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Late Eocene shoreline volcanism along the continental margin: the volcanic succession at Kabuki Iwa, Oga Peninsula, NE Japan

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Abstact: Kabuki Iwa (Rock) at the northwestern shore of Oga Peninsula is composed of Late Eocene basaltic andesite aa lava flows and pillowed lava flows, dacitic pyroclastic flows, debris flows and other epiclastic rocks. This close association of the subaerial and subaqueous volcanic products demonstrates a transitional environment between land and shallow water. NE-SW-trending parallel dikes and normal faults are also associated with these rocks in the surrounding areas, and the volcanic succession at Kabuki Iwa is interpreted to have accumulated in an extensional basin which slowly subsided with volcanism before the rapid opening of the Japan Sea.

Keywords: Late Eocene, shoreline volcanism, continental margin, volcanic succession, Kabuki Iwa, Oga Peninsula, NE Japan

1. Introduction

The Oga Peninsula is situated on the Japan Sea side of the NE Japan Arc (Fig. 1). A Cenozoic succession is well exposed along the coast and has been referred to as a type of Cenozoic succession of northern Japan since Huzioka (1959) established the stratigraphic framework of the succession. Volcanic rocks are extensively exposed in the western part of the peninsula and occupy the lower part of the Cenozoic succession (Huzioka, 1959, 1973). They are believed to represent the initial process of the Japan Sea opening that prevailed during the Early Miocene time, but their volcanological and tectonic aspects remain poorly understood (*e.g.* Kano *et al*., 2007a,b, 2008; Kobayashi *et al*., 2008). This paper describes the occurrence of the volcanic rocks which are exposed at Kabuki Iwa (Rock) near the northern tip of the peninsula (Fig.1), in order to reveal volcanic and associated tectonic activities at that time.

The lower volcanic succession in the western Oga Peninsula is divided into the Akashima Formation, Monzen Formation, and Nomuragawa Formation in ascending stratigraphic order and is unconformably overlain by the Middle to Late Miocene marine sediments of the Nishikurosawa and Onnagawa Formations (Figs. 1 and 2).

The Nomuragawa Formation is a stratigraphic unit newly identified by Kobayashi *et al*. (2004). This formation comprises mainly dacite pyroclastic flows, basaltic andesite lava flows and scoriaceous deposits and is correlative with the main part of the Daijima Formation distributed on the immediate eastern side (Fig. 2). The Daijima Formation is accompanied by non-marine clastic sediments at its uppermost part, but radiometric dates indicate both the Nomuragawa and Daijima Formations are Early Miocene in age and mutually correlative (Kobayashi *et al*., 2004).

The Monzen Formation is a mafic to felsic volcanic complex emplaced in a transition area from land to shallow water (Kobayashi *et al*., 2008) and can be divided into eight units (Fig. 2). Radiometric ages reported for this volcanic succession have been diverse but could span a few million years of Late Eocene to Early Oligocene time (Kano *et al*., 2007b, 2008). There are many contemporaneous dikes extending mostly in a NE-SW direction, as shown by the geological maps (Huzioka, 1959, 1973), perhaps reflecting an NW-SE extensional stress field of that time (Yamamoto, 1991). The upper most subaqueous rhyolite lava dome of Shinzan Rhyolite is over hundreds of meters thick and suggests the increase of crustal rifting. On the other hand, the overlying Nomuragawa Formation and Daijima Formation are characterized by bimodal volcanism and on-land eruptions. Shallow-water sediments of the uppermost Daijima Formation are likely to record the succeeding subsidence of this area in association with

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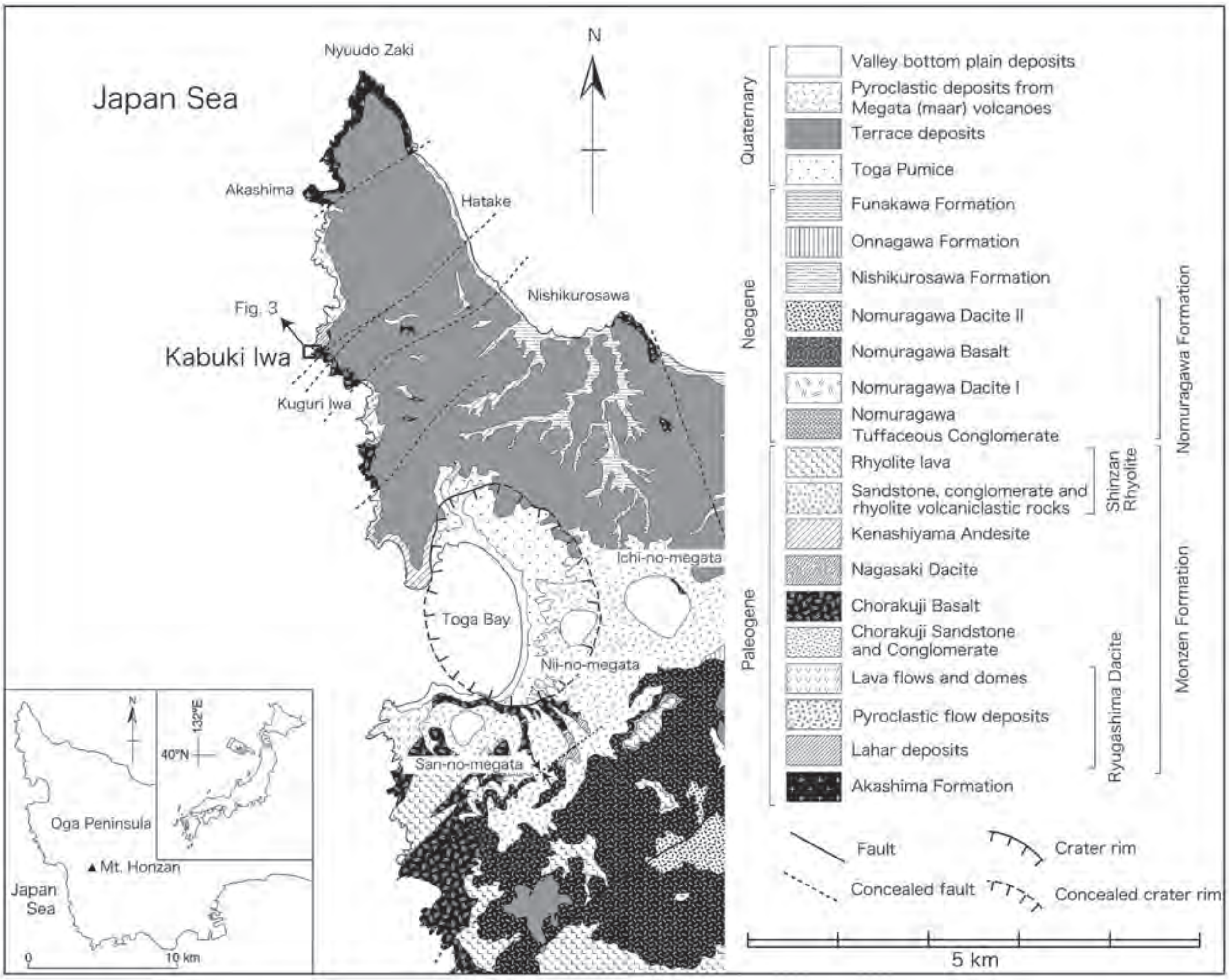

Fig. 1 Geologic map of the western Oga Peninsula, NE Japan, modified after Kobayashi *et al.* (2008)

the rapid opening of the Japan Sea (Kano *et al.*, 2007a).

2. Kabuki-Iwa volcanic succession

Kabuki Iwa constitutes part of the Chorakuji Basalt in the lower Monzen Formation (Kobayashi *et al.*, 2008), which lies mainly horizontally but cut by NE-SW-trending normal faults (Ohguchi *et al.*, 1987). The Chorakuji Basalt is dominated by basaltic aa lava flows but is locally inter-bedded with non-marine conglomerate, sandstone and finer clastic sediments that contain coaly materials and pollen fossils (Kano *et al.*, 2008). The exposed rocks at Kabuki Iwa are mainly volcanic in origin and are divided into five units I to V (Fig. 3) as described below.

The Monzen Formation ranges mainly from 30 Ma to 35 Ma, and a sample from Kabuki Iwa is 34.5±0.9 Ma in whole-rock K-Ar age (Ohguchi *et al.*, 1995). Ar-Ar dates of the biotite phenocrysts from the discordantly overlying Shinzan Rhyolites of the same Formation are, however, c. 34 Ma (Kano *et al.*, 2007b). Kabuki Iwa is, therefore, most likely to be Late Eocene in geologic age.

2.1 Unit I: Lower epiclastic rocks and pumice lapilli tuff

This unit is exposed on the northern side of Kabuki-Iwa and is composed mainly of epiclastic conglomerate and sandstone of debris flow origin. An inversely or inversely-to-normally graded, matrix-supported conglomerate constitutes the main part of the debris flow deposits and grades upward into stratified sandstone. The conglomerate contains fragments of trachytic andesite 5 to 50 cm across, and the matrix is composed of sand-sized fragments of similar rocks.

Debris flow deposits of unit I are stacked thick and commonly channel the underlying debris flow deposits with a width of meters and a thickness up to 5 m. The channels extend mainly in a NS direction and cross bedding is locally developed in the channel fills to indicate a current from north to south.

A 1-m-thick bed of biotite-hornblende pumice lapilli tuff occurs at the topmost part of the epiclastic succession. Constituent pumice clasts are up to 10 cm long,

Geologic age		Stratigraphy			Lithology	Radiometric age (Ma)
Miocene	Middle	Onnagawa Formation			Diatomaceous siltstone, siliceous siltstone and others	
Miocene	Middle	Nishikurosawa Formation			Conglomerate, sandstone, siltstone and others	
Miocene	Early			Tsubaki Sandstone and Conglomerate (Daijima Formation)	Conglomerate, sandstone, siltstone, dacite pyroclastic rocks and others	20.1±0.8 (FT: Kano *et al.*, 2008)
Miocene	Early			Tateyamazaki Dacite (Daijima Formation)	Dacite pumice lapilli tuff and exisotic blocks	21.4±0.8 (FT: Kano *et al.*, 2008)
Miocene	Early	Nomuragawa Formation	Nomuragawa dacite II		Dacite pyroclastic rocks	
Miocene	Early	Nomuragawa Formation	Nomuragawa Basalt	Sugoroku Basalt (Daijima Formation)	Basaltic andesite lavas and pyroclastic rocks	19.1±0.8, 20.9±0.5 (K-Ar: Kobayashi *et al.*, 2004); 20.19±0.78, 19.80±1.65 (K-Ar: Yoshida *et al.*, 2004)
Miocene	Early	Nomuragawa Formation	Nomuragawa Dacite I	Sugorokusawa Dacite (Daijima Formation)	Dacite pyroclastic rocks	21.0±1.2 (FT: Kobayashi *et al.*, 2004); 20.9±0.3, 22.0±1.1 (FT: Suzuki, 1980); 21.8±0.6, 21.9±0.7(FT: Ganzawa, 1987)
Miocene	Early	Nomuragawa Formation	Nomuragawa Tuffaceous Conglomerate	Sugorokusawa Conglomerate (Daijima Formation)	Conglomerate, sandstone and others	
Oligocene		?				
Eocene	Late	Monzen Formation	Shinzan Rhyolite		Subaqueous domes and shalow-sheeted intrusive rocks of rhyolite	34.04±0.16, 34.06±0.7, 36.7±1.3 (Ar-Ar, K-Ar, FT: Kano *et al.*, 2007a); 23.7±0.7 (FT: Ganzawa, 1987); 25.3±0.2 (FT: Suzuki, 1980)
Eocene	Late	Monzen Formation		Shiosenomisaki Sandstone and Conglomerate	Sandstone, mudstone, scoriaceous rocks and others	32.8±1.5, 34.7±1.9 (FT: Kano *et al.*, 2007b)
Eocene	Late	Monzen Formation	Kenashiyama Andesite		Andesite lavas (partly water-chilled)and pyroclastic rocks, sandstone, conglomerate and others	31.4±0.8, 31.9±0.9 (K-A: Ohguchi *et al.*, 1995)
Eocene	Late	Monzen Formation	Nagasaki Dacite		Dacite pyroclastic rocks and tuffaceous conglomerate	35.5±1.2 (FT: Kano *et al.*, 2007a); 27.1±1.3 (FT: Suzuki, 1980)
Eocene	Late	Monzen Formation	Chorakuji Basalt		Aa lavas and pillow lavas and pyroclasticf rocks of alkali olivine basalt and basaltic andesite	26.9±0.6, 29.9±0.7, 31.5±0.8, 32.5±0.8, 34.3±0.9, 34.5±0.9, 33.6±0.8 (K-Ar: Ohguchi *et al.*, 1995)
Eocene	Late	Monzen Formation		Chorakuji Sandstone and Conglomerate	Sandstone, conglomerate and finer clastic rocks	
Eocene	Late	Monzen Formation	Ryugashima Dacite		Trachyte to andesite block lavas and pyroclastic rocks, rhyolite domes, conglomerate and sandstone	27.1±0.6 (K-Ar: Ohguchi *et al.*, 1995); 29.8±0.6 (FT: Ganzawa, 1987); 31.5±1.7 (FT: Suzuki, 1980)
Eocene	Late	Monzen Formation	Butaijima Basalt		Aa lavas and pillow lavas and pyroclasticf rocks of alkali olivine basalt, basalt and basaltic andesite, and conglomerate and sandstone	31.1±0.7, 32.5±0.8, 32.8±0.8, 33.8±1.1 (K-Ar: Ohguchi *et al.*, 1995)
Eocene	Middle					
Eocene	Early	Akashima Formation			Dacite pyroclastic rocks	51.4±2.0 (FT: Suzuki, 1980); 53.4±1.4 (FT: Ganzawa, 1987)
Eocene	Early	Akashima Formation			Volcanic breccias	49.3±2.7 (FT: Suzuki, 1980)
Paleocene		Granite (as blocks in Akashima Formation)			Hornblende-biotite granite	87.0± 1.8 Ma, 89.9± 2.6 Ma, 93.3± 1.9 Ma (U-Pb: Ogasawara *et al.*, 2005); 60.7±2.1 (FT: Suzuki, 1980)

FT: Fission track age, K-Ar: K-Ar age, U-Pb: U-Pb age

Fig. 2　Stratigraphy of the western Oga Peninsula, modified after Kobayashi *et al.* (2008)

set in a matrix of glass shards and other ash grains and are mutually arranged parallel.

The succession of epiclastic debris flow deposits is interpreted to form a volcaniclastic apron. Pumice lapilli tuff contains no evidence for emplacement at high temperatures but comprises mostly monomictic volcaniclastic materials, and therefore, could be a deposit of pumice flow down on the apron.

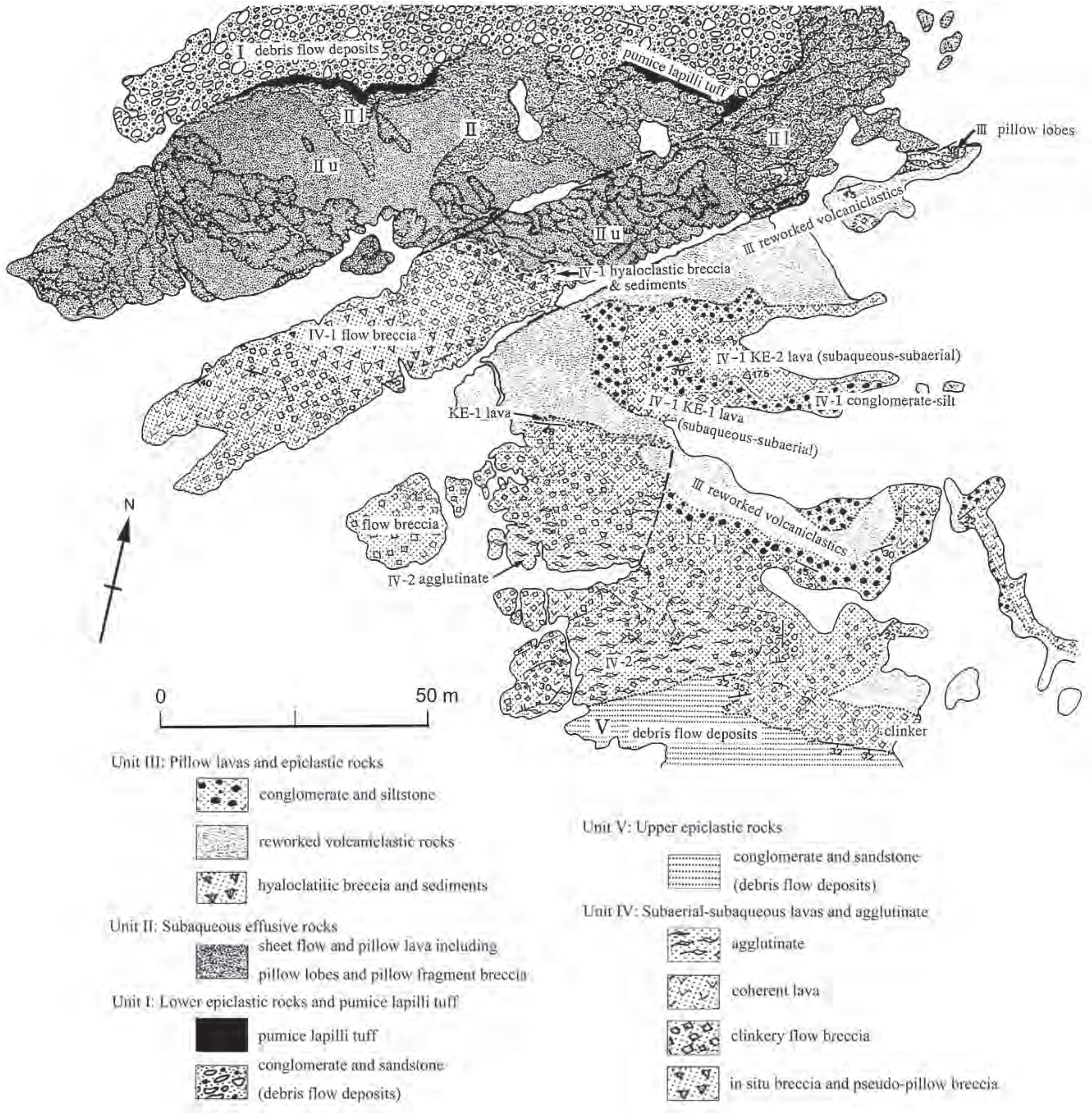

Fig. 3 Geologic map of Kabuki Iwa, Oga Peninsula, NE Japan.

2.2 Unit II: Subaqueous effusive rocks

This unit overlies the dacite pumice-lapilli tuff of unit I and contains a variety of volcanic clasts mainly of olivine basaltic andesite. It is divided into the lower unit II-l and upper unit II-u, which are further divided into units II-l-1 (sheet flows), II-l-2 (lava lobes) and II-l-3 (in-situ breccias/flow breccias), and units II-u-1 (pillow lobe) and II-u-2 (pillow fragment breccia) according to their modes of occurrence (Fig. 4).

2.2.1 Unit II-l: Sheet flows, lava lobes, and flow breccias

The sheet flows of unit II-l-1 have given a stress load to the underlying pumice-lapilli bed. They are jointed at the basal in a 50 cm interval to form tiny columns 10 cm long and 15 cm wide with a glassy margin and are intensely fragmented in situ at the base to form breccias (unit II-l-3). Large fragments of the flow breccias have coarse prismatic joints 1 m wide. Upper surfaces of the sheet flows are also fragmented in situ. The sheet flows are separated by breccias to make flow units 4 to 8 m thick. Lava lobes elliptical in plan view and several to ten meters across are extruded from the sheet flows northeastward (unit II-l-2), just like ‘toes’ of pahoephoe lava flows (Yamagishi, 1991).

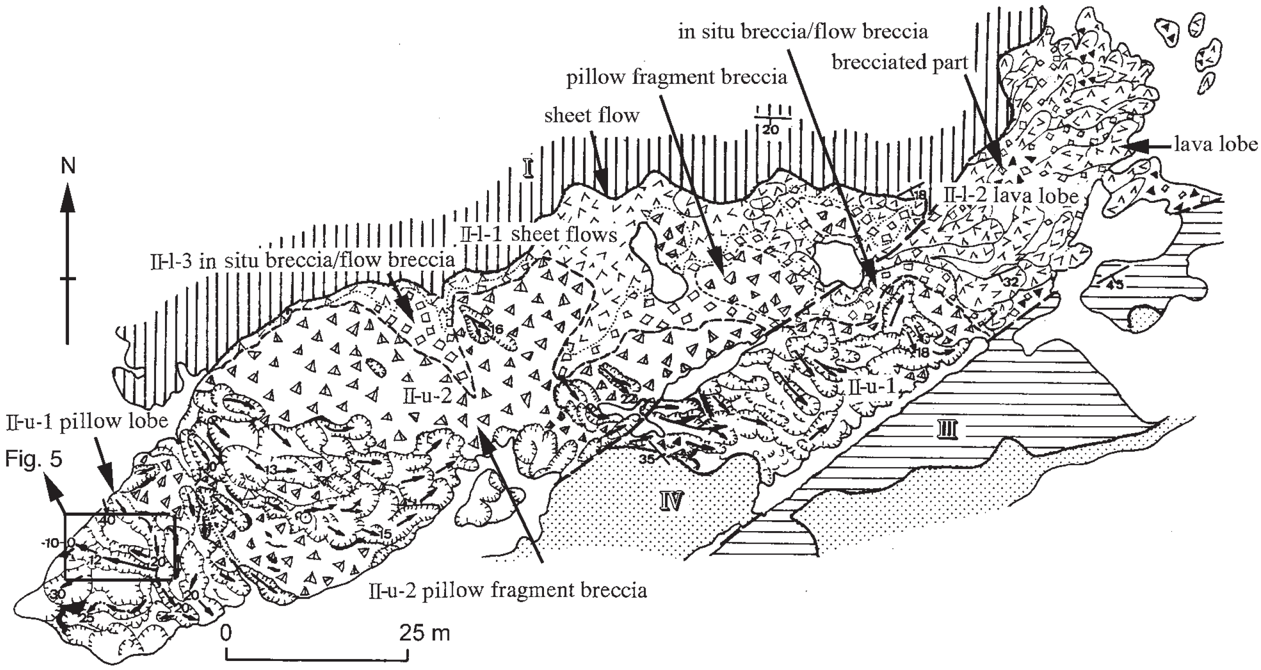

Fig. 4 Sketch map of unit II at Kabuki Iwa.

2.2.2 Unit II-u: Pillow lobes and pillow fragment breccias

Unit II-u-1: Pillow lobes

Pillow lobes in unit II-u-1 well preserve the primary structures (Plates la and 1b; Plates 2a and 2b).

The upper surfaces of pillow lobes are characterized by transverse and longitudinal spreading cracks (Moore, 1975; Yamagishi, 1985), ropy wrinkles, squeezed-up structure and pillow buds (Fig. 5). Transverse spreading cracks show V-shaped depressions, and longitudinal spreading cracks display both V-shaped depressions and tiny grabens. Ropy wrinkles occur on the marginal toes of pillow lobes. They are curved toward the front (Plate 2a and Fig. 4) with a width of 10-20 cm and a length of 1 m or more and appear to fall down from the source in the longitudinal cross section. An oxidized rigid crust 1-2 cm across shapes the wrinkles. The ridges are blunt or vague, perhaps due to erosion.

Pillow lobes drape down as a cylindrical tube (Plate 1a) or tabular flow (Plate 1b) in diverse directions over a distance of 30 m (Photogravure 1a of Ohguchi et al., 1987; Plate 1b). Cylindrical tubes dominate on steep slopes and tabular flows appear to dominate on gentle slopes. Walker (1992) defined the former and the latter as flow-foot pillows and tabular pillowed flows, respectively.

Some pillow lobes drape down on considerably steep slopes to commingle their crusts into the interiors or slip down from vertical spreading cracks on the marginal fronts (Yamagishi, 1985). Some other pillow lobes are folded, probably by further lava drains, and left a draping tongue (Photogravure 1c of Ohguchi et al., 1987). The other pillow lobes have hollows from which a new pillow lobe draped down (Plate 2b). The interstices between the crusts of the early pillow lobe and the new pillow lobe or between the lava crusts are filled with sandstone to siltstone to form peperite by fluidization of wet sediments (Kokelaar, 1982). These pillow lobes have ellipsoidal vesicles up to a few centimeters across in the interior. They extend mainly from the northwest, diverge to the southeast and continue further to the east or northeast (Fig. 4).

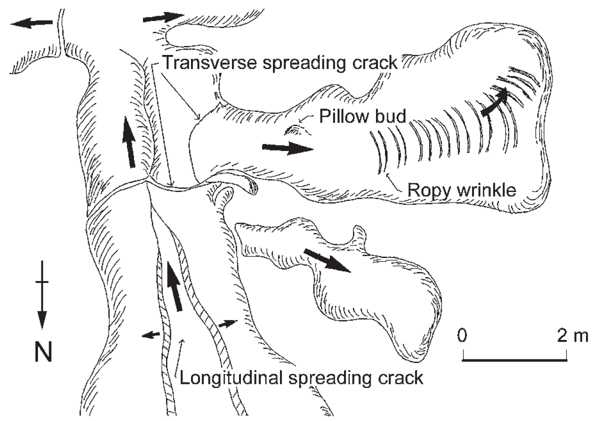

Fig. 5 Schematic sketch of pillow lobes in unit II. The location is shown in Fig. 4.

II-u-2: Pillow fragment breccias

Pillow fragment breccias (Staudigel and Schmincke, 1984) occur along the marginal front of the pillow lobe sequence of unit II-l. They are composed of amoeboid-shaped, isolated pillows with oxidized crusts and a matrix of glassy fragments. Calcite and zeolite fill the interstices between the glassy fragments. Collapsing of pillow lobe toes probably formed this unit.

2.3 Unit III: Pillow lavas and epiclastic rocks

Pillow lavas of porphyritic olivine-pyroxene basaltic andesite occur at the basal part of unit III and also occur in another southern segment. Constituent pillow lobes are vesicular and are 1 m across at most. They have, in places, ropy wrinkles 1 cm wide and high, and also have vertical and longitudinal cracks both of which are 10 cm wide and up to 15 cm deep. Some pillow lobes bury the caves of ancient benches and fill the cracks of ancient cliffs of underlying pillow fragment breccias. Pillow lobes decrease in thickness toward the southwest and are interpreted to have flowed from the northeast.

The main part of unit III is occupied by volcanic breccias. The breccias are chaotic and unsorted, composed of angular to sub-rounded fragments of basaltic andesite bombs and blocks, and a heterolithic coarse-grained matrix. They are interpreted as debris flows in origin though inverse grading has not been recognized.

2.4 Unit IV: Subaerial-subaqueous lavas and agglutinate

Two sheet lavas KE-1 and KE-2 of basaltic andesite are recognized in unit IV. They are up to 5 m thick and have platy joints, inside of which are rude compared with outer margins. Numerous elongate vesicles up to 2 cm by 5 cm long within the lava flows are present along the marginal toes with a preferred-orientation in coincidence with ramp structures (Plate 2c). Aggregates of variably vesicular, partly welded, reddish brown fragments underlie and overlie the sheet lavas with a transitional boundary (Plate 2d). They are over 50 cm thick and are replaced by in-situ pseudo-pillow breccias in the southwestern extensions. The vesicular aggregates are interpreted as aa clinkers that constitute part of aa lava flows, and the lateral change into pseudo-pillow breccias likely represents a subaerial-subaqueous transition (Jones and Nelson, 1970).

Agglutinates occur south of the subaerial to subaqueous lava flows. Amoeboid-shaped (Plate 3a) and spindle-shaped less reddish bombs are 10-30 cm across (Plate 3b), and their fragments are scattered in the agglutinate. An irregular-shaped dike of a few meters across extends in a direction of N30ºE, and agglutinates accumulate on and along this dike (Plate 3c), presumably to form a spatter rampart produced by lava fountains (Macdonald, 1972). Fragments of bombs, several tens of centimeters across with elongate aa-type vesicles of millimeters to centimeters size, are scattered in chaotic collapse breccias of agglutinate 50 m away from this interpretative rampart.

2.5 Unit V: Upper epiclastic rocks

Stratified volcanic conglomerate beds discordantly overlie unit IV. They are 30 m thick in total and are composed of cobbles and boulders of andesite and dacite. The conglomerate beds are inter-bedded with sandstone beds of a few tens of centimeters thick and fill channels 5 to 10 m across. A vertical trace of the boulders and cobbles shows inverse and normal to inverse grading. We suggest that these channel-filling, inversely graded beds are deposits from debris flows and constitute a volcanic apron.

3. Discussion and summary

As summarized in Fig. 6, we have recognized the following five units in the Kabuki-Iwa area: unit I (lower

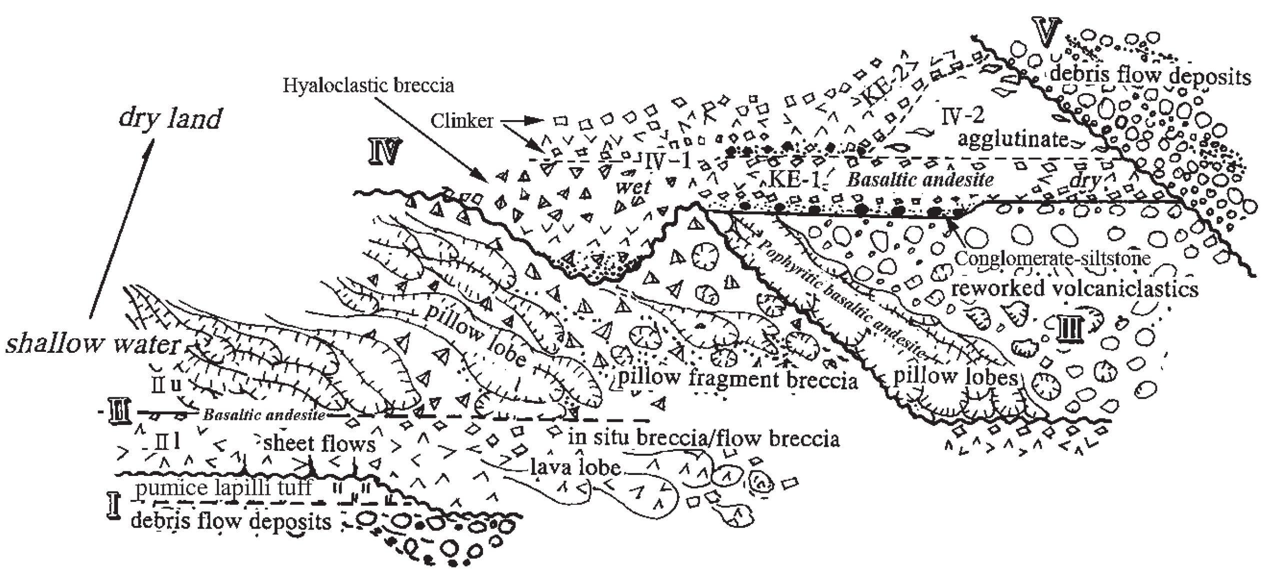

Fig. 6 Schematic illustration of the Kabuki Iwa volcanic succession (not to scale).

epiclastic volcanic rocks and pumice lapilli tuff), unit II (subaqueous effusive rocks), unit III (pillow lava and epiclastic rocks), unit IV (subaerial-subaqueous lavas and agglutinates), and unit V (upper epiclastic rocks). Pillow lavas are associated with pillow fragment breccias in unit II and are interpreted to have flowed from the northwest to the southeast then further to the northeast. The sheet flows of the overlying unit III are also likely to have flowed toward the south. On the other hand, aa lavas in unit IV flowed toward the southwest, entered water to transform its sheet form over the subaqueous slope and fragmented further into pseudo-pillow breccias. At the same time, Hawaiian/Strombolian eruptions through a fissure vent projected spatter clasts, scoriae, and bombs onto land to produce a spatter rampart.

The Kabuki-Iwa succession records deposition of debris flows and a pumice flow on a volcanic apron of unit I, followed by the eruption of units II, III and IV mentioned above, and the deposition of debris flows of unit V. The host Monzen Formation contains contemporary parallel dike swarms, which extend northeast and indicate an extensional stress field, and the gross accumulation rate of the formation is on an order of 100 m per million years (Kobayashi *et al*., 2008). In conclusion, the Kabuki-Iwa succession represents volcanic activity at a subaerial-subaqueous transition (Fig. 6) and suggests the presence of a Late Eocene shallow-water area that was slowly subsided on the volcanic front or back-arc side of the volcanic arc at that time.

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大陸縁辺の後期始新世火山活動：東北日本男鹿半島，かぶき岩の火山岩相

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要　旨

男鹿半島西部北西海岸のかぶき岩は，後期始新世の玄武岩質安山岩アア溶岩・枕状溶岩，デイサイト火砕流堆積物とラハール堆積物などの火山岩再堆積物からなる．陸上火山噴出物と水底火山噴出物との共存は，当時のかぶき岩が水際にあったことを示す．かぶき岩から連続するこれらの岩石は，周辺地域において同時期の，北東南西方向に延びた平行岩脈群と同方向の正断層群と共存しており，前期中新世に日本海が急速に拡大する前の，火山活動を伴いながらゆっくり沈降する展張場に噴出したと考えられる．

Plate 1 (a) Pillow lobes draping down steep slope, showing cylindrical tube (unit II-u-1). (b) Pillow lobes diverging and draping down gentle slope, showing tabular flow (unit II-u-1).

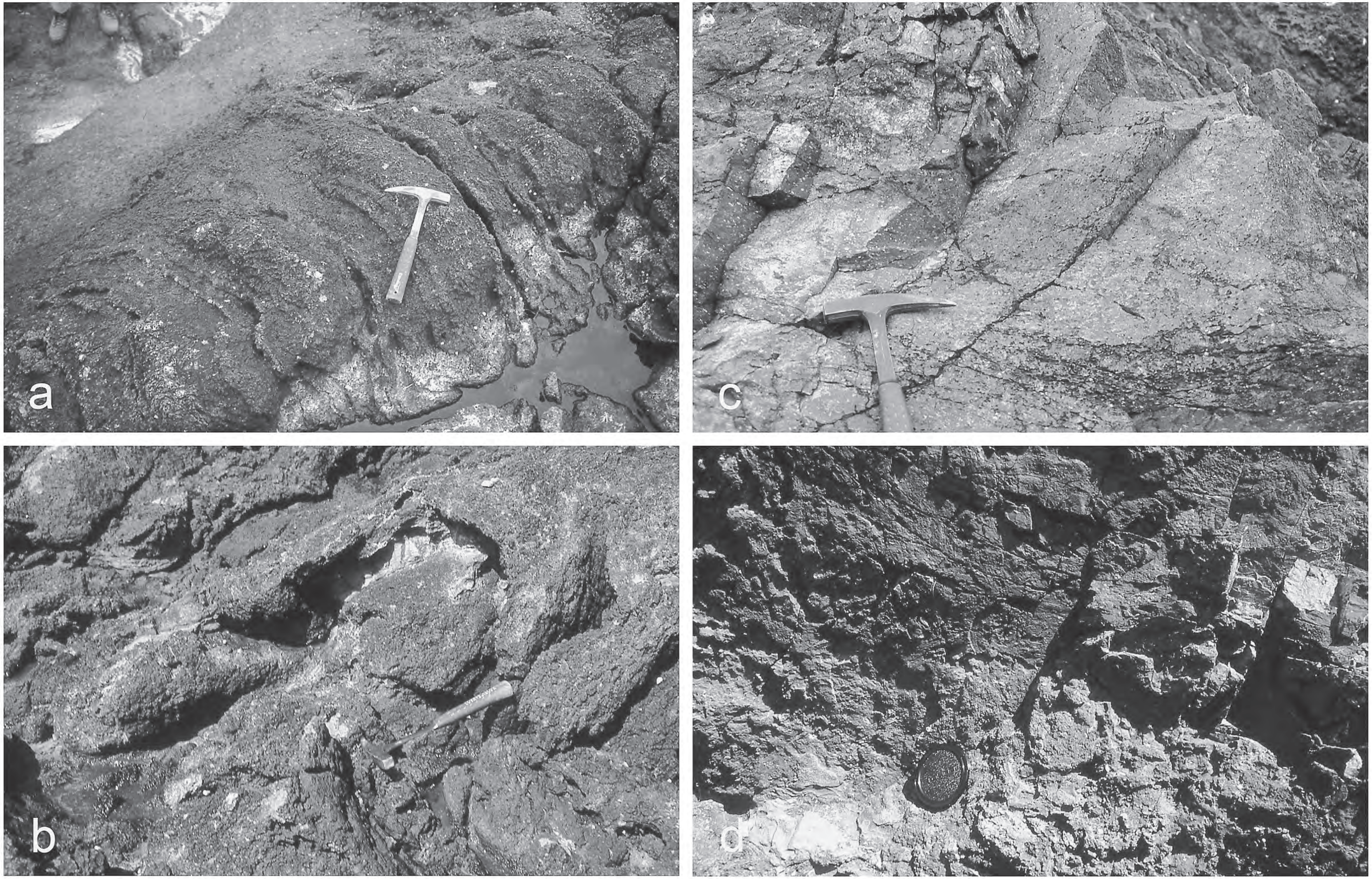

Plate 2 (a) A pillow lobe showing large ropy winkles, the ridges of which are blunt and are convex to the flow direction (unit II-u-1). (b) A pillow lobe draping through the hollow of an early pillow lobe (unit II-u-1). The interstices between the hollow crust and the draping pillow are filled with mudstone. (c) Marginal lava front, showing ramp structures defined by vesicle arrangement (unit IV-1). Flow directs from left to right. (d) Basal aa clinker beneath platy and columnar jointed lava (unit IV-1).

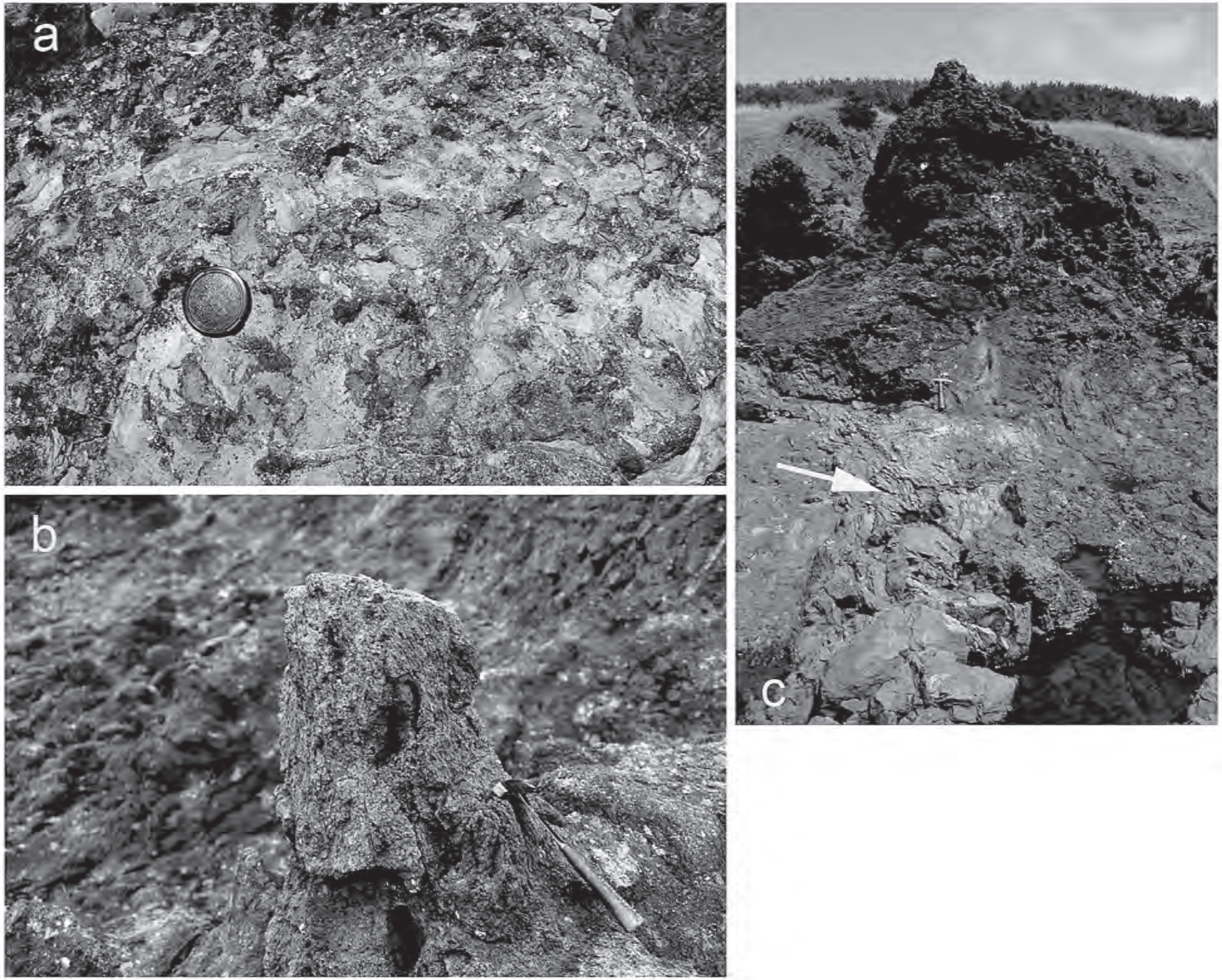

Plate 3 (a) Agglutinate composed mostly of amoeboid-shaped bombs (unit IV-2). (b) Volcanic bomb in the agglutinate (unit IV-2). (c) Spatter rampart and feeder dike associated with agglutinates (unit IV-2). Arrow indicates the feeder dike.