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COMPOSITION OF PALEOGENE VOLCANICS IN THE REGION OF ARDA MOUNTAIN, SOUTH RHODOPES

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ABSTRACT
The Upper Arda graben basin is located in the area of Arda Mountain in the Southern Rhodopes, both on the territory of Bulgaria and Greece. The volcanic and volcano-sedimentary rocks overlie and associate with Upper Eocene and Oligocene terrigenous sediments. Dacites, rhyiolites and tuffs are dominating rock types. Ignimbrites are also quite common. The volcanics are quartz-feldspar rocks containing plagioclase and K-Na feldspar nearly in equal quantities, or with prevalence of plagioclase. Femic minerals are biotite, rarely amphibole and augite. The rocks are high-K and the relation K_2O/Na_2O does not depend on the SiO_2 content. The modal and petrochemical composition indicate calc-alkaline to subalkaline trachydacite-trachyrhyolite or high-K calcalkaline dacite-rhyolite series. The volcanic rocks are part of the Paleogene collision-related volcanics from central part of the Rhodopes region.

INTRODUCTION

The Upper-Arda Graben (trough) or basin (UAG) (Vatsev, 1985, 1989a) is one of the southernmost Paleogene basins in the Rhodope region on the territory of Bulgaria. It is located in the southernmost, high part of the Upper Arda region in the Central Rhodopes (CR) and occupies the area of Arda Mountain. Its southern part extends on the territory of Greece and is known as Dipotama basin (Baker and Liati, 1991). The Bulgarian part of the basin is denoted as Vitina depression (Bahneva, Stefanov, 1973).

Brief information and data on the petrographic composition and stratigraphic position of the volcanics in UAG are given in the publications of Bahneva, Stefanov (1973) and Vatsev (1985, 1989a). They report data on the Oligocene age of the volcanics and occurrence of ignimbrites. More detailed petrologic characteristics of the rocks under consideration have not been reported so far. The petrologic and geochemical data about the same rocks on the territory of Greece are much more complete (Eleftheriadis and Lippolt, 1984; Eleftheriadis, 1995).

The present work, which is a continuation of earlier studies of the author, aims at giving a more detailed information about the volcanics of UAG and improving the understanding of the volcanism in the CR. The volcanic rocks are characterized on the basis of field, micropetrographic and petrochemical studies. For this purpose, 33 silicate analyses were used. 26 of them were made in Bulgaria, of which 21 based on author's investigations and analysed at the "Geochemistry" Central Research Laboratory of the University of Mining and Geology by classical water silicate analysis. The other 6 analyses are from literature sources and 7 are from Greece (Innocenti et al., 1984; Ellefteriadis, 1995).

GEOLOGICAL SETTING

The Palaeogene Upper Arda volcano-sedimentary basin (Vatsev, 1985,1989a), as well as the other depressions in the CR, overlie the Pre-Cambrian basement of the Rhodopes region (RR) as well as Upper Cretaceous and Paleogene granites (Soldatos, Christofides, 1986: Kamenov et al., 1999). It is bordered on the north by several WNW-ESE subparallel faults with subsided southern blocks. The graben is 25-30 km long and 5-8 km wide on the territory of Bulgaria. The southern, wider part of the basin (10-15 km) is located in Greece. The relatively uplifted blocks of the basement, exposed along the Bulgarian-Greek border at the village of Arda, at Gramada summit, south-east of Mochure, at the villages of Vitina and Plovdivtsi, mark the complex block-graben structure of UAG.

The Upper-Eocene sedimentary fill of UAG in its northern, Bulgarian part consists from bottom to top of the following units: 1) Hulevina breccia-conglomerate Formation (200-250m) (Vatsev, 1985); 2) Palova sandstone Formation (70-90 m) (Vatsev, 1985); 3) Radichevo conglomerate Formation (150-200 m) (Vatsev, 1985) and 4) Gudevo argillite-sandstone Formation (450-500 m) (Vatsev, 1985), containing seams of coal and tuff layers. The Late Eocene age is dated on the basis of fossil flora (Vatsev, 1985).

The overlying Oligocene sedimentary and volcanic rocks are represented by: 5) Gozdevitsa sandstone-conglomerate Formation (150-200m) (Vatsev, 1989), containing tuff layers and 6) Gramada volcano-sedimentary Formation (900-1300m) (Vatsev, 1989).

The Gramada Formation is composed of three volcanic units (sequences), divided by two wedge-shaped, fluvial and caldera-lacustrine sedimentary and pyroclastic units: Milenovo tuff-argillite-sandstone Member (15-90 m) (Vatsev, 1989a and Mochure tuff-argillite-sandstone Member (10-25 m) (Vatsev, 1989a). The volcanic rocks of the first (150-200 m), third (500-600m) and fifth (250-300 m) unit show similar composition and structure. They comprise ignimbrites, with and without fiamme, lapilli and ash-tuffs, dacites and rhyolites (rhyodacites). The ignimbrites, dacites and rhyolites with porphyry texture are better developed in the upper parts of the volcanic units. A late element of the volcanic sequences are dacite-rhyolite extrusive rocks, containing phenocrysts (to 10-15 cm) of Na-K-feldspar and less quartz and biotite, as well as amphibole and diopside-augite. In the upper part of the bodies, the rocks are grey-black and poorest in phenocrysts (10-20%).

The Oligocene age of the rocks was proved on the basis of fossil flora, identified in the sedimentary rocks of Malenovo tuff-argillite-sandstone Member and in the late Late Eocene sediments of the underlying units (Vatsev, 1989a,b). The age of the volcanic rocks in Greece is about 27-30.6 Ma – Oligocene (Elefteriadis and Lippolt, 1984).

One of the most important features of UAG is the close interrelation between volcanism and tectonics, development of volcanic-tectonic depressions of block-caldera type and significant volume of ignimbrites.

PETROGRAPHIC CHARACTERISTICS

The volcanic rocks in UAG, regardless of differences in genesis and stratigraphic position, are not essentially altered and have practically identical crystal phases. The phenocrysts (20 to 63 % of the rock volume) are plagioclase, Na-K feldspar, quartz, biotite, amphibole and augite, which are relatively evenly distributed.

Plagioclase crystals (3-6 mm) show a zonal structure. Their composition varies from the centre to the periphery from andesine (An 50-45) to oligoclase (An 30-20). The number of zones varies from 3-5 to 6-7. Normal and locally reverse zonality is observed. The composition of the zones varies by 4-6 numbers of the plagioclase, but spotted zonality may occur as well. Some crystals have more basic cores.

Na-K feldspar is represented by automorphic and broken individuals of sanidine, found in tuffs, ignimbrites and rhyodacites.

Quartz crystals (2-4 mm) are transparent and slightly smoked grains, with irregular outlines, sometimes partially hexagonal or corroded by volcanic glass. Polymineral xenogenous quartz crystals have been found as well, containing powder inclusions, zircon and apatite.

Biotite (2-5%) is represented by varieties rich in iron and is often affected by opacitization and chloritization. There are biotite grains with thin, darker coloured outer zone.

Amphibole is a relatively rare mineral (below 1%) of unsteady development. It is represented by ordinary green, often altered amphibole. Pyroxene is a rare mineral, appearing as single grains of augite, often replaced by amphibole.

Accessory minerals include zircon, apatite, magnetite, rutile and orthite. Magnetite was formed earlier and is more typical. The minerals filling cavities are trydimite, cristobalite, rarely Na-K feldspar.

The ground mass of the volcanic rocks is composed of volcanic glass, devitirified to a different extent. There are rocks with vitrophyric, hyalopelitic, felsitic and spherulitic texture. The latter is related to devitrification of volcanic glass. Some varieties show relatively homogeneous structure of the ground mass, and others – a vague fluidal-striped texture, controlled by liquation processes and magma flow.

The fiamme of the ignimbrites show striped structure and are 1 to 3 cm long and up to 1.5 cm thick. The pumice clastics are lenticular and vary from 2-3 to 5-7 cm in length. The shape, boundaries and structure of the fiamme are indicators of their plastic deformations within the ignimbrite flows.

The volcanic rocks under consideration contain xenoliths and polymineral grains of gneisses and granodiorites.

The observed characteristic associations of phenocrysts, inherent to normal calc-alkaline to subalkaline acid rocks, and the refraction coefficient of the ground mass (1,495-1,510) allow to differentiate amphibole containing biotite and mainly biotite dacites and rhyodacites or rhyolites, ignimbrites and tuffs of analogous composition. They originated most probably from one melt.

PETROCHEMICAL CHARACTERISTICS

The volcanic rocks from UAG are acid (SiO_2 from 64 to 72 wt%) normal calc-alkaline and subalkaline varieties. On the basis of the classification and nomenclature of igneous rocks (CNI) - (Na_2O + K_2O)/SiO_2 diagram (Bogatikov et al., 1985) (Fig. 1a) they are calc-alkaline and subalkaline dacites and rhyodacites. Based on the same data, according to the classification of volcanic rocks (TAS Diagram) (Le Bas et al., 1992), they belong to the trachydacite-trachyrhyolite series (Fig. 1b). According to the K_2O-SiO_2 diagram (Peccerillo and Taylor, 1976, supplemented by Ewart, 1982) they may be classified as dacites and rhyolites with high K content (Fig. 1c). The ratio K_2O/Na_2O for most of the analyses is below 1 (Fig. 1d). Recalculations of the normative mineral composition were carried out by the methods of the American geologists C.I.P.W. Parallel to that a number of important typochemical coefficients and normative characteristics were calculated.

On the basis of the normative mineral composition, according to the AQP diagram (Le Bas, Streckeisen, 1991), the rocks may be referred to the calc-alkaline rhyolite (Fig. 2a) to subalkaline dacite-rhyolite series.

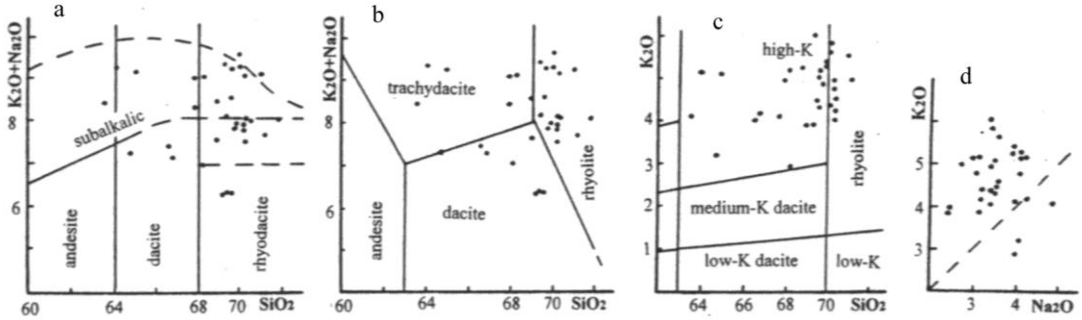

Figure 1. Petrologic diagrams of the Paleogene volcanic rocks from Upper-Arda graben: a) Diagram $Na_2O + K_2O/SiO_2$ wt%; b) Diagram $Na_2O + K_2O/SiO_2$ wt% (TAS); c) Diagram K_2O/SiO_2 wt%; d) Diagram K_2O/Na_2O wt%; data of diagrams see in paper

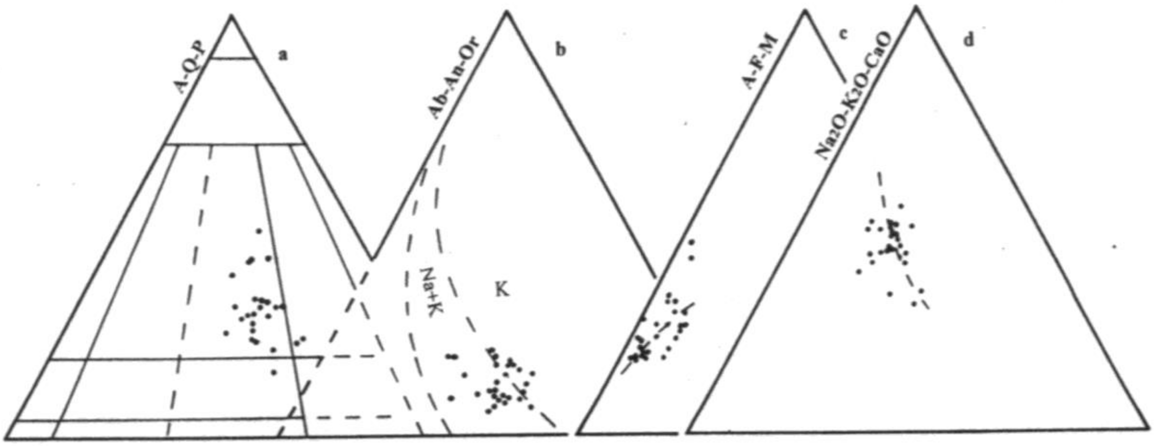

Figure 2. Mineralogical and petrologic diagrams of the Paleogene volcanic rocks from Upper-Arda graben: a) Diagram AQP, A – alkcaly feldspar, Q – quartz, P – plagioclase; b) Diagram Ab-An-Or normative minerals; c) Diagram AFM, A = $Na_2O + K_2O$, F = FeO + 0,9Fe2O3, M = MgO; d) Diagram Na_2O-K_2O-CaO wt%; data of diagrams see in paper

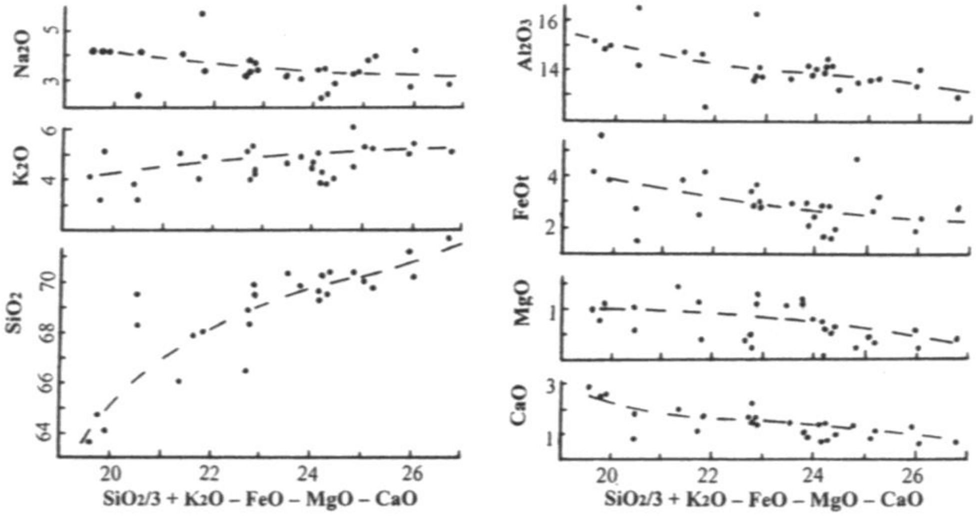

Figure 3. Variation diagrams of the parameter of Larsen of the Paleogene volcanic rocks from Upper-Arda graben

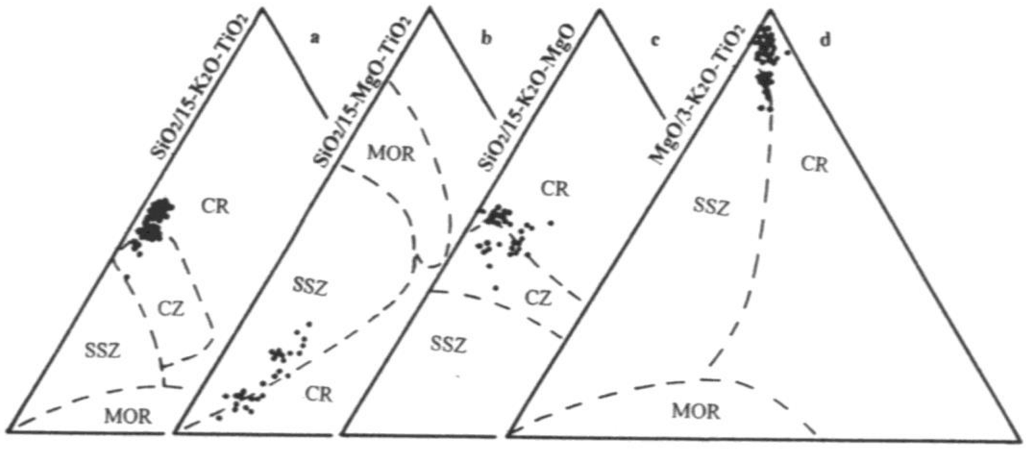

Figure 4. The Paleogene volcanic rocks from Upper-Arda Graben on the diagrams of correlations of Si, Mg, Ti and K. Environments: MOR – middle oceanic ridge, CR – continental rift, SSZ – subduction zone, CZ - continental collision; data of diagrams see in paper

Ignimbrites, dacites and rhyolites with different stratigraphic position do not differ substantially by the content of SiO_2 and alkalies, the content of Na_2O varying from 2.4 to 4.9, on the average 3.55 wt%, and that of K_2O varying from 2.95 to 6.05, on the average 4.48 wt%. On the basis of the total content of alkalies (from 6.3 to 9.6 wt%), the rocks are normal and subalkaline, or high-K calc-alkaline. The data on the Al-An-Or diagram (Fig. 2b) mark the presence of K- and Na-K rocks, according to the distinguishing lines suggested by Irvine and Baragar (1971).

These data, as well as the K_2O/SiO_2 diagram and the characteristic presence of K-containing minerals, emphasise the K specificity of the volcanic rocks. The K-content in them is moderate (K_2O < 7 wt%), and the presence of normative quartz more than 20% characterises these rocks as trachydacites and rhyolites. The normative plagioclase coefficient np = 100An/(Ab + An) varies from 7.5 to 33.3 and its average value is 15.2; the normative quartz coefficient q` = 100Q/(Q + Ab + An) ranges from 16.5 to 56.3, on the average 32.2. It must be pointed out, however, that the rocks do not differ substantially by the content of normative Q, Or, Ab and An; the content of An is low (5-13 %).

The rocks are poor in CaO (from 1.26 to 3.84, with average value 2.38 wt%) and MgO (from 0.24 to 2.58, with average value 2.32 wt%). The content of normative wollastonite and enstatite is in the range of the first several percents. The content of these oxides is in a reverse relation to that of SiO_2 and that of the normative An with respect to Q and Or, respectively.

The content of Al_2O_3 varies from 12.6 to 16.9, the average value being 14.2 wt%, and the rocks are moderate low- and moderate high-aluminous (Bogatikov et al., 1985). Normative corundum practically has not been found.

The UAG volcanics are characterised by low content of TiO_2 - from 0.2 to 0.58, on the average 0.35 wt%, with a tendency to decrease in the more acid rock varieties.

The fiamme ignimbrites and dacites, poor of phenocrysts, are characterized by a decrease of the SiO_2 content by 3-6 wt% and increase of Al_2O_3 by 1-3 wt%, of CaO by 0.5-1 wt%, of MgO by 0.7-1 wt% and a negligible increase of TiO_2 and MnO.

When considering the bulk composition of the volcanics, it is found out that parallel to the increase of the values of Larsen's parameter, the contents of SiO_2 and K_2O also increase, the content of Na_2O slightly decreases and the contents of Al_2O_3, CaO, MgO, TiO_2 and FeO+Fe_2O_3 decrease. The variation diagrams (Fig. 3) as well as the AFM and Na_2O-K_2O-CaO diagrams (Fig. 2c, d) mark the calc-alkaline trend of the volcanics.

Variation diagrams constructed according to Larsen's parameter (Fig. 3), mark the high-K tendency with increasing SiO_2 content. The poorly expressed negative correlation between Na_2O and SiO_2 can be explained by the characteristic property of acid magmas to include Na together with Ca in the fraction of more difficult to melt early crystal phases (plagioclase, biotite, amphibole, zircon) and the early cooled ground mass. In this connection, it should be taken into consideration that, in the relatively more alkaline dacites with grey-black vitrophyritic matrix, the Na_2O content is higher than that of K_2O.

On the basis of the modal and normative composition, as well as of the petrochemical characteristics of the volcanic rocks from UAG, they can be referred to the normal to subalkaline trachydacite-trachyrhyolite series (CNI, TAS) or to the high-K dacite-rhyolite series (K-Si diagram) (Fig. 1). The rocks of this series, represented mainly by ignimbrites and rhyodacites, are characteristic with the great similarity of their petrographic and normative composition. The magma evolution is marked by the subsequent development of ignimbrites, banded rhyodacites and volcanics containing more phenocrysts. These peculiarities of the rocks are related most probably to unstable conditions of crystallisation, transport and magma cooling. The dacite-rhyodacites with phenocrysts of Na-K -feldspar mark the K-character of the volcanics and are element of an opposite trend. This melt was probably derived from the lower parts of the magma chamber.

The volcanics from UAG are analogous to the volcanic rocks in other depressions in CR and WR – Smolian graben (Vatsev, 1989), Bratsigovo-Dospat depression (Vatsev, Katskov, 1988) and Mesta graben (Vatsev, Nedyalkova, 1984).

DISCUSSION AND CONCLUSIONS

Typical for the studied volcanic rocks is that the K_2O/Na_2O ratio does not depend strictly on the SiO_2 content. This feature and the petrologic composition of the rocks are indicators of a crustal tectonic activity (Marakushev, Yakovleva, 1975).

A comprehensive consideration of the problems related to the origin of the volcanics in UAG is impossible without considering the basic questions of magmatic activity as a whole, at least in the Central and Western Rhodopes. This is beyond the scope of the present study and only some basic problems will be outlined:

- Cretaceous-Paleogene zonal metamorphism and granitization were established and dated in the region of Rila Mountain and Central Rhodopes (Arnaudov et al., 1980; Arnaudov, Amov, 1998; etc.); the composition of the granodiorite-granitic metatect is close to that of the gneisses of the basement.
- Uniform in composition Late-Cretaceous and Paleogene granodiorite-granitic plutons (formerly known as South Bulgarian granites) are of wide occurrence (Kamenov et al., 1999; Soldatos,Christofides, 1986; etc.) in the Central Rhodopes, Western Rhodopes and Pirin Mountain (Gagorcev et al., 1987); there are also metamorphosed granitoids in the Rhodopes region.
- The basic tectonic and morphotectonic unit in the Central and West Rhodopes is the West-Rhodopean dome and the neighbouring Madan and other domes, related to the processes and stages of metamorphism during Cretaceous and Paleogene time, sequence granite intrusions and Oligocene dacite-rhyolitic volcanism.
- Development of Paleogene grabens on the background of the metamorphic-magmatic domes, filled with considerable volumes of sedimentary and acid volcanic rocks - UAG, Smolian graben (Vatsev, 1989), Bratsigovo-Dospat depression (Vatsev, Katskov, 1988), Mesta graben (Vatsev, Nedyalkova, 1984), etc.
- Spatial relation and uniform composition of the consecutively intruded Late Cretaceous and Paleogene granite plutons and Paleogene volcanics, indicating uniform conditions of magma generation and emplacement in the same heated conduits.
- The tectonic, metamorphic and magmatic Cretaceous-Paleogene activities mark thickening and activation of the crust and activation of the upper mantle in the RR. Cretaceous-Paleogene basic-ultrabasic rocks are not established in the region, but the activated state of the upper mantle can be deduced from petrological data about the volcanics (Fig. 4) and from isotopic-geochemical data about the Late-Cretaceous, coarse-porphyric K-feldspar granites (Unit 1) of the West-Rhodope batholith; the Paleogene granites (Units 2 and 3) are considered to be late- and post-collisional (Kamenov et al., 1999).

The above considerations lead to the conclusion that the Oligocene dacite-rhyolitie volcanics originated most probably from palingenetic anatectic magmas, connected with tectono-magmatic activisation of RR. Analogous ideas, concerning the genesis of the Oligocene volcanics from the Central Rhodope and West Rhodope depressions, have been reported by the author in the above mentioned publications.

The intensive Cretaceous-Paleogene metamorphism, accompanied by consecutive intrusions of large granite plutons and formation of large magma-metamorphic domes, are indicators of tectonic activation and thickening of the Earth's crust in the RR. They are related during the time with the collision in the Alpo-Himalayan belt (Dercourt et al., 1993; Koronovski et al., 1997; etc.). The development of Eocene-Oligocene grabens and the volcanic activity are related to a following stage of uplift and extension in the West-Rhodope dome and the RR. The Paleogene magmatic products from RR have been related to collisional processes in the papers of Dabovski et al. (1991), Yanev et al. (1998) or to orogenic episode such as a rapid tectonic uplift under an exstensional geotectonic regime (Eleftheriadis, 1995).

The petrologic data about the volcanics from UAG plotted on the diagrams $SiO_2/15$-K_2O-TiO_2, $SiO_2/15$-MgO-TiO_2x2, $SiO_2/15$-K_2O-MgO and MgO/3-K_2O-TiO_2 (Fig. 4) show as well identical grouping; the dividing lines are proposed by Demina, Simonov (1999). The presented petrologic and tectonic data suggests that the volcanics from UAG are most probably collision-related. The distribution of the plots in the next-door neighbour part of the field of continental-rift-related volcanics, indicates tectono-magmatic activation of a stable (40-50 km) continental crust and are probably an indicator of the transition to a following rift stage of development. The data about subduction-related volcanics suggest the idea of the complex character of the collision and of elements of residual sbduction in the lower part of the lithosphere.

The cessation of volcanism around the boundary Paleogene-Neogene is accompanied by an inversion, spread all over the Palaeogene depressions (Vatsev, 1984, 1999). During this stage, minor plutons were intruded in the East Rhodopes (Mavroudchiev, 1992). This is a late-collisional stage of compression, complex faulting and shearing.

The late Late-Oligocene-Neogene post-collisional stage is a stage of arch uplifting, extension and faulting, and having elements of residual collision. It is characterised similarly of development of considerable ore mineralizations (Amov et al., 1993), rare basalt dikes in ER (Marchev et al., 1998) and a new generation of depressions and sedimentary basins in and around Rhodope region (Vatsev, 1984, 1999).

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