Morphologic and physical features of pillow basalts of the Yüksekova Complex around Elazığ (Eastern Anatolia, Turkey)

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Abstract

Pillow basalts, belonging to Late Cretaceous Yüksekova Complex are extensivelly exposed around Elazıg in Eastern Turkey. This unit is a part of southeastern Anatolian ophiolite belt and the Southern Branch of the Neotethys. It represents the products of intra- oceanic subduction volcanism and mainly comprises pillow lavas, dykes and associated with sedimentary rocks. Pillow lavas and feeder dykes are basaltic in composition and subdivided in two geochemically distinct groups. Almost all of them are intruded by carbonate, silica or iron oxide-filled fractures. They are generally gray, red, purple or yellowish green, dark green in color. Thickness of shell of pillow varies between a few mm to 1 cm. Average density of them is 2.69 g/cm^3, and they have average porosity of 5%. Pores with oval structure which is relativelly indicative of high viscosity reach up a few mm to 1 cm. They are filled by amygdules such as silica, calcite, chlorite, zeolites that indicate alteration by sea water.The abundance and extremely coarse size of amygdules in these rocks might signify the presence of a shallow marine environment.Also, there is no clear difference in abundance and type of amygdule observed at group 1 and group 2. Flakes of chloriteform an interpillow matrix are found mostly between of pillows. In according to the frequency distributions of pillowed basalts, samples of group 1 have a more uniform rate of rounding, while samples of group 2 represent more variable rate of rounding. The long and short axis sizes of pillow basalts vary from a few centimeters to meters. Varying sizes of the pillow basalts indicate an effusion environment long-lasting or with multi-stage. The main magmas of the examined pillow basalts, belonging to Late Cretaceous Yüksekova Complex, similar to each other because of the absence of a significant difference in compositions and morphologies of both group.

Keywords: Elazığ, Turkey, Yüksekova Complex, Pillow basalt, Amygdule,Porosity, Rounding.

1–Introduction

Some physical parameters such as pillow size and morphology are commonly utilized to understand the eruption history of pillow lavas and determine the presence of chronologically different types of lava flows and their eruption stages, cooling rate, paleocurrent direction and flow depth (Schnur, 2007). Accordingly, the ascend, growth and cease of a single-stage, long-lasting eruption and the occurrence of a continuing eruption producing pillows of varying size or an eruption forming pillows in multiple-stage can be ascertained (Schnur, 2007). In this study, pillow-structured volcanic rocks widely exposing around Elazığ, which are described as the Yüksekova Complex by previous studies (Perinçek, 1979), are examined with respect to their morphological and physical characteristics.

2–Materials and Methods

The pillow-structured basaltic volcanic rocks are the material of this study. During the field studies, contact relations of pillow-structured basalts with country rocks and macroscopic and morphological features of rocks were determined and measurements were performed from the pillow lavas. For this, from each location pillows with different sizes were measured. The number of pillows measured varied at each location depending on the suitability of locations for measurements. During the studies local geologic maps and 1/500,000 and 1/100,000 scaled geological maps of MTA (2002) (General Directorate Mineral Research and Exploration)were utilized. In addition, Brunton type compass, Magellan SporTrak Color GPS Receiver, hammer, lupe and tape measure were also used and plenty of photos were taken from the measured rocks. Results of measurements were evaluated with respect to groupings (Group 1 and Group 2) constructed based on petrochemical characteristics of rocks (Ural *et al.*, 2012). Porosity of totally 120 pillow-structured basalt samples was measured at laboratories of Geological and Civil Engineering Departments of the Fırat University. Porosity was determined from unit weights of samples in moist and dry state. A source assessment was made using morphological and physical characteristics.

3–Results

3.1- Geology and Petrography

The oceanic lithosphere units and associated rocks described as the southern branch of Neotethys (Şengör and Yılmaz, 1981) or the Amanos-Elazığ-Van Ocean branch (Göncüoglu *et al.*, 1997; Göncüoğlu, 2010) and the belt consisting of subduction zone units occurred as a result of closure of this ocean are composed chiefly of Guleman-Kömürhan-İspendere Ophiolites, Yüksekova Complex, Baskil Magmatites, Helete Volkanites and Maden Group units(Figs. 1 and 2). Above this belt, basic volcanic rocks of upper Cretaceous Yüksekova Complex, a part of southeastern Anatolian ophiolite belt and the Southern Branch of the Neotethys, representing the products of intra- oceanic subduction volcanism. The unit constitutes volcanosedimentary products of Guleman-Kömürhan-İspendere Ophiolites.This unit exposing around the city of Elazığ (Figs. 1 and 2) show similar morphological and physical characteristics in many areas and appear to be massive or pillow-structured volcanic rocks, subvolcanites (dikes feeding the pillows or veins) and associated with sedimentary rocks.

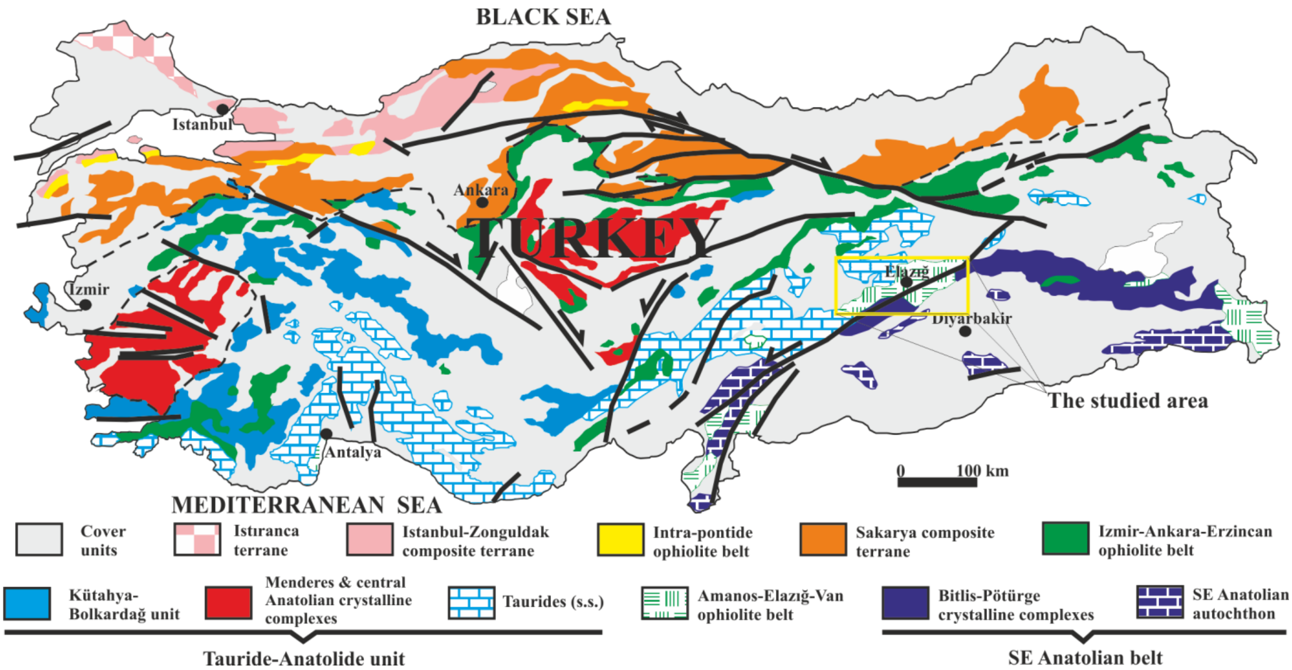

Figure 1) The map showing the location in the country of the study area and the major tectonic units and their zones of Turkey(Göncüoğlu, 2010).

In areas where a complete lava sequence is observed, it changes pillow-structured basalts, massive basic volcanics, and agglomerate or lava breccia from basement to the top. Such sequences are exposed at west of Baskil, at north of Çaybağı, at east of Harput, Dereboğazı and around Hazar (Fig. 2).

The pillow-structured lavas alternating with other massive submarine lavas are very common along the Keban-Elazığ road, around the Harput castle, Baskil-Kızıluşağı-Kuyucak district and İçme. They are partly cut by acidic magmatic rocks and diabase dikes as well. Pillow basalts are mostly cut by carbonate, silica or FeO filled fractures that are detectable in macro and micro scales. They are best exposed along the road cuts and across the river valleys. Pillows are generally 3-dimensioned but 2-dimensioned ones are also common (Figs. 3 and 4).

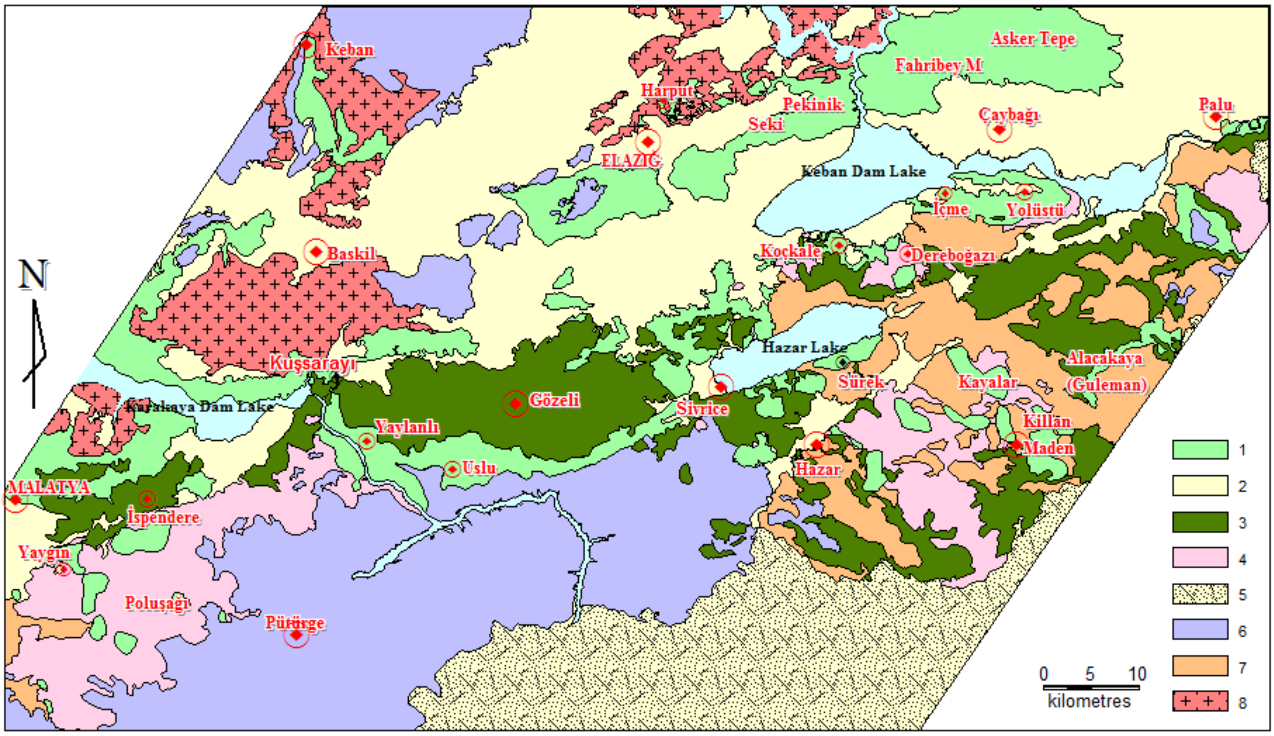

Figure 2) Simplified geological map of the study area (revised from M.T.A., 2000). Symbols, 1: Yüksekova Complex (Late Cretaceous), 2: Tertiary cover units, 3: Guleman-Kömürhan-İspendere ophiolites, 4: Maden Group (Middle Eocene), 5: Lice Formation (Lower Miocene), 6: Keban-Pütürge Metamorphics (Permo-Triassic), 7: Hazar Group (Maestrihtian-E.Eocene), 8: Baskil magmatics (Late Cretaceous).

In the Late Cretaceous Yüksekova Complex exposing around Elazığ, most part of pillow lavas are represented by similar mineralogical and textural characteristics. Petrographic and petrochemical descriptions yield that rocks sampled are in basalt composition and they are microlithic, porphyric, hyalo-microlithic, amygdaloidal, variolithic, glomeroporhyric textures. The mineral assemblage of these rocks is composed of plagioclase ± pyroxene ± olivine ± amphibole ± opaque oxide modal composition (Fig. 5). Detailed observations show that plagioclase is accompanied by pyroxene ± olivine and pyroxene + olivine groups (Ural, 2012).

3.2- Physical and Morphological Properties

The studied pillow lavas are in gray, claret red, purple or yellowish green, dark green colors which are more or less combined at each locality. For intensely altered pillows claret red color is due to FeO coating whilst greenish color is resulted from chloritization and epidotization (Fig. 3). The massive volcanites are mostly claret red and vein rocks are in greenish color.

The length of long and short axes of pillows is in the range of a few cm to meter scale depending on gradient of slope and exposure suitability.

In the study area pillow lavas of both geochemical compositions are represented by mostly glassy or fine grained chilled outer crust with thickness of changing a few mm to 1 cm.

Figure 3) (a) Two-dimensional ellipsoidal shaped pillows, ~ 2 km south of the Baskil Karakas village, (b) spheroidal pillows, Aşağıbağ district, (c) three-dimensional and lobe-shaped pillows, Çaybağı-Fahribey district, (d) epidotization in pillows, Güneyçayırı, (e) Cylindrical / tubular chloride pillows and their envelopes, Koçkale west, (f) lobe-shaped pillows and chloride envelopes, southern slope of the Mastar Hill.

Inner part of pillows are medium to coarse grained. The less thickness of glassy side and the coarse grain size implies the slower cooling rate for the lava (Dimroth *et al*., 1978). According to Swanson and Schiffman (1979), the more material within the pillows indicates the slower cooling rate for the lava. Most of pillow lavas in the studied groups are closely packed and locally overlapped and there is no fill material within the pillows (Fig. 4).

Chloritization which occurs as a result of palagonitization during fragmentation of outer crust and reaction with seawater in the course of pillow formation, are seen as flakes between the pillows (Fig. 3).

Porosity of totally 120 pillow-structured hand samples collected from the study area was measured (Tables 2 and 3) by determining unit weights in moist (left 24 hours in water) and dry (left at 100º for 24 hours in stove) states.

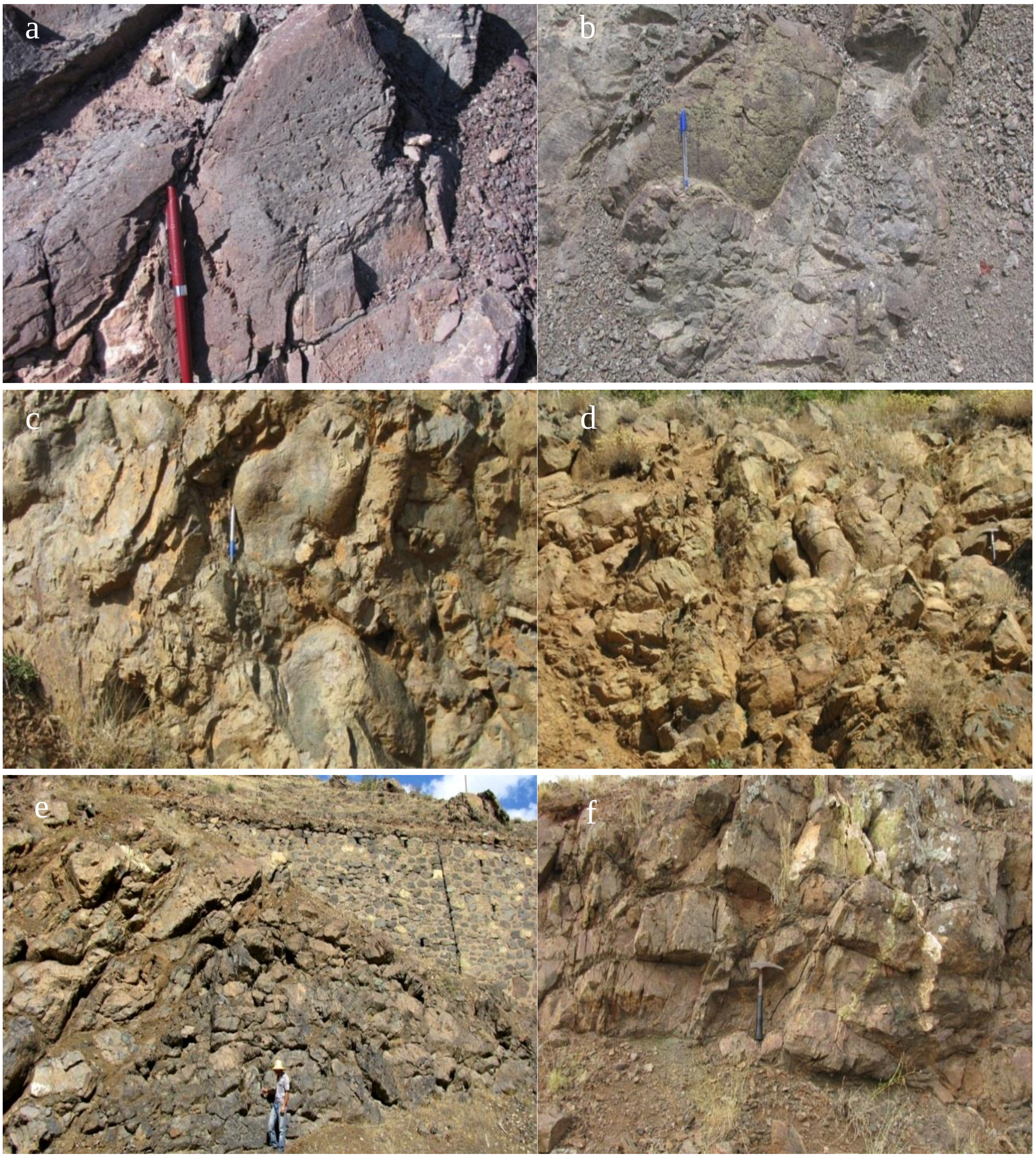

Figure 4) (a) Porous pillowed basalts, Yaygın district, (b) significant pedonkül structure in pillows, Çaybağı (Osmanağa west), (c) tube-shaped pillows, Malatya-Pütürge main road section, (d) pillows in the form of elongated tubes, ~ 10 km northwest of Pütürge district, (e) the massive, elongated pillows, Gezin-Maden road cut, (f) Longitudinal extended and overlapping pillows, Cevizdere area.

In this respect, the porosity of a pillow-structured volcanic sample with an average density of 2.69 g/cm^3 is about 5%. Therefore, the studied rocks have high density and low porous. The length and density of pores in lavas are decreased with increasing water depth which is associated with pressure increase in depth requiring prevention of gas escape (Moore, 1965). Type and distribution of vesicles also reflects a depth control. Pipe vesicles, stretching from the inner pillow to its exterior indicate the escape of gas from pillows formed at shallow depths (Walker, 1992). Concentric vesicle zonation at the tops of pillows also indicates shallow depths of less than 350 to 450 meters (Jones, 1969).

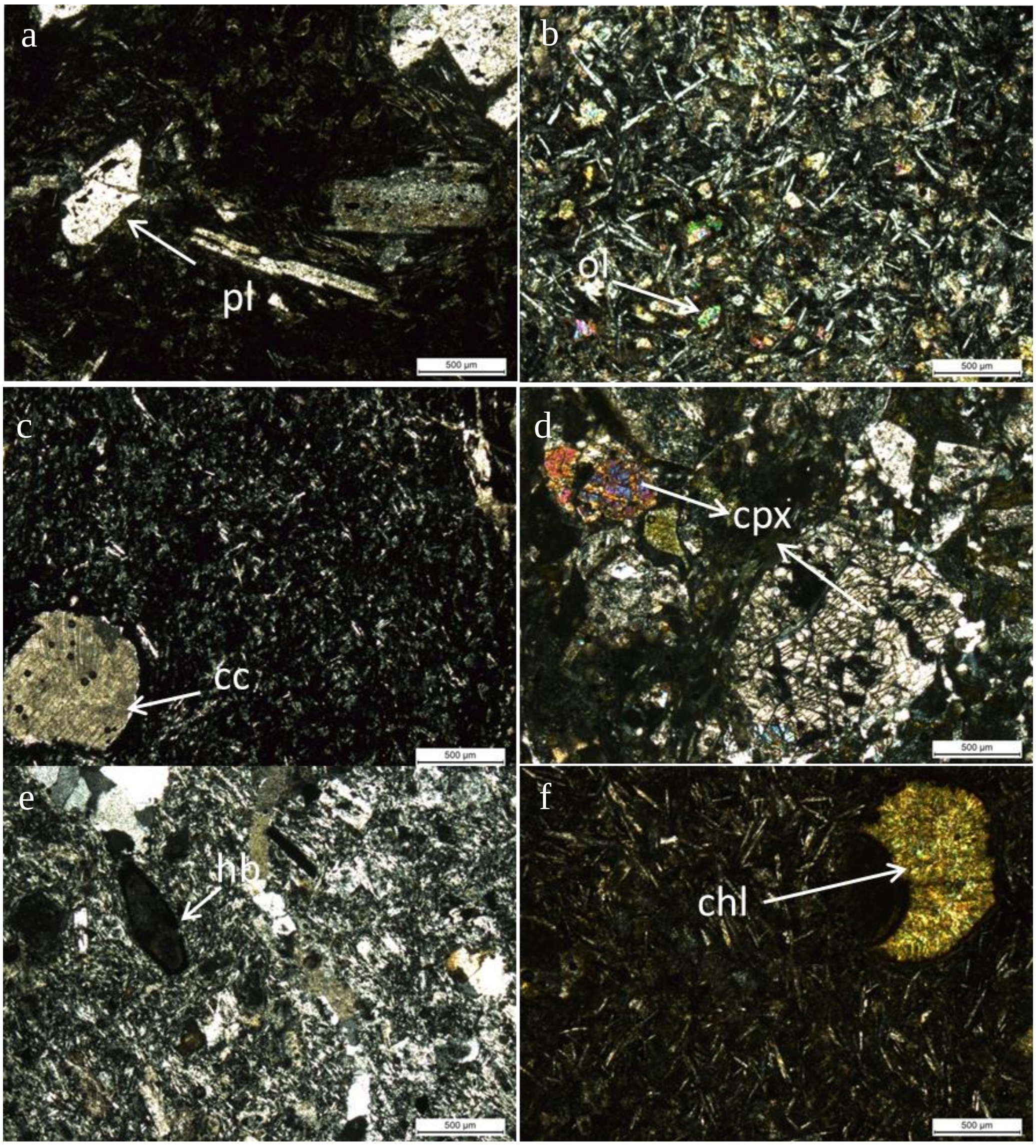

Figure 5. Microphotograph of the examined rocks (a) plagioclase with zone and euhedral, porphyric basalt, (b) microcrystalen olivine, (c) spilitic basalt, (d) basalt with pyroxene, (e) basalt with hornblende, (f) amygdaloidal textured basalt (Cross Nicol; pl: plagioclase, cpx: clinopyroxene, ol: olivine, hb: hornblende, chl: chlorite).

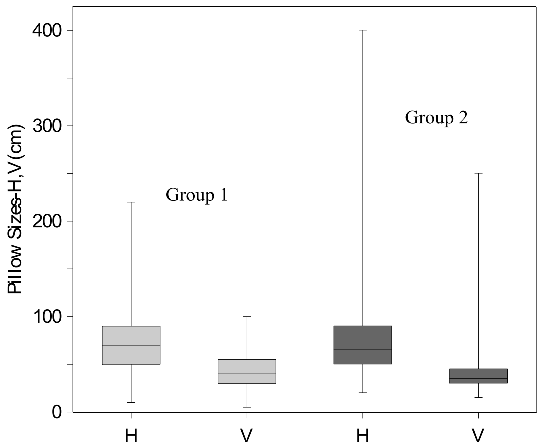

Figure 6. H, V box plots of Yüksekova Complex pillowed basalt samples.

In outer crusts of pillow-structured basalts, there are oviform pores with diameter ranging from a few mm to 1 cm which are mostly filled (Fig. 3). The shapes of vesicles can inform us about the viscosity of the lava. In generally, while spherical shapes mean vesicles grew in low viscosity lavas undergoing little or no movement, distorted shapes mean vesicles grew in higher viscosity lavas and may have been further contorted by continued lava movement.

The abundance and extremely coarse size of amygdules in the examined rocks of Yüksekova Complex might signify the presence of a shallow marine environment and filling of these vesicles by silica, calcite, chlorite, zeolite minerals is indicative of alteration of rocks by the seawater. The vesicles were probably filled under near-surface conditions by means of low temperature hydrothermal solutions (Ingerson, 1958).

Long axis (H), short axis (V) and box diagrams (Fig. 6) of pillow-structured basalt samples showed that the averages of long axis of two geochemical groups are about the same, however, the length of short axis is smaller for the second group samples (Tables 1 and 2).

In some samples of second group (e.g. sample no MD-5; 400/260) external ratios can be explained by short-term increases in lava volume or viscosity depending on lava flows during the emplacement onto irregular basin floor or a new magma pulse in association with short-term increase of volume of magma. Considering tectonic structure of the region, the size and morphology difference might be due to irregularity of the basin floor from which lava was erupted and, in addition, spatial position of the rocks in the form of tectonic slices representing various environments could also be responsible for the size and morphology differences.

H/V frequency distributions of samples from groups are right-skewed (Fig. 7). In percent frequency distribution of first group samples, the presence of kurtosis is more pronounced for samples with low H/V values (in the range of 1.2 to 2 cm). Therefore, rounding ratio is high and distribution is more homogeneous in comparison to the second group. The frequency distributions graphs of second group samples are relatively flat which may implies that they represent a series in which H/V ratios are more heterogeneous, in other words, rounding is more variable.

Table 1) Statistical values of measurements of long-axis (H) and short-axis (V) in cm of Yüksekova Complex pillowed basic volcanics.

Rockgroups	Size	Number ofsamples	Average	Median	Min	Max	Standart deviation
Group 1	H	276	77.37	65	20	400	51.49
	V	276	42.54	35	15	250	27.53
	H/V	276	1.87	1.71	1	5	0.69
Group 2	H	173	71.88	70	10	220	35.54
	V	173	43.60	40	5	100	18.87
	H/V	173	1.71	1.55	1	5	0.63

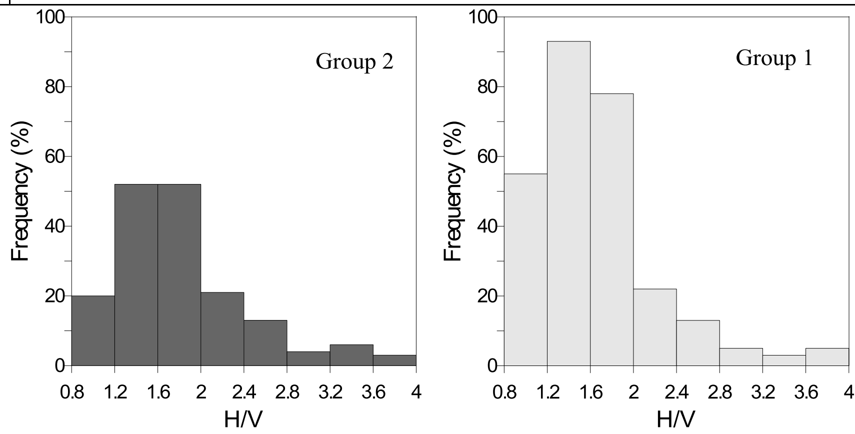

Figure 7. H / V -% frequency distribution graphs of pillow basalt samples of Yüksekova Complex

Table 2) Measurements of long-axis (H) and short-axis (V) in cm of Yüksekova Complex pillowed basic volcanics (Group 1).

Loc.	Sample No	H/V (cm)
Baskil, Keban	BS-1	80/40, 17/10, 25/15, 43/40, 85/35, 60/35, 180/80, 70/35, 35/30, 50/35
	BS-2	95/80, 45/30, 70/35, 110/40, 90/50
	BS-3	40/23, 35/20, 50/40
	BS-4	120/50, 60/30
	BS-6	50/40
	BSK-2	75/55, 70/60, 90/50, 90/60, 80/40, 90/70, 110/55, 85/60, 70/50, 85/65
	BSK-3	110/65, 70/65, 80(80, 50/35, 110/60, 80/50, 100/25,
	KS-1	75/55, 100/50, 70/50, 30/20
	KS-2	50/30, 35/25
	KE-1	90/35, , 30/25, 45/25, 115/40, 80/30, 215/100, 120/40, 65/50
	KE-2	25/20, 50/40, 35/25, 15/15, 30/15
	KE-4	30/25, 75/45, 40/30
Çaybağı , Harput	CB-21	120/40
	CB-22	50/40, 50/10
	CB-23	90/80, 200/80, 20/20, 35/30
	CB-24	90/50, 50/30
	CB-27	70/50
	CB-28	50/45
	CYB-3	65/33, 50/35, 80/60, 70/50, 65/30, 40/30, 60/30, 80/20, 100/70, 50/45
	CYB-4	55/35, 140/60, 180/90, 90/60
	CYB-5	50/40, 100/60, 80/80, 50/35, 65/30, 90/55, 70/60, 100/90, 125/65, 130/50
	CYB-7	50/45, 30/30, 70/50, 45/25, 65/40, 70/30, 70/40, 60/50, 50/40, 65/55
	CYB-8	150/90, 140/60, 220/100, 80/50, 120/70
	CYB-9	60/35, 40/40, 80/45, 115/65, 85/60, 75/40, 75/35, 145/55, 70/55, 50/25
	HPS-1	45/25, 60/30, 10/5
	HPS-2	110/60, 50/45
	HPS-4	25/25, 120/50, 80/45, 100/47, 20/15
	HPS-5	100/55, 60/50, 80/40, 80/80, 15/10, 200/60
	PK-1	100/60, 40/20
	PK-2	33/25, 70/70, 100/70
	PK-5	45/40
	GÇ-2	70/60, 45/40, 35/30, 45/30, 70/45, 50/35, 80/50, 60/45, 80/40, 55/35
	SK-5	110/60, 80/65, 70/50, 100/100
Palu	PA-1	70/45, 60/45, 80/40, 80/55, 60/40, 60/50, 45/30, 100/90, 90/40, 100/60, 90/70, 80/20, 45/35
Mastar Hill and Sivrice	KK-1	60/40, 50/45, 75/60, 70/65, 50/40, 60/45, 60/35, 70/40, 50/30, 90/25
	YOL-1	70/35, 25/20, 70/45
	YOL-2	35/18, 40/24, 60/33, 60/40
	YOL-3	85/40, 50/40, 70/40, 50/28
	YOL-4	100/40, 85/20, 48/20, 120/50
	SIV-1	195/100, 46/40, 30/15, 130/55, 80/60, 90/75
	SIV-2A	20/12, 40/20, 40/25, 30/25, 30/20, 45/30, 45/35, 85/55, 110/38, 55/15, 90/40
	SIV-5B	50/45, 17/15, 40/30
	SIV-7	120/50, 150/100, 80/45, 40/35
	SIV-8	90/35, 55/45
	SIV-9	150/85, 65/45, 55/40, 110/65, 26/20, 20/17
	IC-1	33/30, 30/25, 40/34, 70/20, 60/50, 20/15
	IC-2	60/40, 35/25, 90/70, 65/30, 45/25
	SRK-2	90/45, 65/30, 50/38, 50/45, 65/35, 45/28, 70/50, 80/50, 70/40, 55/30
	YO-2	60/50, 30/22, 45/38
	CLM-1	90/35, 100/25, 130/50, 150/65, 90/60, 55/55, 85/30
	GK-1	50/50, 35/35, 65/45, 30/30, 45/40, 70/40
	ALC-3	85/55, 65/50, 90/70, 80/40, 90/45, 80/60, 75/30, 40/30, 150/90, 100/80

Table 3) Measurements of long-axis (H) and short-axis (V) in cm of Yüksekova Complex pillowed basic volcanics (Group 2).

Loc.	Sample No	H/V (cm)
İçme, Sivrice	IC-3	70/50, 50/40, 43/40, 65/45, 20/15
	SIV-4	55/40
	DR-9A	47/30, 90/35, 70/40, 30/20, 40/30, 60/35, 50/33, 45/25, 60/40, 65/35, 35/30, 35/15
	CLM-2	30/22, 60/35, 55/30, 53/25, 50/20, 80/50, 100/45, 30/20, 40/30, 80/40, 75/45, 70/40, 60/30
	CLM-3	75/45, 90/40, 125/60, 110/50, 70/30, 135/40, 80/40, 70/30, 90/40, 70/30, 105/50, 40/25
	CLM-5	80/30, 110/100, 80/35, 130/25, 115/45, 55/25, 70/40, 110/40, 90/25, 50/30
Yaygın, Poluşağı, İspendere	PL-3	55/26, 25/15, 60/30, 40/20
	PL-4A	45/35, 65/40, 45/38, 85/45
	PL-5	45/30, 55/45, 30/25, 35/25
	PL-6	35/25, 80/25, 47/45, 20/20
	PL-7	55/30, 38/25, 65/40, 50/35, 50/35, 50/16
	PL-9	90/55, 60/35, 70/33
	KR-1	70/30, 120/45, 47/23, 35/22
	KR-4	50/20, 50/35, 25/15, 30/25, 30/20
	PT-1	130/45, 100/60
	PT-2	100/50, 40/40
	PT-3	65/35, 100/60, 90/60, 70/65, 30/30
	PT-4	50/45, 100/90, 80/55, 50/45, 95/70
	İS-6	65/35, 80/45, 50/25, 120/35, 55/30, 120/45, 90/50, 100/30, 45/30, 75/40
Palu	PA-3	120/35, 120/55, 100/60, 70/60, 190/110
	PA-4	70/60, 90/60, 230/60, 35/35
	PA-6	60/45, 55/40, 70/40, 60/40, 40/30, 70/35, 55/35, 60/35, 32/25, 75/50
Maden	MD-1	50/30, 60/30, 90/50, 50/20
	MD-2	230/60, 170/70
	MD-3	45/30
	MD-5	100/40, 70/30, 130/65, 250/180, 60/35, 210/125, 350/150
	MD-6	90/60, 100/70, 190/110, 150/80
	MD-8	30/20
	MD-9	60/45, 42/40, 26/15, 400/250
	MD-10	80/45, 130/40, 80/20, 20/15, 40/30, 20/15, 40/30, 85/50, 20/16, 50/50
	KV-4	95/35, 75/35, 120/40, 45/30, 55/40, 60/50, 60/35, 130/70, 40/30, 80/30

3–Discussion and conclusion

Schnur (2007) states that calcite replacement represents depths above the carbonate stability level which corresponds to 3.6 km before the Eocene-Oligocene border in Pacific. However, deposition that took place below the carbonate stability level which is suitable for radiolarites, the calcite replacement would be occurred by a regional uplift following the formation of rocks in the study area.

Small-scale pillow structures are indicative of high flow rate, steep or slopes > 10º or low viscosity which result in formation of more flat or elongated pillows (Figs. 6 and 7). Large-scale, rounded, onion-like pillows and close packing show high-slope and high-viscosity flow which give rise to formation of tube-like pillows (Walker, 1992). In the study area pillow-structured volcanites are ellipsoidal, spherical, swollen tube-like lobes and contain local pedoncules. In this respect, the close association of elongated and spheroid pillows might be related to periodical change in flow velocity and irregularity of basin floor from which lava was erupted. Furthermore, partly brecciated appearance of pillows is associated with fragmentation and breaking during the emplacement. One of the main factors controlling the growth of pillow is cooling rate which is a combination of several parameters such as water and lava temperature and eruption speed (Schnur, 2007). The volume of lava material extruded from the active vein is another important factor (Schmincke and Bednarz, 1990). Furnes and Friedleifsson (1978) point out that lava with composition of olivine tholeiite forms pillows in size greater than its alkali olivine basalt types. Considering the mineralogic composition of studied rocks and their tectonic character, the absence of a significant difference in composition and size of both groups indicates the magmas have similar physical characteristics. Greg and Fink (1995) conducted several tests at laboratory conditions on the morphology of submarine lava flows and stated that pillow lavas are formed in areas where basement slope is close to horizontal. The fact that pillow lavas in the study area are not horizontal but generally inclined to the north indicates that rocks lost their original positions probably because of thrusting of the Yüksekova Complex onto the Maden Group. Chemical characteristics reported in previous works (e.g. Ural, 2012 and Ural et al., 2012) and physical and morphologic properties given in this study yield sources with similar parent magmas.

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