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THE GENESIS OF VOLCANIC SANDSTONES ASSOCIATED WITH BASALTIC PILLOW LAVAS : A CASE STUDY AT THE JIWO HILLS, BAYAT AREA (KLATEN-CENTRAL JAVA)

S. Bronto *), *S. Pambudi* **), *G. Hartono* **) *and D. Purwanto* **)

SARI

Asosiasi batupasir gunungapi, lava bantal basalt dan batuan sedimen gampingan tersingkap baik di perbukitan Jiwo dan kaki utara Pegunungan Selatan, Klaten-Jawa Tengah. Batuan tersebut termasuk Formasi Kebo-Butak (Surono drr., 1992; Samudra & Sutisna, 1997). Penyelidik terdahulu (missal, Rahardjo, 1983; Suryono & Setyowiyoto, 2001) menyatakan bahwa batupasir gunungapi itu merupakan bagian endapan turbidit yang diendapkan di lingkungan kipas bawah laut. Batupasir gunungapi itu berasosiasi dengan lava bantal berkomposisi basalt berwarna abu-abu gelap sampai hitam sekalipun bagian yang lapuk dan teralterasi berwarna coklat sampai coklat kehijauan. Di bawah mikroskop batupasir gunungapi itu tersusun oleh butiran sangat meruncing, terpilah baik, kemas tertutup, berbentuk pipih dan berstruktur massif hingga berlubang sangat jarang. Hampir semua bahan batupasir gunungapi itu tersusun oleh fragmen gelas gunungapi, sebagian memperlihatkan struktur radier dan pecahan konkoidal. Kristal sangat halus dan sangat jarang (3%) memperlihatkan tekstur pendinginan sangat cepat, terdiri dari klinopiroksen diopsidik dan plagioklas basalt yang hal ini sebanding dengan komposisi lava bantal basalt. Analisa geokimia juga mendukung kesamaan komposisi tersebut dengan memberikan kandungan SiO_2 sebesar ± 52 %. Data tersebut mengindikasikan bahwa batupasir gunungapi itu di endapkan sangat dekat dengan sumbernya yang berupa suatu gunungapi bawah laut. Kegiatan gunungapi itu baik yang bersifat non eksplosif maupun erupsi eksplosif lemah menghasilkan piroklast basalt yang masuk ke dalam air laut dengan temperatur sangat tinggi (± 1000°C). Kondisi ini menyebabkan proses pendinginan sangat cepat sehingga membentuk fragmen gelas gunugapi berbentuk sangat meruncing. Studi ini memberikan implikasi bahwa tidak semua batupasir gunungapi di sana merupakan endapan turbidit epiklastik yang berasal dari luar cekungan pengendapan. Dalam rangka memperbaiki model fasies di daerah penelitian, pembedaan antara fasies gunungapi bawah laut, fasies gunungapi darat dan fasies non gunungapi sangat penting. Studi lebih lanjut untuk mendapatkan fasies pusat erupsi gunungapi bawah laut diharapkan dapat menunjang eksplorasi mineral vulkanogenik di lautan dan prospek hidrokarbon.

ABSTRACT

In the Jiwo Hills and northern foot of the Southern Mountains, Klaten-Central Java, association of volcanic sandstones, basaltic pillow lavas and calcareous sediments are exposed. Those rocks are grouped into Kebo-Butak Formation (Surono *et al.*, 1992; Samodra & Sutisna, 1997) and previous studies (e.g. Rahardjo, 1983; Suryono & Setyowiyoto, 2001) stated that the volcanic sandstone is a part of turbidite deposited in submarine fan environment. The volcanic sandstone associated with basaltic pillow lavas is dark grey to black in color although the weathered and altered parts are brown to greenish brown. Under the microscope the volcanic sandstone shows very angular grains, well sorted and grain supported, massive to poorly vesicular with platy shards in shape. Nearly all material is composed of volcanic glass fragments, some of them showing radiated structures and conchoidal fractures. Crystals are very rare (<3 %) showing quenching textures and consisting of diopsidic clinopyroxene and calcic plagioclase which are comparable with the composition of basaltic pillow lavas. Geochemical analyses also support the similar composition by having about 52 % SiO_2 content. These data suggest that the volcanic sandstone was deposited very close to the source, that is a submarine volcano. Volcanic activities there, either non-explosive or weakly explosive eruptions produced basaltic pyroclasts having high temperature (ca. 1000 °C) into (deep ?) sea water that has very low temperature and high hydrostatic pressure. This condition caused very rapid cooling process of the material to form very angular fragments of volcanic glass. This study implies that not all volcanic sandstones there are epiclastic turbidites coming from outside of the basin. In order to revise the facies model there it is necessary to differ between submarine volcanic facies, on land volcanic facies and non-volcanic facies. Further study to obtain the central facies of submarine volcanoes will probably help in exploration of marine volcanogenic mineral deposits and hydrocarbon prospects.

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INTRODUCTION

Background

So far, in the Jiwo Hills and the Southern Mountains sedimentary processes of volcanic rocks, particularly volcanic sandstones, are mostly considered as reworked material or volcanic epiclastic rocks, e.g. turbidites (Rahardjo, 1983; Surono drr., 1992; Samodra & Sutisna, 1997; Suryono & Setyowiyoto, 2001). The material has been interpreted originally coming from outside of the basin following submarine models of Walker (1980) and Lajoie & Stix (1992). Although there are some pyroclastic deposits erupted by primary volcanic activities and intercalated with volcanic epiclastic deposits, those pyroclastic rocks are also believed coming from volcano(es) at outside of the depression.

The research area is located at the Jiwo Hills and the northern foot of Baturagung escarpment, northern part of the Southern Mountains, Central Java (Fig. 1). Administratively, this area belongs to Kecamatan Bayat Kabupaten Klaten and Kecamatan Gedangsari Kabupaten Gunungkidul. Among the sequence of volcaniclastic rocks in this area there are some basaltic pillow lava flows that were already reported by previous workers (e.g. Rahardjo, 1983; Samodra & Sutisna, 1997) as products of ancient volcanism. However, those lavas have never been studied in term of their sources and their genetic relationship with volcaniclastic rocks near by. This paper emphasizes the presence of volcaniclastic rocks in the research area, especially volcanic sandstones, as primary products of submarine volcano(es) located in the basin as pyroclastic rocks and hyaloclastites which are associated with basaltic pillow lava flows there.

Aim

The aim of this study is to understand the genesis of volcaniclastic rocks, especially volcanic sandstones associated with basaltic pillow lavas. Those volcaniclastic rocks may be or may be not syngenetic with the basaltic pillow lava as products of submarine volcanic eruptions. This topic has never been studied yet, but will play in role on sedimentation processes particularly in the inner arc basin such as along volcanic arc in Indonesia.

Hypothesis

Sedimentation processes in the volcanic area (inner arc basins), such as in Indonesia, can be derived from four sources (Fig. 2), namely:

1. Reworked, non volcanic epiclastic material from the land,
2. Submarine volcanic activities,
3. Biologic activities and chemical processes in the sea, and
4. Volcanic activities from the land or near the shore.

The reworked non volcanic deposits originally came from older rocks, such as igneous, sedimentary and or metamorphic rocks. Those material may form siliciclastic rocks or calcareous sediments. The activity of submarine volcano is not only effusive eruptions extruding (pillow) lava flows, but it can be explosive eruptions producing pyroclastic material. This submarine volcanic activity could develop and the volcano becomes bigger and higher and in one time the submarine volcano forms an island volcano or even a volcano on land.

The third source is due to the biologic activity and chemical processes producing non clastic sedimentary rocks, e.g. reef limestones, radiolarian cherts etc. The fourth source is from volcanic activity on land or in shore near the basin. Volcanic activities may produce coherent lavas, pyroclastic flows, pyroclastic surges, pyroclastic falls, lahars and volcanic debris avalanches, similar to the products of island volcanoes.

Problem

Based on the background and hypothesis the problem in this study is to identify volcaniclastic

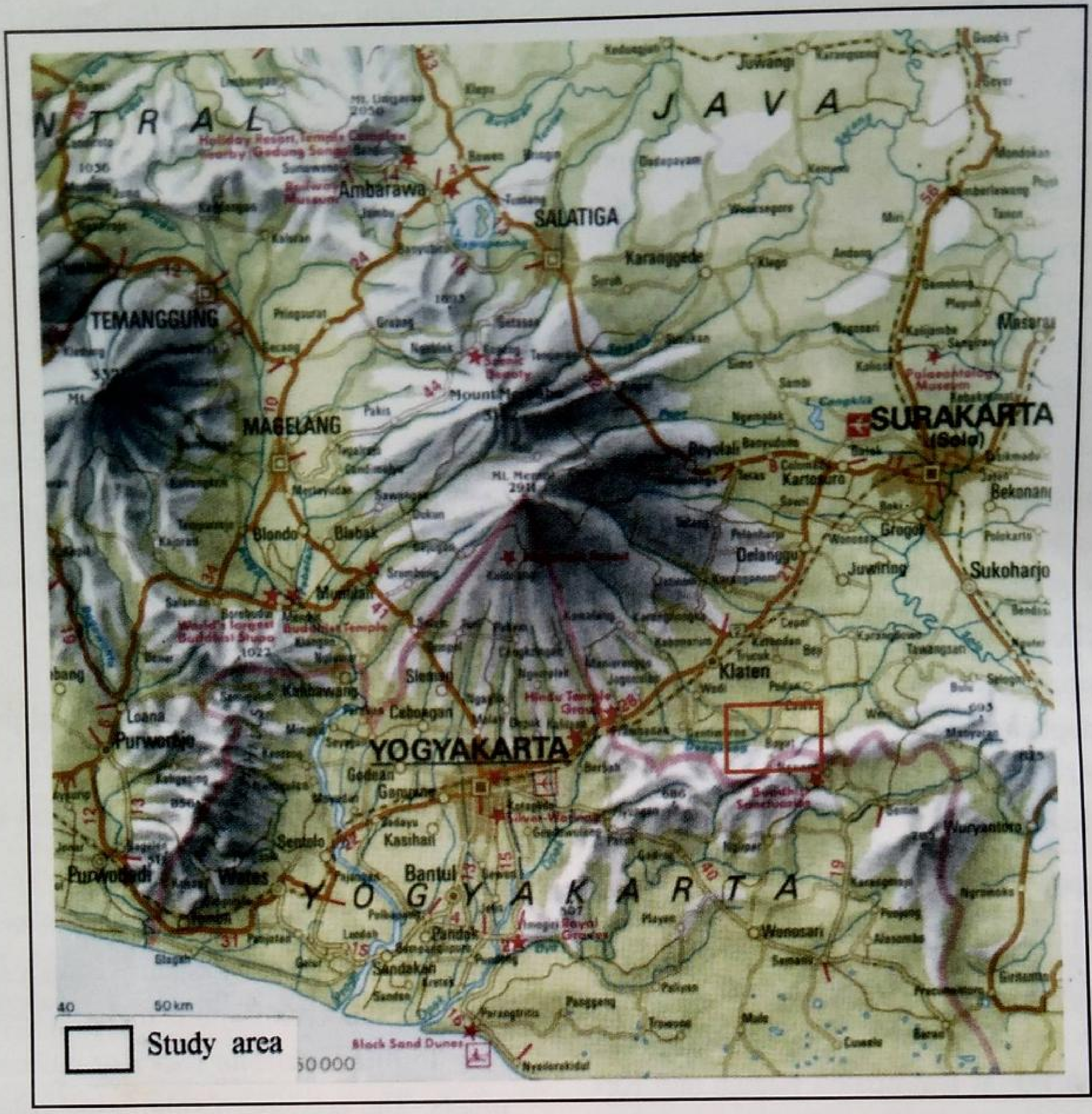


Fig. 1. Location map of study area in the Jiwo Hills and nothern part of the Southern Mountains, Kecamatan Bayat, Kabupaten Klaten, Central Java.

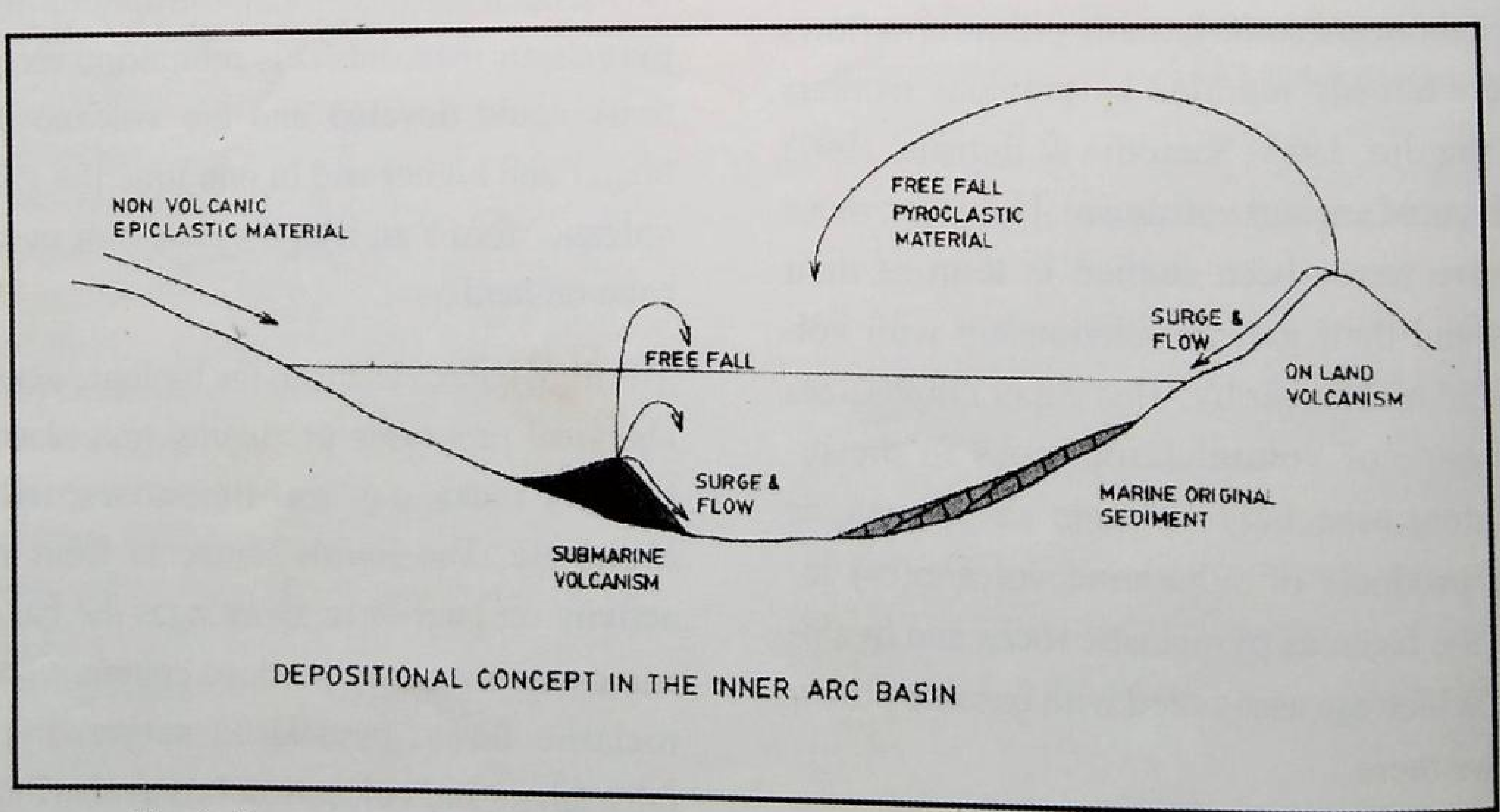


Fig. 2. Four sources of sedimentation into an inner arc basin, i.e. reworked, non volcanic epiclastic material from land, submarine volcano, organic activities and chemical processes in the sea, and volcanism from land.

rocks, particularly volcanic sandstones, as products of submarine volcanism together with basaltic pillow lavas. Those vulcaniclastic rocks are probably pyroclastic deposits or hyaloclastites.

Method

The method applied to solve the problem here is:

1. to observe and to describe megascopically outcrops in the field.
2. to describe microscopically representative samples in the Petrography Laboratory, Geological Research and Development Centre, Bandung.
3. to analyse geochemical composition (major oxides) of rock samples in the Geochemistry Laboratory, Geological Research and Development Centre, Bandung.
4. to analyse all compiled data, primary and secondary, in order to clarify the genesis of the volcaniclastic rocks.

Basic Theory

Volcanic sandstones are volcanic rocks produced by direct or indirect volcanic eruptions having clastic texture and sand size material. The term 'direct' means primary volcanic eruptions, either explosive eruptions or effusive eruptions. While 'indirect' is addressed to secondary processes, such as weathering, erosion, transportation, deformation and redeposition. The terminology of 'volcanic sandstones' is developed from 'volcaniclastic rocks'. According to Fischer (1961 & 1966) and Fisher & Smith (1991) volcaniclastic rocks are the entire spectrum of clastic materials composed in part or entirely of volcanic fragments, formed by any particle-forming mechanism, e.g. pyroclastic, epiclastic, autoclastic, transported by any mechanism, deposited in any physiographic environment, or mixed with any non volcanic fragment types in any proportion. Pettijohn (1975) and Lajoie & Stix (1992) shortly stated that volcaniclastic rocks are all fragmental volcanic rocks that result from any mechanism of fragmentation. Whereas, Mathisen & McPherson (1991) defined that a volcaniclastic rock is a clastic rock containing volcanic material in whatever proportion, and without regard to its origin.

McPhie *et al.* (1993) developed a sedimentation model of volcanic rocks that originally not only coming from volcano on land but also erupted from submarine volcano in the basin (Fig. 3). The figure shows associated rocks coming from volcano on land that were deposited on land, shoreline, shallow marine and deep sea environments. Names of volcanic rocks are not based on descriptive terminology only but also genetic aspects.

Effusive eruptions of the submarine volcano extrude either lava domes or lava flows, while explosive eruptions eject pyroclastic materials. Subvolcanic activities form high level intrusions, such as volcanic necks, dikes, sills and cryptodomes. Submarine lava flows may form pillow structure, and due to super cooling processes both lava domes and lava flows can be fragmented to produce hyaloclastites. The submarine explosive eruptions may generate pyroclastic falls, pyroclastic flows and possibly pyroclastic surges. Hyaloclastite was named by Alfred Rittmann (Macdonald, 1972), literally as 'broken glass rocks' or non vesiculated juvenile glass fragments. According to Gary *et al.* (1972) hyaloclastite is a deposit resembling tuff that is formed by the flowing of basalt underwater or ice and its consequent granulation or shattering into small, angular fragments. This terminology is synonymous to aquagene tuff. McPhiet *et al.* (1993) defined hyaloclastite as clastic aggregates formed by non-explosive fracturing and disintegration of quenched lavas and intrusions. The term is used for both unconsolidated clastic aggregates and their equivalents. Fragmentation occurs in response to thermal stress, built up during rapid cooling and stress imposed on chilled outer parts of lava flows and intrusions by continued movement of the ductile interior (e.g. Kokelaar, 1986). When hyaloclastite is still in place that is termed in situ hyaloclastite, whereas the transported material is called redeposited hyaloclastite (Fig. 4). In situ hyaloclastite is characterized by very angular coarse grains with jigsaw fit textures, massive unsorted and unbedded, glassy mono-

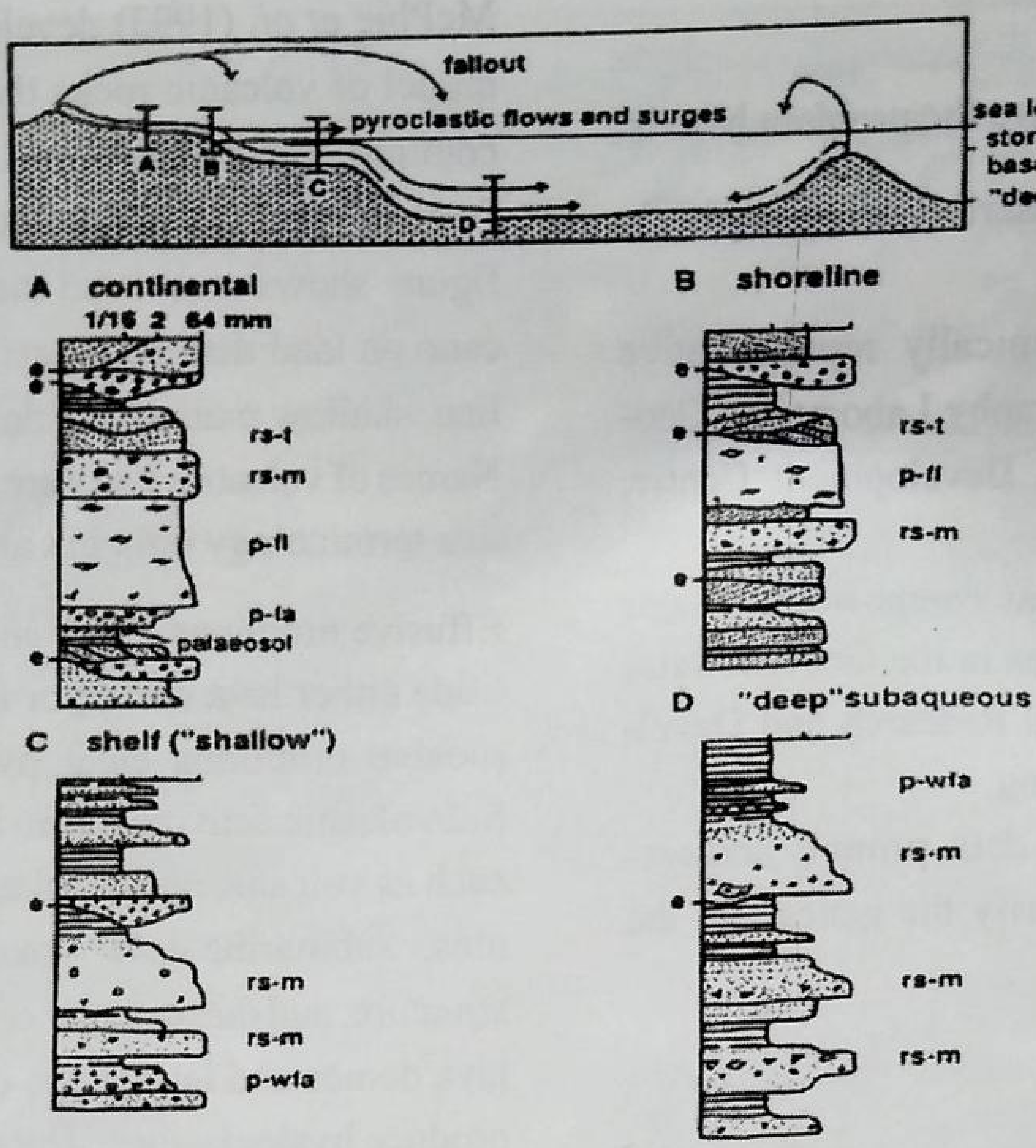


Fig. 3. Sedimentary environments and volcanogenic sedimentary facies associations near active volcanoes (Mcphie *et al.*, 1993). The top frame gives the positions of the schematic sections A-D below. (A) Continental (fluvial and alluvial). (B) Shoreline. (C) Subaqueous shelf. (D) "Deep" subaqueous (lake or ocean). P-pyroclastic deposits; fl-flow; fa-falaout; wfa-water settled fallout; rs-resedimented syn-eruptive deposit; t-traction; m-mass flow. The grain size subdivisions in (B), (C) and (D) are the same as those shown in (A).

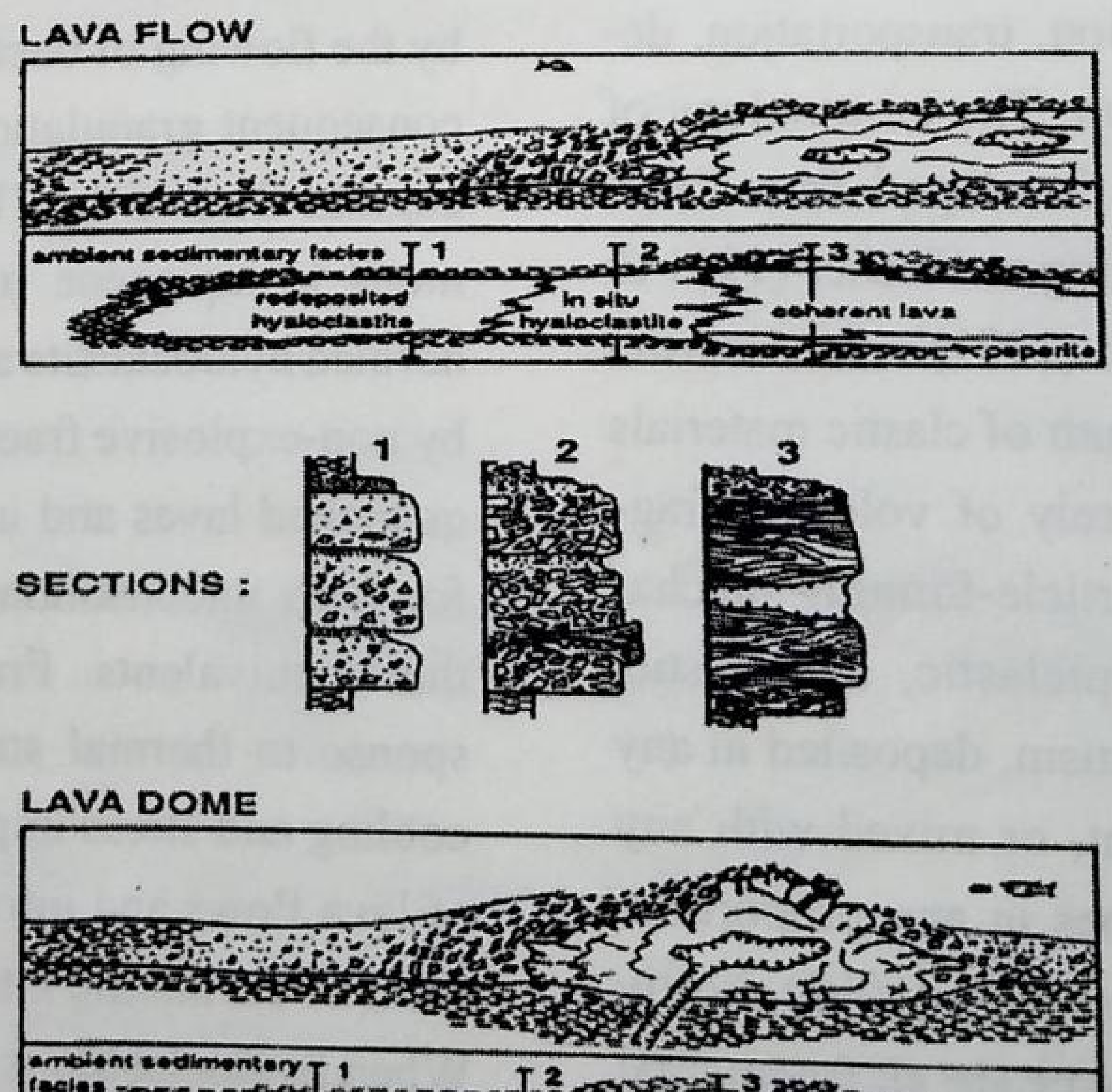


Fig. 4. Hyalocalatite as clastic aggregates or broken glass rocks formed by non-explosive fracturing and disintegration of quenched lavas (and intrusions; McPhie *et al.*, 1993). In situ hyaloclatite when the material is still in place; whereas redeposited hyaloclastite if it was already transported.

lithology, very close or blankets coherent lava. Redeposited hyaloclastite may be layering, finer grains in size, mixed with components from other sources, no more jig saw fit textures and can be distributed in a considerable distance from the coherent lava.

Quench fragmentation can also occur on pyroclasts erupted into or deposited on (sea) water (e.g. Yamagishi, 1987). However, fragments in hyaloclastite differs from most of the fragments in pyroclasts. Fragments in hyaloclastite is mostly non vesiculated juvenile glass fragments. They tend to be flat plates or angular chips with only occasional curved surfaces of disrupted vesicles. Submarine pyroclasts formed by the blowing a part of rock froth by expanding gas bubbles. Consequently, the fragments have many curved surfaces that were once the edges of bubble holes (Macdonald, 1972). Cas & Wright (1987) added that in hyaloclastite more than 20 percentages of fragments is planar, while in pyroclasts the fragments form concave, convex and vesicles. In addition, subaerial volcanic ash or pyroclasts are typical having glass shards and vesicles.

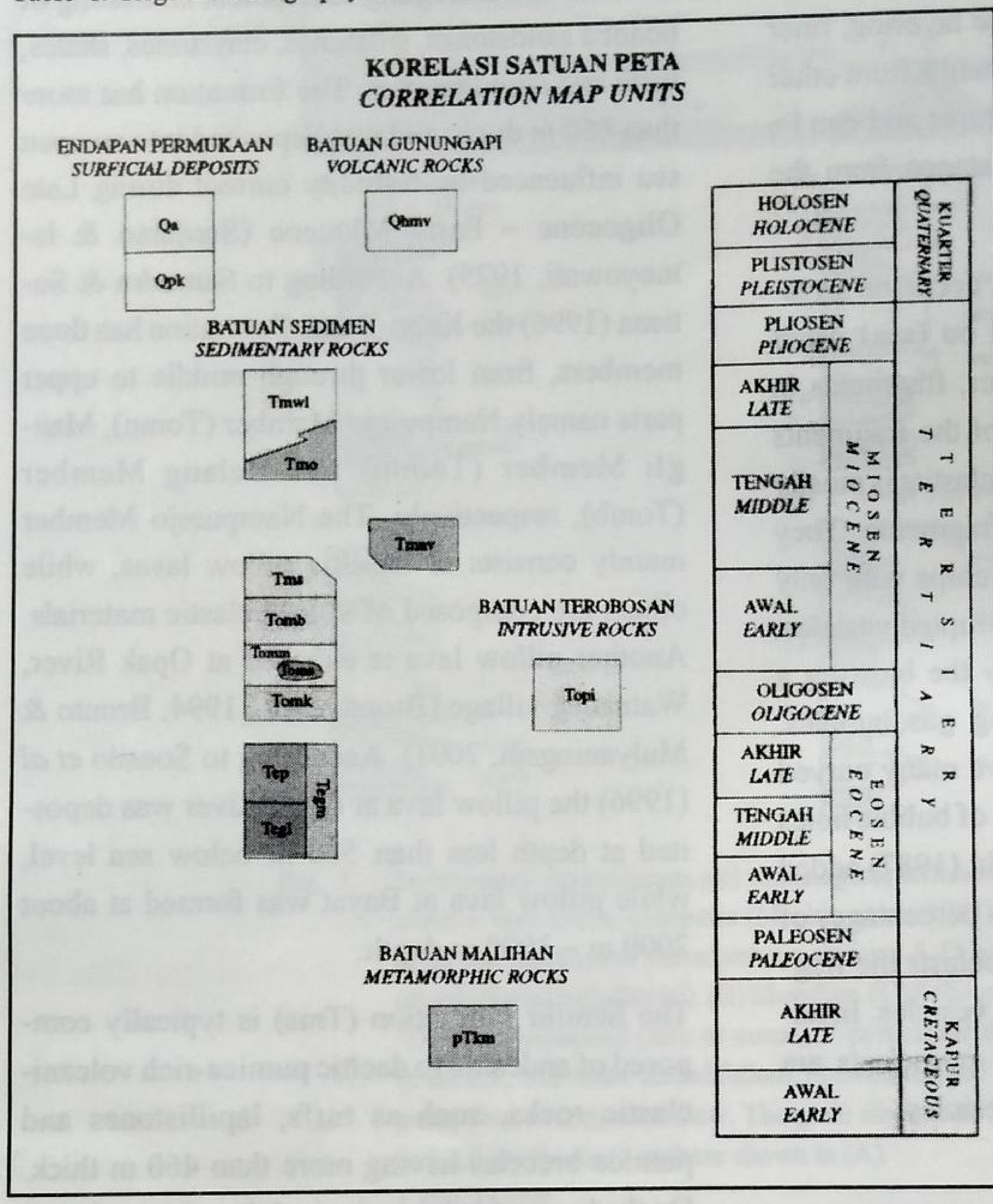
Regional Stratigraphic Setting

Regional stratigraphy of the Jiwo Hills and the western part of the Southern Mountains (e.g. Surono *et al.*, 1992; Samodra & Sutisna, 1997) is started with pre-Tertiary metamorphic rocks (KTm, Table 1) that consist of schists, marbles, phyllites and metasediments. Unconformably, those rocks are overlain by Gamping-Wungkal Formation (Tew) composed of alternating between sandstones and siltstones with lenses of limestones having Middle Eocene in age and was deposited into shallow marine environment.

Volcaniclastic sediments were deposited unconformably above the Gamping-Wungkal Formation, and are grouped into Kebo-Butak Formation (Tomk), Semilir Formation (Tms), Nglanggeran Formation (Tmng) and Sambipitu Formation (Tmss). The Kebo-Butak Formation is located in the base of Baturagung escarpment consisting of bedded sandstones, siltstones, claystones, shales, tuffs and agglomerates. The formation has more than 650 m thick, and was deposited into an open sea influenced by turbidity current during Late Oligocene – Early Miocene (Sumarso & Ismoyowati, 1975). According to Samodra & Sutisna (1996) the Kebo-Butak Formation has three members, from lower through middle to upper parts namely Nampurejo Member (Tomn), Mangli Member (Tomm) and Belang Member (Tomb), respectively. The Nampurejo Member mainly consists of basaltic pillow lavas, while others are composed of volcaniclastic materials. Another pillow lava is exposed at Opak River, Watuadeg village (Bronto *et al.*, 1994; Bronto & Mulyaningsih, 2001). According to Soesilo *et al* (1996) the pillow lava at Opak River was deposited at depth less than 500 m below sea level, while pillow lava at Bayat was formed at about 2000 m – 3000 m depth.

The Semilir Formation (Tms) is typically composed of andesitic to dacitic pumice-rich volcaniclastic rocks, such as tuffs, lapillistones and pumice breccias having more than 460 m thick. On the basis of paleontological data this rock unit was deposited in Early to Middle Miocene into shallow to deep marine environments. The Nglanggeran Formation (Tmng) consists of volcanic breccias, aglomerates, tuffs or volcanic sandstones and lava flows of andesite to basaltic andesite in composition, and the total thickness is about 530 m. Paleontological data give an age of Early-Middle Miocene to this formation. However, absolute dating using K-Ar method yields Late Oligocene age (26 Ma, Soeria-Atmadja *et al.*, 1994). This is comparable with the age of diorite intrusion of Mt. Pendul in the Jiwo Hills area that has an age of 24 Ma, although another analysis gives an age of 33 Ma (Soeria-Atmadja *et al.*, 1994). In addition, Hartono (2000) reported that his rock sample taken from Ngalang River has an age of 58.58 ± 3.24 Ma or Late Paleocene.

Table 1. Regional stratigraphy of Klaten Quadrangle (Samodra & Sutisna, 1997).



The Sambipitu Formation (Tmss) is mainly composed of fine grain volcaniclastic rocks such as volcanic sandstones, volcanic siltstones and volcanic claystones. Only in the upper part, this rock unit contains calcareous material. This formation is about 230 m thick and was deposited in shallow to deep marine environments during Lower to Middle Miocene.

All of those volcanic rock units are overlain by predominantly calcareous sediments that are grouped into Oyo Formation (Tmo), Wonosari Formation (Tmwk) and Kepek Formation (Tmpk). These calcareous rock units were deposited in a shallow marine environment during Middle Miocene to Pliocene. During Quaternary time alluvial deposits have been deposited and those are divided into three rock units, i.e. Old Alluvium (Qt), Young Alluvium (Qa) and Volcanic epiclastic deposits from Merapi Volcano (Qvm).

On the basis of lithologic characters author has interpreted (Bronto, 1999) that Tertiary volcanism in this area probably begun during Oligo-Miocene when submarine volcano(es) erupted pillow lava flows of the Kebo-Butak Formation. The peak of volcanism occurred in Early-Middle Miocene where the Semilir Formation and Nglanggeran Formation were deposited. The Semilir Formation implies a destruction phase due to very explosive eruptions of a caldera forming event, whereas the Nglanggeran Formation indicates a construction period of composite volcano(es) in the Southern Mountains. The Tertiary volcanism declined and finally ceased in the end of Miocene age.

Result

In the area of Jiwo Hills and the northern foot of Baturagung escarpment pillow lavas are exposed in some places around Nampurejo village, Kecamatan Gedangsari, Kabupaten Gunungkidul (Fig. 5). Those lava flows are occasionally observed together with volcanic sandstones and volcanic breccias, beside clastic fine grained limestones. The volcanic sandstone is mostly oxidized, altered and weathered, reddish brown to greenish brown in color to form sphaeroidal weathering (Fig. 6). However, in the core of the sphaeroidal weathering fresh volcanic sandstone material is still found having black to dark gray in color (Fig. 7). Microscopically, the volcanic sandstone shows very angular grains, medium to coarse sand size, fairly well sorted and grain supported, massive to very poor vesicularity with platy shards in shape (Fig. 8). Nearly all materials composed of volcanic glass, as broken glass fragments, some of them showing radiated to fibrous structures, shatter cracks, and conchoidal fractures. Crystals are very rare (<3 %), and they show quenching textures and consist of diopsidic clinopyroxene and calcic plagioclase. This mineralogical composition is comparable with the composition of basaltic pillow lavas. Geochemically, they are also similar by having about 52 % SiO_2 and 16 % Al_2O_3 (Table 2 & Fig. 9). Siginificant differences among of them particularly in contents of CaO, Na_2O and not for K_2O (Table 2). These are probably due to normal differentiation processes and further crystallization of clinopyroxene and calcic plagioclase in the lava, beside alteration to calcite and influences of sea water, especially in increasing of sodium content. In figure 9 samples of basaltic pillow lavas, volcanic sandstone (vitric tuff) and sill from Bayat exhibits a linear trend. This suggests that those rocks were derived from the same source and then affected by normal differentiation. On the basis of those data it is argued that the volcanic sandstone is pyroclastic material and it was erupted as weakly explosions by submarine volcano in the area in association with basaltic pillow lava extrusions. Basaltic magma that was not able to be erupted on the sea floor formed subvolcanic intrusion(s) such as sill as reported by Bothe (1929), Hartono (2000), and Suryono & Setyowiyoto (2001).

A Paleontological analysis of fine-grainedimestone (biomicrite) interbedded with pillow lavas and the volcanic sandstone exhibits some fossils of planktonic and benthonic foraminifera. Those planktonic foraminifera fossils are *Globoquadrina baroemoensis* (LEROY), *Globigerina yeguenseis* WEINZIERL & APPLIN, *Globoquadrina praedehiscens* BLOW & BANNER, *Globorotalia nana* BOLLI, *Globorotalia Kugleri* BOLLI, *Catapsydrax dissimilis* (CUSHMAN & BERMUDEZ), *Globigerina binaiensis* KOCH and *Globigerina tripartita* KOCH. These associated fossils give an age of sedimentation in N5. Benthonic foraminifera fossils are *Robullus sp, Pullenia obliquiloculata* (PEUSS), *Cibicides sp aff. C. floridanus* CUSHMAN, *Textularia sp, Eponides antillarum* D'ORBIGNY and *Cassidulina subglobosa* (BRADY). These associated fossils suggest that sedimetation of the limestone was occurred in a middle neritic environment.

Meanwhile, in a small hill north of Talun, Tegalrejo village, weathered lava flows are exposed associated with volcanic breccias and bedded volcanic sandstones. A lava flow has changed gradually to volcanic breccia and volcanic sandstone (Fig. 10& 11). In the lava flow there are some veins and veinlets of barite having white in color. The association of basaltic pillow lava, volcanic breccia and volcanic sandstone probably indicates hyaloclastite as stated by McPhie *et al.* (1993). The autoclastic breccia is considered as insitu hyaloclastite and the volcanic sandstone is probably redeposited hyaloclastite. Another autoclastic breccia of possibly hyaloclastite is also found at Cemoro, Tegalrejo village, that alternates with bedded volcanic sandstones.

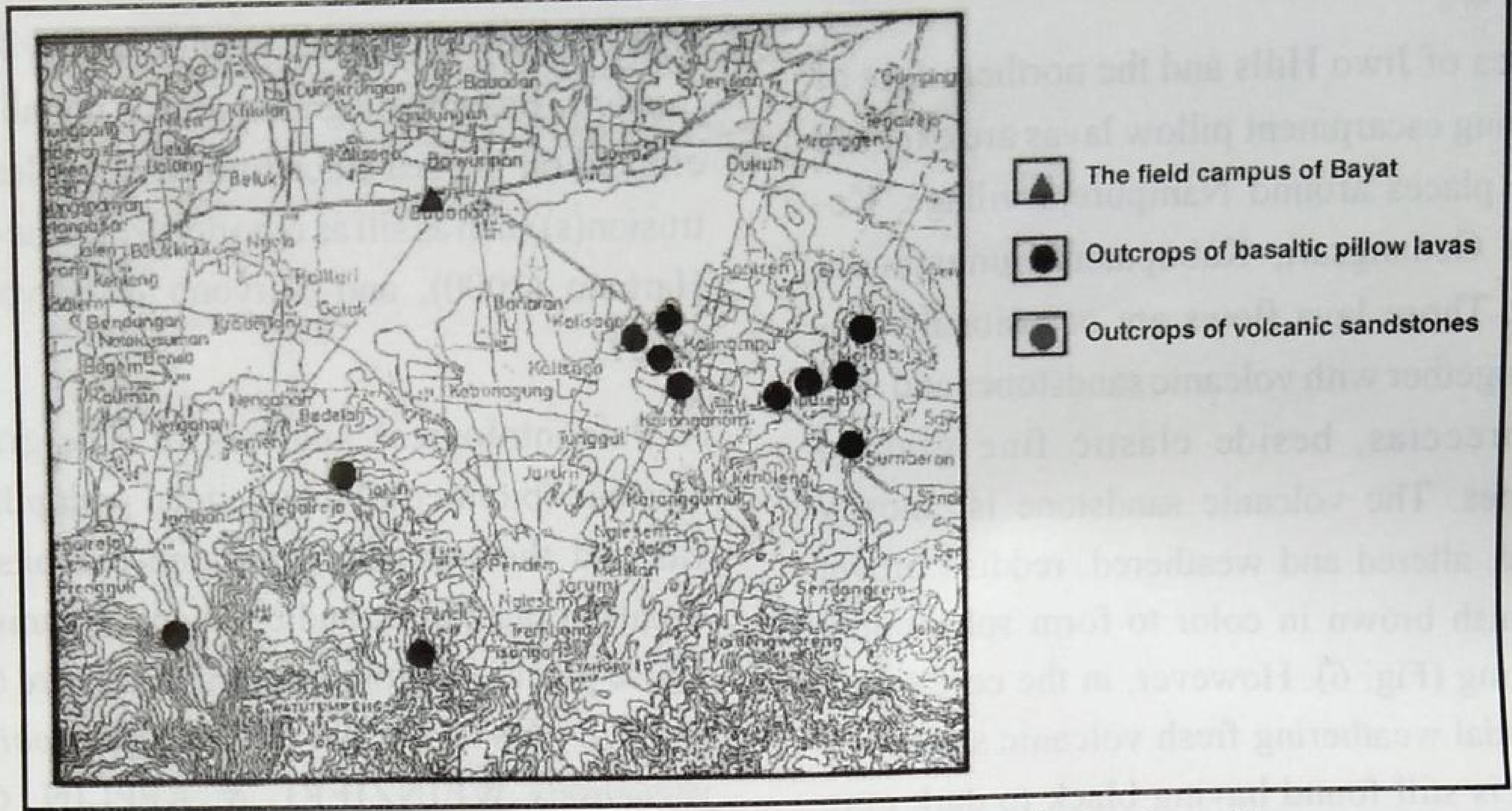


Fig. 5. Location map of outcrops of basaltic pillow lavas and volcanic sandstones.

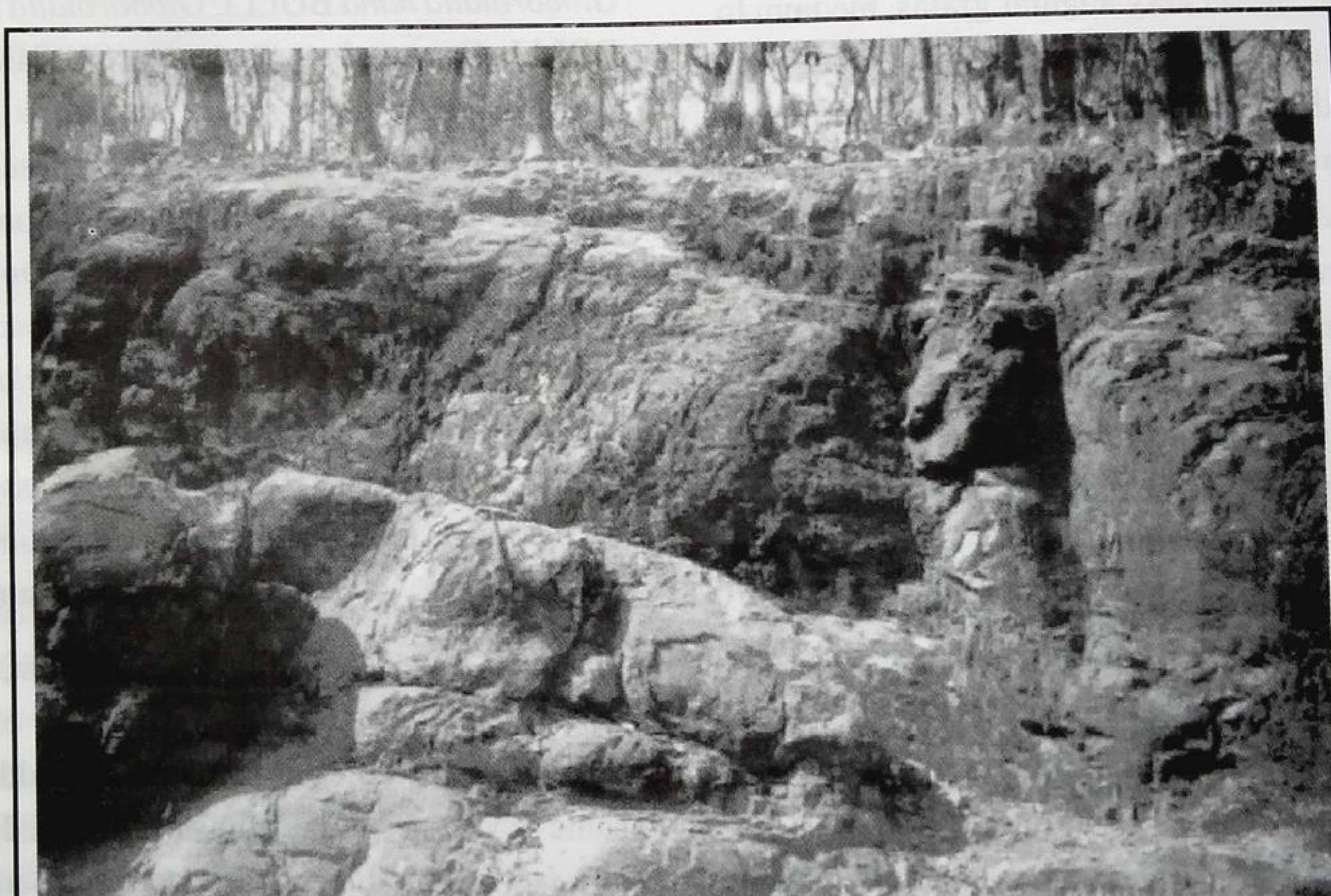


Fig. 6. And outcrop of volcanic sandstone in the Kalinampu village. The volcanic sandstone is highly oxidized, altered and weatheres, reddish brown to greenish brown to form spaheroidal weathering.

Discussion

The presence of basaltic pillow lavas and their hyaloclastite and pyroclastic rocks of vitric tuff are clearly confirmed that those rocks were erupted by submarine volcano, probably as an intial stage of volcanism in the area. The super-cooling processes of hyaloclastites and pyroclastic rocks were due to suddenly decreased of temperature from basaltic magma temperature (ca. 1000°C) into deep sea water temperature (~ 0°C). This supports the hypothesis that in the inner arc basin volcanic sedimentary processes were not

Fig. 7. Core of spaheroidal weathering of volcanic sandstone in figure 6, showing black to dark grey in color.

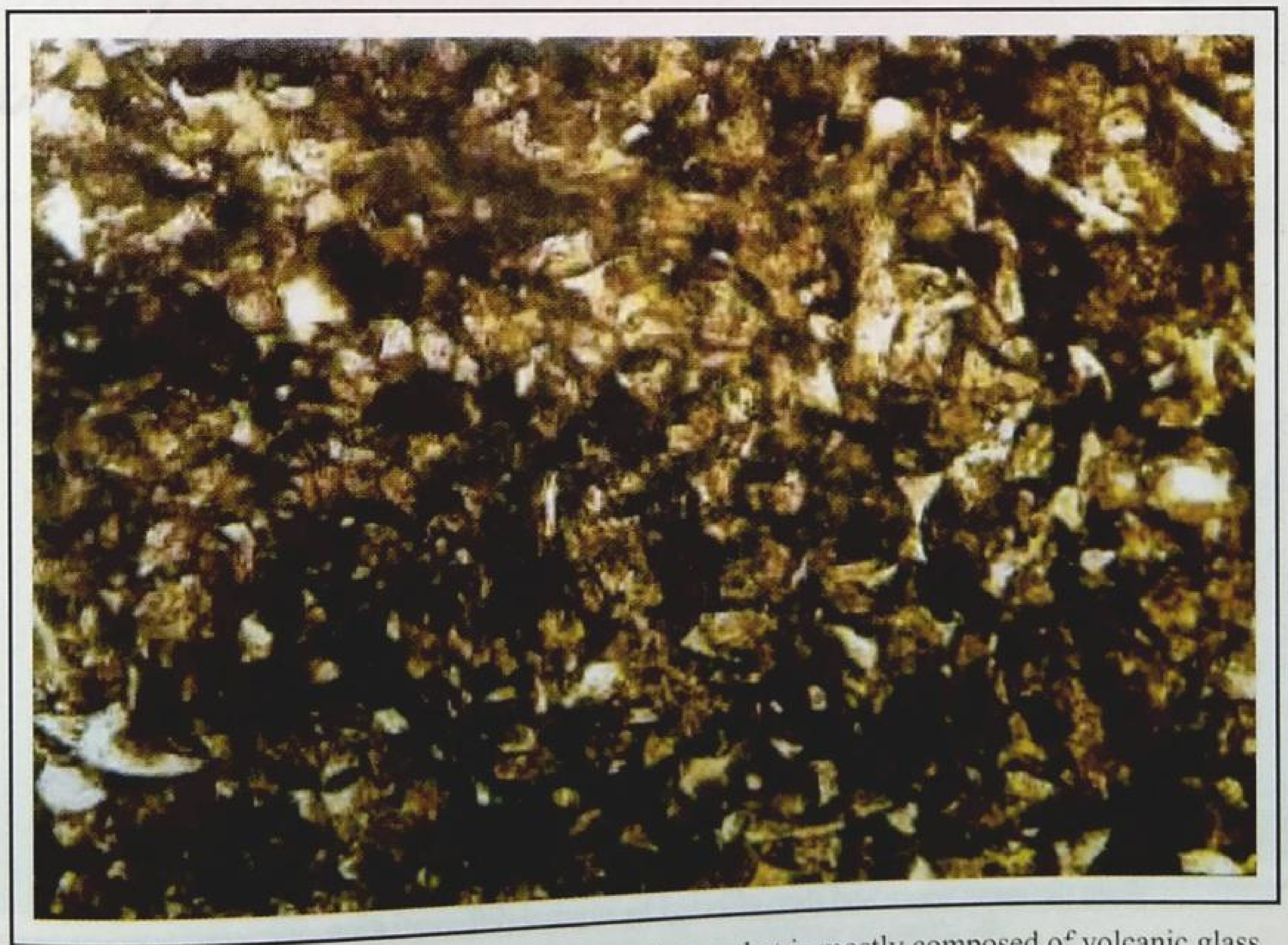


Fig. 8. Microscopic feature of the volcanic sandstone that is mostly composed of volcanic glass fragments, very angular grains, concave and convex forms but very poor vesicles.

only from outside of the basin, but also came from inside the basin. In term of facies and stratigraphy those rocks should be differed in order to analyze their genesis, including non volcanic epiclastic material and original marine derived sedimentary rocks. Bronto (2000) ever questioned whether

Table 2. Geochemical compositions of basaltic pillow lava (PLB1 & BYT9A), sill (GH051) and volcanic sandstone (BYT4) in Bayat area. PLB1 is taken from Bronto *et al.* (1994), while GH051 is cited from Hartono (2000). PLWA is a sample basaltic pillow lava from Watuadeg (Bronto *et al.*, 1994).

Unsur Mayor	PLB1	BYT9A	BYT4	GH.051	PLWA
SiO2	52.16	52.23	52.76	50.52	50.37
TiO2	1.23	1.66	1.26	1.45	0.74
Al2O3	17.56	16.13	16.91	17.28	18.42
Fe2O3*	9.96	10.24	11.80	11.65	10.78
MnO	0.14	0.16	0.19	0.18	0.27
MgO	5.05	5.45	3.66	6.15	5.78
CaO	9.61	11.25	5.76	8.54	9.76
Na2O	2.63	1.89	4.86	3.00	2.89
K2O	1.14	0.16	1.35	0.88	0.63
P2O5	0.52	0.83	1.45	0.35	0.36
Total	100.00	100.00	100.00	100.00	100.00

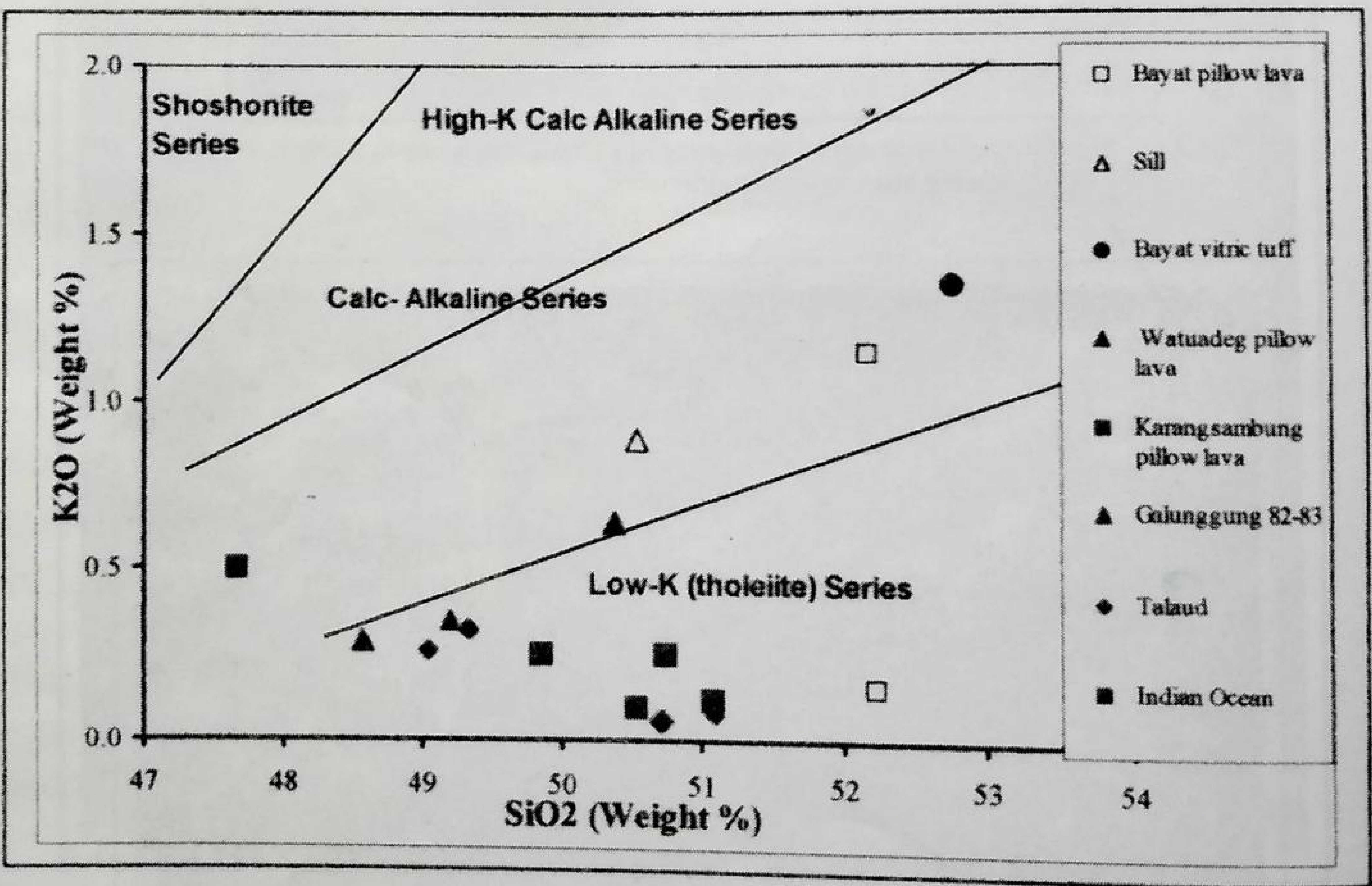


Fig. 9. SiO_2 vs K_2O of basaltic pillow lavas, sill and volcanic sandstone from Bayat compared with basaltic rocks from other areas (Karangsambung; Suparka & Soeria-Atmadja, 1991); Galunggung; Bronto, 1989; Talaud; Evans *et al.*, 1983; Indian Ocean; Fleet *et al.*, 1976). Those samples from Bayat shows a linear trend indicating that were derived from the same souce and then effected by normal differentiation.

Tertiary volcanic rocks in the Southern Mountains are (classical) turbidite or in situ paleovolcanoes. By studying this volcanic sandstone and pillow lavas, and other author's reports (e.g. Bronto & Mulyaningsih, 2001, Bronto & Pambudi, 2002 and Bronto *et al*, 1999) it can be given preliminary answer that some of volcanic rocks there are parts of an in situ paleovolcanic body. Turbidites were most likely generated on the slope of the volcano as volcanic turbidites. How-

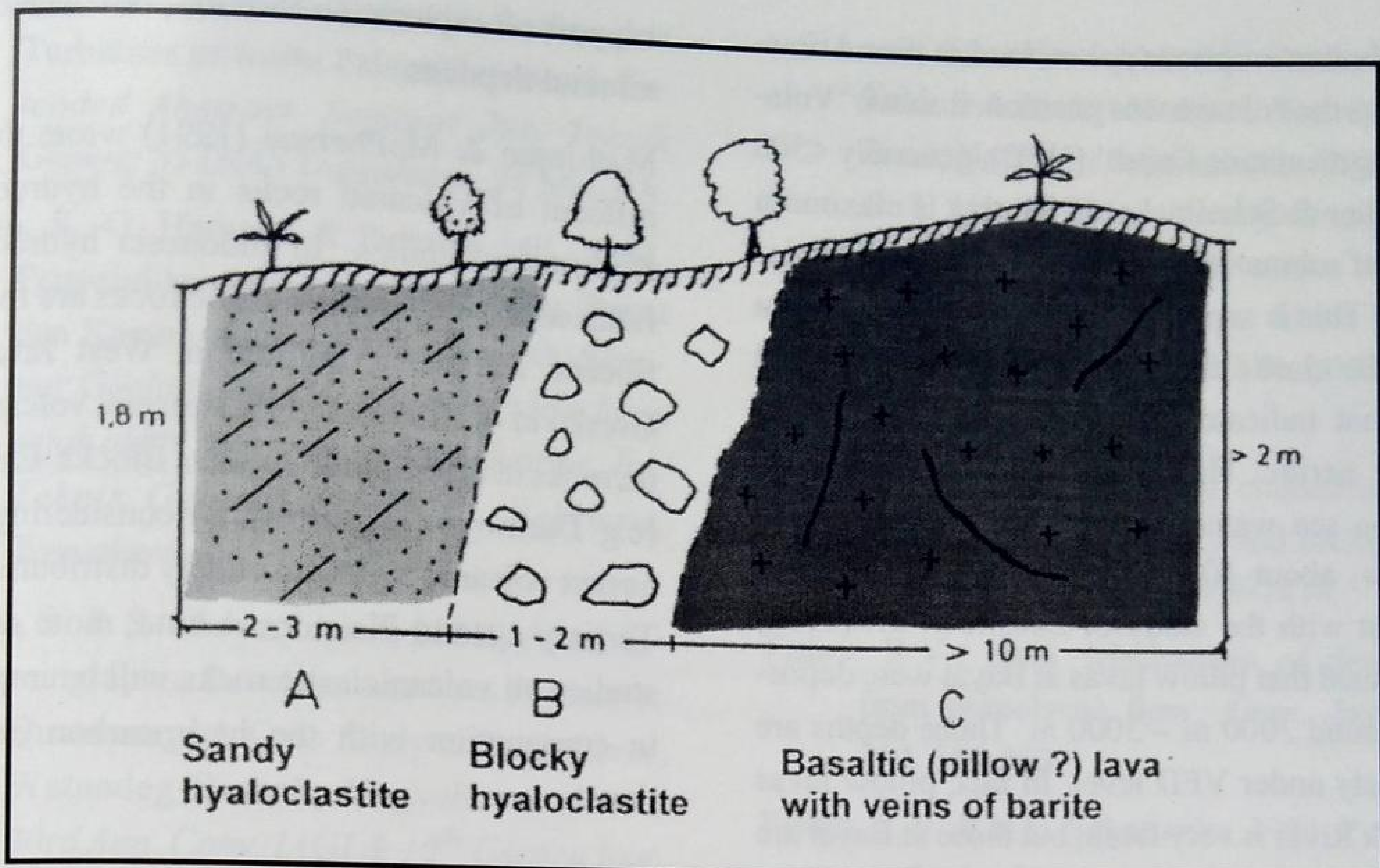


Fig. 10. A lava flow with volcanic breccia and volcanic sandstone of hyaloclastite. The outcrop is located at a small hill north of Talun-Tegalrejo village. In the lava there re some veins and veinlets of barite.

Fig. 11. Volcanic breccia of hyaloclastite of figure 10.

ever, it is still unclear yet whether those volcanic turbidites were directly triggered by volcanic explosive eruptions or as secondary slumpings of primary volcanic deposits.

The presence of pyroclastic rocks (pyroclastic volcanic sandstone or vitric tuff) implies that the submarine volcano there could erupt explosively, although relatively weak and comparable with

Strombolian eruption type on land in recent time. It means the volcano was positioned above 'Volatile Fragmentation Depth' (VFD), generally <500 m (Fisher & Schmincke, 1984) that is maximum depth of submarine volcano ables to erupt explosively. This is supported by paleontological data from the clastic fine grain limestone associated with that indicate depositional environment at middle neritic. Those paleontological data suggest the sea water depth at the time was quite shallow, about 100 m depth or less. This is in contrast with the study of Soesilo *et al.* (1996) who stated that pillow lavas at Bayat were deposited around 2000 m – 3000 m. Those depths are definitely under VFD level. In fact, pillow lavas at Opak River is very fresh, but those at Bayat are already weathered. This condition probably affected the measurement of vesicles on the surface of the pillow lavas at Bayat.

Furthermore, it is urgently required to revise stratigraphy and rock unit determination of the whole rocks in the basin sedimentation. In a broader scope it is also suggested to differ stratigraphy based on the tectonic setting. Stratigraphy in the back arc basin may resemble to continental stable depressions where 'layered cake stratigraphy' can be applied. However, this is not probably suitable to be applied in the inner arc basins and fore arc basins.

The presence of veins and veinlets of barite implies a process of epithermal alteration of sulphide minerals due to hydrothermal processes in the ancient volcanic area. Veins of barite have maximum thickness between 2-3 cm, white in color, relatively hard and heavy, non calcareous and form radiate structures. Those veins fill irregular and systematic cracks in the basaltic lava flow. Metal sulphide deposits may be formed in the central facies of the ancient volcano, as reported by McPhie *et al.* (1993). Thus, further studies are required in order to find out central facies of ancient submarine volcano(es) in the Southern Mountains. Hopefully, this study will support on exploration activities of volcanogenic mineral deposits.

Mathiesen & McPherson (1991) wrote the significant of volcanic rocks in the hydrocarbon exploration studies. In Indonesia hydrocarbon fields associated with volcanic rocks are found in Eocene Jatibarang Formation, West Java (e.g. Gresko *et al.*, 1995) and Pleistocene volcaniclastic rocks in the Lapindo Brantas Blocks, East Java (e.g. Darmoyo *et al.*, 2001). By considering Indonesian volcanic rocks are widely distributed from Tertiary ages to Pleistocene time, more detailed studies on volcaniclastic rocks will be important in conjunction with the hydrocarbon explorations.

Conclusion

Some volcanic sandstones in Jiwi Hill associated with pillow lavas are pyroclastic rocks and hyaloclastites erupted by submarine ancient volcano in the sedimentary

basin. In order to evaluate stratigraphic units and their genesis it is necessary to differ between volcanic facies erupted in the basin and those derived from outside of the basin and non-volcanic facies. Hopefully this study will be useful for exploration activities to volcanic resources, particularly volcanogenic minerals and hydrocarbons.

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