Bulletin of the Geological Society of Malaysia, Volume 72, November 2021, pp. 223 - 232
DOI: https://doi.org/10.7186/bgsm72202118

Petrography and field study of andesitic ignimbrite in Temangan, Kelantan

Nur Shafiqah Shahman[1,2,*], Elvaene James[3], Arham Muchtar Achmad Bahar[3], Muhammad Irfan Hadhi[3], Norazif Anuar[1,2]

[1] Department of Geoscience, Universiti Teknologi PETRONAS (UTP),32610, Seri Iskandar, Perak, Malaysia
[2] Centre of Excellence in Subsurface Seismic Imaging & Hydrocarbon Prediction (CSI), Universiti Teknologi PETRONAS (UTP),32610, Seri Iskandar, Perak, Malaysia
[3] Faculty of Earth Science, Universiti Malaysia Kelantan Kampus Jeli, Locked Bag 100, 17600 Jeli, Kelantan, Malaysia
* Corresponding author email address: nurshafiqah_hafish94@yahoo.com

Abstract: The volcanic rocks in Temangan, Kelantan consist of felsic to intermediate volcanic rocks, that is mainly of pyroclastic with rhyolitic, dacitic, and andesitic tuff. A geological review has been carried out in Kampung Bukit Besi, Temangan, in Kelantan, Malaysia, which is composed of schist, shale, andesite, and ignimbrite. In Temangan, andesite and ignimbrite show an intimate relationship, as the ignimbrite exists as the fragments and andesite as the matrix. The methodology used in this study are petrography and X-ray Diffraction (XRD) analyses, to determine the mineralogical composition of andesitic ignimbrite. Andesite shows aphenitic and porphyritic textures and consist of pyroxene, plagioclase, alkali feldspar, quartz, biotite and iron oxides. A range of plagioclase textures indicate imperfect equilibrium condition from andesite, reflecting plagioclase dissolution and regrowth. The structural analysis suggest that thrust fault occurred in the study area. Andesite and ignimbrite of the two stages are suggested to have derived from the andesite magma eruption which produced pyroclastic flow eruptions in small amount in most caldera volcanoes at high temperature gradient.

Keywords: Andesitic ignimbrite, petrography, Temangan, Kelantan

Abstrak: Batuan gunung berapi di Temangan, Kelantan terdiri dari batuan gunung berapi felsik hingga pertengahan, yang terdiri daripada batuan piroklastik dengan riolit, dasit, dan tuf andesit. Kajian geologi telah dilakukan di Kampung Bukit Besi, Temangan, di Kelantan, Malaysia, yang terdiri dari syis, batuan lempung, andesit, dan ignimbrit. Di Temangan, andesit dan ignimbrit menunjukkan hubung rapat, kerana ignimbrit wujud sebagai fragmen dan andesit sebagai matriks. Metodologi yang digunakan didalam kajian ini ialah kajian petrografi dan sinar-X Difraksi yang digunakan untuk menentukan komposisi mineralogi ciri-ciri ignimbrit andesit. Andesit menunjukkan tekstur afenitik dan porfiritik serta mengandungi komposisi mineralogi seperti piroksen, plagioklas, feldspar alkali, kuarza, biotit dan oksida besi. Pelbagai tekstur plagioklas menunjukkan keadaan keseimbangan yang tidak sempurna daripada andesit, yang mencerminkan pembubaran dan pertumbuhan semula plagioklas. Berdasarkan kepada kajian struktur menunjukkan sesar sungkup terdapat di kasawan kajian. Andesit dan ignimbrit terdiri daripada dua tahap mencadangkan kemungkinan berasal daripada letusan magma andesit yang menghasilkan letusan aliran piroklastik dalam jumlah yang sedikit di kebanyakan gunung berapi kaldera pada kecerunan suhu tinggi.

Kata kunci: Andesit ignimbrit, petrografi, Temangan, Kelantan

INTRODUCTION

In Peninsular Malaysia, andesite distribution is widespread from north Kelantan, through Pahang to Kluang in Johor in the south (Hutchison & Tan, 2009). In Kelantan, the andesite is porphyritic and fine-grained, containing abundant phenocrysts of pyroxene, and rarely feldspar phenocryst, while groundmass is holocrystalline with minerals of feldspar, pyroxene and opaque minerals (MacDonald, 1967). Andesite from the Temangan area is a dark green, medium to large grained porphyritic rock, with plagioclase, pyroxene and hornblende phenocrysts (Minerals and Geoscience Department Malaysia, 2015). The SiO_2 content in andesite of Temangan is more than 52 wt. %. Further, the andesite of Temangan features ignimbrite characteristics. Ignimbrite is unconsolidated or consolidated (cemented) deposits of pyroclastic flows (Sparks *et al*., 1973; Williams & McBirney, 1979), and most ignimbrite deposits resulted from ash flow and pumice flow of gas-rich evolved materials. Ignimbrite must contain more than 75% by volume of pyroclasts, with the remaining materials generally being of epiclastic, organic, chemical sedimentary or authigenic origin. The majority of pyroclastic rocks are polymodal and classified according to the proportion of their pyroclasts size (Fisher, 1966; Schmid, 1981). Ignimbrite is formed due to the emplacement of high-temperature pyroclastics flows that compacted their weight. Exsolution of volatiles from

0126-6187; 2637-109X / Published by the Geological Society of Malaysia.

pyroclasts after emplacement can cause alteration of the surrounding groundmass and generate vesicles. Rheomorphic flow of ignimbrites can occur after emplacement resulting in deformation of layerings, clasts and vesicles. Normally, ignimbrite formed through the column collapse mechanism, which means by an explosive eruption process (Branney *et al*., 2002). Volcanoclastic rocks or pyroclastic deposits can be divided into three types, which are as fragments of new lava, individual crystals, and lithic fragments. The fragments of new lava range between solid un-vesiculated material to fragments of highly vesiculated lava, with individual crystals present as phenocrysts or lithic fragments (older rocks in the deposit) (Jerram & Petford, 2011). Many research on pyroclastic flow has realized that pyroclastics fragments are mixed with other types of fragments. Fragments are generated by disruption as a direct result of volcanic action and can be individual crystals, or crystal, glass, or rock fragments (Fisher & Schmincke, 1984). According to Fisher & Schmichke (1984), their shapes that were acquired during a disruption or subsequent transportation to the primary deposit must not have been altered by later re-depositional processes. If the fragments have been altered, they are called reworked pyroclasts, and epiclasts if their pyroclastic origin is uncertain. The various types of pyroclasts are mainly distinguished by their size (Table 1). In Temangan, andesite and ignimbrite show an intimate relationship, as the ignimbrite exists as the fragments and andesite as the matrix. Based on Robin *et al*. (1994), less acidic (andesitic) pyroclastic flow is a common feature of andesitic volcanoes, but they generally involve less amount of magma. Therefore, it is uncommon for ignimbrite to have andesitic rocks in its pyroclastic flow and the combination of ignimbrite and andesite may occur if the andesitic ignimbrite was formed through column collapse mechanism. This study presents a discussion on the mineralogy of andesite and ignimbrite, the eruptive mechanism characteristics and, their deposits in the Temangan area.

Table 1: Types of pyroclasts and their characteristics.

Bomb	Pyroclasts the mean diameter of which exceeds 64 mm and whose shape or surface indicates that they were in a wholly or partly molten condition during their formation and subsequent transport.	Schmid, 1981
Block	Diameter of which exceed 64 mm and which angular to sub-angular shape indicates that they were solid during their formation.	Schmid, 1981
Lapilli	Pyroclasts of any shape with a mean diameter of 64 mm to 2 mm.	Blatt *et al*., 2006
Ash	Pyroclasts with a mean diameter of less than 2 mm. They may be further divided into coarse ash grains (2 mm to 1/16 mm) and fine ash (dust) grains (less than 1/16 mm).	Blatt *et al*., 2006

GEOLOGICAL AND TECTONIC SETTING BACKGROUND

Peninsular Malaysia forms an integral part of the Southeast Asian continental core of Sundaland and comprises two tectonic blocks, the Sibumasu Block in the west and Sukhothai arc (Indochina Block) at the east. The age of the Sukhothai arc is the same as Sibumasu Terrane that is Paleo-proterozoic, with the age being 1.9 to 2.0 Ga (Metcalfe, 2013). The collision between two continental plates i.e. Sibumasu and Indochina has lead to the formation of the Bentong-Raub Suture Zone which is striking across the mid-line of Peninsular Malaysia that stretches northward across the Thailand-Burma border. Scrivenor (1928) suggested that Peninsular Malaysia is divided into three zones, which are the western, central, and eastern zones (Figure 1), based on differences in mineralization styles. The central zone consists of four facies, which are argillaceous, volcanic, calcareous, and arenaceous (Nazaruddin *et al*., 2015). In general, the area is overlain to a large extent by Permian-Triassic clastic volcanic and limestones (Khoo & Tan, 1983). The oldest rocks comprising of schists and phyllite with Devonian fossils (Jaafar, 1976) are restricted to the western margin of this Central belt. The sedimentation is associated with acid to basic volcanic and interbedded tuffs and, pyroclastics are common occurrences. In the Central Belt, significant acidic to intermediate volcanism compositions occurred in the Permian and Triassic marine sediments. After the cratonization of Peninsular Malaysia, volcanic activities continued to manifest in the Late Mesozoic, Early Tertiary and Pleistocene (Khoo & Tan, 1983). The largest tract of regional metamorphic rocks in the Central Belt is the Taku Shist in north Kelantan.

Temangan is located in the north-west part of Kelantan and underlain by metamorphic rocks comprising the Taku Shist, as well as igneous rocks (Figure 1). The Temangan area consists of Taku Schist, Telong Formation, Temangan Ignimbrite, and alluvium deposit. The size of Taku Schist is 80 km long and 8 to 22 km wide from the Thailand border near Tanah Merah to the central east Kelantan. It consists of quartz mica schists and quartz-mica-garnet schists (Yee, 1983). According to Khoo & Lim (1983), the age of Taku Schist is uncertain and not younger than Upper Triassic. Taku Schist is characterized by a simple asymmetric structure where the lower grade overlying rock is isoclinal folded (Hutchison, 1973). The Taku Schist terrain is not known to contain marble and metamorphosed acid volcanics (Khoo & Tan, 1983). The overlying rocks which are unmetamorphosed in the metamorphic event had occurred, attained the garnet grade on Taku Shist.

Based on MacDonald (1967), ore bodies lie along the north-south contact line; with the Taku Shists Formation on

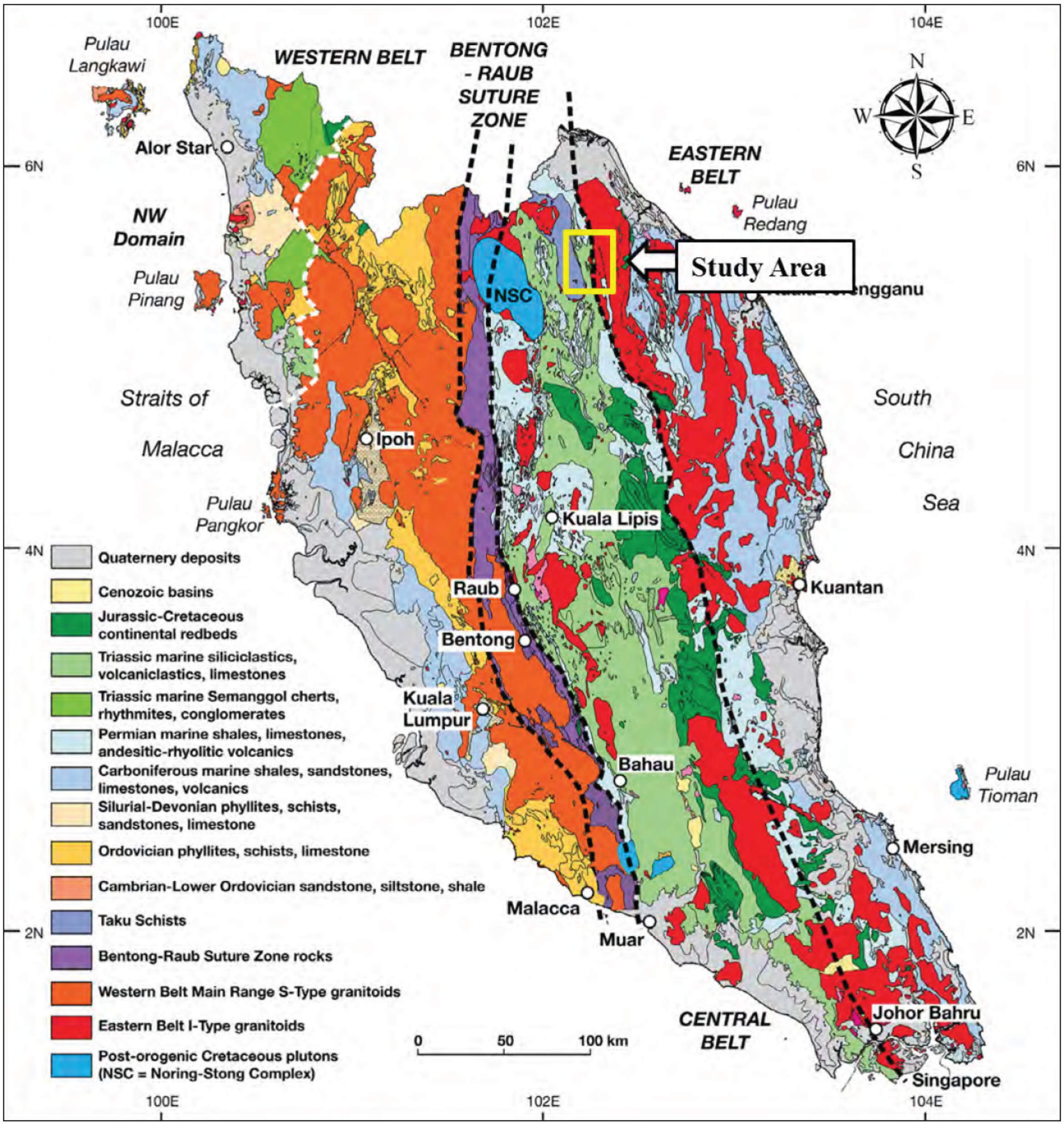

Figure 1: Simplified geological map of the Malay Peninsula, modified after Metcalfe (2013).

the west and, overlain by shale on the east. The Temangan Ignimbrite forms a prominent ridge trending approximately north-south in central Kelantan (Aw, 1967). The contact brecciation of the shale between shale and schists indicates a possible fault contact at Temangan iron-mine. The foliation of the metamorphic rocks in both Taku Schists and the adjacent low grade metamorphic rocks is found to be in concordant with the bedding and foliation that have not encountered (MacDonald, 1967). The ignimbrite bodies are exposed in Temangan, Kelantan (Figure 2). The geological structures found in Temangan are joints and faults. The fault occurs at the quartz-porphyry dyke which is located at the south end of Temangan (MacDonald, 1967). Existance of quartz-porphyry dyke is noted at the east of the Temangan deposit because of the hydrothermal solution is probably to be found in the magmatic deposit, so that the iron ore are interval along the length of the dyke where the dyke reached at maximum width (Bean, 1969). In south Temangan, the fault has exposed the quartz-porphyry dyke (MacDonald, 1967) that reached maximum width. Iron ores is present at intervals along the length of the dyke, as a result of the hydrothermal solution (Bean, 1969). The dyke is dominantly porphyritic with quartz and feldspar phenocrysts in a felsitic matrix. The contact between schist and shale in the Temangan iron mine exposed irregular weathered tuff (Khoo & Lim, 1983). The sedimentary rocks were deposited during Permian to Triassic. The Permian Taku Schist is conformably overlain by the Triassic Telong Formation.

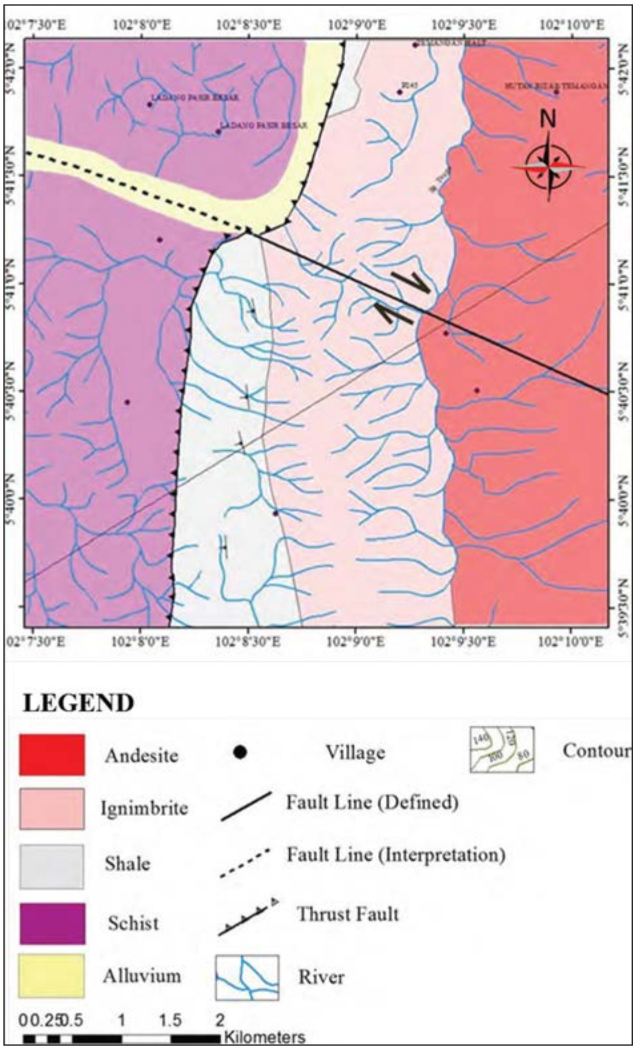

Figure 2: Geological Map of Kampung Bukit Besi, Temangan, Kelantan.

The study area is dominated by schist that consists predominantly of quartz-mica schist. The andesite located at the south-west of Temangan is approximately 50 m long and 10 m high, while the coordinate is 05°42'30.1" N, 102°09'56.4" E.

METHODOLOGY

The methodology can be divided into two parts which are geological mapping and petrographic analysis. The geological mapping involved structure geology, geomorphological mapping, and stratigraphy. In the second part, X-Ray Diffraction (XRD) analysis was carried out to estimate the relative mineral phase composition of rock types and the result was interpreted using Diffrac.EVA software.

PETROGRAPHIC ANALYSIS

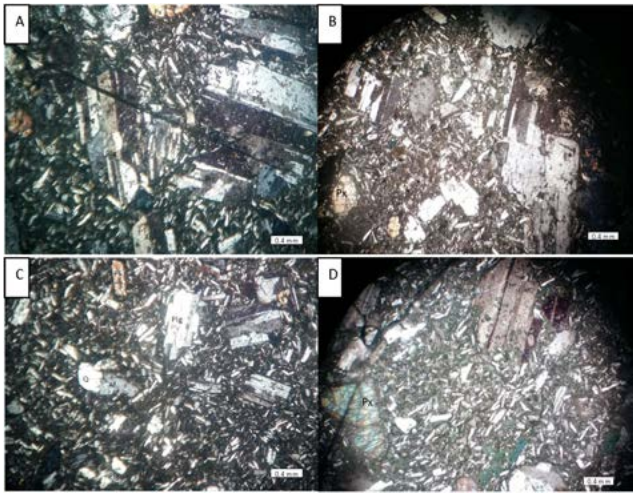

Figure 3: Photomicrographs showing the characteristic of the andesite (A) porphyritic texture and composed of pyroxene, plagioclase and alkali feldspar. The groundmass (aphanitic) is composed of mainly lath shaped plagioclase feldspar and minor quartz phenocrysts, (B) texture of matrix are aphanitic and porphyritic, pyroxene phenocryst showing brownish colour, (C) plagioclase phenocryst showing albite twinning, and (D) pyroxene phenocryst showing bluish colour, (Plg = plagioclase, Px = pyroxene, Q= Quartz, A = Alkali Feldspar)

The andesite shows porphyritic and hypocrystalline textures, and is composed of clinopyroxene, orthopyroxene, hornblende, plagioclase, and quartz phenocrysts (Figure 3A). Meanwhile, the groundmass is composed mainly of lath shaped plagioclase, quartz, and iron oxides minerals. Clinopyroxene shows light brownish to dark brown color twins, and cleavage intersects near 90˚ (Figure 3B). Higher Fe contents correspond to a darker color in orthopyroxene. Quartz phenocrysts are greyish and mostly subhedral. Plagioclase phenocrysts occur as euhedral tabular laths up to 0.5 mm in size and have twinning. The size of the pyroxene phenocrysts is smaller and up to 0.2 mm. Ignimbrite meanwhile consists of alkali feldspar and quartz phenocrysts, while the groundmass is made up of quartz, alkali feldspar, biotite, muscovite and iron oxides (Figure 4A, 4B, and 4C). The ignimbrite has aphanitic and porphyritic textures, with very fine matrix. Quartz is colourless under plane-polarized light (PPL) and subhedral. The size of the quartz phenocryst range from 0.1 mm to 0.3 mm. Quartz also shows an irregular and wavy extinction. Amygdules and embayment textures were observed in the quartz. The embayment is related to fractures in the crystal, where the atoms are more loosely bonded than in the crystal when the fracture began to dissolute. The embayment in quartz may be growth features. Biotite, muscovite, and iron oxides occurrences are very small, less than 2 percent (Vernon, 2004).

X-RAY DIFFRACTION

X-ray diffraction (XRD) analysis shows the mineral compositions of andesite and ignimbrite. The graph for sample 1 andesite (Figure 5a) shows the higher peak of

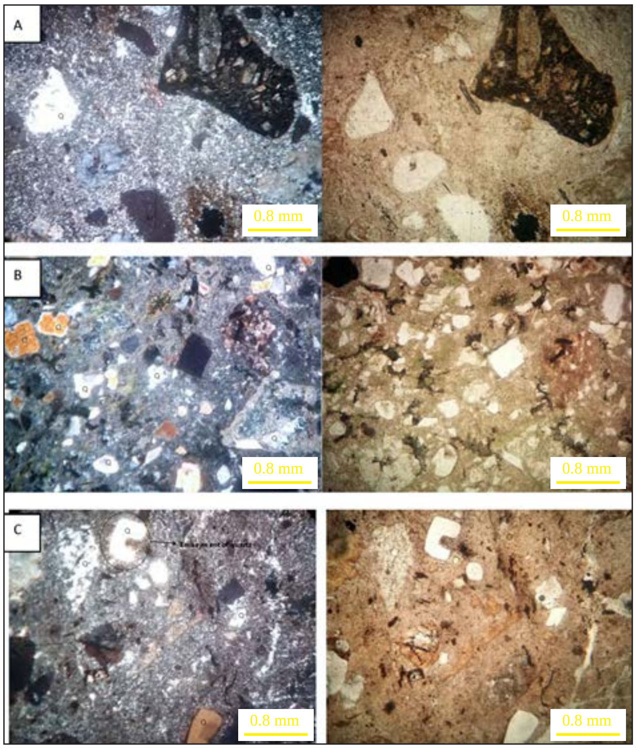

Figure 4: Photomicrographs showing the characteristics of ignimbrite (A), (B), (C) the texture of rock in thin section is aphanitic and porphyritic. The phenocrysts are alkali feldspar, plagioclase, quartz and sericite, the groundmass consists of quartz, alkali feldspar, biotite and heavy minerals (Q = quartz, Af = alkali feldspar, Plg = plagioclase, Ser = sericite).

percentage is albite at 55.71% and followed by pyroxene at 46.16%. Graph for sample 2 and sample 3 andesite (Figure 5b and 5c) shows a higher peak of quartz with 84.61% and 17.88%, respectively. For samples 1 and 2 ignimbrites (Figures 5d and 5e), the high peak contains quartz at 27.44% and 65.58%, respectively. Figure 5f also shows the higher peak is the quartz mineral at 65.58%. Ignimbrite also contains berlinite mineral.

STRUCTURAL ANALYSIS

The study area is mostly under forestation. The highest elevation is 300 m which is at the north-east while the lowest elevation is 20 m in the north-west and south-west parts of the study area. The drainage pattern (Figure 6) includes dendritic, radial, and rectangular patterns. A dendritic pattern is characterized by irregular branching of tributary streams in all directions. Duggal & Burrett (2010) mentioned that the dendritic pattern is characteristic of essentially flat-lying valleys where the river and its water channels flow between ridges, resulting in a pattern that appear like a tree and its branches. A radial pattern develops around a central elevated point where the water flows from a high point to low point of elevation contours (Howard, 1967). Additionally, the rectangular pattern has rivers with right-angle bends and forms when the bedrock is jointed or faulted (Zhang & Guilbert, 2012). Watershed is an area or ridge of land that separates the water which are flowing to different rivers, basins, or seas and represents all the stream tributaries that flow along the stream channel. In the study area, the

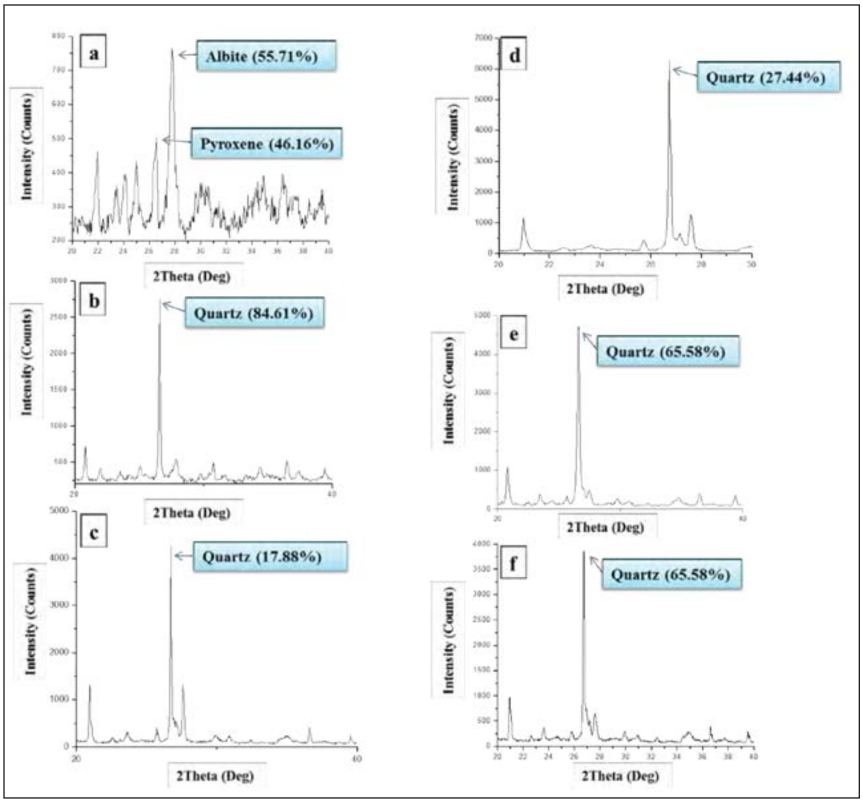

Figure 5: Results of XRD analysis for andesite samples (left), (a) the higher peak of percentage is albite at 55.71% and followed by pyroxene at 46.16%, (b) and (c) show higher peak of quartz at 84.61% and 17.88%, respectively. Results of XRD analysis for ignimbrite (right), (d) and (e) the high peak contains quartz is 27.44% and 65.58%, respectively, (f) the higher peak is the quartz mineral at 65.58%.

watershed has three different parts, which are A, B, and C which indicates different drainage patterns (Figure 6). The lineament, joint and fault analysis suggest that thrust fault occurred in the study area. The observed joint sets (Figure 7) are conjugate joints for dihedral angles from 30° to 60°. The forces which acted upon the joint areas were mainly from the north and south directions, while the tensions were from the east and west directions. Based on the rose diagram analysis (Figure 7), the principle forces is from the north-east (N12.5°E), and the lowest force comes from the north-west (N282.5°W). The conjugate joint is closely associated with a fault zone. Fault (Figure 8a) occurs as a minor fault (95°/86°). Slickenside (Figure 8b; 95°/86°) corresponds as a fault indicator, where it occured along the shear zone when two bodies of rock rub against each other, and made their surfaces smooth and lineated. The stereonet (Figure 8c) shows the trend and plunge of the σ1 is 004°/64°, σ2 is 276°/86° and, σ3 is 184°/26°. Schist occurs at the north-west due to the thrust fault and is the oldest unit followed by shale and andesite of late Triassic to Permian, while the youngest is the ignimbrite of Late Permian that is an intrusion, as a dyke porphyry (Aw, 1967) (Figure 2). The Temangan area was deformed by minor folds drag, and the folds were a result of the deformation of the rock which produced dextral faults and joints trending north-west and south-west.

DISCUSSION

The features of andesite rocks show porphyritic texture, and the existence of phenocrysts assemblages is dominated by pyroxene and visible crystal floating in a fined grained groundmass dominated by plagioclase. The pyroxene indicates that the crystals sustained in andesite in equilibrium with melts that the compositionally different from the

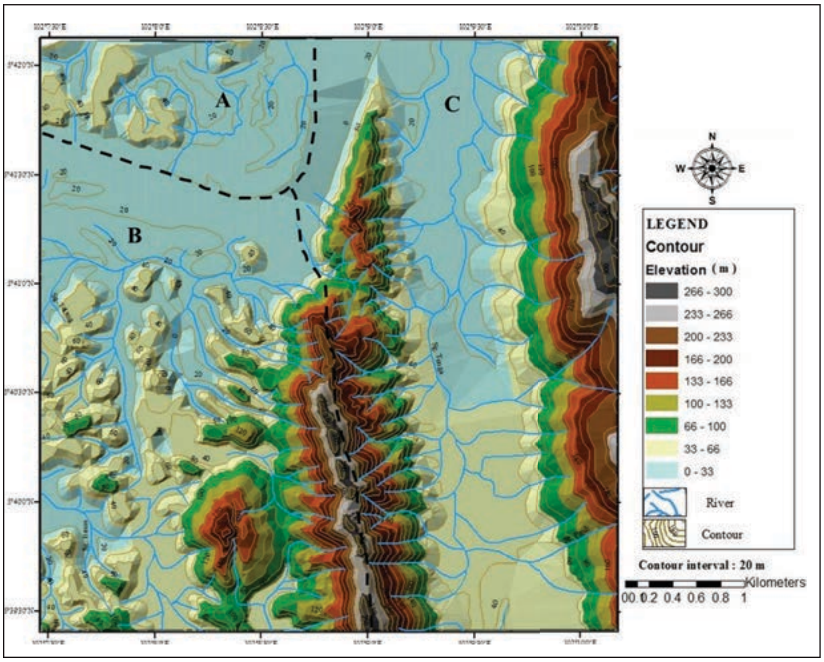

Figure 6: 3D drainage patterns of Kampung Bukit Besi, Temangan which include (i) a dendritic pattern, (ii) a radial pattern, (iii) a rectangular pattern. The watershed (A, B and C) is divided into three different parts according to drainage flow patterns.

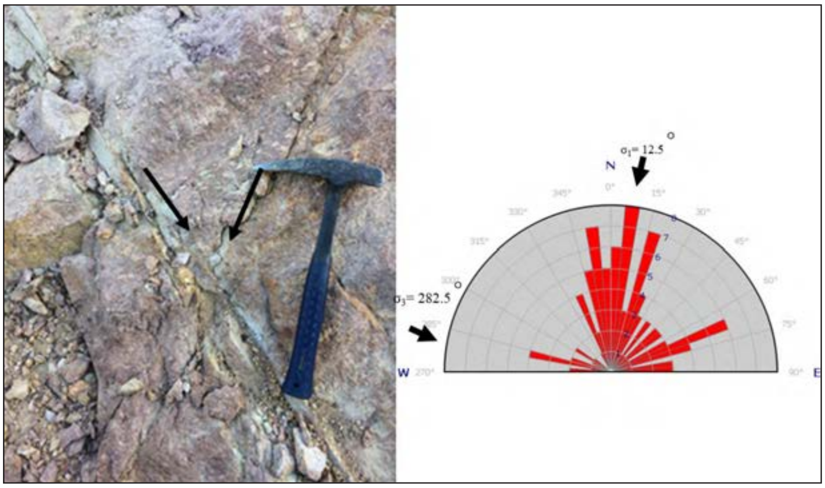

Figure 7: Conjugate joint (102° 09' 10.25" E, 05° 39' 31.4" N) (left) and rose diagram for conjugate joint (right).

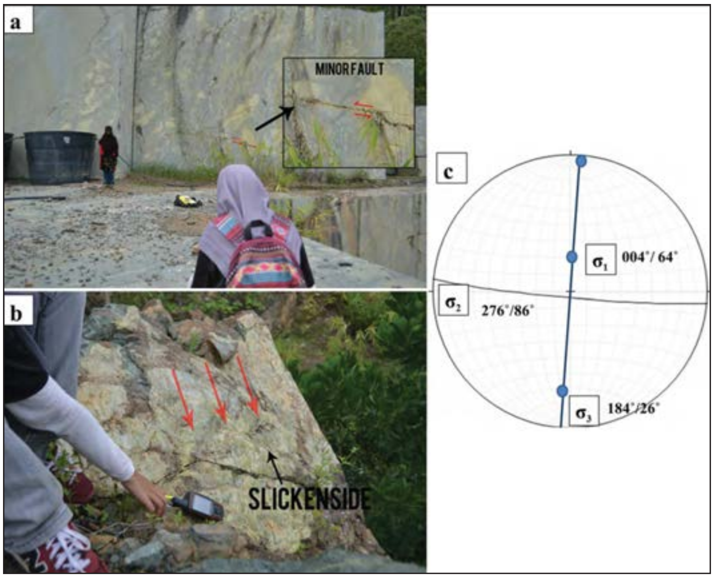

Figure 8: (a) Fault within andesite, (b) existence of slickenside as a fault indicator, (c) the stereonet of faults plane by trend and plunge.

groundmass (Price *et al.*, 2012). When the plagioclase undergoes a crystallisation process, the plagioclase minerals will migrate between variable mixed mafic and felsic conditions (Słaby & Martin, 2008). According to Gill (2010), andesite has lower liquidus and solidus temperatures which allows hydrous mafic minerals such as hornblende to crystallise in place of pyroxene. Ignimbrite has a higher viscosity and melts more polymerised high amount of SiO_2 contents than andesite, as more silicic lavas tend to be more viscous (Winter, 2014). The crystal habit of plagioclase is lath shaped, showing the decrease of size with decreasing temperature and late plagioclase microlites related to quenching crystallisation (Nandedkar *et al.*, 2014).

The process of crystal cooling rate depends on the diffusion rate in the magma melt, as diffusion for more siliceous melts is much slower than poor siliceous melt (Gill, 2010). Due to the abundant amount of silica, the cooling process will continue at different reactions with different discontinuous divisions. Referring to Bowen (1928), these illustrated processes lead to increasingly sodium-rich plagioclase, and ultimately a form of quartz and potassium feldspars. The behaviour of intermediate magma in the cooling process lies in between felsic and mafic magmas, showing the composition of the magma near the top magma chamber will turn to more felsic. According to Melekhova *et al*. (2013), the crustal magmatic processes are associated with equilibrium, fractional crystallisation, assimilation, and mixing to form the more silicic magma, while mafic magmas tend to involve mingling with magma by the regeneration of magma bodies (Bateman, 1995). As it tends to lose some iron and magnesium-rich segments, instead of that, if the process change to the melting point, the crystal settling at the bottom chamber will make a more mafic magma. Vice versa, crystal settling does not change due to high viscosity. Then the process of cooling will continue by Bowen series reaction series. The cooled liquid magma with embedded crystals will flow farther up into the cooler part of the crust until the surface during volcanic eruptions (Bowen, 1928). Sequences in which phenocrysts emerge and change to their relative fraction in a sequence of intermediate to pyroclastics demonstrate thrive fractional crystallisation. This occurs in large magma chambers that become stable and remain at a fixed depth in the crust (Nandedkar *et al*., 2014). Crystallisation at depth under such thermodynamic conditions results from cooling, and the leakage of magma to the feed the surface eruptions will generate lavas with showing obviously distinction in grain size between phenocryst and groundmass (Gill, 2010). Likewise, andesite to those intermediate in composition between mafic and felsic rocks is the calc-alkaline magma series (Kuno, 1968).

The mixing at the different phenocryst compositions can lead to a step in the crystallisation of mineral composition by assuming that the condition for crystal growth is well maintained (Cassidy *et al*., 2015). If the phenocryst in the magma does not have to undergo sufficient undercooling up to mixing with more silicic magma, at this point, the eruption could occur before an isothermal period of crystal growth which could trap intermediate melt inclusion (Koleszar *et al*., 2012).

The porphyritic texture is regarded as a result of the stage during the cooling of magma rapidly changing conditions. When the crystallisation magma process below in the volcano has erupted before completing the crystallisation, the remaining lava force crystallisation more rapidly, which produces smaller crystal size. The earlier formed minerals started growing and formed slowly to produce large crystals known as phenocryst. The remaining melts that have undergone rapid cooling will produce fine-grained minerals which form the aphanitic texture when crystallisation is complete. Meanwhile, those crystals undergoing slow cooling will produce large sizes. When the eruptions magma occurs as a lava flow, it may cause the texture to produce a large crystal embedded in a fine-grained matrix. In general, preceded by andesite magma eruption automatically produced pyroclastic-flow eruptions in small volume in most caldera volcanoes. The high-temperature gradient of the process will involve melting of the lower temperature at least about 1000 °C (Kuno, 1968).

Based on fieldwork and petrography analyses, the pyroclastic rock shows the relationship between the fragments of the ignimbrite and andesite matrix are tightly bound together while indicating the fining upward beds (Figure 9a), which indicate the volcanic fragments were carried by the turbulence, resulting in the existence of the fragments in the rock. Fragments were still plastic in the early formation stage and tend to be more compact and tightly bound together. Load cast (Figure 9b) shows the syn-depositional of pyroclastic flow in different eruptions. The minor shear zone does not uniformly deposit. Ignimbrite formed from the pyroclastic deposit that contains fragmented materials (Figure 9c). The deposition mode of pyroclastic can be either pyroclastic falls (Mansfield & Ross, 1935) or pyroclastic flows (Marshall, 1935; Fenner, 1948). Normally, ignimbrite is formed through a column collapse mechanism (explosive eruption) and welded tuff (Branney & Kokelaar, 2002). The previous study by Hamzah & Hamzah (2014) indicates that ignimbrite consists of phenocrysts that vary in size and shape. Most of the phenocrysts formed in sharp crystalise and the fragmented rocks have a coarse size, while the dark particles show that ignimbrite consists of metasediment and pumice material and looks like tuff in hand specimen (Hamzah & Hamzah, 2014). The outcrop in the study area resembles the andesite ignimbrite showing ignimbrite as fragments and andesite as its matrix. Fresh crystalline shows the shape boundaries and consists of inclusions of silica materials. The fragments of the ignimbrite are composed of fine silica material, possibly from slate that had undergone recrystallisation. The ignimbrite is characterised by subhedral to euhedral quartz phenocrysts, which is also an essential constituent of the groundmass. Quartz and feldspar are observed in a fine matrix. According to Cox *et al.* (1979), when andesites are much higher in silica and are highly porphyritic, the phenocryst being strongly and complex zoned plagioclase that generally has very calcic cores and andesine rims are very common as a result of imperfect equilibrium during cooling. X-ray diffraction measurements showed that the ignimbrite contains maximum microline, indicating slow cooling at depth (Liew, 1977). The occurence of slow cooling can describe the ignimbrite as intrusive (Aw, 1967). Despite that, andesite as an extrusive rock has the composition of ignimbrite (Aw, 1964, 1967) (Figure 9d), and the age of ignimbrite is Triassic (The Malaysian and Thai Working Groups, 2006).

CONCLUSION

The textures and structures of andesite and ignimbrite support the interpretation that it was emplaced as andesitic ignimbrite. The porphyritic texture of andesite in Temangan is widely ascribed to the effects of a period of slow cooling during which the phenocrysts grew, followed by a period of rapid cooling during which the groundmass crystallized. The presence of the ignimbrite features formed in andesite and the pumices material in ignimbrite indicates a pyroclastics flow mechanism.

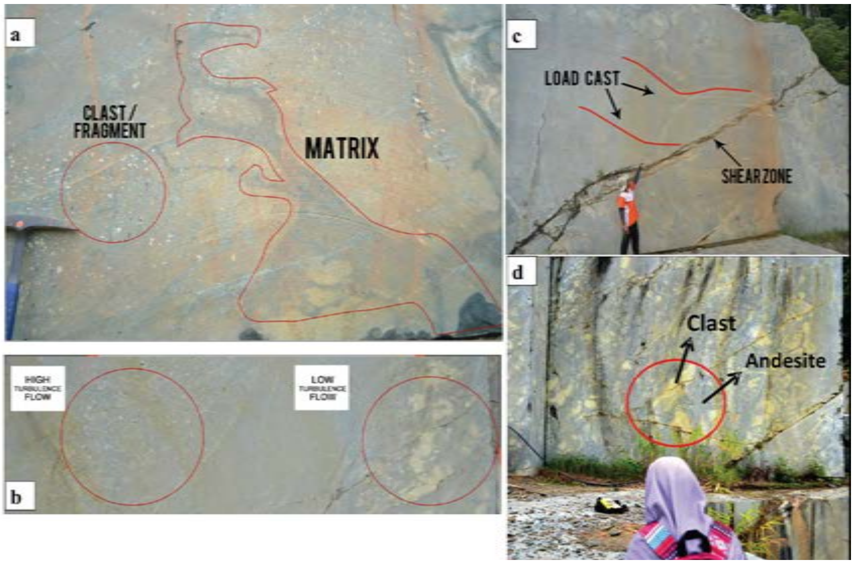

Figure 9: (a) Matrix and clast or fragments (b) the turbulance flow pattern on surface of outcrop, (c) pyroclastic outcrop, and (d) pattern of pyroclastic flow.

ACKNOWLEDGEMENTS

The authors acknowledge numerous friends in the Geoscience courses who have provided us with opportunities for the involvement in various geology projects. We also would like to thank the Faculty of Earth Sciences, Universiti Malaysia Kelantan (UMK), and coursemates for supporting the fieldwork and literature search. Thanks to the two anonymous reviewers for constructive comments which helped to improve the quality of the manuscript.

AUTHOR CONTRIBUTIONS

NSS formulated the study, carried out geological mapping and data collection, analysed, interpreted the results and wrote the paper. EJ analysed and interpreted the petrography results and helped to draft the manuscript. AMAB and MIH helped in geological mapping, structural analysis and data collection. NA helped in draft manuscript preparation. All authors reviewed the results and approved the final manuscript.

CONFLICT OF INTEREST

The authors have no conflicts of interest to declare that are relevant to the content of this article.

REFERENCES

Aw, P.C., 1964. The geology of the Temangan-Sokor area, Kelantan. Tesis B.Sc (Hons). Jabatan Geologi Universiti Malaya (tidak diterbitkan).

Aw, P.C., 1967. Ignimbrite in Central Kelantan, Malaya. Geological Magazine, 104(1), 13–17.

Bateman, R., 1995. The interplay between crystallization, replenishment and hybridization in large felsic magma chambers. Earth Science Reviews, 39(1-2), 91-106.

Bean, J.H., 1969. Geology of the Bukit Besi ore-deposits. West Malaysia. Geological Survey Headquarters, Jabatan Chetak Kerajaan, Ipoh. 194 p.

Blatt, H., Tracy, R.J. & Owens, B.E., 2006. Petrology : igneous, sedimentary, and metamorphic (3rd Edition). W.H. Freeman and Company, United States of America. 530 p.

Bowen, N.L., 1928. The Evolution of The Igneous Rocks. Princeton University Press, Princeton. 334 p.

Branney, M.J., Kokelaar, P. & Kokelaar, B.P., 2002. Pyroclastic Density Currents and the Sedimentation of Ignimbrites. Geological Society London, 27, 7-8.

Cassidy, M., Edmonds, M., Watt, S.F.L., Palmer, M.R. & Gernon, T.M., 2015. Origin of basalts by hybridization in andesite-dominated arcs. Journal of Petrology, 56(2), 325-346.

Cox, K.G., Bell, J.D. & Pankhurst, R.J., 1979. The Interpretation of Igneous Rocks. Springer, Dordrecht, 176-196.

Duggal, G. & Burrett, P., 2010. Geography. Dorling Kindersley, New Delhi. 9 p.

Fenner, C.N., 1948. Incandescent Tuff Flows in Southern Peru. Geological Society of America Bulletin, 59(9), 879 p.

Fisher, R.V., 1966. Rocks composed of volcanic fragments and their classification. Earth-Science Reviews, 1, 287-298.

Fisher, R.V. & Schmincke, H., 1984. Pryroclastic rocks (illustrate). Springer Science & Business Media, Berlin, New York. 472 p.

Gill, R., 2010. Igneous Rocks and Processes: A Practice Guide. Wiley-Blackwell, Chichester. 448 p.

Hamzah, A.H. & Hamzah, M., 2014. Geologi dan sumber mineral kawasan Tanah Merah, Kelantan (Laporan peta 25). Jabatan Mineral dan Geosains Malaysia, Kementerian Sumber Asli dan Alam Sekitar Malaysia, Kuala Lumpur. 71 p.

Howard, D., 1967. Drainage Analysis in Geologic Interpretation: A Summation. The American Association of Petroleum Geologists Bulletin, 51, 2259 p.

Hutchison, C.S., 1973. Metamorphism. Geology of the Malay Peninsula. Wiley-Interscience, New York, 253-303.

Hutchison, C.S. & Tan, D.N.K., 2009. Geology of Peninsular Malaysia. Published jointly by the University of Malaya (and) the Geological Society of Malaysia, Kuala Lumpur. 479 p.

Jaafar, A., 1976. Geology and mineral resources of the Karak and Temerloh areas, Pahang. Mem. Geological Survey Malaysia, 15, Malaysia. 138 p.

Jerram, D. & Petford, N., 2011. The field description of igneous rocks. John Wiley & Sons, West Sussex, UK. 256 p.

Khoo, T.T. & Lim, S.P., 1983. Nature of the contact between the Taku Schist and adjacent rocks in the Manek Urai area, Kelantan and its implications. Bulletin of the Geological Society of Malaysia, 16(12), 139-158.

Khoo, T.T. & Tan, B.K., 1983. Geological Evolution of Peninsular Malaysia. Workshop on Stratigraphic Correlation of Thailand and Malaysia, 253-290.

Koleszar, A.M., Kent, A.J.R., Wallace, P.J. & Scott, W E., 2012. Controls on long-term low explosivity at andesitic arc volcanoes: Insights from Mount Hood, Oregon. Journal of Volcanology and Geothermal Research, 219–220, 1–14.

Kuno, H., 1968. Origin of andesite and its bearing on the Island arc structure. Bulletin Volcanologique, 32(1), 141-176.

Le Maitre, R.W., 2002. Igneous Rocks : A Classification and Glossary of Term. In Recommendations of the IUGS subcomissions on the Systematics of Igneous Rocks (2nd Editio). Cambridge: Cambridge University Press, 30-39.

Liew, T.C., 1977. Petrology and structural relationship of rhyolitic rocks and microgranodiorite east of Genting Sempah, Pahang. Unpubl. BSc thesis, University Malaya.

MacDonald, S., 1967. The Geology and Mineral Resources of North Kelantan and North Terengganu. Geological Survey Headquarters, West Malaysia. 202 p.

Mansfield, G.R. & Ross, C.S., 1935. Welded rhyolitic tuffs in southeastern Idaho. Transactions, American Geophysical Union, 16(1), 308 p.

Marshall, P., 1935. Acid rocks of the Taupo-Rotorua volcanic district. Trans. Roy. Soc., NZ, 64, 323-366.

Melekhova, E., Annen, C. & Blundy, J., 2013. Compositional gaps in igneous rock suites controlled by magma system heat and water content. Nature Geoscience, 6(5), 385-390.

Metcalfe, I., 2013. Tectonic evolution of the Malay Peninsula. Journal of Asian Earth Sciences, 76, 195-213.

Minerals and Geoscience Department Malaysia, 2015. A Glimpse of the Geodiversity of Malaysia: Rocks, Minerals and Fossils, 21-22.

Nandedkar, R.H., Ulmer, P. & Müntener, O., 2014. Fractional crystallization of primitive, hydrous arc magmas: An experimental study at 0.7 GPa. Contributions to Mineralogy and Petrology, 167(6), 1-27.

Nazaruddin, D.A., Fadilah, N.S. & Zulkarnain, Z., 2015. Geological review of the rafflesia trail, near Kampung Jedip, Lojing highlands: inputs for a nature-based tourism site in Kelantan, Malaysia. Journal of Tropical Resources and Sustainable Science, 3(1), 86-97.

Price, R.C., Gamble, J.A., Smith, I.E.M., Maas, R., Waight, T., Stewart, R.B. & Woodhead, J., 2012. The anatomy of an andesite volcano: A time-stratigraphic study of andesite petrogenesis and crustal evolution at Ruapehu Volcano, New Zealand. Journal of Petrology, 53(10), 2139-2189.

Robin, C., Eissen, J.-P. & Monzier, M., 1994. Ignimbrites of basaltic andesite and andesite compositions from Tanna, New Hebrides Arc. Bulletin of Volcanology, 56(1), 10-22.

Schmid, R., 1981. Descriptive nomenclature and classification of pyroclastic deposits and fragments - Recommendations of the IUGS Subcommission on the Systematics of Igneous Rocks. Geologische Rundschau, 70(2), 794-799.

Scrivenor, J, 1928. Mines and Mineral Resources-Malaya Geology. Macmillan, London. 216 p.

Słaby, E. & Martin, H., 2008. Mafic and felsic magma interaction in granites: The Hercynian Karkonosze pluton (Sudetes, Bohemian Massif). Journal of Petrology, 49(2), 353-391.

Sparks, R.S.J., Self, S. & Walker, G.P.L., 1973. Products of ignimbrite eruptions. Geology, 1(3), 115-118.

The Malaysian and Thai Working Group, 2006. Geology of the Batu Melintang-Sungai Kolok Transect Area Along the Malaysia – Thailand Border. The Malaysia-Thailand Border Joint Geological Survey Committe (MT-JGSC), 6, 7-71.

Vernon, R.H., 2004. A Practical Guide to Rock Microstructure. The Press-Syndicate of the University of Cambridge, New York, 13-37.

Wilkinson, J.F.G., 1986. Classification and average chemical compositions of common basalts and andesites. Journal of Petrology, 27(1), 31-62.

Williams, H. & McBirney, A.R., 1979. Volcanology. Freeman, Cooper, San Francisco. 391 p.

Winter, J.D., 2014. Principles of Igneous and Metamorphic Petrology. Pearson Education Limited, Harlow. 739 p.

Wright, J.V., & Walker, G.P.L., 1981. Eruption, transport and deposition of ignimbrite: A case study from Mexico. Journal of Volcanology and Geothermal Research, 9(2–3), 111-131.

Yee, F.K., 1983. The Palaeozoic Sedimentary Rocks of Correlation of Thailand and Malaysia-Stratigraphy and Correlation. Warta Geologi, 9(9-10), 5.

Young, D.A., 2003. Mind over Magma: The Story of Igneous Petrology. Princeton University Press, 100p.

Zhang, L. & Guilbert, E., 2012. A Study of Variables Characterizing Drainage Patterns in River Networks. ISPRS - International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XXXIX-B2 (September), 29-34.

Manuscript received 29 December 2019;
Received in revised form 2 November 2020;
Accepted 9 November 2020
Available online 16 November 2021