory minerals and the vesicles are filled with calcite in its disseminated form of opaque and quartzo-feldspathic groundmass indicates sudden chilling effect.

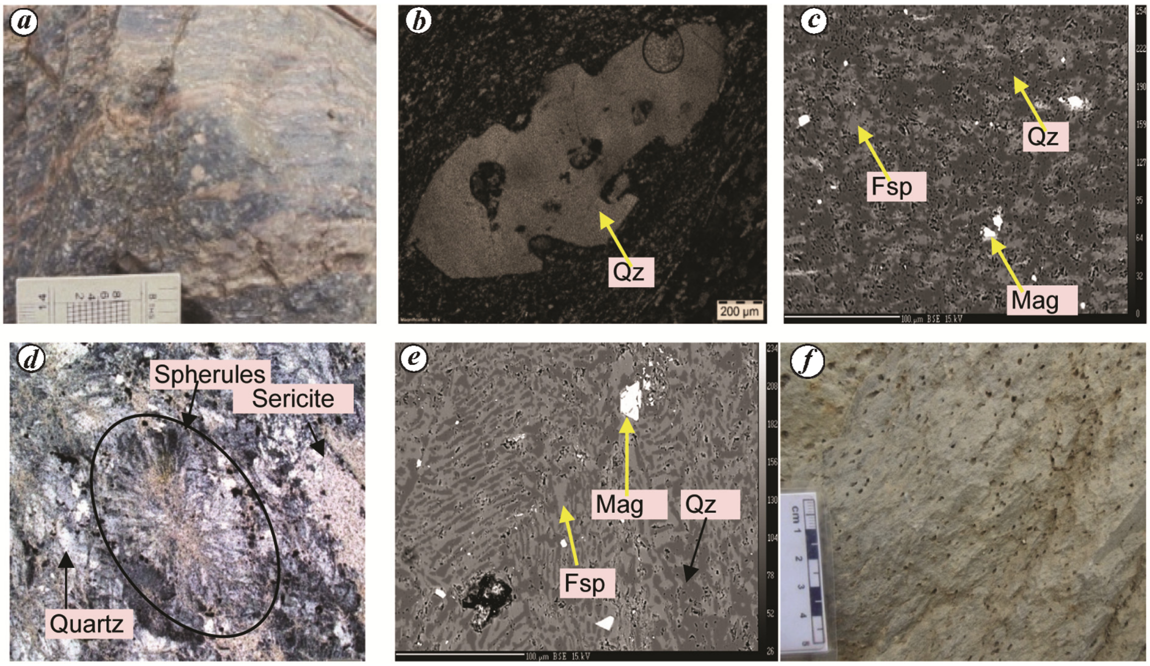

Figure 3. ***a***, Porphyritic rhyolite lavaflow with flow banding along the Umiam River section. ***b***, Bipyrmidal quartz phenocryst shows embayed boundary and round resorption texture in porphyritic rhyolite. ***c***, BSE image of glassy rhyolite comprising more than 30% feldspar disseminated within quartz. ***d***, Oval-shaped spherules of spherulitic rhyolite. ***e***, BSE image of spherulitic rhyolite showing thin fibres of feldspar and quartz. ***f***, Scoria with more than 30% vesicles along the Sohiong bypass. Qz, quartz; Fsp, feldspar; Mag, Magnetite.

The spherulitic textures are identified under microscope. It indicates high-temperature devitrification of coherent volcanic glass. It consists of radiating arrays of crystal fibres of quartz and feldspar. Each crystal fibre is in different crystallographic orientation. The spherules are of different shape and size. The shape varies from spherical (Figure 3 *d*) to fan and axiolitic (Figure 3 *e*) type[11]. The spherules also develop along the boundaries of feldspar phenocrysts. Spherical spherulites are common in spherulitc rhyolite exposed near the Umiam Lake. Near Nongmulong, the spherulitic rhyolites mostly have spherical to auxiolitic shape. Scoria beds are interbedded with tuff and lapilli tuff and are exposed in southwest part of the basin**.** These are grey to dark grey in colour when fresh and very light grey when weathered. Weathered varieties are very soft. The vesicles are circular to oval in shape with thick wall, size greater than 5 mm and contribute more than 40% by volume (Figure 3 *f*). The vesicles are filled with quartz and opaque. The groundmass comprises quartz, feldspar, mica and opaque.

Pyroclastic deposits are the widely spread variant of felsic meta-volcanics of Shillong Group. These are grey in colour, mostly soft but hard and compact variety are also common. These are interbedded with lava flows, tuffaceous phyllite, phyllite and quartzite. Tuffs are further classified as tuff breccia, lapilli tuff and tuff (ash) based on the proportion and size of the constituent materials in field. The tuff breccias have more than 30 cm angular lithic fragments (Figure 4 *a*) whereas lapilli tuff has less than 64 mm lapilli (Figure 4 *b*) embedded within fine-grained devitrified groundmass. In thin section, based on the proportion and type of constituent material, tuffs are classified as vitric tuff, crystal tuff and lithic tuff. Vitric tuffs are very fine grained (Figure 4 *c*). In the central part of the basin, tuffs are crystal dominated. The vitric tuff of central part of the basin comprises crystals of feldspar and quartz, pumiceous clast with diffused boundary (Figure 4 *d*). The crystal tuffs have more than 70% crystal of feldspar and quartz. Most of the crystals are broken and angular in shape. The tuff breccia was considered as lithic tuff during petrography as it contains more than 30% of lithic fragments of volcanic origin. The quartzo-feldspathic groundmasses within and outside the lithic fragments are of similar nature but show difference in textural framework and proportion of crystal. The boundaries of the fragments are diffused. The glass shards are devitrified and are difficult to identify. The groundmass consists of quartz, feldspar, mica and opaque. Secondary calcite is common in pyroclastic deposits of central part of the basin. Biotite developed cross cutting the foliation plane of tuff in the SW part of the basin.

Those pyroclastics, which exhibit eutaxitic (hot flow banding) and fiamme textures, are classified under ignimbrite as pyroclastic flow deposits. It is a poorly sorted mixture of volcanic ash and pumice lapilli with scattered lithic fragments (Figure 4 *e*). Presence of ignimbrite indicates a collapsing stage of the volcanic column due to lesser amounts or decreasing contents of volatile matter in the melt system. As a result, the buoyancy required for the explosive eruption decreases and hot material along with clast, lapilli, crystal, etc. flow like a hot density current[11]. In SW part of the basin, the ignimbrite is very

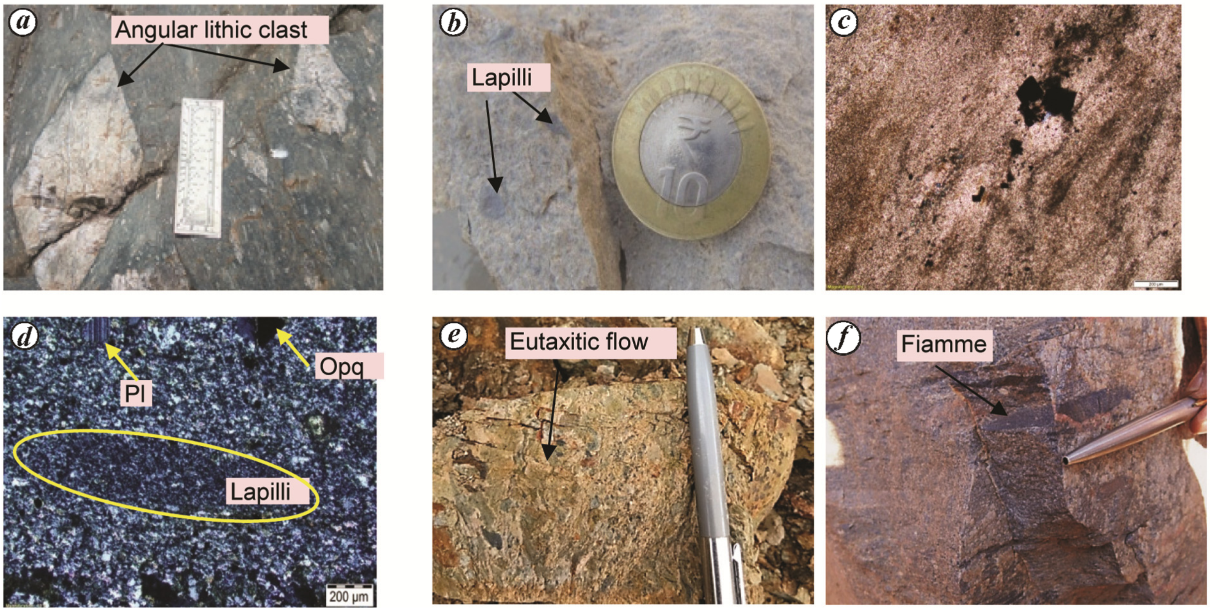

Figure 4. ***a***, Tuff breccia with angular lithic fragments of more than 30 cm. ***b***, Lapilli tuff with circular lapilli embedded within fine-grained groundmass. ***c***, Very fine-grained vitric tuff. ***d***, Vitric tuff with plagioclase crystal, opaque and lapilli with diffused boundary embedded within the devitrified fine-grained groundmass. ***e***, Poorly sorted ignimbrite showing eutaxitic flow structure. ***f***, Ignimbrite showing fiamme structure. Pl, Plagioclase; Opq, Opaque.

Table 2. Major oxide data of lava flow and scoria of Shillong Group

Rock type	Lava flow								Scoria	
SiO_2	73.95	66.13	74.38	81.17	78.34	74.72	78.83	75.82	68.39	68.80
TiO_2	0.30	0.70	0.29	0.13	0.14	0.26	0.15	0.12	0.55	0.59
Al_2O_3	12.04	12.80	13.39	9.52	11.16	13.40	11.18	11.80	17.42	16.56
Fe_2O_3	3.50	5.89	3.09	1.24	1.16	1.64	1.16	1.13	4.36	3.60
MnO	0.06	0.21	0.04	0.01	0.01	0.01	0.01	0.04	0.05	0.01
MgO	0.22	1.78	0.61	0.07	0.09	0.07	0.21	0.32	2.09	1.34
CaO	1.27	2.46	0.13	0.01	0.01	0.03	0.01	1.09	0.06	0.01
Na_2O	3.26	5.47	1.05	2.17	2.14	0.18	1.79	3.79	0.13	0.11
K_2O	4.09	2.95	6.60	5.20	5.89	8.83	6.03	4.50	4.25	4.02
P_2O_5	0.03	0.21	0.03	0.03	0.02	0.04	0.03	0.02	0.09	0.11

thick (greater than 50 m) and fiamme are greater than 5 cm (Figure 4*f*) whereas in the central part of the basin near Umiam Lake, the ignimbrite is less than 10 m thick. Fiamme are developed with whips end and consist of chlorite, feldspar, opaque and quartz as revealed by the BSE image. The phenocrysts were partly rounded and fractured occasionally. Muscovite developed in the groundmass encompassing the feldspar phenocryst. It is in contact with spherulitic lava flow in SW part of the basin and in contact with tuff bed in the central part of the basin.

Epiclastic deposits are exposed along Sohiong road in the SW part of the basin in contact with tuff. It consists of rounded clast of rhyolite and tuff, mud clast, phyllite and quartzite. It is deposited solely by sedimentary process by erosion of volcanic and sedimentary landform and indicate quiescence period between successive eruptions when the sedimentary process dominated over volcanic process[11].

Ten fresh samples of lava flow and scoria from SW and the central part of the basin were collected and analysed for major oxide at the Chemical Lab, GSI, NER by X-ray fluorescence spectrometer. Major oxides were determined on pressed powder pellets in aluminium disc. International references were used for calibration. The obtained geochemical data of felsic volcanics (Table 2) exhibits variable composition in major oxides.

SiO_2 varies from 66.13 to 81.17 wt% in lava flow. This indicates that the bulk of the volcanic materials was derived from rhyolitic to dacitic magmas. TiO_2 varies from 0.27 to 0.7 wt%. The Al_2O_3 content is noticeably high (17.42 wt%) in scoria and Fe_2O_3 is 5.89 wt% in glassy rhyolite. CaO is <1 wt% except two samples with 1.09–2.46 wt% because of secondary calcite Na_2O (0.18–5.47 wt%). Sample number 2 (glassy rhyolite) has comparatively high $K_2O + Na_2O$ and belongs to trachy dacite field in TAS diagram[12] whereas scoria sample belongs to the dacite field and other to rhyolite field. The felsic

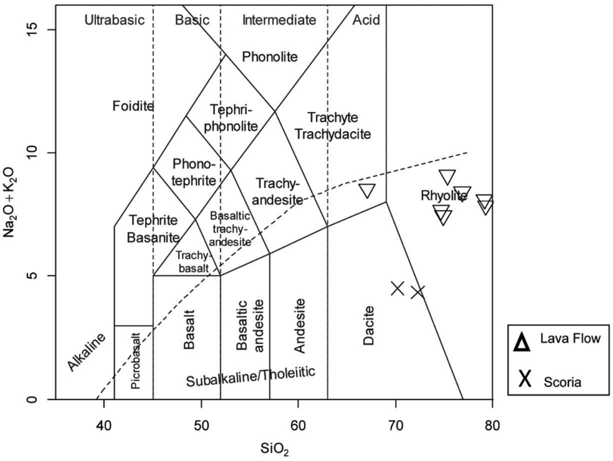

Figure 5. TAS diagram to decipher the major chemical variation of lava flows and scoria of Shillong Group[12].

volcanics dominantly fall in rhyolite and dacite field and only one in the trachy dacite field (Figure 5).

The felsic meta-volcanics of Shillong Group comprises lava flows and pyroclastic deposits. They show compositional variation from rhyolitic to dacitic as well as textural variation from SW to NE part of the present day basin configuration. The porphyritic texture of lava flows indicates two-stage cooling and solidification of magma. The crystals formed during early, slow, subsurface cooling of magma and typically grow as euhedral whole crystal. The resorption texture and embayed boundary indicate disequilibrium between crystals and melts due to change in physical–chemical condition of magma chamber during magma ponding. During rise and eruption of the quartz phenocryst-bearing magma, SiO_2 solubility in the melt increases as the pressure decreases and, as a result, quartz phenocrysts that were initially in equilibrium with the melt are partially resorbed[10]. The round resorption in quartz phenocryst may form by dissolution[10]. Similarly, the resorption of feldspar took place when the pressure increases. The pressure temperature condition and composition of the melt gives rise to feldspar–phyric, porphyritic lava which does not support the growth of quartz phenocryst. The sieve texture in plagioclase phenocryst may be due to rapid decompression[13] or magma mixing. The disparity of development of spherules in spherulitic rhyolite depends upon cooling temperature and solidification rate, presence of any aqueous solution specially alkali-rich solution[14]. The crystal-rich tuff also indicates magma ponding before eruption. Presence of tuff breccias near to the lapilli tuff and glassy rhyolite indicates near vent deposits. Occurrences of lithic tuff with brecciated lithic fragments, crystal tuff with angular and fractured crystal, ignimbrite with fiamme and eutaxitic texture and absence of any hyaloclastite texture suggest for sub-aerial explosive eruption. The porphyritic rhyolite with flow banding in contact with spherulitic and glassy rhyolite indicate different layer of a thick lava flow. Restricted occurrences of scoria in the SW and porphyritic rhyolite in central and NE part of the present day basin at the same stratigraphic horizon may indicate the compositional variation and presence of more than one eruptive centre in the basin.

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