Subaqueous dacite lavas were found in three older central cones in the northern part of the Aso caldera basin, Kyushu. The upper limit of distribution of the subaqueous lavas is about 510 m above sea level, above which subaerial lavas are developed. This evidence suggests that the water level of the Palaeo-Aso Lake had reached to this elevation at the time of eruption.

The subaqueous lavas consist of numerous dacite blocks and their comminuted fragments. Some of the larger blocks have a pillow-like appearance with columnar joints. These blocks are named "pseudo-pillow lava" because of difference in many respects from basaltic pillow lava. The mechanism of formation of the pseudo-pillow lavas can be interpreted as follows: - The viscous lava is cracked with curved or spheroidal fissures during movement and cooling in water. Water penetrates into the fissures, and cooling contraction produces columnar joints perpendicular to the fissure. Then, pillow-like blocks split away, and the outer rim of the blocks cuts the flow layers obliquely. This is an important feature that distinguishes the acidic pseudo-pillows from basaltic pillows.

INTRODUCTION

It is well known that pillow lavas and hyaloclastites are produced by subaqueous eruptions of basaltic lava (Rittmann, 1962; Macdonald, 1972; Moore, 1975). Subaqueous eruptions of andesite lava also yield similar products (Snyder and Fraser, 1963a; Kuno, 1968; Yamagishi, 1973; and others). Even in the case of subaqueous dacite and rhyolite, pillow lavas have been rarely reported (Snyder and Fraser, 1963b; Ivanov, in Macdonald, 1972). Stark (1939, p. 207) mentioned that the term “pillow” is not genetic but simply a morphologic term for ellipsoidal structure. However, such pillow lavas of acid composition must be different from those of basalt in many respects, as inferred from their higher viscosity at the time of eruption. Recently, the authors found some subaqueous acid lavas with pillow-like structure in the northern part of the Aso caldera basin, Kyushu. The term "pseudo-pillow lava" is used here for such subaqueous lavas. This report is intended to give 1) occurrence of the pseudo-pillow lavas, 2) geological significance of existence of the subaqueous lavas in the caldera basin, and 3) comparison between the pseudo-pillow lavas and basaltic pillow lavas.

* Presented by the senior author at the 85th Meeting of the Western Japan Branch of the Geological Society of Japan held at Kagoshima on Feb. 23, 1975. (Manuscript received December 10, 1975)
GEOLOGICAL SETTING

The Aso caldera is located in central Kyushu, Japan, and is one of the largest calderas in the world (24×18 km across) (Fig. 1). The caldera was formed in late Pleistocene as a result of eruptions of large amounts of acid to intermediate magma mainly as pyroclastic flows. Subsequent to the depression of the caldera, the Palaeo-Aso Lake appeared in the caldera basin, probably in two stages as inferred from field evidence near the Tateno barranco (Matumoto, 1952; Watanabe, 1972). The lake of the first stage soon disappeared when the barranco was developed, and a second lake was formed by the damming up of the barranco with central cone lavas.

In the northern part of the caldera basin, there are three isolated hills, i.e. Hon-zuka, Kita-zuka and Hai-zuka (Figs. 1 and 2). The caldera floor in this region is a flat plain with an elevation of about 500 m above sea level. The hills project through the plain up to heights ranging from 20 to 74 m. No chronological data of the hills are available, but their eroded topography suggests that they were formed during the earlier stage of the central cone activity in the Aso caldera.

Fig. 1. Aso caldera and location of pseudo-pillow lavas.

Fig. 2. Geologic sketch map. 1: subaqueous dacite lavas including pseudo-pillow, 2: subaerial dacite lavas, 3: hypersthene-bearing olivine-augite-andesite, 4: Alluvial sediments, 5: volcanic ash.

Younger volcanic ash layers mostly derived from the central cones, cover the hills and surrounding plain. Beneath the ash layers, bog iron beds are found in the surrounding plain. A lava flow of hypersthene-bearing olivine-augite-andesite which was derived from the central part of the caldera, covers the volcanic ash layers to the
south of the hills. The hills are largely composed of dacite lavas. However, due to very limited exposure, the relation between the dacite lavas and the bog iron beds cannot be observed.

Iki (1901) did not regard the hills as independent volcanoes but simply as the remnants of an eroded terrain of volcanic sediments. Matumoto (1943) supposed that the hills were small cones erupted in the earlier stage of the central cone activity. But later he (Matumoto, 1952) mentioned that they might be remnants of an old volcano which formed prior to the depression of the caldera. Recent observations by the present authors lead to a conclusion that the hills are central cones erupted through the Palaeo-Aso Lake.

**Occurrence of Subaqueous Lavas and Pseudo-pillow Structure**

The best occurrence of subaqueous lavas can be observed at the southwestern part of Hon-zuka. The subaqueous lavas mainly consist of numerous blocks which are angular or subangular in form, pale or dark grey in color, and several to tens of centimeters in diameter. Moreover, in this outcrop, many large blocks up to few meters in diameter, are found. Weak stratification can be observed in some parts. The shape of the large blocks varies from roundish to angular. It is characteristic feature that elongated or collapsed forms such as commonly present in basaltic pillow lavas is not developed. However, columnar joints perpendicular to the surface of each block are well developed as in basaltic pillows. The width of each of the columns usually becomes narrower toward the surface of the block. Since both inner and outer parts of the blocks are mostly composed of dacite glass (Table 1), no clear chilled margin can be observed. However, the outer rim (1–2 cm in thickness) is less vesiculated and cut by very fine joints. In some parts, the outer rim is cracked and is similar in appearance to a tortoise shell or the surface of breadcrust bombs. The inner part is very vesiculated as in pumice, and large voids up to 10 cm in diameter are rarely found.

Figs. 3, 4, 5 and 6 show the occurrence and interpretation of formation of the pseudo-pillow structure. The occurrence as shown in Fig. 4 suggests the following mechanism. The large mass of viscous lava is cracked with curved or spheroidal fissures by releasing of stresses caused by its movement and cooling contraction. Water penetrates into the fissures. Cooling by the

![Fig. 3. Pseudo-pillows splitting from a large lava mass.](image)

![Fig. 4. Close up of Fig. 3 showing development of columnar joints perpendicular to a new fissure.](image)
Fig. 5. A pseudo-pillow. The outer rim cuts the flow layers. Large cavities in the interior were formed by vesiculation after chilling of the outer part.

Fig. 6. A pseudo-pillow. Note columnar joints perpendicular to the surfaces, higher vesiculation in the interior, and curved surfaces (concave and convex) and edges of fracture origin.

water produces isothermal surfaces parallel to the fissures. Thus, cooling contraction may result in formation of columnar joints which extend toward both sides from the fissures at right angle to the isothermal surfaces. Consequently, blocks surrounded by curved surfaces with columnar joints, are produced. These blocks are not completely spheroidal but have edges at the junction of curved surfaces which are either convex or concave as shown in Figs. 4 and 6. When vesiculation of the inner part still continues after surface chilling, the blocks become more roundish in form and a surface structure similar to bread-crust bombs is produced. Such roundish lava blocks resemble in appearance to ordinary pillows of subaqueous basaltic lava. However, it is remarked here that the outer rim of the lava blocks obliquely crosses the flow layers which are represented by the parallel arrangement of gas cavities, as well shown in Fig. 5. Such a feature, together with above mentioned characteristics, clearly distinguishes the pseudo-pillows from basaltic pillows.

The larger blocks with pseudo-pillow structure are filled up by comminuted fragments. These fragments are usually angular in outline and have the same petrographic characteristics as the larger blocks. These fragments may also be product of fragmentation of subaqueous lava, such as described by Kuno (1968). If fragmentation is extensive, the pseudo-pillows may be destroyed. Pichler (1965) reported such an occurrence in acid hyaloclastite in which no pillows were found.

**COMPOSITION OF THE SUBAQUEOUS LAVA**

The lavas of the three hills consist of glassy dacite. Phenocrystic minerals in these lavas are about one tenth in volume, and the groundmass is made up colorless glass ($N_D=1.514\pm0.002$) with a few micro-lites. Chemical and modal compositions of a pseudo-pillow lava from Hon-zuka are given in Table 1. The lava is hornblende- and augite-bearing hypersthene dacite. It is noticed that the Hon-zuka lava resembles some lavas of the Eboshi-dake group which also erupted in the earlier stage of the central cone activity in the Aso caldera (Matsumoto, 1963).
Table 1. Chemical composition, norm, and mode of a pseudo-pillow lava*.

<table>
<thead>
<tr>
<th></th>
<th>water free</th>
<th>C.I.P.W. Norm</th>
<th>Mode of S*</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>65.04</td>
<td>O</td>
<td>Phenocrysts</td>
</tr>
<tr>
<td>TiO₂</td>
<td>0.48</td>
<td>Or</td>
<td>10.6</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>16.83</td>
<td>Ab</td>
<td>Plagioclase</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>0.75</td>
<td>An</td>
<td>Hypersthene</td>
</tr>
<tr>
<td>MnO</td>
<td>3.08</td>
<td>C</td>
<td>Magnelite</td>
</tr>
<tr>
<td>CaO</td>
<td>2.08</td>
<td>Hornblende</td>
<td>0.1</td>
</tr>
<tr>
<td>MgO</td>
<td>0.78</td>
<td>Fs</td>
<td>Groundmass</td>
</tr>
<tr>
<td>Na₂O</td>
<td>5.10</td>
<td>Mt</td>
<td>3.21</td>
</tr>
<tr>
<td>K₂O</td>
<td>4.21</td>
<td>Ht</td>
<td>Glass</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>0.10</td>
<td>Ap</td>
<td>0.23</td>
</tr>
<tr>
<td>MgO</td>
<td>0.47</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>100.00</td>
<td>100.00</td>
<td>100.00</td>
</tr>
</tbody>
</table>


GEOLOGICAL SIGNIFICANCE OF EXISTENCE OF SUBAQUEOUS LAVAS

The existence of subaqueous lavas in the Aso caldera basin may provide three important contributions to the history of the caldera as follows:

1) The three hills are central cones erupted in the Palaeo-Aso Lake. Consequently, post-caldera volcanism has taken place not only in the central part but also in the northern part of the caldera basin (Fig. 1).

2) The upper limit of distribution of the subaqueous lavas is about 510 m above sea level, above which subaerial lavas are developed in the three hills. The same level of the limit of exposure of the subaqueous lavas suggests that no significant vertical movement has occurred after the eruption and that the water level of the Palaeo-Aso Lake had reached about 510 m above sea level at the time of eruption.

3) The water probably rose to this level because of the damming up of the Tateno barranco with a central cone lava flow (“Tochinoki-2 lava” by Watanabe, 1972). This corresponds to the formation of the second stage lake.

Recently, the senior author has found subaqueous lavas of andesite at several meters above sea level in Moe-jima, an islet in the Aira caldera of south Kyushu. This evidence suggests that these andesite lavas solidified in a subaqueous environment, and then uplifted. Similar subaqueous lavas are also reported from Okinoshima, an islet in the same caldera (Aramaki, 1975). In many other caldera basins, subaqueous lavas are also expected to be found.

COMPARISON BETWEEN BASIC AND ACIDIC SUBAQUEOUS LAVAS

A comparison between pillows of basic lava and pseudo-pillows of acidic composition is attempted as listed in Table 2.

Table 2. Comparison between acidic pseudo-pillow lava and basic pillow lava.

<table>
<thead>
<tr>
<th>Type</th>
<th>Acidic</th>
<th>Basic</th>
</tr>
</thead>
<tbody>
<tr>
<td>size</td>
<td>variable in each deposit</td>
<td>relatively uniform in each deposit</td>
</tr>
<tr>
<td>profile</td>
<td>pentagonal to polygonal</td>
<td>pentagonal to collapsed cone</td>
</tr>
<tr>
<td>surface特征</td>
<td>cool surface covered or covered, variegated shell, or broad-crested</td>
<td>smooth, minute, variable, variegated shell, flat</td>
</tr>
<tr>
<td>cooled margins</td>
<td>solid, not indurated in blocky mass</td>
<td>usually distinct</td>
</tr>
<tr>
<td>joint</td>
<td>perpendicular to surface, cavities always indurated by margin</td>
<td>radial</td>
</tr>
<tr>
<td>rock fabric</td>
<td>no relation between form and flow layer</td>
<td>Cloud layers conformable to the water flow of origin</td>
</tr>
<tr>
<td>water at base</td>
<td>trills to rock-rafted</td>
<td>usually fluid</td>
</tr>
</tbody>
</table>

The morphological features of the subaqueous andesitic lavas described by Kuno (1968) are roughly intermediate between those of subaqueous basic and acidic lavas. Some pillow lavas of Oshoro in Hokkaido (Yamagishi, 1973), and subaqueous lavas of Moe-jima in the Aira caldera have similar features.
The difference in form and mechanism of formation between basic pillows and acidic pseudo-pillows of subaqueous lavas may largely depend on differences in the viscosity which is mainly controlled by both chemical composition and temperature at the time of eruption.

ACKNOWLEDGMENTS

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REFERENCES


阿蘇カルデラ内の偽枕状溶岩

渡辺 一徳・勝井 章雄

阿蘇カルデラ内北部の木塚・北塚・灰塚はいずれも石灰安山岩の溶岩からなる古い中央火口丘で、それらの下流部には幅約 510 m のレベルまで水没により破壊された溶岩が発達している。故にこの水中溶岩が噴出した時期にはカルデラはこのレベルまで湖であったと推定される。この水中溶岩は大小の岩塊と同質の無片からなり、その中には枕状溶岩に類似した柱状節理をもつ岩塊が含まれている。この種の岩塊は多くの点で通常の枕状溶岩とは異なっているので、偽枕状溶岩と呼ぶことにする。その産状の詳細は観察によれば、偽枕状溶岩は水中を前進中の柱状の高い溶岩に層積した割れ目が入り、これに沿って侵入した水で急冷され、分離したものである。このため仮枕状溶岩は表面に垂直な柱状節理を生じているが、通常の枕状溶岩とがって外形はもとの流理構造を明瞭に切っている。