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RESEARCH ARTICLE

Petrographic and Geochemical Fingerprints of Sub-Volcanic Dykes and their Host Harzburgites from the Ulaş Ultramafics (Sivas, Turkey)

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ABSTRACT

In the southern Ulaş region (Sivas, mid-Anatolia), the ophiolitic fragments of the Neotethys oceanic lithosphere are widespread. The study area consists of commonly harzburgite, with minor dunite and chromitite pods and also pyroxenites. The latter are sub-volcanic gabbro and diabase dykes. In this study, the petrographic and geochemical importance of the mantle harzburgites and the sub-volcanic dykes cutting them were evaluated, within these ophiolitic units. The textural properties of the harzburgites were generally anhedral, granular and partially poikilitic. They consisted of olivine, orthopyroxene and minor amount of clinopyroxene and chromian spinel. On the other hand, the textural and mineralogical characteristics of sub-volcanic dykes, consisted of plagioclase, pyroxene, hornblende, opaque minerals and their secondary products, reflected semi-depth characters. The major, trace and rare earth element compositions indicated that the harzburgites were similar to that of both abyssal and supra-subduction (SSZ) peridotites with depleted character. Furthermore, the sub-volcanic dykes that formed the focus of this study in the mantle harzburgites exhibited N-MORB (Normal Mid-Ocean Ridge Basalt) type patterns of rare earth (REE) and trace elements. Especially, negative Nb anomaly showed the presence of a subduction component with the late stage modification of subduction-derived fluids/melts. All results indicated that the dykes characterized as N-MORB and late recorded the characteristics of Ocean Island Basalts (OIB). Consequently, geochemical features of the harzburgites and sub-volcanic dykes that cut them showed that peridotites were affected by two different tectonic setting conditions such as MORB and SSZ.

1. Introduction

Ophiolite suites represent ancient oceanic lithospheric remnants in continental orogenic belts and provide important records on the petrological evolution, metamorphism and tectonic processes of oceanic basins. In these ophiolite suites, sub-volcanic dyke intrusions such as micro-gabbro and diabase and also ultramafic pyroxenite dykes are quite common in mantle peridotites and are known as magmatic rocks produced by partial melting of mantle (Pearce et al., 1981).

In this context, petrological and geochemical studies on the world's best known ophiolites (Troodos, Oman, Anatolia, etc.) show that they offer similar features to the SSZ environment (Pearce et al., 1984; Parlak and Delaloye, 1996; Collins and Robertson, 1998; Dilek et al., 1999; Andrew and Robertson, 2002; Robertson, 2002; Parlak et al., 2006; Parlak et al., 2013; Robertson et al., 2013; Bilici, 2015; Parlak, 2016; Bilici and Kolaylı, 2018).

The Tauride ophiolite belt is represented by fragmented ophiolitic rocks embedded and/or cropped out in north of the Tauride platform (Şengör and Yılmaz, 1981; Parlak et al., 2006). In the Sivas region within this belt, the ophiolitic or related units are overlain by the Tauride carbonate platform. Many studies have been carried out about sub-volcanic dyke intrusions intruded the mantle peridotites of the Tauride ophiolites in Sivas province or in central Anatolia. Especially, the geochemical properties of these dykes display that they formed in a supra-subduction zone environment and point out their origin from an Island Arc Tholeiite (IAT) for Taurid ophiolites (Dilek et al., 1999; Çelik and Delaloye, 2003; Parlak et al., 2006; Parlak, 2016).

These features have been interpreted by previous researchers (Dilek et al., 1999; Shervais, 2001; Parlak et al., 2006) as the explosion of MORB-like or Ocean Island Basalt (OIB) lavas on the previously formed arc-related tholeiitic lavas in the final stage of magmatic activity above a supra-subduction zone environment. In this paper, we presented the whole rock major, trace and rare earth element geochemistry of the sub-volcanic dykes and their host harzburgites to discussing their petrogenetic significance and formation conditions within the related tectonic environment.

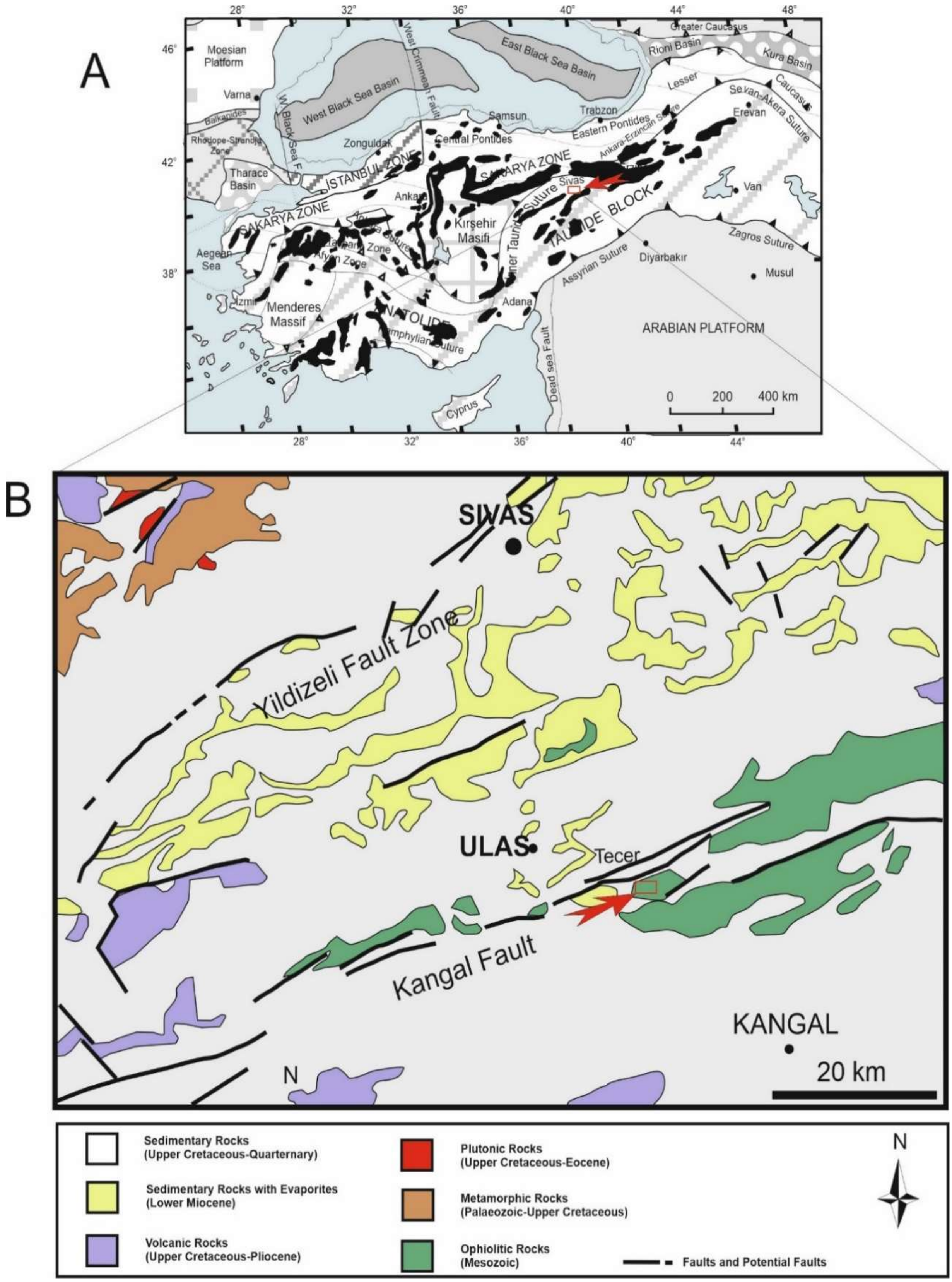

Fig. 1. Illustration of ophiolite belts and related tectonic map of Turkey with the major sutures and continental blocks of northeastern Mediterranean (modified after MTA (2002) and Okay and Tüysüz (1999)), (b) General geological map of the southern Sivas including the study area (Ulaş district) (modified after Yılmaz et al. (1989))

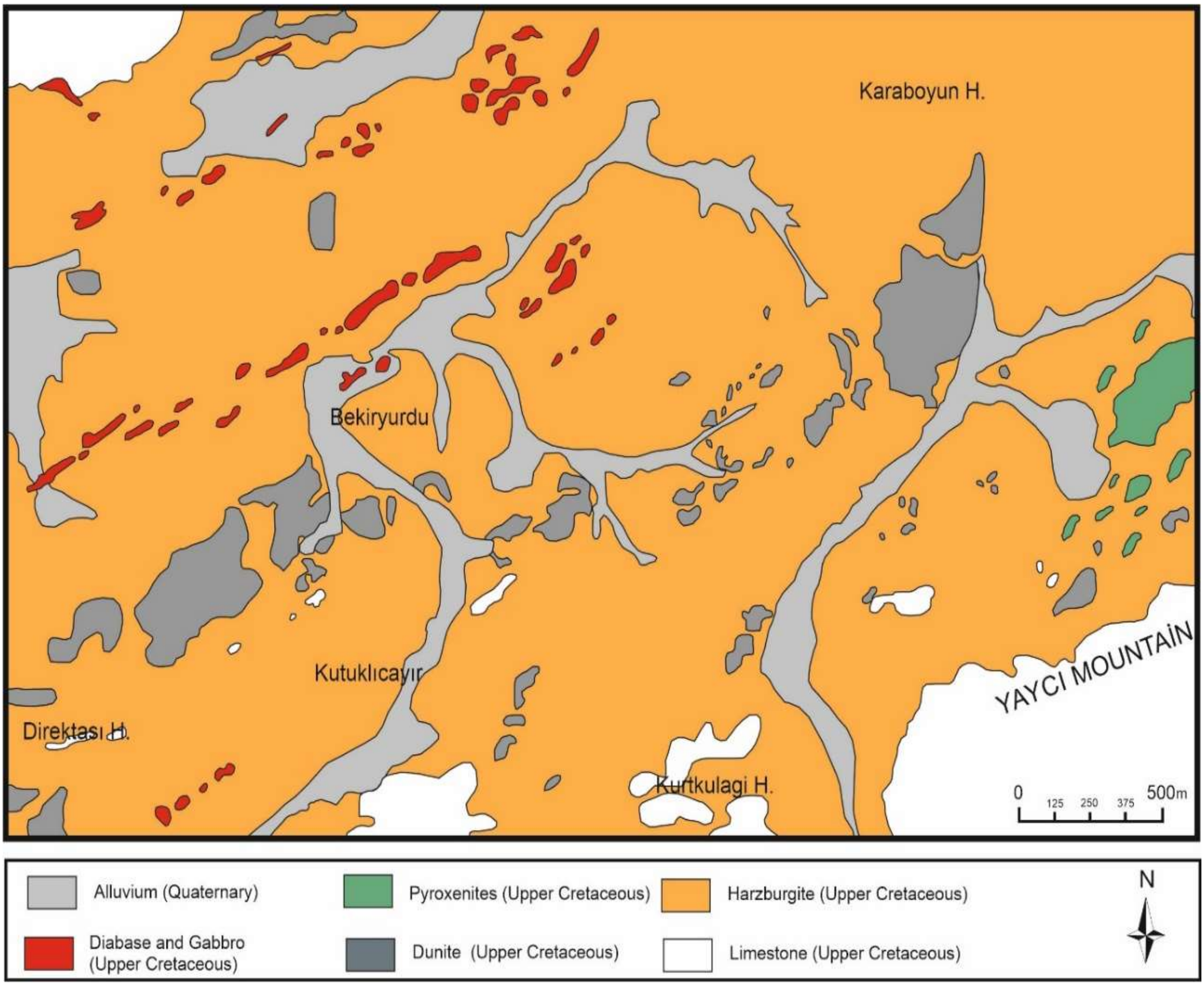

Fig. 2. Detailed geological map of the study area (Bilici, 2015)

2. Geological Summary

Turkey is located in a very important position in terms of tectonic emplacement and depending on the relative motions of continents have been exposed to intense orogenic activity. As a result of the closure of the Neotethys ocean, which started from the Cretaceous period, many basins were closed by the compressive regime and ophiolite settlements have been thrust onto the continents (Şengör and Yılmaz, 1981; Robertson and Dixon, 1984; Robertson et al., 2013; Parlak, 2016) (Fig. 1a). The remnants of these oceanic basins, which have an important place in understanding the geological evolution of Neotethys, are represented by ophiolites, ophiolite base metamorphics and ophiolitic melange in Anatolia (Dilek et al., 1999; Robertson, 2002). As a remnant basin, Sivas region, which also includes the study area, is located between Taurid and Pontid platforms (Cater et al., 1991; Poisson et al., 1996) and occurred during the closure of the northern branch of Neotethys (Yılmaz and Yılmaz, 2006). The ophiolitic units, previously called the Divriği ophiolite (Yılmaz et al., 2001), bear ultramafics mostly of Cretaceous age transported in soils that are ubiquitous and stretch over hundreds of kilometres in Turkey, especially in the Sivas region (MTA, 2002).

This region was composed of autochthonous platform carbonates, ophiolitic mélange, metamorphic sole, ophiolitic rocks, volcano-sedimentary units, granitoid rocks, and sediments (Yılmaz et al., 2001; Yılmaz and Yılmaz, 2004; Parlak, 2016) (Fig. 1b). The mantle peridotites observed in the study area (southeast Ulaş, Sivas) consist of harzburgites containing dunite lenses with chromitites. These widespread harzburgites were cut with different levels of sub-volcanic dykes such as diabase (partially gabbroic and doleritic) (Bilici, 2015; Bilici and Kolayli, 2018) (Fig. 2).

3. Analytical Method

As a result of field studies, a series of samples were collected for geochemical studies, such as petrological characteristics and the tectonic environment of the peridotites and the sub-volcanic dykes that cut them. All samples were carefully cleaned and then ground in a special ring grinder. For this region, major oxide (ICP-ES method) and trace element

(ICP-MS method) analyses of total nine samples were performed in ACME Laboratories (Canada). The analytical indefiniteness was predicted to be 10% for trace elements with abundances of <10 ppm and approximately 5% for those with abundances of >10 ppm.

4. Results and Discussion

4.1. Field observation and petrography

In the study area located in the southeast of Ulaş district of Sivas province, the most common ultramafic lithology, the harzburgites, were systematically sampled. The harzburgites whose distant appearance were characteristic reddish colours and easily distinguished from other units, were observed as dark brown and green outcrops in some places (Fig. 3). On the other hands, during the field studies, a large number of sub-volcanic dykes were observed, which cut harzburgitic peridotites and lined up with a certain geometry. These dyke masses were seen as outcrops up to a few meters in diameter which increased in number as they approached the areas where chromitite bodies (Fig. 3).

As a result of the microscopic investigations the harzburgite samples, it was determined that most samples underwent intensely serpentinization. The harzburgites, whose textural properties were generally anhedral, granular and partially poikilitic, also have been seen stockwork and cataclastic textures due to serpentinization (Fig. 4).

The harzburgites generally consisted of olivine (70-80%), orthopyroxene (15-20%) and to a lesser extent (about 1-5%) clinopyroxene and chromian spinel minerals in terms of modal mineral abundances. In addition, there were trace amounts of alteration minerals (serpentine, brucite, chlorite etc.) (Fig. 4).

Fig. 3. Field photos showing the lithological boundaries from the study area

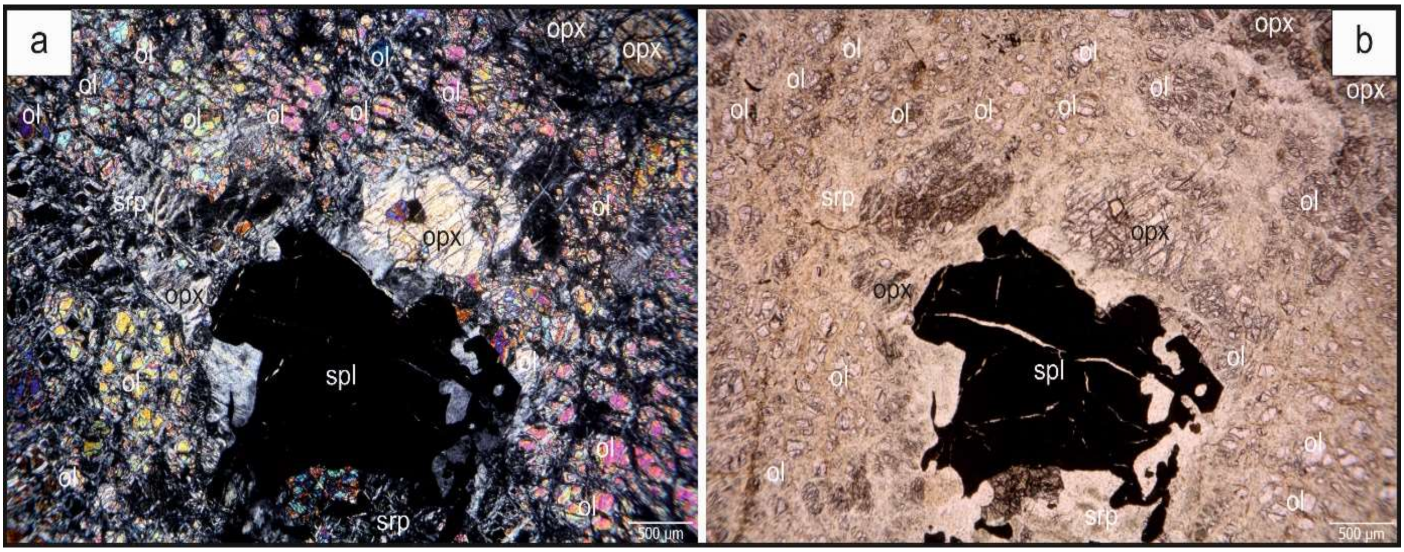

Fig. 4. Photomicrographs of the harzburgite. a and b were taken cross-polarized light and plane polarized light, respectively (ol: olivine; opx: orthopyroxene; spl: chromian spinel; srp: serpentine)

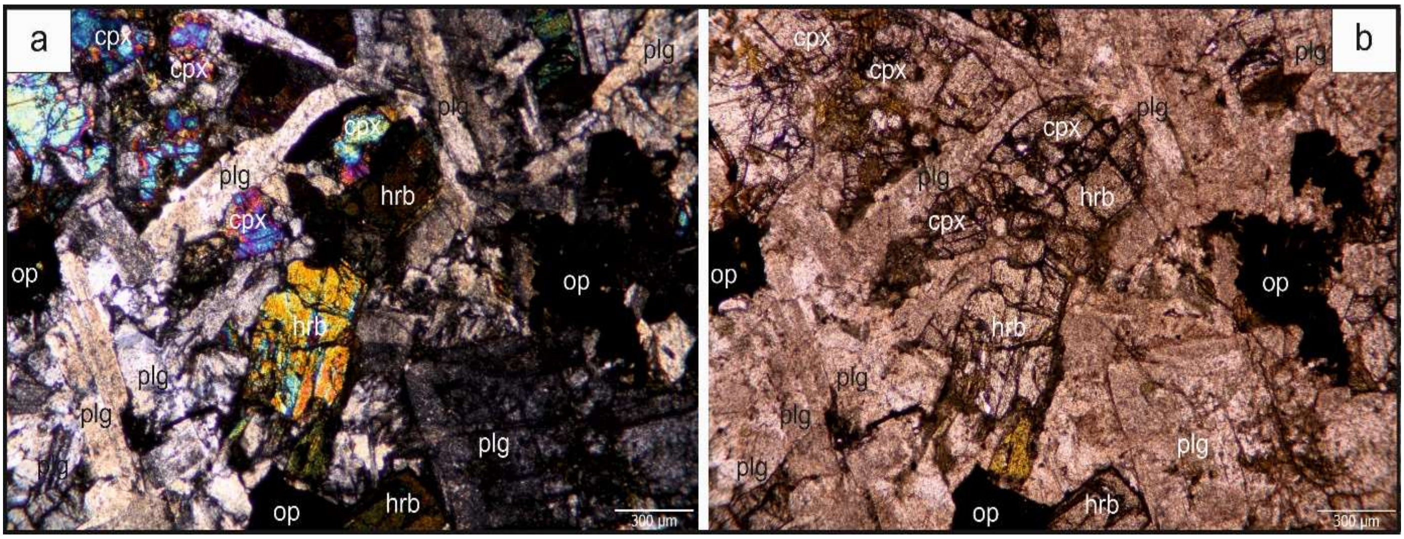

Fig. 5. Photomicrographs of the sub-volcanic dykes. a and b were taken cross-polarized light and plane polarized light, respectively (plg: plagioclase; cpx: orthopyroxene; hrb: hornblende; op: opaque mineral)

All dyke samples collected from the study area were examined in detail under a polarizing microscope. Although the macro samples appear as quite fresh, it was found that they underwent intensely alteration in microscopic observation. Textures were generally observed as intersertal and to a lesser extent doleritic and also poikilitic (Fig. 5). Plagioclases, which were determined pervasively altered, have formed all of the light colored minerals. Altered pyroxenes and opaque minerals were seen, among the plagioclases generally formed as leaning against each other. Partially or fully chloritized and uralitized pyroxenes minerals were determined in the samples at a rate of about 10% in terms of modal composition (Fig. 5).

Moreover, most pyroxene crystals were determined to be augite, altered partially to actinolite and tremolite. Hornblende minerals along with augites, have also participated in a significant amount of modal mineralogy. As a result, it was determined that these dykes were in lithology ranging from micro-gabbro to diabase and even dolerite.

4.2. Geochemistry and tectonic implications

Whole-rock major, trace and rare earth element (REE) analyses were performed on four harzburgite and five sub-volcanic samples and results were given in Table 1. Firstly, LOI values were high more than 10 wt% because of the serpentinization of all harzburgite samples. According to the analysis results, the Al_2O_3, CaO, Fe_2O_3, TiO_2, MnO, Cr_2O_3 contents (% by weight) of the harzburgites ranged between 0.43-1.87, 0.22-0.51, 7.03-8.56, 0-0.05, 0-0.1, 0.15-1.01, respectively. The harzburgite samples have relatively high MgO (average 35.14 wt%), whereas low Al_2O_3 (average 1.87 wt%) and alkalis (Na_2O <0.07 wt%; K_2O<0.04 wt%) contents.

These elemental abundances of the harzburgites were found to be relatively lower compared to sub-volcanics, and it was observed that these distributions (apart from MgO and Cr_2O_3 (%wt.) contents) showed positive orientations from the harzburgites to the sub-volcanics, according to SiO_2 contents (Fig. 6a-j). This trend was an expected result, consistent with the observed modal mineralogical compositions. The MgO content in the mantle peridotite represents the consumption or partial melting degree of the mantle. It shows higher degree of the partial melting processes with high MgO contents and low CaO, Al_2O_3 and SiO_2 contents (Coleman, 1977; Hartmann and Wedepohl, 1993). In other words, when evaluated petrologically, incompatible components such as CaO, Al_2O_3 and SiO_2 tend to melt during the melting of a basic magma developing in the upper mantle. As the melting degree increases, mantle peridotites now become richer in MgO and the mantle becomes more depleted.

Here, this process was discussed on the Al_2O_3/SiO_2 vs. MgO/SiO_2 diagram (Fig. 7). The bulk compositions of the peridotites tend to run just below the mantle sequence, but in parallel (Hart and Zindler, 1986; Wu et al., 2017). This depletion trend may indicate the MgO loss or SiO_2 addition from the system during serpentinization. While the Al_2O_3/SiO_2 ratios are significantly reduced, MgO/SiO_2 ratios increase slightly in orthopyroxene and clinopyroxene during partial melting. As melting progresses, pyroxene, especially clinopyroxene, is depleted very quickly, and the modal content of olivine increases, resulting in an increase in the MgO/SiO_2 ratio. As the degree of partial melting increases, the bulk MgO/SiO_2 ratio increases. It is then understood that partial melting may not be the only reason that the observed bulk MgO/SiO_2 ratio is below the mantle sequence. Here, all of the analysed harzburgite samples have a slightly lower MgO/SiO_2 ratio than the mantle sequence, which means some loss of Mg due to alteration previously suggested by Niu (2004). Moreover, some samples may contain lower concentrations of major and trace elements due to the effect of this alteration or serpentinization.

In this paper, the MgO/SiO_2 and Al_2O_3/SiO_2 ratios of the harzburgites were much higher than primitive mantle (PM) despite small differences between samples and they had relatively high mantle depletion or partial melting (Fig. 7). When compared to the abyssal and fore-arc SSZ mantle peridotites, the compositions of the Ulaş harzburgite samples were similar to that of abyssal peridotites, and two harzburgite samples fall in the fore-arc SSZ peridotites field or near (Fig. 7).

Table 1. Representative major oxide (wt %), trace (ppm) and rare earth (ppm) element composition of the harzburgite and sub-volcanic samples

Lithology	**HARZ**	**HARZ**	**HARZ**	**HARZ**	**SVLC**	**SVLC**	**SVLC**	**SVLC**	**SVLC**
Sample	**Y-1**	**Y-6**	**AT-12**	**AT-13**	**S-8**	**S-15**	**S-21**	**AT-8**	**AT-9**
SiO_2	37.86	39.92	40.11	39.84	48.50	48.58	47.03	49.98	51.46
Al_2O_3	0.59	0.43	1.18	1.87	15.61	14.91	15.76	15.74	15.47
Fe_2O_3	7.17	7.03	8.54	8.56	10.68	9.28	8.95	9.70	10.66
MgO	37.11	34.27	36.09	33.10	5.80	7.37	8.12	7.15	6.98
CaO	0.22	0.23	0.51	0.34	9.79	9.60	10.91	10.60	9.58
Na_2O	0.01	0.00	0.07	0.06	5.11	4.62	3.38	3.54	2.88
K_2O	0.00	0.00	0.04	0.02	0.29	0.21	0.87	0.66	0.65
TiO_2	0.00	0.00	0.05	0.04	1.11	1.00	0.88	1.01	1.03
P_2O_5	0.00	0.00	0.06	0.04	0.07	0.08	0.06	0.12	0.14
MnO	0.10	0.10	0.10	0.07	0.17	0.15	0.15	0.17	0.18
Cr_2O_3	0.31	0.35	0.16	1.01	0.01	0.03	0.04	0.02	0.01
LOI	15.80	16.80	12.55	12.10	2.70	3.90	3.60	2.02	1.04
Total	99.17	99.13	99.46	96.98	99.84	99.73	99.75	100.71	100.08
Ni	1933.00	2031.00	1682.00	2680.00	38.00	75.00	103.00	43.00	36.00
Sc	8.00	7.00	24.00	13.00	35.00	36.00	37.00	48.00	41.00
Ba	2.00	0.00	7.00	4.10	24.00	33.00	93.00	23.00	15.00
Be	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00
Co	95.30	92.20	104.80	113.60	35.80	35.70	38.20	41.00	56.00
Cs	0.00	0.00	0.00	0.00	0.20	0.50	2.50	0.00	0.00
Ga	0.00	0.00	1.60	2.80	15.60	13.70	13.50	12.00	15.00
Hf	0.00	0.00	0.00	0.00	1.90	1.70	1.50	4.00	1.00
Nb	0.00	0.00	0.50	0.20	0.20	0.60	0.40	3.00	0.90
Rb	0.20	0.20	0.30	0.00	3.90	4.60	17.80	4.00	6.20
Sn	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sr	1.10	2.80	4.70	3.20	103.00	250.20	138.00	34.00	156.00
Ta	0.00	0.00	0.00	0.00	0.10	0.30	0.20	0.20	0.10
Th	0.00	0.00	0.00	0.00	0.50	0.10	0.20	0.10	0.10
U	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
V	38.00	28.00	0.00	0.00	345.00	267.00	266.00	330.00	301.00
W	0.00	0.00	1.10	0.80	0.00	0.00	0.00	0.00	0.00
Zr	0.10	0.00	1.90	1.70	58.10	58.10	48.50	58.00	61.00
Y	0.00	0.00	0.10	0.60	25.20	21.50	20.10	25.00	23.00
La	0.30	0.10	0.50	0.00	2.50	2.30	2.10	3.98	2.32
Ce	0.10	0.00	0.90	0.50	7.20	7.20	5.80	10.36	7.45
Pr	0.00	0.01	0.09	0.06	1.24	1.26	1.08	1.54	1.25
Nd	0.02	0.01	0.00	0.00	6.50	6.80	5.90	7.89	4.01
Sm	0.01	0.00	0.00	0.00	2.38	2.21	2.05	2.55	2.33
Eu	0.01	0.03	0.04	0.03	0.95	0.88	0.83	0.98	0.79
Gd	0.00	0.12	0.07	0.07	3.37	3.25	2.80	3.12	3.39
Tb	0.01	0.00	0.01	0.01	0.66	0.63	0.53	0.55	0.58
Dy	0.00	0.02	0.06	0.09	4.27	3.94	3.37	3.78	4.17
Ho	0.03	0.00	0.02	0.02	0.98	0.78	0.80	0.84	0.98
Er	0.04	0.02	0.05	0.07	2.82	2.49	2.25	2.34	2.68
Tm	0.01	0.00	0.02	0.03	0.42	0.36	0.33	0.35	0.41
Yb	0.06	0.01	0.06	0.09	2.58	2.35	2.12	2.33	2.64
Lu	0.02	0.00	0.01	0.03	0.43	0.37	0.33	0.34	0.39
ΣREE	0.61	0.32	1.83	1.00	36.30	34.82	30.29	40.95	33.39

(HARZ: harzburgite, SVLC: sub-volcanic)

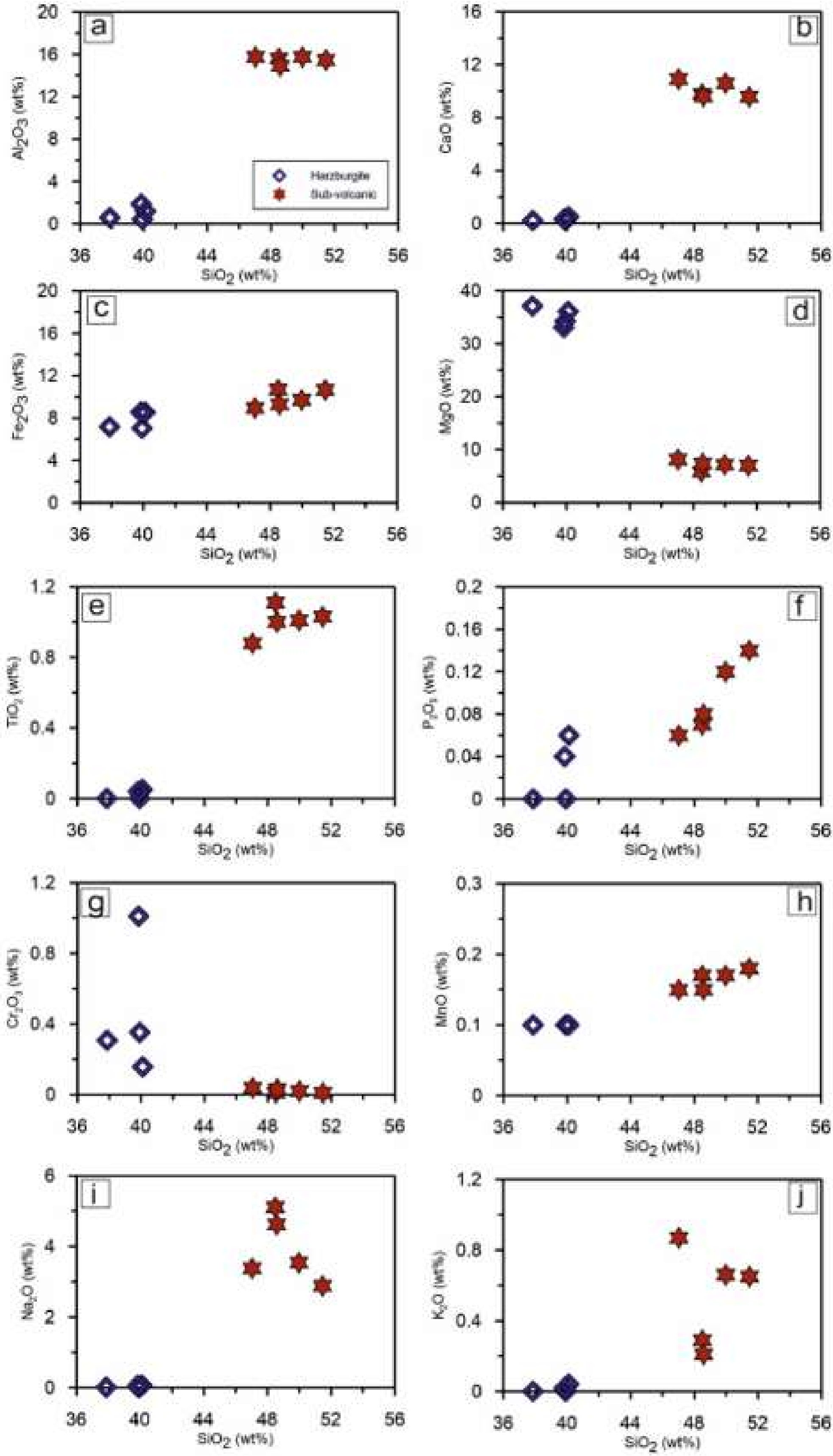

Fig. 6. Whole rock major element variation diagrams of the Ulaş harzburgites and sub-volcanic dykes

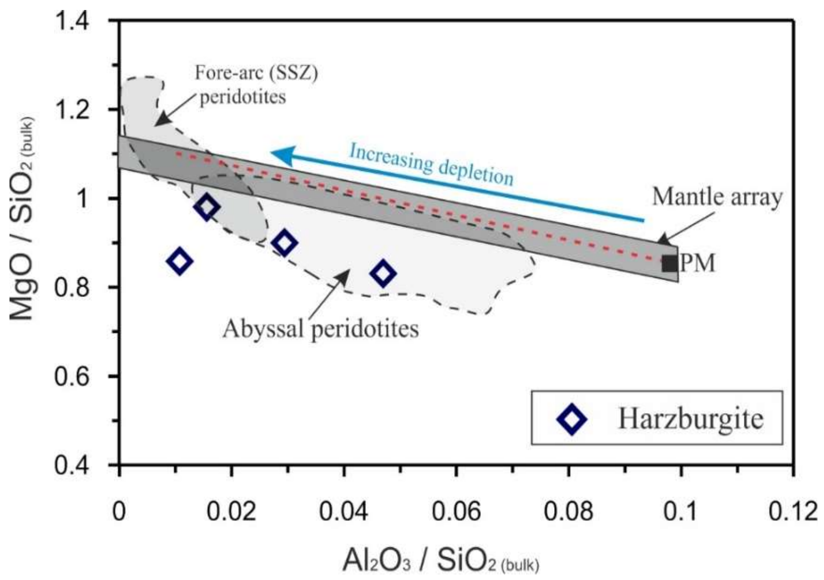

Fig. 7. Whole rock major element distribution of harzburgites in MgO/SiO_2 and Al_2O_3/SiO_2 exchange diagram (after Wu et al. (2017))

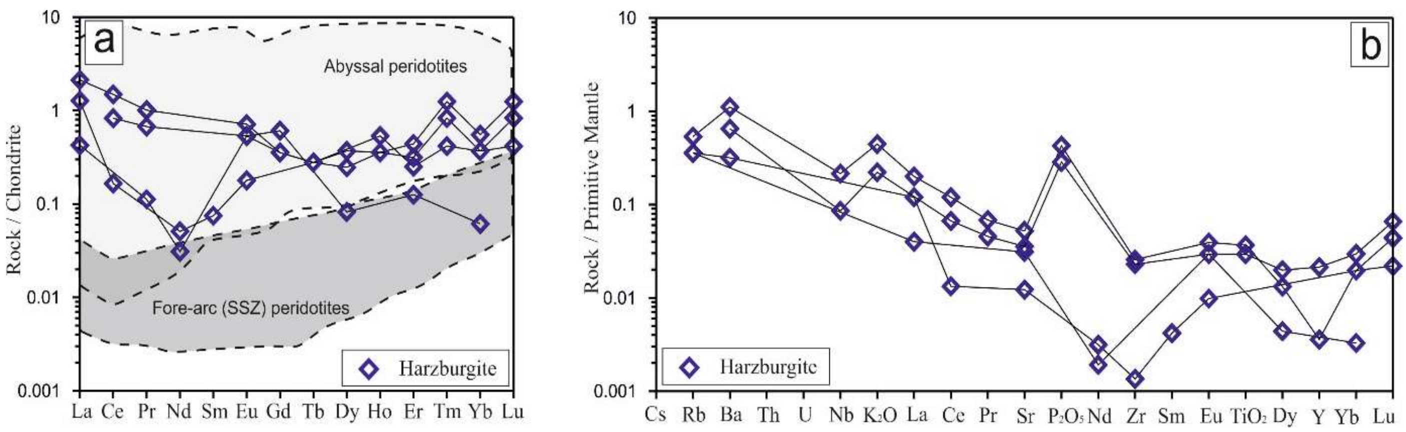

Fig. 8. REE and trace element distributions in whole rocks of the harzburgites; (a) the REE patterns (b) trace elements spider diagram (chondrite and primitive mantle normalizing values were taken from Sun and McDonough (1989)). Abyssal and fore-arc peridotite fields were taken from Niu et al. (1997) and Parkinson and Pearce (1998), respectively

The harzburgite samples have very low REE compositions, and their ΣREE contents range between 0.324–1.83 (ppm) (Table 1). This indicates that the harzburgites exhibited significant depletion as a result of high and/or moderate degrees of partial melting (Miller et al., 2003). The chondrite normalized REE patterns and primitive mantle normalized multi-element distributions were illustrated in Fig. 8. Although the low REE contents varied not considerably, their distribution patterns were very significant (Fig. 8a). Especially, two of the samples were slightly enriched in light REE. The REE pattern of the Ulaş harzburgites was distinctively different from the REE-depleted pattern of the fore-arc SSZ peridotite with low total REE contents that were quite depleted.

They showed similarity with the abyssal and SSZ peridotites (Fig. 8a). However, this light REE enrichment feature has widely been interpreted as a penetration of subduction-derived melts or fluids (Wu et al., 2017). Here, our data were not exactly matched with the modelled SSZ or abyssal REE patterns, but they were more compatible with light REE enrichment produced by melt-peridotite interactions beneath a MOR-type setting. Previous researchers suggested that this process originated in the cold thermal boundary layer, through which melts react with an earlier residual mantle, resulting in both light REE and high field strength element (HFSE) enrichments in abyssal peridotites (Niu, 2004). However, this light REE (Fig. 8a) and HFSE (Fig. 8b) enrichments showed by Ulaş harzburgites might have been a result of their interaction with SSZ melts (Dilek and Furnes, 2014). Especially, the primitive mantle-normalized multi-element diagram of the harzburgites exhibited right dipping patterns (Fig. 8b). The large ion-lithophile elements (LILE) enrichments might be due to crustal fluid interaction of the subduction zone. Moreover, high field strength elements exhibit both depletion of Nb, high REE enrichment indicating the depleted mantle source and different degrees of metasomatic processes above a subduction zone.

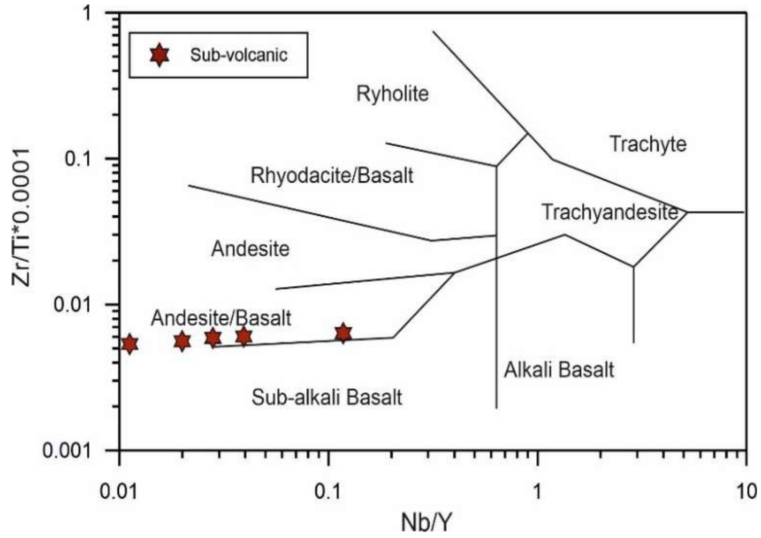

Fig. 9. Zr/ TiO_2 vs Nb/Y classification diagram for sub-volcanic rocks cutting the harzburgites (Floyd and Winchester 1978)

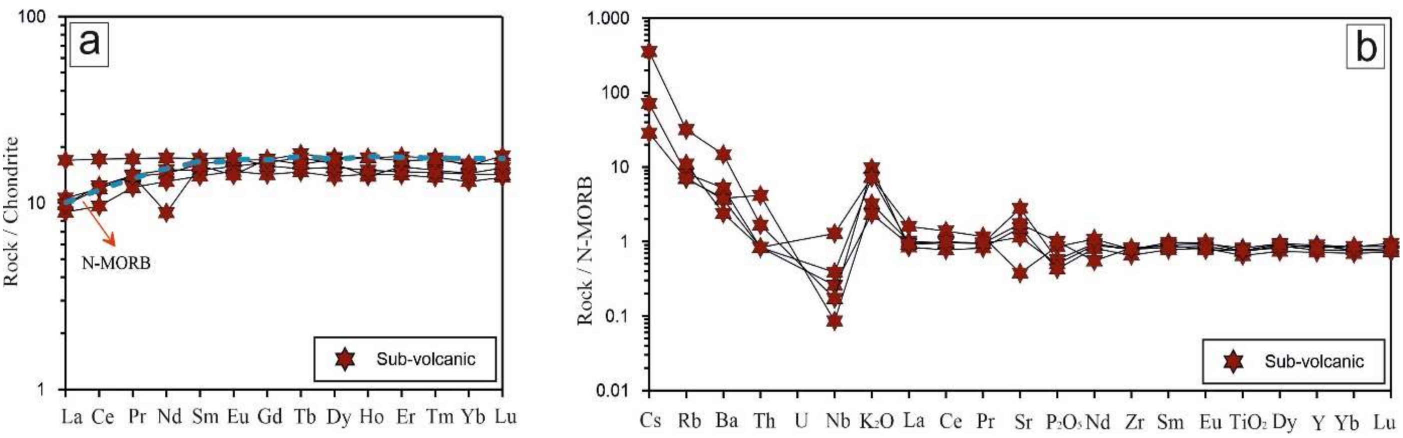

Fig. 10. Chondrite normalized REE patterns (a) and N-MORB normalized multi-element patterns (b) for the sub-volcanic dykes in the Ulaş ultramafics (normalizing values were taken from Sun and McDonough (1989))

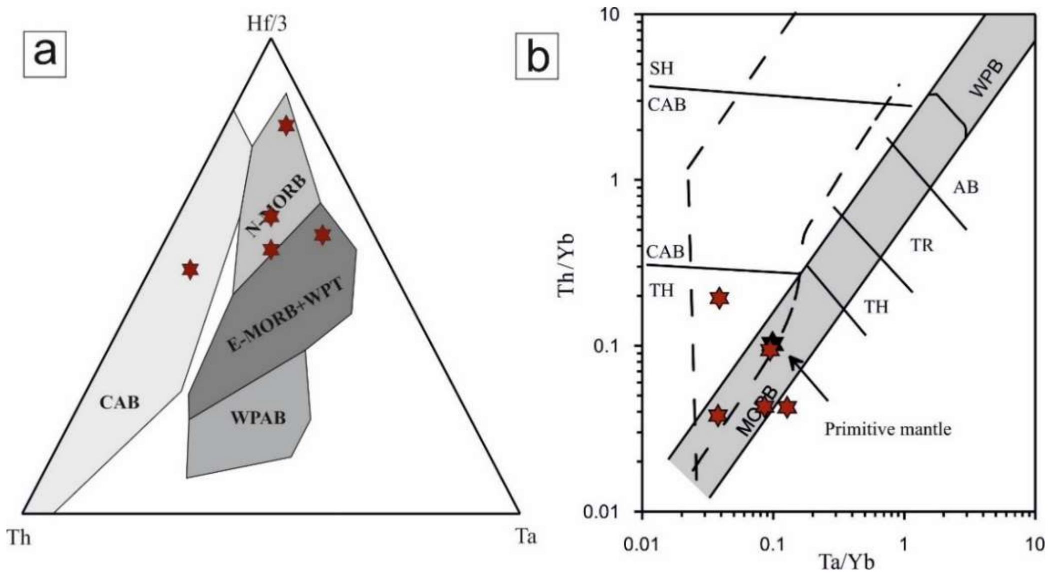

Fig. 11. Tectonic discrimination diagrams for Ulaş sub-volcanic dykes cutting the mantle harzburgites: a) Diagram of Hf/3 vs. Th vs. Ta (suggested by Wood (1980)); b) Diagram of Ta/Yb vs. Th/Yb (suggested by Pearce et al. (1984)). MORB: Mid-Ocean Ridge Basalt, WPB: Within Plate Basalts, CAB: Calc-alkaline Basalt, SH: Shoshonite, TH: tholeiite, TR: transition basalt, IAT: Island-Arc Tholeiites

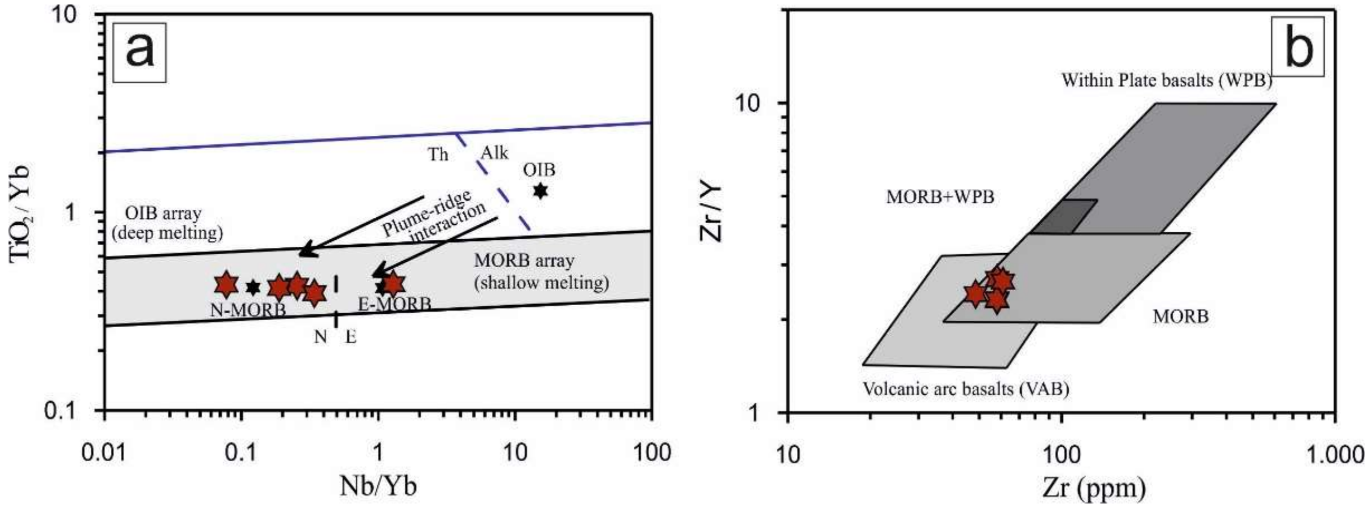

Fig. 12. Tectonic discrimination diagrams for Ulaş sub-volcanic dykes cutting the mantle harzburgites; a) Diagram of Nb/Yb vs. TiO_2/Yb (after Pearce (2008)), b) Diagram of Zr vs. Zr/Y (suggested by Pearce and Norry (1979)). OIB, N-MORB and E-MORB were taken from Sun and McDonough (1989).,

Primitive mantle-normalized trace element patterns of the harzburgites showed that they were highly depleted in terms of lithophile elements, with concentrations well below those of abyssal peridotites (Fig, 8b). The sub-volcanic dykes cutting the mantle harzburgites in the Ulaş ultramafic massif showed moderate alteration according to the geochemical results and they had up to 4 wt % LOI values (Table 1). In the Zr/TiO2 vs. Nb/Y diagram suggested by Floyd and Winchester (1978), these sub-volcanic dykes plotted in the andesite/basalt field with high values of TiO_2 (0.88 to 1.11 wt %), Zr (48.5 to 61 ppm), Nb (0.20 to 3 ppm) and Y (20.10 to 25.20 ppm) (Fig. 9). The chondrite-normalized REE patterns and N-MORB normalized multi-element distributions of the sub-volcanic dykes were illustrated in Fig. 10a-b.

It was observed that there was a similar distribution with N-MORB in REE contents and slightly depletion in terms of incompatible light REEs (Fig. 10a). This is compatible with the REE contents of other diabase dykes in the Taurid belt ophiolites (Parlak and Delaloye, 1996; Çelik and Delaloye, 2003; Parlak et al., 2006). Furthermore, due to these REEs indicated that the Ulaş sub-volcanic dykes were similar as N-MORB, which formed in a MORB-like setting and were mounted by the features of OIB. The N-MORB normalized multi-element distributions of sub-volcanic dykes exhibited enrichment patterns (Fig. 10b). In particular, consumption of Nb in these dykes and their enrichment in large-ion lithophile elements (LILE) such as Sc, Rb, Ba, U and K_2O even offered similarity with the alkali melts changed in the subduction zone. This situation showed similarity with the OIBs suggested by Parlak et al. (2006). The hornblende minerals in the modal mineralogy of the sub-volcanic dykes can also be cited as evidence.

In terms of determining the tectonic formation environments of ophiolites, some elements such as Hf, Ti, Zr, Y, Nb and Sr are distinctive trace elements for volcanic and/or sub-volcanic rocks (Pearce and Cann, 1973; Xu et al., 2019). Here, on the Hf/3-Th-Ta ternary diagram (Fig. 11a), the sub-volcanic dykes plotted within the MORB area and on the Ta/Yb vs. Th/Yb diagram (Fig. 11b) most of these dyke samples plotted in the N-MORB area except for two samples. One of these two samples plotted in the calc-alkali basalt (CAB) field and other plotted in enriched mid-ocean ridge basalt (E-MORB) field.

In the Nb/Yb vs. TiO2/Yb diagram, the Ulaş sub-volcanic dykes plotted close to the N-MORB field with low Nb/Yb ratios (Fig. 12a), but one sample falled in the E-MORB field. This situation indicated that the source of the dykes was more depleted than the N-MORB source. On other hand, in the Zr vs. Zr/Y diagram all samples showed similarity in each other and plotted in the intersection field of the MORB and volcanic arc basalt (VAB) fields (Fig. 12b).

5. Concluding Remarks

The Ulaş ultramafic massif as a part of the Divriği ophiolite (Sivas) consists mainly of harzburgite, with minor dunite-chromitite and pyroxenite, suggested the involvement of mantle material. Based on field observations, the results in this study indicated that these harzburgites cutted by sub-volcanic dykes may source from deeper mantle. The composition of the Ulaş harzburgites were similar to that of both abyssal and the SSZ peridotites with depleted character. The Ulaş sub-volcanic dykes in the mantle harzburgites exhibited N-MORB-type patterns of REEs and trace elements. These patterns showed that they were slightly depleted in highly incompatible elements (light REEs) with respect to less incompatible elements (heavy REEs). Especially, pronounced negative Nb anomalies, suggesting the presence of a subduction component. All results indicated that the dykes characterized as N-MORB and late recorded the characteristics of OIBs. The presence of hornblende crystals in these sub-volcanic units showed the late stage modification of subduction-derived fluids. All these features of the studied harzburgites and sub-volcanic dykes suggested that the Ulaş ultramafic section of the Divriği ophiolite might have been formed in two different tectonic settings (MORB and SSZ). These data imply that the ophiolites in the north of Tauride belt were characteristic of the two stage evolution. First, the development of harzburgitic peridotites with moderate-degree of the partial melting, from the mid-ocean ridges to the subduction zone. The second was the interaction of these peridotites reaching the subduction zone with MORB-like melt, which occurs with different angle and/or breaking of the subducted lithosphere plate.

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