50 years University of Mining and Geology "St. Ivan Rilski"
Annual, vol. 46, Part I, Geology and Geophysics, Sofia, 2003, pp.201-206

ON THE PALEOGENE DACITE-RHYODACITE VOLCANICS IN THE WESTERN AND CENTRAL RHODOPES AND THEIR GEODYNAMIC SETTING

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ABSTRACT
The Late Eocene–Early Oligocene dacite-rhyodacite volcanics are related to graben depressions located around block-dome structures that were metamorphosed during the Late Cretaceous and intruded by Late Cretaceous and Paleogene granite plutons. The volcanic rocks associate with coarse terrigenous successions of molasse type. Their petrographic and petrochemical composition is similar and typical of dacites, rhyodacites and trachyrhyodacites. The rocks form a normal to subalkaline potassium-sodium or hige-K calc-alkaline dacite-rhyodacite series and occurrence of ignimbrites. According to petrologic and geological data they are products of collision-related magmas related to tectono-magmatic activation of the metamorphic basement.

INTRODUCTION

The Paleogene sedimentary, volcano-sedimentary and volcanic rocks in the area of Western (WR) and Central Rhodopes (CR) are related to graben depressions superimposed upon Precambrian metamorphic basement of the Rhodope region (RR) and in parts upon Late Cretaceous-Paleocene granodiorite-granite plutons. The main Paleogene graben depressions or sedimentary and volcanic basins discussed in the present paper are: Mesta basin (MeB); Dospat basin (DoB) or Bratsigovo-Dospat depression from WR; Smolyan (SmB) and Upper Arda UaB) basin from CR, situated to the north of boundary Bulgaria- Greece. The volcanic rocks in Hvoina basin (HvB) are not discussed as an independent unit since they are similar to those in Smolyan basin and form part of the latter. The volcanic rocks in the area of Luky comprise latites, quartz-trachytes and trachy-rhyolites (Stoinov, Stoinova, 1969). They are analogous in composition to the volcanics of Borovitsa volcanic region in the Eastern Rhodopes (IR) and are also not discussed and interpreted in this paper.

The present work is a continuation of earlier studies of the author. The aim is, based on new geological and analytical data, to summarize the available information on the volcanic rocks from individual basins, to reveal their common and specific features, their regional geodynamic setting and to contribute to the understanding of the volcanism as a whole.

STRUCTURAL AND STRATIGRAPHIC FRAMEWORK

Structural framework

The development of Paleogene grabens and associated volcanic activity was related to Late Cretaceous-Paleogene tectono-magmatic activization of RR or to collisional events, respectively. The RR experienced Late Cretaceous amphibolite facies metamorphism and related magmatic activity (Arnaudov, Lilov, 1998; etc.). Main rock types are amphibolites, diverse gneisses and migmatites. Their mineralogical and petrographic composition is very close to that of the granitoids from the metamorphic-magmatic domes. The age of the coarse porphyric granites in WR, interpreted as synmetamorphic (Kamenov et al., 1999), is 70 Ma. The plutons in Northern Pirin are dated as Late Cretaceous (Zagorchev et al., 1987), the Barutin-Buinovo pluton (Elatia in Greece) – Late Cretaceous-Paleocene (Soldatos, Christofides, 1986; Cristophides, 1996). The interval Middle Eocene-Early Miocene marks a new stage in the development of RR. In WR, medium-grained hornblende-biotite granites (or granites of second type) were intruded 40 Ma ago (Kamenov et al., 1999) and in the area of Pirin – granites dated 37-32 Ma (Zagorchev et al., 1987). The growth of the domes was related to block-dome uplift and fracturing of the upper parts of the crust. Faulting was controlled by older faults and internal boundaries. During the Middle Eocene and later, graben depressions developed around the growing domes (Vatsev et al., this volume). The intramontane-type Late Eocene grabens accumulated coarse-terrigenous and terrigenous molasse. Around the boundary Eocene-Oligocene, extension and deep fracturing affected the crust and initiated calc-alkaline volcanic activity in the whole RR. The successions of sedimentary and volcanic rocks indicate a transition from early to mature and "hot" grabens.

The age of the sedimentary and related volcanic rocks from the depressions in WR (Vatsev, 1978a,b; 1991; Vatsev, Nedyalkova, 1984) and those from CR (Vatsev, 1981, 1982, 1985, 1988, 1989; Vatsev, Hristov, 1982; Vatsev, Cholakov, 1978), is Late Eocene-Oligocene as indicated by fossil flora. The same radiometric age is reported for some volcanic rocks (Palshin et al., 1974; Pecskay et al., 1991). The volcanic rocks in IR form a bimodal association of basic and intermediate subalkaline rocks and calc-alkaline rhyolites (Yanev et al., 1998, etc.) of Late Eocene-Early Oligocene age. In general, the volcanic activity in RR commenced toward the end of the Late Eocene, culminated around the boundary Eocene-Oligocene and terminated probably in the end of the Early Oligocene.

PETROGRAPHIC CHARACTERISTICS

The volcanic and volcano-sedimentary rocks from the individual depressions in WR and CR and their parts are of different stratigraphic position and origin but show a relatively similar mineralogical, petrographic and petrochemical composition (Bahneva, Stefanov, 1973; Vatsev, Nedyalkova, 1984; Vatsev, Katskov, 1988; Vatsev, 1989; Vatsev, 2002; etc.). The phenocrysts are idiomorphic, fractured and consist of plagioclase, K-Na feldspar, quartz, biotite, amphibole and augite. Their quantity varies from 10-20 to 40-65%. The plagioclase crystals (3-6 mm in size) are zonal, varying from the central parts toward the periphery from andesine (An 50-42) to oligoclase (An 30-22). Normal and inverse zoning is observed. There are also crystals of more basic composition, probably relictic nuclei. The K-Na feldspar (0,3 – 5 cm) is sanidine and in the ingnimbrites – orthoclase (2V = 60-64) (Vatsev, Katskov, 1988). Quartz crystals (0,2–6 mm) are irregular in shape with embayments of volcanic glass. There are also polymineral, xenogenic quartz grains and such containing gas and dust inclusions. Biotite is the basic and constantly present (3-6%) femic mineral. Varieties of relatively iron-rich biotite are typical. There are also crystals with thin and darker brown-green peripheral zones. Amphibole is a relatively rare (below 1%) mineral in the discussed K-Na rocks. It is represented usually by green hornblende, occurring mainly in dacites at the base of the volcanic successions. Small semi-automorphic grains of augite or diopside-augite are also present. They are replaced by amphibole. Accessory minerals are zircon, apatite, orthite, magnetite, titano-magnetite, titanite, etc. The rocks contain also crystobalite, tridimite, K-Na feldspar, ore minerals, etc.

The groundmass of the volcanic rocks consists entirely of volcanic glass, re-crystallized to different extent, but the minerals are analogous to the phenocrysts. The groundmass is uniform or two-phase. The latter variety is characterized by banding, indistinct brecciation of two immiscible components showing black and black-reddish color. There are also secondary devitrification structures – hyalopilitic, felsitic, spherulitic, etc.

Ignimbrites, ranging in thickness from the first tens of meters to 500-600 m occur in DoB, SmB and UaB (Vatsev, Katskov, 1988; Vatsev, 1989; 2002; Bahneva, Stefanov, 1973).

The mineral associations in the volcanic rocks are of polygenic origin. There is a strong positive correlation between the composition of the volcanics and their relictic inclusions of metamorphic and magmatic rocks from the basement.

The phenocrystal associations are typical of normal calc-alkaline biotite to amphibole-biotite dacites and rhyodacites.

PETROCHEMICAL CHARACTERISTICS

The Late Eocene – Early Eocene volcanic rocks in WR and CR are acidic rocks that do not differ essentially in the content of SiO_2 (64-74 wt%) and the other major petrogenic oxides. The subdivision of the main types of volcanic rocks is based on: 1) the classification and nomenclature of magmatic rocks (CN) - $(Na_2O+K_2O)/SiO_2$ (Bogatikov et al., 1981); 2) the classification of volcanic rocks (TAS diagram, Le Bas et al., 1992) complemented by Yanev, Andreev (2000); 3) the classification according to K_2O/SiO_2 content of Peccerillo, Taylor (1976) complemented by Ewart (1982). The normative mineral composition is calculated by the C.I.P.W. method using: 1) AQP diagram with field lines by Le-Bas Streckeisen (1991); 2) AbAnQ diagrams with field lines by Irvine and Barragar (1970). The rock complexes are characterized also by AFM and Na_2O-K_2O-CaO diagrams and the variation diagrams $SiO_{2/3}$+K_20-FeO-MgO-CaO of Larsen - Fig. 1-4.

The TAS plots of volcanic rocks from the depressions in WR and CR concentrate around the point that divides the fields of dacites, trachydacites and rhyolites (Fig. 1) and are defined as a trachydacite-rhyolite or trachyrhyodacite series. On the K_2O/SiO_2 diagram, according to the dividing lines of the cited authors but without a rhyodacite field, the volcanics from WR and CR may be characterized individually and as a whole as a high-K dacite-rhyolite series. The CNI – $(Na_2O+K_2O)/SiO_2$ diagram shows that the Paleogene volcanic rocks in WR and CR are of uniform dacite-rhyodacite composition. Rhyolites occur in SmB only, i. e. rocks with SiO_2 content over 73 wt% (in this case 73 to 74 wt %). The rocks from DoB, SmB and UaB are entirely of rhyodacite composition while in MeB there are dacites and rhyodacites but without any differences in the stratigraphic position and spatial distribution. According to the sum of alkaline oxides, the volcanics are normal calc-alkaline and subalkaline dacites and rhyodacites or trachydacites and trachyrhyodacites.

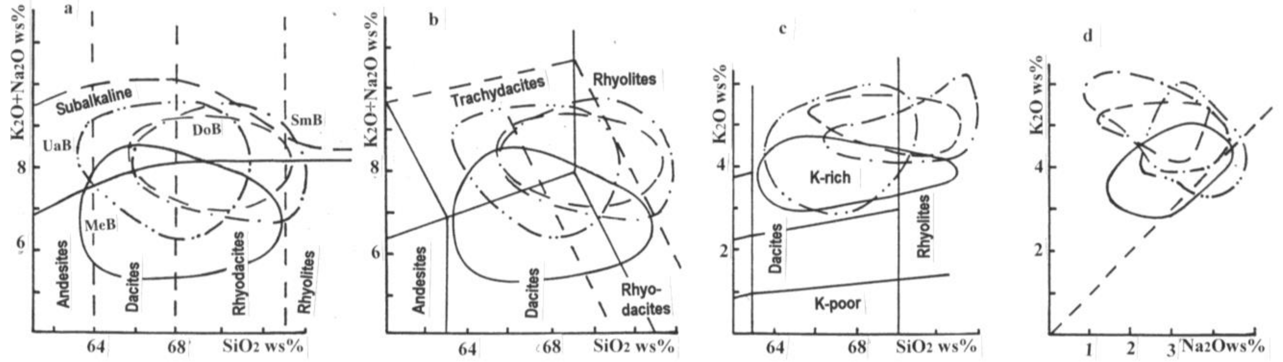

Figure 1. Petrologic diagrams of the Paleogene volcanic rocks from Western and Central Rhodopes: a) Diagram Na_2O + K_2O/SiO_2 wt%; b) Diagram Na_2O + K_2O/SiO_2 wt% (TAS); c) Diagram K_2O/SiO_2 wt%; d) Diagram K_2O/Na_2O wt%; data of diagrams see in paper.

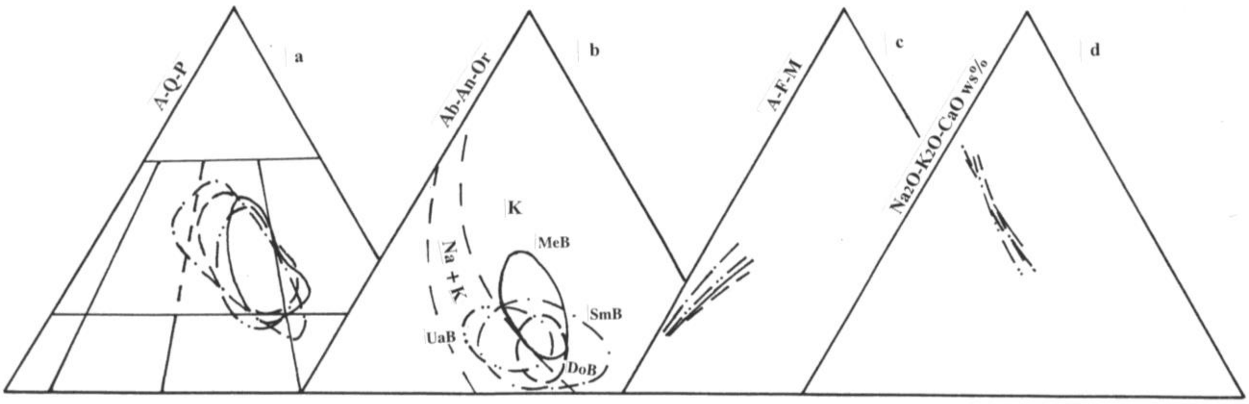

Figure 2. Mineralogical and petrologic diagrams of the Paleogene volcanic rocks from Western and Central Rhodopes: a) Diagram AQP, A – alkcaly feldspar, Q – quartz, P – plagioclase; b) Diagram Ab-An-Or normative minerals; c) Diagram AFM, A = Na_2O + K_2O, F = FeO + 0,9Fe_2O_3, M = MgO; d) Diagram Na_2O-K_2O-CaO wt%; data of diagrams see in paper.

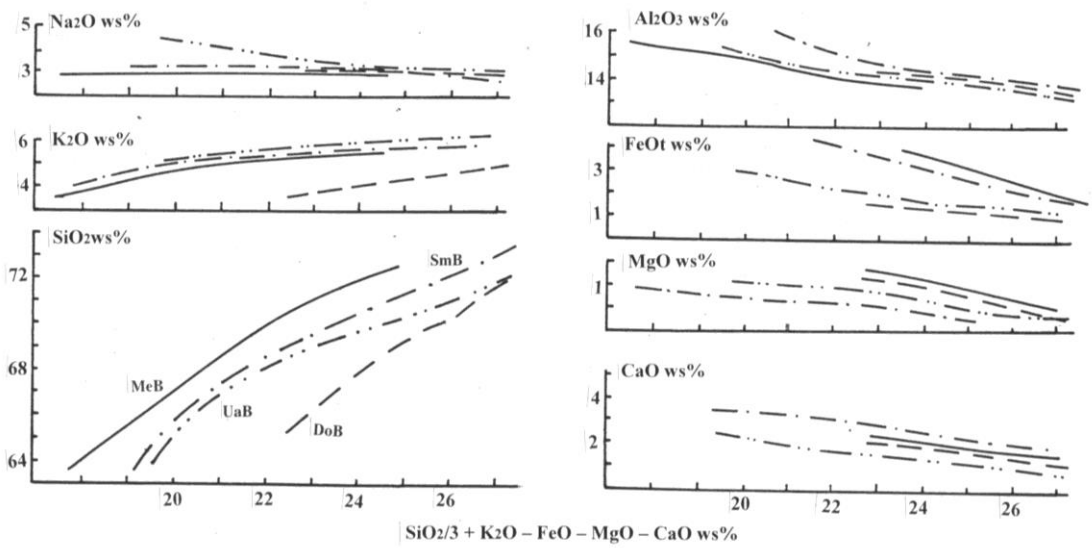

Figure 3. Variation diagrams of the parameter of Larsen of the Paleogene volcanic rocks from Western and Central Rhodopes.

According to the AQP diagram, the volcanic rocks in WR and CR may be defined as rhyolites and those from MeB – as dacite-rhyolites. There is no rhyodacite field in the diagram but the concentration of plots in the lower right part of the diagram shows that these are rocks of rhyodacite composition of relatively higher alkalinity. Single samples plot in the field of quartzlatites. According to the relationships between normative Ab-An-Or the rocks from MeB and DoB are K rhyodacites and those from UaB and SmB are K and K-Na rhyodacites.

Summarizing the above data on the volcanic rocks from the basins in WR and CR it is evident that they belong to a uniform in composition normal calc-alkaline to subalkaline dacite-rhyodacite series (CNI diagram) or trachydacite-rhyodacite (TAS diagram) series. Relatively more basic rocks (dacites) occur in MeB and UaB and more acidic (rhyolites with relatively lower SiO_2 content) – in SmB. In respect of the alkalinity it must be pointed out that the sum Na_2O+K_2O varies between 4,5 and 9,6 wt%, i. e. the rocks are calc-alkaline and subalkaline varieties. In general, K_2O dominates over Na_2O (Fig. 2). The relation between these oxides is inverse in hyalodacites poor in phenocrysts but they are represented by single or insignificant number of samples and the rocks are of limited occurrence. The ratio Na_2O/K_2O is not lower than 0,4 and as a whole the discussed rocks belong to the K-Na series (Bogatikov et al., 1981, p. 19). The alkaline K trend of the initial melts is not expressed but there is a higher-K content only.

In general, characteristic features of the volcanics are: low TiO_2 content (0,2-1,3 wt%), TiO_2 and FeO decreasing with increasing SiO_2 as a result of magnetite separation and depletion of the melts, FeO remaining low; a depletion of rocks and melts with respect to Al_2O_3 with decreasing SiO_2 is not well expressed – the rocks show moderately low and moderately high Al_2O_3 content, normative corundum is very rare; CaO increases with decreasing SiO_2; the rocks are poor in CaO and MgO, the content of normative wolastonite and enstatite varying in the range of the first several per cents; the content of P_2O_5 is low (0,05-0,4 wt%).

The Paleogene volcanics in WR and CR show similar mineral and petrochemical composition and form a typical Late Eocene-Early Oligocene K-Na calc-alkaline to subalkaline dacite-rhyodacite series. The composition and the similarity of the volcanic rocks from WR and CR show that a distinct differentiation is not expressed. The low amounts of rhyolites may be explained by a relatively rapid uplift of the melts. The depth of the magma chambers was probably about 15 km (Bahneva et al., 1978) and that of the intermediate chambers – 2-7 km (Katskov, 1987).

DISCUSSION AND CONCLUSIONS

Three stages can be distinguished in the Late Cretaceous-Pliocene evolution of RR: 1) early collisional, Late Cretaceous-Paleocene - formation of granite plutons and domes; 2) mid-collisional, Eocene-early Early Miocene – formation of grabens and volcanism; 3) late collisional Early Miocene – Pleistocene – graben formation without volcanism.

The Late Cretaceous collision resulted in reactivation of RR, amphibolite facies metamorphism, migmatization, growth of metamorphic-magmatic domes and intrusion of granite plutons as suggested by the discussed data. These processes were accompanied by development of zonal magmatic fields superimposed on a basement of diverse structure, thickness and tectonic activation. This is the field of normal granodiorite-granites in RR and of subalkaline gabbro-granodiorites, monzonites and syenites in the Srednogorie. These geological phenomena, the later Paleogene granites and volcanics, and the Early Miocene granites indicate high thermal gradients in the crust – now in an over 50 km thick.

During the second, Eocene-Early Miocene stage, like the previous one, there was initial accumulation of heat energy and compositional changes in the mantle and the lower crust that were less intensive in the upper crust. At that time, at the boundary with the upper crust, the heat and substance flow were directed also in the opposite direction. These processes initiated block-dome uplift, extension of the growing mountain structure and fracturing of the crust. In the upper crust there was inflow of heat energy – granite plutons, block-dome uplifts and rift depressions (grabens) formed. The latter were of intramontane type and accumulated Late Eocene – Early Oligocene dacite-rhyodacite volcanics and sediments. The depressions developed in the conditions of alternating compression and uplift, extension and subsidence (Vatsev et al., this volume). The extension was in general weak and related to block-dome uplift but typical rift valleys with rift volcanism were not initiated. The successive formation of uniform in composition Late Cretaceous-Paleocene, Paleogene and Early Miocene granite plutons and Late Eocene – Early Oligocene dacite-rhyodacite volcanic rocks suggests a repeated ascent of uniform in composition melts from the metamorphic, relatively uniform and partially melted in depth basement. The character of the lower crust and upper mantle in RR is not well known (Velev, 1996; Shanov, 1998). Taking into account the amphibolite-gneiss-granite composition of the basement composed of Proterozoic and probably unexposed Archean complexes and related granite plutons and migmatites in depth, we can assume a tonalite-amphibolite composition of the lower parts of the crust.

The Mid- and Late Alpine tectonic, metamorphic and magmatic phenomena and processes in RR were related to the collision between the Afro-Arabian and Eurasian plates as discussed in a number of publications. RR has been interpreted as part of the Eurasian plate (Dabovski et al., 1991, etc.) or at present – as part of the African plate (Yanev, 1999; etc.). In particular, in the area of the Balkan Peninsula (Boccaletti et al., 1974; etc.), the Vardar branch of Tethys subducted below the Eurasian plate and closed in the end of the Cretaceous. The Srednogorie zone has been interpreted as an island arc and the related volcanics – as ensimatic. During the Eocene, the last branch of Tethys – Pindos closed (Ricou, 1994). On these grounds the Eocene-Oligocene volcanic rocks in RR are assumed to be of ensialic origin (Dabovski et al., 1991).

We assume that the volcanism in RR was a result not only of deep regional processes below the volcanic regions, related to a strongly heated “anomalous” mantle and lower crust and its uplift, but also to global collisional processes that controlled the pattern of continental deformations in the neighboring blocks (terranes) including also the stress fields of extensional and wrench faulting. The thickening of the crust, the metamorphic processes and the fracturing of rock masses created favorable conditions for the origin of granite melts. The Early Miocene-Pleistocene stage is characterized by development of a new system of graben sedimentary basins without volcanic activity and cyclic structure of their fill (Vatsev, 1998 and others). From the end of the Cretaceous to the end of the Quaternary, typical continental structures developed in RR – dome-block uplifts, graben depressions and consolidation of the crust.

The development of graben depressions and sediment deposition in them in WR and CR covered the interval Middle Eocene (Vatsev et al., this volume) while in IR this occurred toward the end of the Paleocene (Atanasov et al., 1990; etc.). Cycles of lower order and transgressive-regressive depositional successions have been established in the development of the grabens (Vatsev et al., this volume and others). In general, the volcanic activity in the depressions in RR took place during the Late Eocene – Early Oligocene time span. A temporal shift of the Paleogene volcanic activity from NNW to SSE is reported in IR (Yanev et al., 1995; etc.). The available radiometric data on the age of the granite plutons in Pirin Mts. and south of it, in Greece and those from WR and CR in Bulgaria and Greece, mark a migration of the magmatic activity from NNE to SSW, i. e toward the collisional front and opposite to that in island arcs. The discussed regions are located at a distance of 250-400 km away from the Vardar zone. Late Cretaceous in RR and Priabonian (35 Ma) in IR metamorphism with typical crustal strontium ratio has been dated (Peitcheva et al., 1995). These facts indicate a stage character of subduction and collision. The subduction processes most probably did not affect directly the Late Cretaceous, Paleogene and Early Miocene granite plutons and Eocene-Oligocene volcanics in RR but created stress conditions that were favorable for metamorphism, origin of magmas and their ascent to the surface. The development of diverse in age granite plutons and Eocene-Oligocene volcanics is an evidence for repeated generation of magma of the same composition and ascent of melts within the same zone into the consolidated block and on the surface. In our opinion, the origin of granite plutons and volcanics was related to melting within the deep isostatic "root" and growth of magma chambers in the upper crust of RR. Yanev et al. (1998) suggested that, toward the end of the Eocene, the subducting and eclogitized plate broke off, penetrated into the mantle and disturbed its thermal gradient. The occurrence of Late Oligocene basalt dikes in IR and their petrologic and geochemical characteristics indicate deep fracturing of the crust (Marchev et al., 1998). This leads to the assumption that the transfer of heat energy from the activated upper mantle was accomplished probably through basalt melts. This induced an irregular increase of the thermal gradient in the crust.

One of the important features of the origin and development of graben depressions and their volcanic successions is the close mutual relation and even mutual control of the tectono-magmatic processes. This is marked on one hand by the concentration of volcanic rocks and activity within the grabens and, on the other, by the development of volcano-tectonic depressions (caldrons) in them. The latter are filled with volcanic and volcano-sedimentary rocks comprising wedge-like and inpersistent packets of terrigenous rocks.

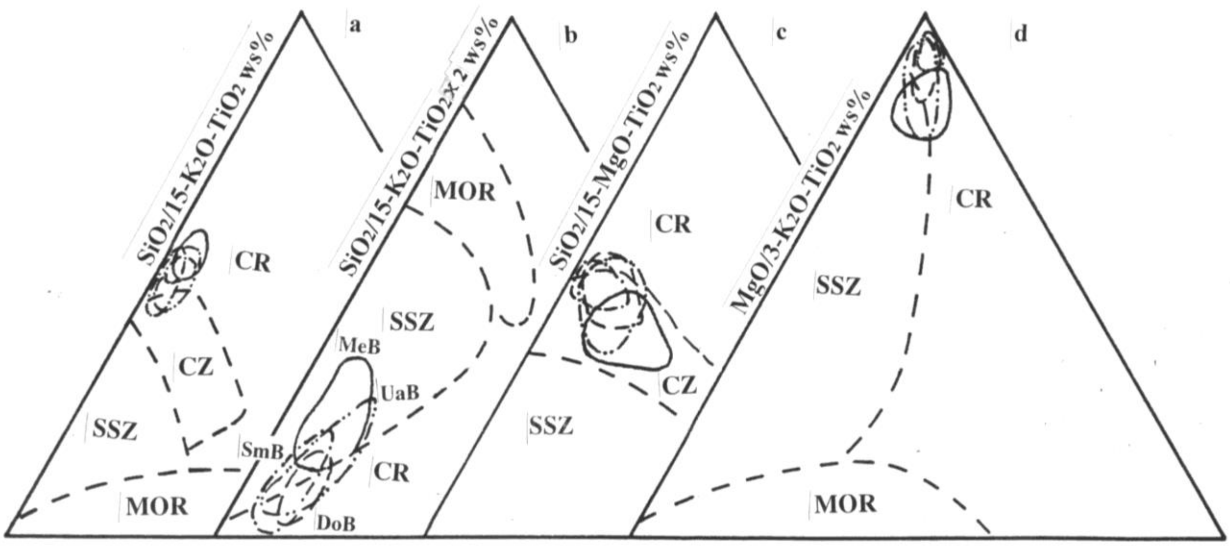

Figure 4 The Paleogene volcanic rocks from Western and Central Rhodopes on the diagrams of correlations of Si, Mg, Ti and K; environments: MOR – middle oceanic ridge, CR – continental rift, SSZ – subduction zone, CZ - continental collision; data of diagrams see in paper.

The variation diagrams based on Larsen's parameter (Fig. 4) mark an increase of SiO_2 and K_2O – a potassic trend, weak variations of Na_2O and decrease in the content of the other main petrogenic oxides. The curved trend of the variation lines on the diagrams suggests that the portions of enclosed material in the melts did change. The volcanic successions in all depressions show a homodromous trend. It is marked by the development of relatively more basic, glass containing and poor in phenocrysts rocks in the lower parts of the successions. The upper parts contain larger amounts of phenocrystals (40-65%) and are relatively more acid in composition with higher alkalinity – subalkaline rocks. The crosscutting veins and necks, containing higher amounts of sanidine phenocrystals and relatively higher K_2O, mark an antidromous trend most probably related to melts from the lower parts of the magma chambers. However, these crosscutting bodies are rare. A calc-alkaline trend of poor in MgO volcanics is indicated on the AFM diagrams. The Na_2O-K_2O-CaO diagrams show an indistinct potassic trend and relatively higher content of K_2O. In general, the discussed volcanic rocks are characterized by a K_2O/Na_2O ratio that does not depend on the SiO_2 content . According to this parameter, they may be referred to the second series of magmatic rocks typical of tectonically activated stable crustal blocks (Marakushev, Yakovleva, 1975). The above geological data suggest that this is a collisional activation.

The petrochemical data on the volcanic rocks from WR and CR on the diagrams (Fig. 4) a) $SiO_2/15$-K_2O-TiO_2, b) $SiO_2/15$-K_2O-MgO, c) $SiO_2/15$-MgO-TiO_2x2 and d) MgO/3-K_2O-TiO_2 show a uniform grouping of the plots with respect to the dividing lines of Demina, Simeonov (1999). As a whole, the discussed volcanic rocks or melts may be defined as collisional. The concentration of plots close to the line of continental rifts (Fig. 4, a, c) may be explained by their origin in rifted "hot" graben depressions and block displacements in an over 50 km thick crust. The clustering of plots near the line that divides subduction zones and continental rifts (Fig. 4, b, d) may be related to synchronous occurrence of these events and processes in RR during the Late Eocene-Oligocene and an available in magma of components of the mantle, down crust and ancients subduction zone. The distribution of the plots depends also on the lower MgO and TiO_2 content in the rocks of. The disposition of the points of diagrams is analogical in big part with these of the volcanics of Africa rifts; the last are presented in paper of Demina and Simov (1999, Fig. 2). These data and the evidence from the geological development of the Rhodope and neighbouring regions suggest a complex tectono-metamorphic-magmatic character of the activation of RR during the collision.

The geological, petrographic and petrochemical data on the Late Eocene-Oligocene volcanic rocks in WR and CR, discussed in the present and previous papers of the author (Vatsev, Nedyalkova, 1984; Vatsev, Katskov, 1988; Vatsev, 1989b; Vatsev, 2002; etc.), allows to infer that most probably these rocks are products of eutectic melting of continental type crust, but in this process it is possible a participate of the down crust and mantle fluids or magmas. The successive formation of considerable in volume and uniform in composition acid melts in RR was related to complex and changing in time geodynamic settings and processes, related to the collision and activation of crustal blocks of different thickness and geological history.

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Recommended for publication by Department of Geology and Paleontology, Faculty of Geology and Prospecting