MEMOIRS OF THE FACULTY OF SCIENCE, KYOTO UNIVERSITY, SERIES OF GEOL. & MINERAL.,
Vol. XXXIX, No. 2 pp. 83–98, Feb. 28, 1973

Spilitic Pillow Lava in Panjal Trap of Kashmir, India*

By

Keiji NAKAZAWA and Hari Mohan KAPOOR**

(Received August 8, 1972)

Abstract

The spilite exhibiting pillow structure has been discovered from the Permian Panjal Trap at Guryul Ravine about 12 km east of Srinagar in Kashmir in the year 1969. The field occurrence, major and rare earth compositions, and microscopical description are given in this article.

The chemical compositions indicate a strong resemblance with the late Paleozoic geosynclinal basic rocks having some "oceanic" nature in Japan, in spite of the fact that the pillow lava occurred under the coastal or lagoonal environment.

Introduction

The spilitic lava-flows and pillow structures were not known in the Panjal Trap till the present find. These were recognized by authors during the course of studies on the Permian-Triassic boundary of Guryul Ravine section in the year 1969 (NAKAZAWA *et al.*, 1970). Guryul Ravine, situated about a kilometer north of Khunamuh is nearly 12 km east of Srinagar (Fig. 1).

Among several volcanic activities of the geologic past in Indian subcontinent, pillow structures are known from Dharwars (Archeans) of Mysore (RAQHUNATHA RAO, 1937; PICHAMUTHU, 1950 and 1957; and others), from a number of localities in Deccan Trap area (WALKER, 1969) and in flows of Kheti of U. P. Himalaya (K. K. SRIVASTAVA, personal information). The spheroidal or sack-like structures in the lavas of Kumaon Himalaya considered to be weathering product by KRAFFT (1902) are referred to be pillows according to CHATTERJEE (1959, p. 22).

Spilites, on the other hand, are known from several volcanic activities. The pillow lavas of Mysore and Kheti are spilitic in composition. SHAH (1966) and WAKHALOO and SHAH (1968) also reported spilites from Western Pir Panjal in the Lower Paleozoic Bafliaz volcanics and IYENGAR and ALWAR (1965) and IYENGAR and BANERJEE (1964) from Orissa.

Panjal Trap

General occurrence

LYDEKKER (1883) introduced the name Panjal Trap to an enormous series

---

* Published with the permission of the Director General, Geological Survey of India.

** Geological Survey of India, Lucknow, India.

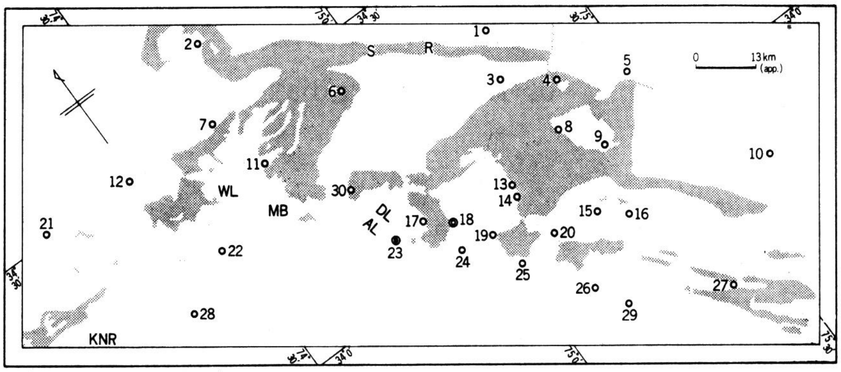


Fig. 1. Sketch map showing distribution of Panjal Trap in part of Kashmir. Dotted area: Panjal Trap, white: other formations. Numbers refer to localities. 1. Sonamarg, 2. Kanzaiwan, 3. Basmai, 4. Kolahoi, 5. Astanmarg, 6. Haramukh, 7. Tragbal, 8. Arau, 9. Pahlgam, 10. Wardwan, 11. Aragam, 12. Sogam, 13. Narastan, 14. Lam, 15. Lehindajjar, 16. Aish Maqam, 17. Bren, 18. Guryul Ravine, 19. Mandikpal, 20. Tral, 21. Trahagam, 22. Sopor, 23. Srinagar, 24. Pampur, 25. Awantipur, 26. Bijbiara, 27. Naubug, 28. Baramula, 29. Anantnag, 30. Gandarbal. SR: Sogput Range, MB: Manasbal Lake, DL: Dal Lake, AL: Anchor Lake, KNR: Kazi Nag Range. (adopted from Geological Map of the Kashmir Valley by C. S. MIDDLEMISS, H. S. BION and D. N. WADIA in Manual of the Geology of India and Burma, volume 2 by E. H. PASCOE, 1959; facing p. 638).

of basic lava flows, after Pir Panjal Range of Kashmir Himalaya. The Trap also continues on the northwest extension of the Zansker Range, beyond Nun-Kun to as far as Hazara and also developes in Ladakh farther east to the very far borders of Kashmir territory; a few exposures are met within Baltistan-Skardu area (WADIA, 1961) (Fig. 1).

Panjal Trap forms the upper part of the Panjal Volcanic Series; the lower one being Agglomeratic Slate, which represents explosive volcanic action (MIDDLEMISS, 1910) and is equivalent to the Panjal Conglomerates of LYDEKKER (1883)*.

Panjal Trap, in general, occupies a position between the Agglomeratic Slate and the Lower Gondwana bed, but commenced from varying horizons from the Moscovian, Uralian and Permian in different places, and extended with its upper limit likewise to the Lower Permian in some places and to the Upper Triassic in others (WADIA, 1961). The volcanic activity was most intense during the middle part of the Lower Permian when it reached climax, after which it diminished up to the end of the Lower Permian.

Recently, one of the authors (HMK) noticed that Panjal Trap in the western part (Nagmarg-Bren) is underlain by plant-bearing Lower Gondwana sediments of a shallow water environment. Even the flows overlying the Lower Gondwana

* LYDEKKER included sediments from Pre-Cambrian to Panjal flows into a single 'Panjal System'. His classification was revised by MIDDLEMISS (1910).

of Nagmarg-Bren were laid under shallow condition and has rhythmic deposition as evidenced by intertrappean shales and slates. The volcanic activity gradually moved towards east in Srinagar and Liddar Valley areas, since the flows in this part of valley are younger than those of west as revealed by plant fossils present in shales and slates. The study of Agglomeratic Slate in recent years indicates that the basin was gradually rising and shifting, which might have continued during the time of the upwelling of the trap.

The maximum thickness of flows is not yet certain though they have been estimated to acquire thickness more than 2131 m, 2500 m and 1800 m in Lolab Valley, Erin Valley and Gulmarg, respectively (WADIA, 1934; MIDDLEMISS, 1911).

The presence of number of flows is known but the exact number in any of the locality has not so far been worked out. Thickness of individual flow is variable from a few centimeters to 30 m. In many places monotonous continuity of unit flow is seen extending for kilometers.

According to PASCOE (1959, p. 780) the eruptions took place either on a coastal land surface subject to occasional transgressions of the sea, or on a submarine shelf. In northwest Kashmir, traps were laid subaerially (WADIA, 1961), and in the southern and eastern Kashmir they were erupted under marine condition (WADIA, 1934, p. 161). The present authors, however, feel that subaqeous conditions are almost definite for this part of Kashmir, but whether these were laid under marine, lagoonal or coastal conditions are to be ascertained. A very few volcanic structures are so far known from the trap excepting for vesicular and amygdaloidal structures, and lonely record of GANJU (1944, p.127) of flow structures is in a slide of acid rock. The characters of 'bedding' show that lavas must have been in a highly fluid state.

Lithology

C. A. MCMAHON was the pioneer to give petrographic descriptions of the trap rocks (LYDEKKER, 1883), which have been slightly modified by different workers. MIDDLEMISS (1910) thought traps as "genuine old basic lava flows", but the report of rhyolites from Panthachuk near Srinagar by MATHUR and WAKHALOO (1933) subjected the view to revision. WADIA (1934) considered rhyolites to be not true acid types but formed by the silicification of ordinary basic flow. MATHUR (1934) contradicted this statement by giving analysis and norm of Panthachuk rhyolites. WEST (1934) in response to MATHUR's answer remarked "although rhyolites may be quantitatively unimportant, nevertheless their discovery is of much interest". Later WADIA (1961) viewed such rocks as acid and intermediate differentiation products of basic rocks. A number of acidic flows were noticed in different parts of Kashmir by COULSON (1938), GANJU (1944) and one of the authors (HMK). They are mainly confined to the top flows of the activity.

Pillow lava in Panjal Trap of Guryul Ravine

Occurrence

Pillow lava is seen as a single interflow in the upper part, not exactly the uppermost, of the Panjal Trap near the confluence of two small tributaries of the ravine. The outcrop is very small, 20 by 4 m, and is exposed along course of water channel; most part of this is covered under debris. A number of thin flows (mostly andesites and basalts) can be distinguished above and below this flow. The pillow-bearing flow is about 3.5 m thick. A number of boulders lying along the channel course also show well developed pillows. The stratigraphic position of pillow lava at Gruyul Ravine is as follows in discending order:

Limestone, shale and calcareous sandstone with rich marine fossils (Upper Permian—Zewan Series)	90 m
Novaculite, siliceous shale and tuff with plant and vertebrate fossils (Lower Gondwana)*	14.5 m
Panjal Trap	
Vesicular, amygdaloidal and massive flows, and tuff-breccia	*ca* 20 m
Spilitic pillow lava	3.5 m
Massive, amygdaloidal and vesicular flows, and tuff-breccia	unknown

Description of pillows

The pillows in the mass are closely packed, leaving very little or no space in between. Each pillow has definite boundaries. Portions which are not filled with pillows (interstitial part) are either triangular or rectangular, rarely rounded or irregular (Pl. 3, Figs. 1 and 2).

Individual pillow is mostly renal (kidney) and spheroidal. The maximum axial length varies from 20 to 200 cm, while the other one 10 to 85 cm. Each pillow is distinguishable into two parts, margin and core. The margin (crust or rim) ranges in thickness from 3 to 12 cm. Its outer portion which is of yellowish green tinge similar to the interstitial part, is non-vesicular and shows layering parallel to the outline of pillow. The inner portion is greenish and gradually merges into the core through transitional part tinged with purple. The core is dark green to steel grey, fine-grained, hard and compact showing conchoidal fracture; grey coloured prismatic laths of feldspars showing vitreous lusture are seen on the fresh surfaces under hand lens. Besides this cherry-red haematite is mottled in the groundmass along the fracture planes; development of greenish flaky chlorite is sometimes noticed.

---

* Dr. N. IMOTO found sponge-like spicules by ethcing novaculite with fluoric acid. The presence of sponges? suggests novaculite to be of marine origin.

Microscopic descriptions

(a) Core (Pl. 3, Figs. 3 and 4):—Core is made of plagioclase and pyroxene with subordinate amount of quartz and glass; secondary minerals are mostly represented by chlorite, and epidote and carbonates are also noticed. Opaque minerals are present. The main constituents not only show micro-porphyritic texture but also glomeroporphyritic texture; occasionally sub-ophitic texture is also noticed around a few prisms of pyroxenes.

Plagioclase is represented by minute grains and phenocrysts. Phenocrysts are distinguished into slender (length to breadth ratio up to 10 : 1) and stout (length to breadth 4 : 1) prisms. Stout ones have less corroded margins, but carry more inclusions of chlorite and/or altered pyroxenes which indicate that crystallisation of pyroxene had started earlier than phenocrysts of plagioclase (showing twinning on albite and Carlsbad laws). The composition is in no way more calcic than oligoclase. Plagioclase shows alteration to epidote (mostly) and carbonates.

Colourless to nearly non-pleochroic pyroxenes occur as short prisms and can be distinguished into augite (extinction angle 37° to 40° and $2\,V=(+)50°$). Simple twinning is occasionally seen. Most of the prisms show alteration to chlorite.

Quartz is intergranular and inequigranular. Glass (brown) is seen in association with quartz, and sometimes it is surrounded by other constituents of the rocks whose shape may partially be governed by the outline of glass.

Epidote can be distinguished into pistacite prisms which are often cracked. Some of the epidote prisms show indistinct zoning.

Chlorite (penninite), in addition to the close association with pyroxenes, as an altered product, occurs also as cavity filling.

Macro-vesicles are completely filled with secondary minerals (mainly chlorite and less amount of epidote and quartz). The crystal habit of chlorite at margins appears to be different than that of the core of vesicles (mostly fibrous). Lining of the chlorite in some cavities is preceeded or followed by zeolites(?), and some are lined also by haematite.

Opaque minerals are represented by titaniferous magnetite which has contributed leucoxene and haematite and shows *Schlieren* type texture. Sphene is also sometimes noticed.

(b) Margin (Pl. 3, Figs. 5 and 6): —The inner margin under microscope is almost alike to that of core except that it has less crystallinity, larger vesicles, and no brown glass; extinction of augite up to 50°; ophitic texture is shown by amphibole mineral, suggesting uralitization of pyroxenes. The amount of amphibole in different slides is variable. Outer margin looking superficially like the interstitial part has not been examined microscopically.

(c) Interstitial part (Pl. 3, Figs. 7 and 8): —The interstitial part under microscope has very fine granular texture consisting mainly of epidote, chlorite and quartz (amorphous silica) and sporadically muscovite(?). The minerals occur in random aggregate. However, epidote crystal aggregate is veined and/or metasomatised infrequently by chlorite and quartz aggregate. Muscovite(?) scattered in single grain, in the above mineral masses, is very dirty and irregular-shaped, and also has frequently spherulitic linear structure. Muscovite is an alteration product of some mineral, which is difficult to determine. The original texture and mineral assemblage are entirely absent due to complete metasomatism.

The X-ray diffraction analysis made by Dr. T. UEDA in order to confirm the mineral composition indicates the presence of quartz, chlorite and a little amount of epidote. Feldspar is entirely absent. The analysis agrees fully with microscopic observation.

Chemical composition of pillow lava

Major chemical composition

The chemical analyses of chip samples collected from inner margin and core of two pillows and also from interstitial part were carried out at Geological Survey of Japan by Mr. T. ABE and at Geological Survey of India by Mr. YUDHISHTHIR. The analyses are given in Table 1.

Table 1. Chemical analyses of pillow lava at Guryul Ravine, Kashmir

	Pillow 1*			Pillow 2**	
	a	b	c	a	b
SiO_2	43.19	53.41	61.76	48.39	54.43
TiO_2	2.72	2.19	0.68	2.40	2.30
Al_2O_3	15.21	13.04	11.58	16.53	14.77
Fe_2O_3	2.16	5.88	4.80	2.86	4.64
FeO	10.89	6.83	5.27	9.94	8.35
MnO	0.24	0.20	0.20	0.21	0.14
MgO	6.87	4.03	4.74	6.07	3.83
CaO	5.18	6.34	5.36	4.61	4.10
Na_2O	3.73	4.58	0.10	4.94	5.20
K_2O	0.67	0.42	1.42	trace	trace
P_2O_5	0.44	0.41	0.08	—	—
H_2O+	7.74	2.04	3.70	3.70	2.27
H_2O-	0.52	0.20	0.29	—	—
Total	99.56	99.57	99.98	99.65	100.03

a: chilled margin, b: core, c: interstitial part between pillows

* Analysed by T. ABE, Geological Survey of Japan

** Analysed by YUDHISHTHIR, Geological Survey of India

Table 2. Norms of pillow 1 of Table 1

		a	b	c
	Q		8.12	36.65
	Or	4.34	2.56	8.73
	Ab	34.58	39.82	0.84
	An	23.30	14.15	27.11
Di	Wo	0.71	6.45	
	En	0.24	10.27	12.25
	Fs	0.49	4.58	5.17
Hy	En	1.98		
	Fs	1.62		
Ol	Fo	11.58		
	Fa	10.38		
	C			0.36
	Mt	3.43	8.77	7.26
	Il	5.67	4.29	1.35
	Ap	1.14	0.97	0.20
	Total	99.46	99.98	99.92

Calculated by T. ABE, Geological Survey of Japan

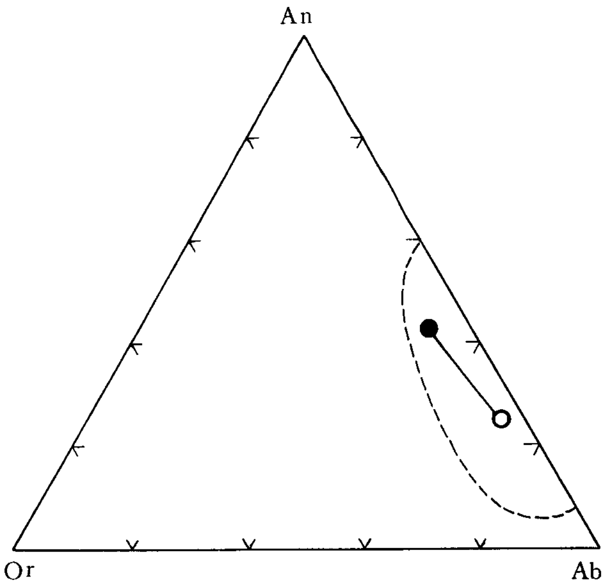


Fig. 2. Normative An-Or-Ab diagram of pillow lava. Open circle: core, solid circle: margin. Encircled area by broken line is a compositional field of spilite studied by SANDIUS (1930).

Core and margin are somewhat different in chemical composition from each other, and the both considerably differs from the interstitial part. Pillow as a whole shows a spilitic composition, that is, in relatively high content of Na_2O, extremely poor K_2O, rich TiO_2 and relatively low content of MgO and CaO (SANDIUS, 1930; VALLANCE, 1960). Norm ratio of An-Ab-Or also falls in the field of spilite studied by SANDIUS (*ibid.*) (Table 2 and Fig. 2).

Comparing the compositions between core and margin, Na_2O and SiO_2 decrease in the margin while MgO and H_2O increase in that part. Such tendency of compositional change is reported in many spilitic pillows (HOPGOOD, 1962; VALLANCE, 1965). The interstitial part is characteristic in high SiO_2 content, and low Al_2O_3 and Na_2O in contrast to the margin.

Rare earth elements

The result of analysis of rare earth elements (lanthanide group) by neutron activation method carried out by Dr. S. NISHIMURA, is given in Table 3. The

Table 3. Analysis of rare earth elements (lanthanides) in ppm

La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
15.2	42.8				7.20	2.52		1.54					3.70	0.63

Analysed by S. NISHIMURA, Kyoto University

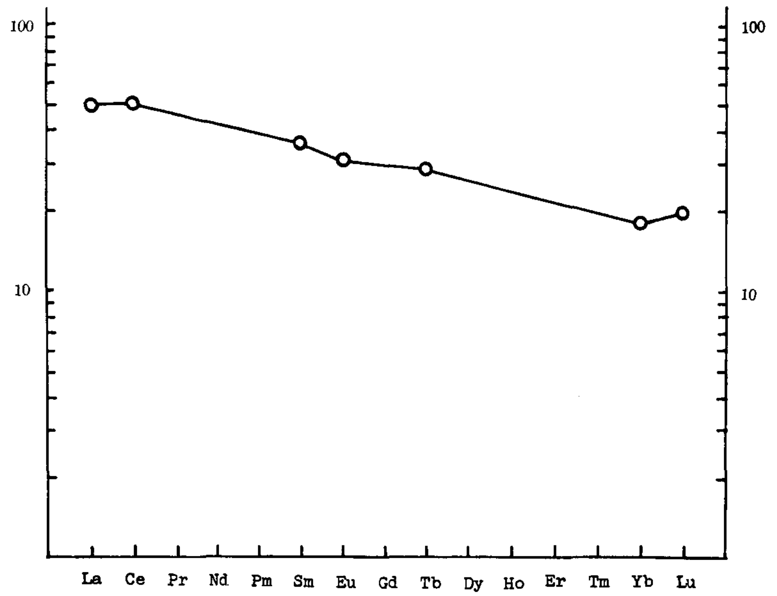


Fig. 3. Relative abundance to chondrite of the rare earth elements on logarithmic scale.

relative abundance pattern to chondrite of the rare earth elements clearly shows a straight pattern on a logarithmic scale, which is called "solid type" (MASUDA, 1966a, b) (Fig. 3)

Discussion

Although the estimation of magma type for altered rocks, such as under consideration has several problems to examine (AMSTUTZ, 1968; HASHIMOTO, 1969), KUNO's diagrams (KUNO, 1960 and 1965) of (Na_2O+K_2O)-SiO_2 and SiO_2-(K_2O+Na_2O)-Al_2O_3 are here adopted for convenience of comparison with the other rocks. On silica-alkali diagram (Fig. 4), the margin of the pillow falls in the field of alkali basalt while the core, in the field of high alumina basalt (or high-alkali tholeiite in the sense of low content of alumina; KUNO 1965), but on silica-alkali-alumina diagram both core and margin are plotted in alkali basalt (Fig. 5). High TiO_2 content and low K_2O are characteristic in major chemical composition.

Recently, UCHIDA (1965 and 1970), TANAKA (1971), HASHIMOTO *et al.* (1970), SUGISAKI and TANAKA (1971), and SUZUKI *et al.* (1971), carried out extensive study on the green rocks of late Paleozoic geosyncline of Japan. SUGISAKI *et al.* (1970) pointed out that the remarkably low content of potassium and high K/Rb ratio suggest that the geosynclinal basalts in southwest Japan are more allied to oceanic basalt than the Japanese Cenozoic volcanics. According to TANAKA (1970) the geosynclinal basalts in central Japan occupy the intermediate portion

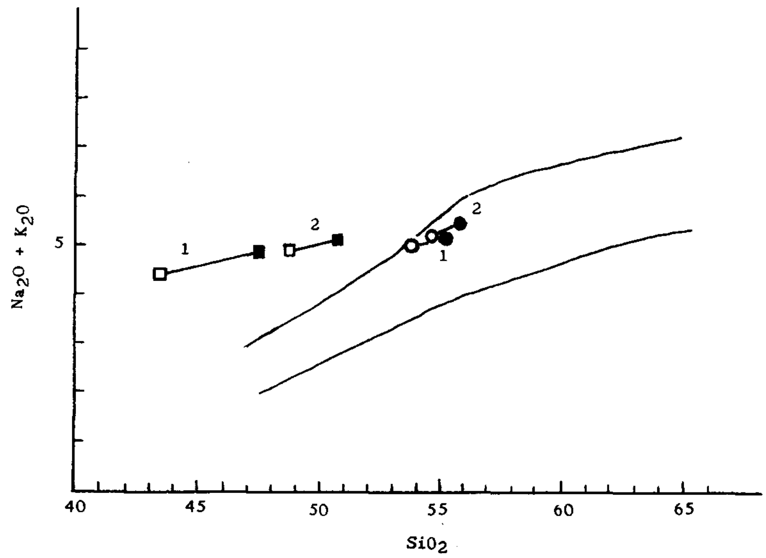
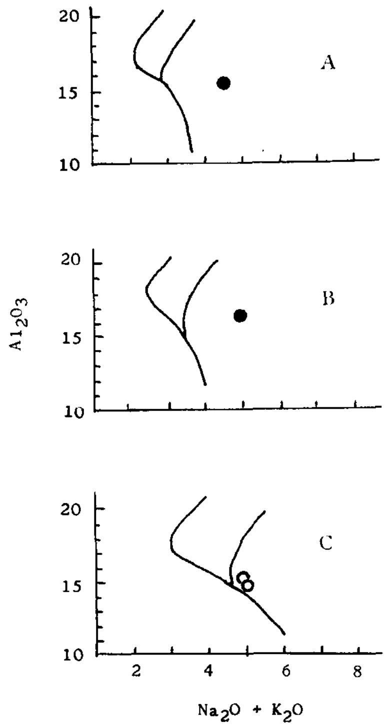


Fig. 4. (Na_2O+K_2O)-SiO_2 diagram of pillow lava at Guryul Ravine. Open circles and squares are plots of core and margin, respectively. Solid ones represent recalculated anhydrous analyses.

Fig. 5. Al_2O-$(Na_2O+K_2O)-SiO_2$ diagram of pillow lava at Guryul Ravine. Core and margin are represented by open and solid circles, respectively. A: SiO_2=45.00–47.50%, B: SiO_2=47.51–50.00%, C: SiO_2=52.51–55.00%. One analysis having silica content of 43.19% is tentatively plotted on diagram A.



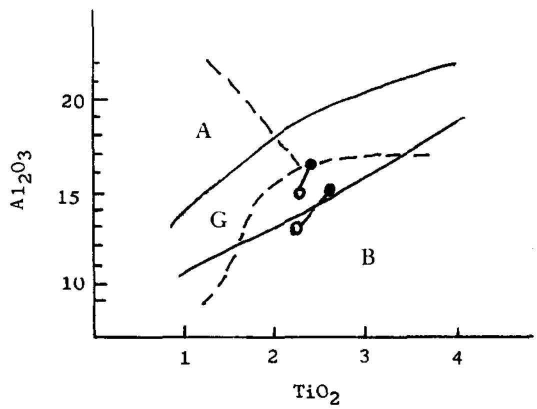


Fig. 6. Al_2O_3-TiO_2 diagram.
A: field of Cenozoic basalt of Japan (circum-oceanic) and oceanic ridges, B: field of Hawaiian tholeiite and alkali basalt (oceanic islands), G (between solid lines): field of late Paleozoic green rocks of central Japan (geosynclinal), drawn by TANAKA (1970). Broken line modified from SUZUKI *et al.* (1971).

between oceanic basalt and the Japanese Cenozoic volcanics on Al_2O_3-TiO_2 diagram. The Kashmir spilitic lava falls in the field of geosynclinal basalt of TANAKA and in the oceanic side of this diagram (Fig. 6).

From the geochemical characteristics, two submarine volcanic provinces of the Paleozoic green rocks can be distinguished in central and west Japan, that is, central zone (Mikabu belt) and flankzones (outside Mikabu belt) (TANAKA *et al.*, 1971; SUGISAKI *et al.*, 1971). SUGISAKI and MIZUTANI (1972) called the rocks belonging to the former province as "Mikabu type" and those of the latter as "Mino type". Mikabu type rocks are mostly high- and low-alkali tholeiite and partly alkali basalt; high alumina basalt is almost lacking (SUGISAKI and TANAKA, 1971; SUZUKI *et al.*, 1971). The chondrite normalized rare earth pattern is similar to that of "solid type", which is called B type by TANAKA *et al.* (1971). For the same SiO_2 content the type B rocks are richer in MgO than type A rocks which are characterized by "liquid type" rare earth pattern.

The volcanic rocks outside the Mikabu belt are mainly alkali basalt and high-

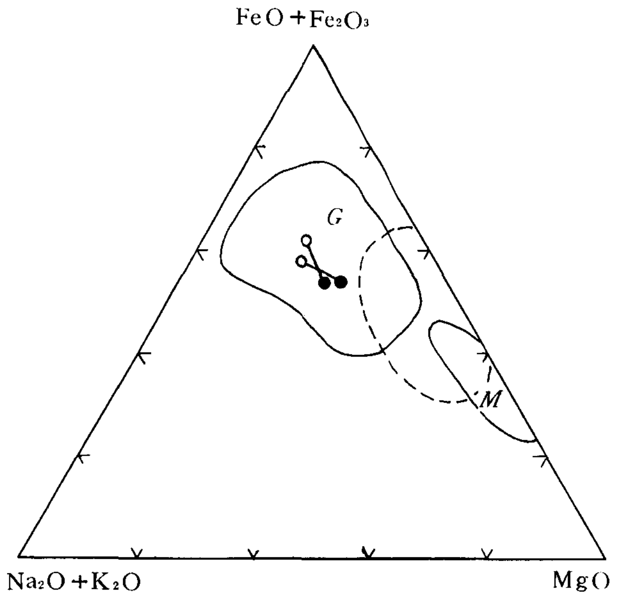


Fig. 7. $(FeO+Fe_2O_3)-(Na_2O+K_2O)-MgO$ diagram
Open circle: core, solid circle: margin.
The encircled areas *M* and *G* are compositional fields of Mikabu green rocks and Paleozoic green rocks outside Mikabu belt in Kwanto Mountainland, respectively (UCHIDA, 1970). The area encircled by broken line is a field of Mikabu rocks in Shikoku (SUZUKI *et al.*, 1971).

alkali tholeiite. Low-alkali tholeiite is scarcely found and high- alumina basalt is very limited in distribution. Rare earth pattern is of type A ("liquid type"). The lava at Guryul Ravine is of "liquid type" as already stated.

To sum up the above-mentioned facts the pillow lava in Kashmir is quite similar to geosynclinal basalts of the late Paleozoic in Japan, especially, to "Mino type" green rocks, in major chemical composition and in rare earth elements as well. This is also proved by plotting on $(FeO+Fe_2O_3)$-(Na_2O+K_2O)-MgO diagram and MgO-SiO_2-Al_2O_3 diagram (Figs. 7 and 8).

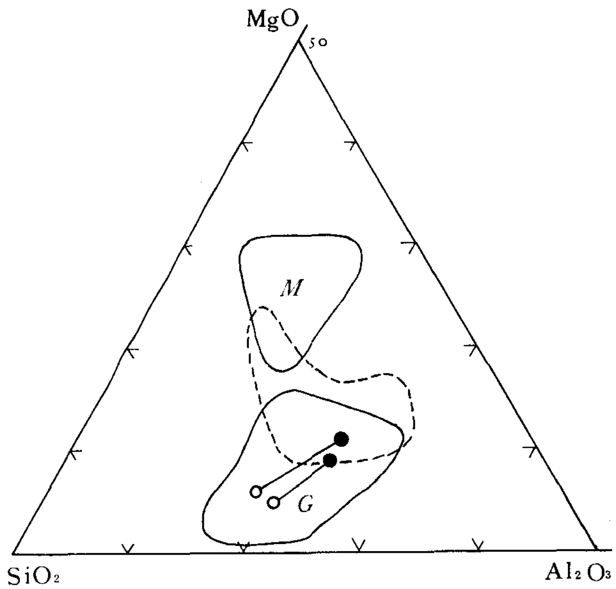


Fig. 8. MgO-SiO_2-Al_2O_3 diagram
Open circle: core, solid circle: margin.
The encircled area *M* is a compositional field of Mikabu green rocks in Kwanto Mountainland (UCHIDA, 1970), and *G* is that of Paleozoic green rocks outside Mikabu belt in Kwanto Mountainland (UCHIDA, *ibid.*) and central Japan (TANAKA, 1970). The area encircled by broken line is a compositional field of Mikabu rocks in Shikoku (SUZUKI *et al.*, 1971).

The present data on Panjal Trap including the pillow lava at Gruyul Ravine are too poor to deduce some conclusion, but its strong resemblance with the geosynclinal basalts of Japan is worthy for considering the genesis of basalt with "oceanic" nature. The geosynclinal basalts in Japan are generally considered to occur at off-shore and in the deeper part of the geosyncline. SUGISAKI *et al.* (1971) viewed that the magma of the Mikabu type rocks was produced by almost total melting of the mantle and extra-Mikabu rocks were probably products of partial melting, and taking into consideration the geological evidences, they presented the following as most plausible explanation, that these basic rocks were formed by eruption through the rift made by ocean expansion, like that of the Gulf of Eden and the Red Sea. SUZUKI *et al.* (1971) concluded that the Mikabu green rocks in Shikoku, west Japan are differentiation products of oceanic tholeiite magma at the deeper part of the crust or upper mantle.

As stated in the geological section, the pillow lava at Guryul Ravine, unlike the geosynclinal volcanics in Japan, erupted at very shallow sea-bottom, presumably coastal if not lagoonal. The Panjal Trap including the pillow lava is underlain by various formations, such as Salkhalas (Pre-Cambrian), Dogra Slate (Algonkian), Muth Quartzite (Devonian) and Tanawals (Permo-Carboniferous) (MIDDLEMISS, 1910; PASCOE, 1959; WADIA, 1961), and the basement is certainly of continental nature. The close resemblance of basic rocks between Kashmir and Japan in spite of the different environment may offer an interesting problem on the genesis of basalt with so-called oceanic nature.

Acknowledgements

We are most grateful to Dr. H. YOSHIZAWA, former Professor of Kyoto University and Mr. K. K. SRIVASTAVA of Geological Survey of India who offered us useful suggestions examining the thin sections of rocks and made a critical reading of the manuscript.

We would like to express our cordial thanks to the following persons who helped our study in various ways. Dr. T. UEDA of Kyoto University made an X-ray analysis of the interstitial part of the pillows. Dr. S. NISHIMURA of Kyoto University analysed rare earth elements of the core of pillow by neutron acitivation method. Major chemical analyses were given by Mr. T. ABE of Geological Survey of Japan and Mr. YUDHISHTHIR of Geological Survey of India. Mr. ABE further calculated norms of core and margin. Dr. T. IMOTO of Kyoto University of Education examined the microfossils of novaculite and siliceous shale from the Lower Gondwana which overlies the Panjal Trap. Mr. T. TENPAKU of Kyoto University helped us in preparation of photomicrographs.

We are also indebted to the members of the research party of the Permian-Triassic problems who co-worked with us in the field survey. Lastly we must put on record that the study was carried out under the support of Geological Survey of India and the Ministry of Education, Government of Japan.

References

AMSTUTZ, G. C. (1968): Spilites and Splitic Rocks. in H. H. HESS and A. POLDERVAART (edit.), the Poldervaart Treatise on Rocks of Basaltic Composition. *Basalt*, Vol. 2, pp. 737–754, Interscience Publishers.

CHATTERJEE, S. C. (1959): Epochs of Igneous Activity in India. *Bull. Mysore Geologists Assen.* **17**, pp. 3–28.

CHAYES, F. (1965): Titania and Alumina Content of Oceanic and Circum oceanic Basalt. *Miner. Mag.*, **34**, pp. 126–131.

COULSON, C. A. (1938): Annual General Report of the Geological Survey of India. *Rec. Geol. Surv. India*, **73** (1), p. 18.

GANJU, P. N. (1944): The Panjal Traps; Acid and Basic Volcanic Rocks. *Proc. Ind. Acad. Sci.*, **18** (B), pp. 125–131.

HASHIMOTO, M. (1969): On the Spilite Problems. *Bull. Nat. Sci. Museum*, **12** (4), pp. 875–882. (in Japanese with English abstract)

————, KASHIMA, N. and SAITO, Y. (1970): Chemical composition of Paleozoic greenstones from two areas of southwest Japan. *Jour. Geol. Soc. Japan*, **76** (10), pp. 463–376. 4

HOPGOOD, A. M. (1962): Radial distribution of soda in a pillow of spilitic lava from the Franciscan, California. *Amer. Jour. Sci.*, **260**, pp. 383–396.

IYENGAR, S. V. P. and BANERJEE, S. (1964): Magmatic Phases Associated with the Pre-Cambrian Tectonics of Mayurbahanj District. Orissa State, India. *22nd I. G. C., New Delhi, Abstract.* pp. 149–150.

IYENGAR, S. V. P. and ANAND ALWAR, M. A. (1965): The Dhanjori Eugeosyncline and its bearing on the Stratigraphy of the Singhbhum, Keonjhar and Mayurbhanj Districts. *Min. Met. Inst. India*, D. N. Wadia Comm. Vol., pp. 138–162.

KRAFFT, A. von (1902): Notes on the 'Exotic Blocks' of Malla Johar in Bhot Mahals of Kumaon. *Mem. Geol. Surv. India.* **32** (3), pp. 127–188.

KUNO, H. (1960): High-alumina basalt. *Jour. Petrol.*, **1**, pp. 121–145.

———— (1965): Fractionation trends of basalt magmas in lava flows. *ibid.*, **6**, pp. 302–231.

LYDEKKER, R. D. (1883): The Geology of Kashmir and Chamba Territories and the British Districts of Khagan. *Mem. Geol. Surv. India*, **22**, pp. 211–224.

MASUDA, A. (1966a): The difference in lanthanide abundance pattern between the crust and the chondrite and its possible meaning to the gnenesis of crust and mantle. *Geochim. Cosmochim. Acta*, **30**, pp. 239–250.

———— (1966b): Lanthanides in basalt of Japan with three distinct types. *Geochem. Jour.*, **1**, pp. 11–26.

MATHUR, K. K. (1934): Panthachuk (Srinagar, Kashmir) Rhyolites. *Curr. Sci.*, **3**, (10) p. 492.

———— and WAKHALOO, S. N. (1933): The Panjal Traps. *ibid.*, 2 (4), p. 126.

MIDDLEMISS, C. S. (1909): Gondwana and Related Marine Sedimentary Systems of Kashmir. *Rec. Geol. Surv. India*, **37** (4), pp. 286–327.

———— (1910): Revision of Silurian Trias Sequenc in Kashmir. *ibid.*, **40** (3), p. 235.

———— (1911): Sections in the Pir Panjal Range and Sind Valley, Kashmir. *ibid.*, **41** (2), pp. 115–144.

NAKAZAWA, K., KAPOOR, H. M., ISHII, K., BANDO, Y., MAEGOYA, T., SHIMIZU, D., NOGAMI, Y., TOKUOKA, T. and NOHDA, S. (1970): Preliminary Report on the Permo-Trias of Kashmir. *Mem. Fac. Sci. Kyoto Univ., Ser. Geol. & Miner.*, **37** (2) pp. 163–172.

PASCOE, E. H. (1959): A Manual of Geology of India and Burma 2, pp. 785–795.

PICHAMUTHU, C. S. (1950): Pillow Structures in the Lavas of Dharwar Age in the Chitaldrug District, Mysore State. *Curr. Sci.*, **19** (4), pp. 110–111.

RAGHUNATHA RAO, B. N. (1937): Pillow Structures in the Mica Traps of the Chitaldrug Schist Belt. *Curr. Sci.*, **6**, pp. 179–280.

SANDIUS, N. (1930): Studies of Some Ophiolites. On the Spilitic Rocks. *Geol. Mag.*, **67**, pp. 1–17.

SHAH, S. K. (1966): Studies of some Ophiolites of Pir Panjal in the Poonch District. *Pub. Cent. Pal. Him. Geol.*, **1**.

SUGISAKI, R., TANAKA, T. and HATTORI, H. (1970): Rubidium and Potassium Contents of Geosynclinal Basalts in the Japanese Islands. *Nature*, **227**, pp. 1338–1339.

——— and MIZUTANI, S. (1972): Paleozoic Geosyncline and its volcanic activity—geochemistry of geosynclinal basalt. *Kagaku* (*Science*), **42** (2), pp. 170–180. (in Japanese)

———, MIZUTANI, S., ADACHI, M., HATTORI, H. and TANAKA, T. (1971): Rifting in the Japanese Late Palaeozoic Geosyncline. *Nature* (*Physic. Sci.*), **233**, (37), pp. 30–31.

——— and TANAKA, T. (1971): Magma types of volcanic rocks and crustal history in the Japanese Pre-Caenozoic geosynclines. *Tetconophysics*, **12**, pp. 393–413.

SUZUKI, T., SUGISAKI, R. and TANAKA, T. (1971): Geosynclinal Igneous acitivity of the Mikabu Green Rocks of Ozu City. *Mem. Geol. Soc. Japan*, no. 6. Studies of Geosynclinal Deposits. (in Japanese with English abstract)

TANAKA, T. (1970): Chemical Composition of Geosynclinal volcanic rocks from the Paleozoic Chichibu group in central Japan. *Jour. Geol. Soc. Japan*, **76** (7), pp. 323–335.

———, MASUDA, A. and SUGISAKI, R. (1971): Rare earth in Palaeozoic geosynclinal basalts in Japan. *Nature* (*Physic. Sci.*), **232**, pp. 105–107.

UCHIDA, N. (1969): On the chemical composition of pillow lavas (Several facts on the geology of northern Kwanto Mountainland, 4). *Seikei-Ronso*, no. 8, pp. 157–179. (in Japanese)

——— (1970): Chemical composition of tuffs of Sambagawa Formation (Several facts on the geology of northern Kwanto Mountainland, 5). *ibid.*, no. 9, pp. 102–113. (in Japanese)

VALLANCE, T. G. (1960): Concerning spilites. *Proc. Linn. Soc. N. S. W.*, **85**, pp. 8–52.

——— (1965): On the chemistry of pillow lavas and the origin of spilites. *Miner. Mag.*, **34**, pp. 471–481.

WADIA, D. N. (1934): The Geology of Poonch State Kashmir and adjacent parts of Punjab. *Mem. Geol. Surv. India*, **51** (2).

——— (1961): Geology of India. Student Edit. McMillan & Co.

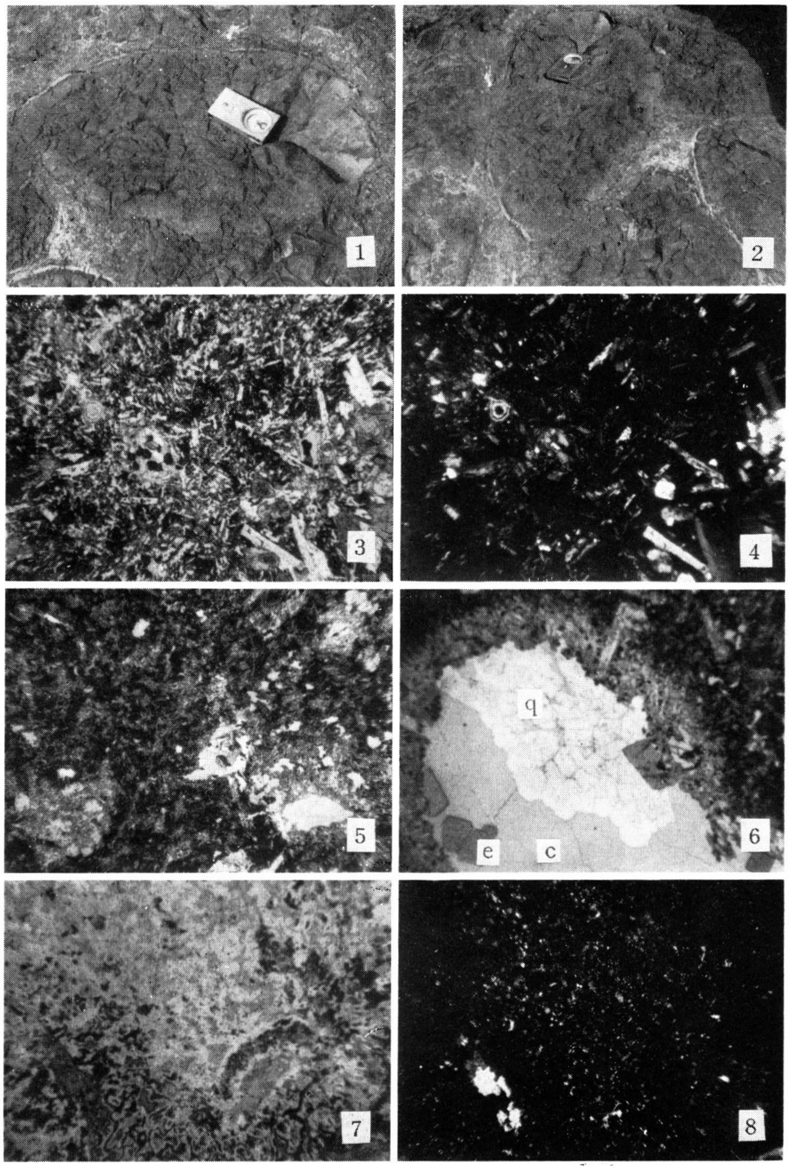
WAKHALOO, S. N. and SHAH, S. K. (1968): A Note on the Bafliaz Volcanics of Western Pir Panjal. *Publ. Adv. Sud. in Geol., Punjab Univ., Chandigarh.* 5, pp. 53–64.

WALKER, George P. L. (1969): Some observations on the Deccan Traps. *Adress at Symposium, Univ. Saugor.*

WEST, W. D. (1934): Some Recent Advances in Indian Geology. *Curr. Sci.*, **3** (10), p. 234.

Explanation of Plate 3

Figs. 1, 2. Outcrop of pillow lava at Guryul Ravine.
Figs. 3, 4. Photomicrographs of the core of pillow, 3: single nicol, 4: crossed nicols.
Fig. 5. Photomicrograph of the margin of pillow, single nicol.
Fig. 6. Photomicrograph of the large vesicle of the marginal part of pillow, single nicol. c: chlorite, e: epidote, q: quartz.
Figs. 7, 8. Photomicrographs of the interstitial part between pillows, 7: single nicol, 8: crossed nicols.
Figs. 1 and 2 photographed by T. Tokuoka.
Figs. 3–8 photographed by K. Nakazawa, all $\times 30$.



Nakazawa & Kapoor: Pillow Lava, Guryul Ravine