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Acid pyroclastic rocks from the Sheinovets caldera, Eastern Rhodopes: Lithostratigraphy, characteristics and age

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Abstract. The Sheinovets caldera is located in the easternmost parts of the Eastern Rhodopes Paleogene volcanic area, beside the border with Greece. The caldera is filled up with more than 1000 m thick sequence of pyroclastic, epiclastic, and sedimentary rocks crossed by several rhyolite domes. This intracaldera sequence is divided into 2 informal lithostratigraphic units: sedimentary and pyroclastic. The sedimentary unit, which consists of sandstones and mudstones, interfingers and is replaced laterally by the lowermost exposed parts of the pyroclastic unit and is covered by its upper levels. The pyroclastic unit is divided into 2 packets: lower, pumice tuff packet and upper, lithic breccia one. The lower packet consists mainly of zeolitized ash and lapilli-tuffs with some breccia levels. These rocks are massive, ungraded and poorly sorted and we suggest that they must have been deposited from subaqueous pyroclastic pumice flows. The upper, lithic breccia packet consists of coarse-grained clast-supported pyroclastic breccia containing mainly dense rhyolite fragments. These rocks could have been vent-derived or/and deposited from rock avalanches, formed during emplacement and growth of rhyolite domes. Volcanic activity began with some high-energetic plinian phases, resulted in creation of the Sheinovets caldera, continued and terminated with dome formation (Peléan-type activity). Samples both from the sedimentary and pyroclastic units have been studied for their nannofossil content. It has been found nannofossil association assigned to NP 21 zone including the topmost part of Priabonian and the base of Rupelian.

Keywords: acid pyroclastics, Paleogene, calcareous nannofossils, NP 21, Eastern Rhodopes
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Иванова, Р., К. Стойкова, Й. Янев. 2000. Киселите пирокластични скали от калдерата Шейновец, Източни Родопи – стратиграфия, характеристика, възраст. – *Геохим., минерал. и петрол.*, **37**, 47-56.

Резюме. Калдерата Шейновец се намира в най-източната част на Източнородопската палеогенска вулканска област. Калдерата е изпълнена с дебела над 1000 m серия от пирокластични, епикластични и седиментни скали, пресечена от няколко риолитови купола. Тази серия е разделена на 2 неофициални литостратиграфски единици: седиментна и пирокластична. Първата, съставена от пясъчници и алевролити, латерално се замества и се покрива от най-долните части на пирокластичната задруга. В последната се обособяват 2 пачки: долна, на пемзовите туфи и горна, на литокластичните брекчи. Долната пачка е изградена от зеолитизирани пепелни и лапилиеви туфи с нива от брекчи. Те са масивни, без градация на късовете, зле сортирани и вероятно са отложени от подводни, пирокластични, пемзови потоци. Горната пачка е от груби литокластични брекчи, в които късовете, риолитови по състав, преобладават. Те вероятно са откъснати от проводящия канал при изригванията и/или са отложени от скални лавини, възникнали по време на внедряването и растежа на куполите. Вулканската дейност е започнала с високоенергийни, плиниански фази, в резултат на които се е формирала Шейновецката калдера. Дейността е продължила и завършила с внедряване на риолитовите куполи (Пелейски тип активност).

За наличие на нанофосили са изследвани образци както от седиментната, така и от седиментни прослои сред пирокластичната задруга. Установеното съобщество е отнесено към зона NP 21, която обхваща най-горните части на приабона и основата на рупела.

Ключови думи: кисели пирокластити, палеоген, варовит нанопланктон, NP 21, Източни Родопи
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Introduction

The object of this study is the pyroclastic succession infilling a volcanic structure situated in the easternmost parts of the Eastern Rhodopes Paleogene volcanic area, about 10 km southwest of Svilengrad, to the south of the villages Malko-Gradishte and Mezek (Fig. 1a). To the east the studied field continues in Greece (Filippidis et al., 1995).

It is known as Malko-Gradishte volcano (Ivanov, 1960), Valche-Pole (Yanev et al., 1983) or Sheinovets dome-cluster located within a caldera of the same name (Yanev, 1995, 1998). Through the post-Paleogene tectonic movements the caldera was broke up and only a part of it, included in the Ibredjek horst, is exposed nowadays. The Ibredjek horst is a submeridional structure developed between Lozen and Bryagovo depressions (Kozhoukharov et al., 1995). The northern Lozen depression is filled with Neogene (Ahmatovo Formation) and Quaternary deposits. To the south, within the Bryagovo depression, the rocks of Valche-Pole Molasse Formation (Upper Oligocene-Miocene [?]) are exposed. These younger sedimentary rocks cover north and south margins of the Sheinovets caldera and only south-western part of caldera fault is possible to be seen now; it is best exposed to the west of Sheinovets peak (Fig. 1a).

The Sheinovets caldera is filled up with a very thick (more than 1000 m) sequence of pyroclastic, epiclastic and sedimentary rocks crossed by several rhyolite domes with zeolitized perlite peripheries forming the Sheinovets dome-cluster (Fig. 1a). A few submeridional rhyolite dykes are intruded along the south margin of now exposed part of the caldera. Mainly Upper Eocene sedimentary rocks and metamorphites from the basement of the Paleogene depression are outcropped within the Ibredjeck horst (Boyanov et al., 1963; Kozhoukharov et al., 1995), to the west of the caldera fault. To the southeast of Malko-Gradishte village the Upper Eocene conglomerates and sandstones are cut by plenty of strongly altered sill-like rhyolite bodies and dykes (not shown in Figure 1a).

The aims of this research are to characterize the pyroclastic rocks, to fix the chronostratigraphic position of the intracaldera sedimentary and epiclastic rocks in the Paleogene section and to determine the succession and type of the volcanic events.

Previous works

There are no many detailed descriptions of this most eastern manifestation of the Paleogene volcanic activity in Bulgaria. Based upon a characteristic fossil assemblage Boyanov et al. (1963) assign the sedimentary rocks from the studied field to the IVth horizon of Priabonian. In limestone breccia south of Malko-Gradishte village were found the following species[1]: *Nummulites fabiani* (Prever) A, B, *Nummulites chavannesi* de la Harpe, *Nummulites striatus* (Brug), *Discocyclina augustae* Von der Weijden, *Discocyclina merthae* (Schlumberger), *Asterocyclina stella* Gumbel. About the thick pyroclastic sequence

[1] Boyanov, I., P. Mavroudchieva, M. Ruseva, I. Vaptsarov, I. Ivanov, M. Maksimova, G. Valeva, V. Valkov, N. Valkova, Y. Shabatov, A. Vacheva, S. Iliev, S. Vasilev, B. Mavroudchiev. 1962. Report on the geological mapping and searching for mineral resources in the eastern parts of Rhodopes and the westernmost part of Sakar Mountain, on scale 1:25 000, carried out in 1961. Geofond, CG (in Bulgarian).

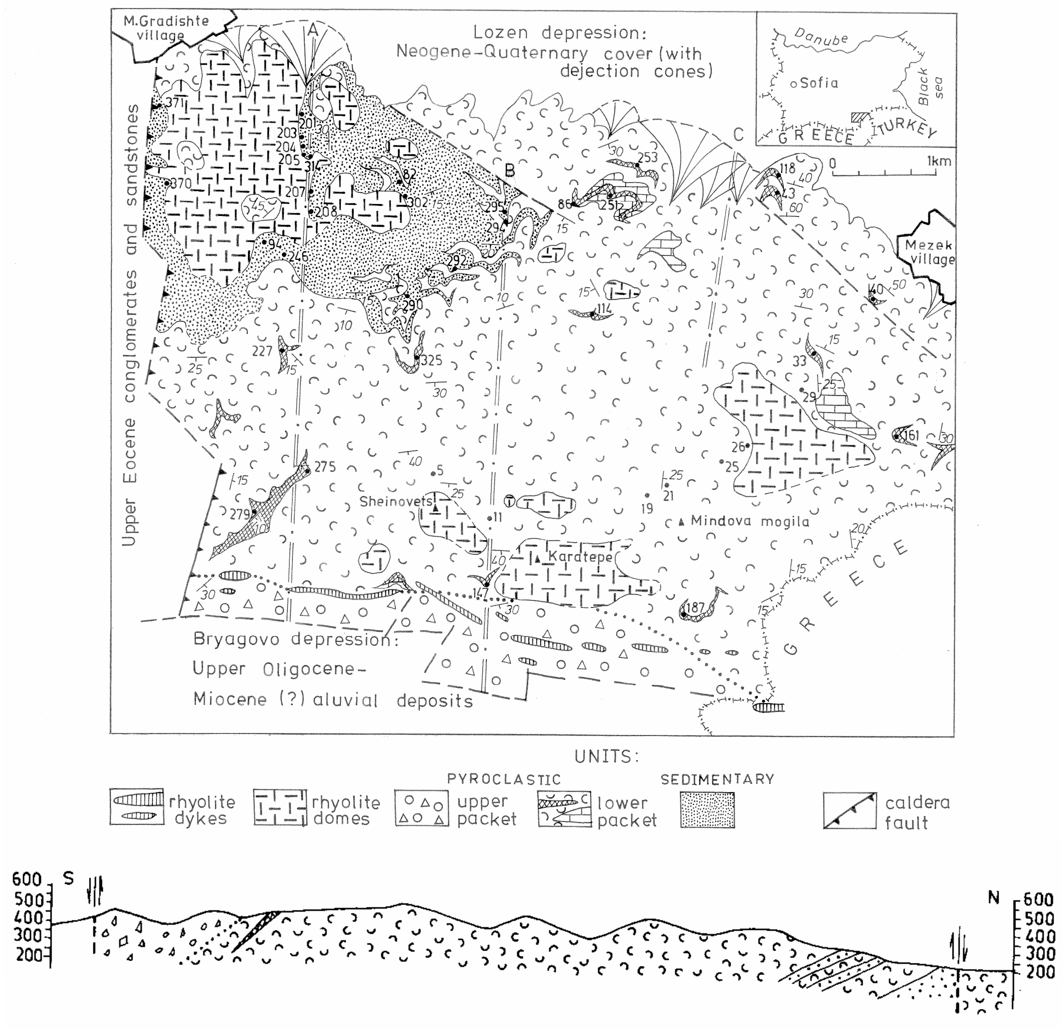

Fig. 1a. Location and geological map of the Sheinovets caldera. The numbers indicate samples analized for calcareous nannofossil content. A, B, C - approximate position of the studied sections (Fig. 3, 4 and 5)
Fig. 1b. North-south cross section (along line B) through the caldera
Фиг. 1а. Геоложка карта на калдерата Шейновец. С цифри са означени анализираните за нанофосили проби. А, В, С - приблизително разположение на изследваните профили (фиг. 3, 4 и 5)
Фиг. 1б. Геоложки профил (по линия В) през калдерата

covering these sediments the authors consider to be of Oligocene age.

In some general works on the Eastern Rhodopes Paleogene volcanism (Yanev et al., 1983, 1990; Harkovska et al., 1989; Yanev, 1998) this volcanic activity is thought to be Priabonian on the analogy of the near-by Lozen volcano (Harkovska et al., 1976) and because of the identical geochemical characteristics of their lava products.

Goranov (in Kozhoukharov et al., 1995) accepts the Priabonian age of the sedimentary rocks on the base of the aforesaid data and by analogy with the Upper Eocene sedimentary layers alternating with rhyolite tuffs at the base of Lozen volcano (Harkovska et al., 1976). According to the author the pyroclastic sequence laterally replaces the sedimentary one and also is of Priabonian age (Fig. 2).

The investigations of the Greek part of the Sheinovets caldera are turned mainly to the zeolites resulting from alternation of the volcanic glass (Kirov et al., 1990; Filippidis et al., 1995). According to the quoted authors these rocks are Priabonian.

The intracaldera sequence: Characteristics and stratigaphic implications

The rock sequence filling up the Sheinovets caldera is divided into two informal lithostratigraphic units: sedimentary and pyroclastic.

Sedimentary unit

This unit occupies the lowermost part of the intracaldera sequence. It is best developed just

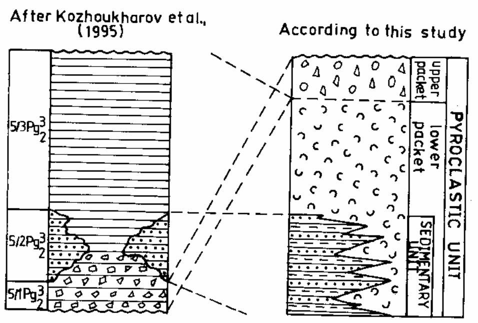

Fig. 2. Relationship between stratigraphic schemes of Kozhoukharov et al. (1995) and the proposed in this study. $5/1Pg_2^3$ - breccias and rhyolite tuffaceous breccias packet, $5/2Pg_2^3$ - sandstone packet, $5/3Pg_2^3$ - acid tuffs, tuffites and bioconstructed limestones packet

Фиг. 2. Съпоставка на стратиграфската схема на Кожухаров и др. (1995) и предложената в настоящата работа. $5/1Pg_2^3$ - пачка на брекчи и риолитови туфобрекчи, $5/2Pg_2^3$ - пясъчникова пачка, $5/3Pg_2^3$ - пачка на кисели туфи, туфити и органогенни варовици

to the southeast of Malko-Gradishte village (Figs. 1a and 3). Its lower boundary is not exposed. The sedimentary unit is an alternation of dark, greyish-green to greyish-black polymictic sandstones and mudstones containing redeposited pyroclasts. To the east and southeast it interfingers and is replaced laterally by the lower parts of the pyroclastic unit. The zone of transition is an alternation of the sedimentary rocks and finegrained tuffs. The pyroclastic beds become thicker in the southeast, whereas the sedimentary ones disappear.

It has been found that the fossils-containing limestone breccia (Boyanov et al., 1963) has a quite uncertain stratgraphic position. It can be seen as a few not large, separate blocks along the periphery of the rhyolite dome crossing the sedimentary unit south of Malko-Gradishte village. It contains mainly angular limestone clasts; rarely fragments of metamorphic rocks can also be seen. It is likely these blocks to have been risen in the examined stratigraphic level together with the rhyolite dome (Fig. 1a). Besides, the features of the breccia do not rule out a possible redeposition of described species, as it was noted by the authors. Therefore, these data should be received with reservations.

Pyroclastic unit

This unit consists chiefly of pyroclastic and less epiclastic rocks. It is exposed to the south of Mezek village and occupies the southeastern parts of the studied field. On the base of lithological features reflecting differences in mode of formation the pyroclastic unit has been divided into two parts: lower, pumice tuff packet and upper, lithic breccia packet.

Pumice tuff packet. It comprises greater part of the pyroclastic unit. The lower levels of this packet interfinger with the sedimentary unit and the upper ones cover it (Figs. 1 and 3).

Pumice tuff packet consists mainly of ash or lapilli-tuffs (according to the non-genetic classification of Fisher, 1961). Some levels are matrix-supported breccias containing block-sized lithic fragments (commonly a few tens of cm, rarely more than 1 m and as an exception - over 10 m). The tuffs contain

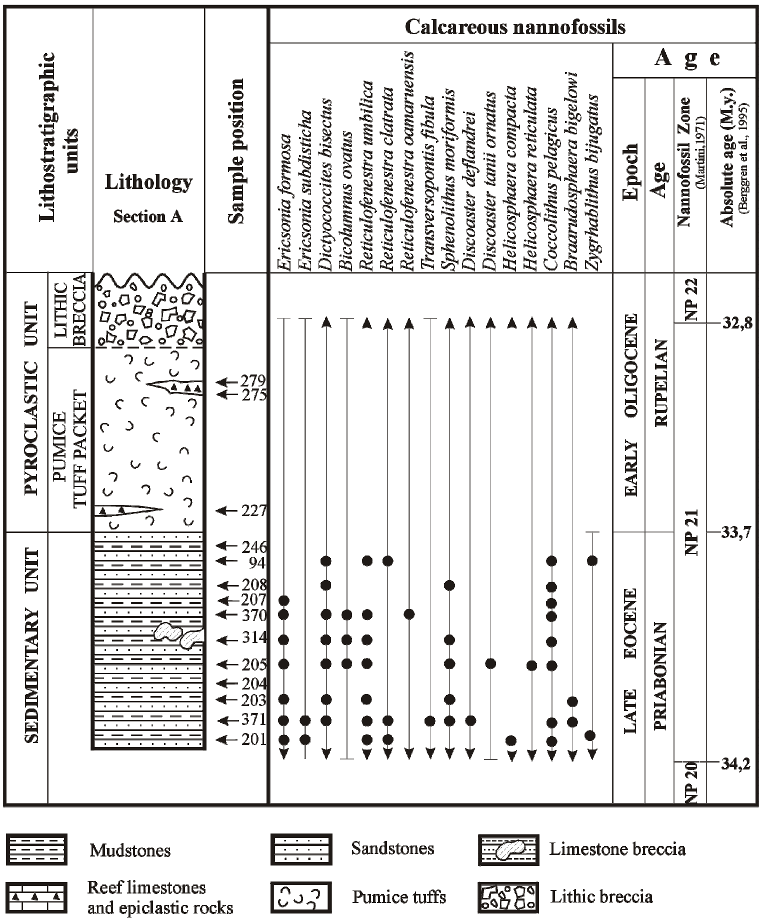

Fig. 3. Range-chart of the calcareous nannofossil taxa recorded in the section A with inferred litho- and chronostratigraphy

Фиг. 3. Вертикално разпространение на установените нанофосилни таксони в разрез А, заедно с отделените лито- и хроностратиграфски единици

lithics, crystals and crystal fragments, and fine glass shards in varying proportions.

Normally lithics having a wide range of degrees of vesiculation and sizes predominate. Juvenile, highly vesiculated pumice is most abundant. Usually pumice clasts are ash or lapilli-sized but rarely can be larger than 10 cm. Lapilli- and ash-sized fragments showing perlitic cracks are most typical of the central and upper parts of the packet. Dense rhyolite clasts are present in the whole packet but the breccia levels are rich in very large rhyolitic blocks (over 1 m and larger). The largest rhyolite blocks have been found near the border line, to the east of Mindova-Mogila peak. Large lithic fragments, defined as “rhyolite bombs”, are also known from the Greek part of the caldera (Kirov et al., 1990). Accessory clasts of metamorphic rocks can have various sizes (usually 1-3 mm) and are also possible to be found. Angular fragments and rarely free crystals of plagioclase, biotite, quartz, and sanidine are always present but commonly in small quantity. The glass shards are angular, fine ash-sized particles, which result from the magmatic explosive fragmentation of pumice vesicle walls. Rich in glass shards are only separate beds to the west

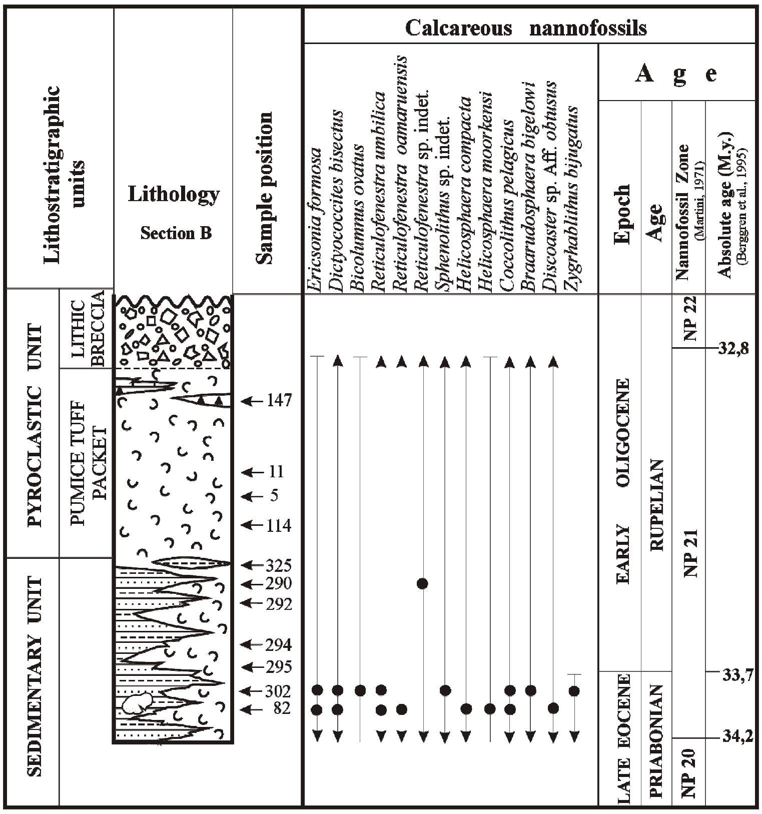

Fig. 4. Range-chart of the calcareous nannofossil taxa recorded in the section B with inferred litho- and chronostratigraphy

Фиг. 4. Вертикално разпространение на установените нанофосилни таксони в разрез В, заедно с отделените лито- и хроностратиграфски единици

and south of Mezek village. Irrespective of their type and size all clasts made of volcanic glass are completely zeolitized (Tzvetanov et al., 1983; Kirov et al., 1990; Aleksiev, Djourova, 1995).

Thin beds and lenses of epiclastic rocks have been found at different levels within the pumice tuff packet (Figs. 4 and 5). These rocks are dark-colored, fine-grained, finely laminated and contain mainly normally deposited or re-deposited volcanic material. Sometimes they contain carbonates and fossil remnants. Some lenses of reef limestones can be seen to the west and south of Mezek village. They are exposed within a tectonic block with northwest-southeast direction (Fig. 1a) that might have been subsided during the post-Paleogene horst formationThe limestones might reflect some shallowing of the marine basin resulting from its fast filling with pyroclastic material and probably correspond to some upper levels of the pumice tuff packet.

Lithic breccia packet. The pumice tuff packet is overlain by coarsegrained, clast-supported pyroclastic breccia. The last one is exposed on the south flank of the Ibredjeck horst, just south of the rhyolite domes occupying the highest summits. Its lower boundary is gradational and the upper is not exposed. According to Goranov (in Kozhoukharov et al., 1995) this breccia occurs at the base of pyroclastic interval (Fig. 2), but it is not the case (Fig. 1b).

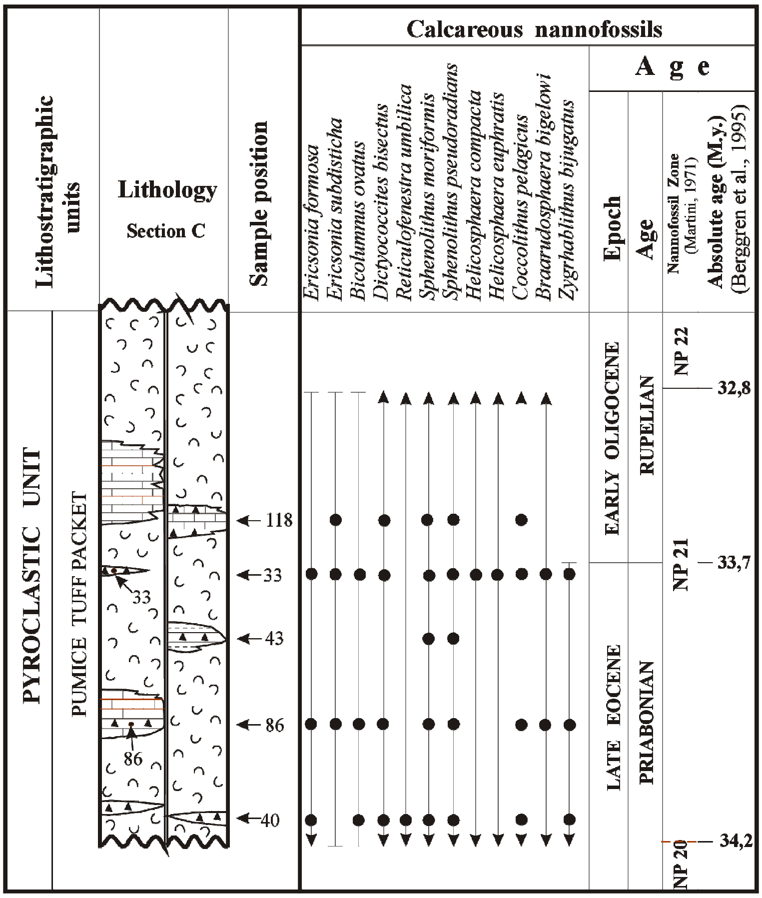

Fig. 5. Range-chart of the calcareous nannofossil taxa recorded in the section C with inferred litho- and chronostratigraphy

Фиг. 5. Вертикално разпространение на установените нанофосилни таксони в разрез С, заедно с отделените лито- и хроностратиграфски единици

The thickness of the lithic breccia packet is about 100-150 m. It consists mainly of cognate lithic clasts, which strongly prevail over matrix. Lapilli to block-sized rhyolitic fragments (usually up to 10-12 cm) are most abundant. Lapilli-sized clasts of metamorphic rocks (amphibolites, gneisses and schists) are also present. They are much better rounded and probably have been derived from the Upper Eocene coarse-grained sedimentary rocks. The matrix includes fragments mainly of plagioclase, quartz, sanidine and biotite, finegrained lithic and zeolitized particles having perlitic cracks. As an exception fine pumice clasts and glass shards may also be seen in the lowermost levels of this packet.

Calcareous nannofossil biostratigraphy

Sixty-four samples, not only from the intracaldera sequence but also from the Upper Eocene coarsegrained sediments outside the caldera, have been processed and studied for their nannofossil content. Seventeen of them contain well-preserved nannofossil species and they all are from the intracaldera units. For the sake of convenience the samples are arranged along three sections (Fig. 1). Nannofossil abundance and diversity varies significantly along each of the studied sections. Richest nannofossil samples come from the mudstone interbeds of the sedimentary unit, whereas the poorest and barren samples are located within the pyroclastic unit (Figs. 3-5). The barren samples are not included in the figures.

Almost identical nannofloristic associations have been recorded both in the sedimentary unit and in the epiclastic lenses of the lower packet of pyroclastic unit. They comprise the following species: *Ericsonia formosa, E. subdisticha, Dictyococcites bisectus, Bicolumnus ovatus, Reticulofenestra umbilica, R. oamaruensis, Sphenolithus moriformis, S. pseudoradians, Helicosphaera compacta, H. reticulata, Discoaster tanii ornatus, Zygrhablithus bijugatus, Braarudosphaera bigelowi, Coccolithus pelagicus.* This association is assigned to NP 21 nannofossil zone of Martini (1971), spanning the topmost part of Priabonian and the base of Rupelian Stage. According to the recent data, the absolute age of the lower and upper boundaries of this zone are respectively 34,2 and 32,8 M.y. (Berggren et al., 1995).

This age assignment is based on the co-occurrence of *Ericsonia formosa* (last occurrence in top NP 21), *Ericsonia subdisticha* (total range in NP 21), *Bicolumnus ovatus* (total range in NP 21), *Helicosphaera moorkensi* (total range in NP 21), *Discoaster tanii ornatus* (first occurrence in base NP 21). As far as *Zygrhablithus bijugatus* is usually interpreted as characteristic Eocene species, its last occurrence in the sections studied is tentatively used to separate two parts of NP 21 zone. This species is not considered as reliable diagnostic marker for Eocene/Oligocene boundary and our biostratigraphic interpretations are tentative (Figs. 3-5).

These age assumptions can be applied to the lowermost levels of the intracaldera sequence - the sedimentary unit and laterally replacing it lower part of the pumice tuff packet. They also concern the epiclastic and sedimentary rocks-containing levels of the pumice tuff packet from tectonically displaced sections of the intracaldera succession. Unfortunately, there are not nannofossil data about the age of the upper part of the pyroclastic interval including the most upper parts of pumice tuff packet and the upper, lithic breccia packet.

The study of the reef limestones, located within the rocks of pyroclastic unit, has shown some fragments of spongia, corals, bryozoans, foraminifers, ostracods, nummilitids, gastropods, worms, all habitants of a warm, shallow-marine basin, well aerated. Two species of nummulitids have been identified (by V. Sapundjieva) only: *Nummulites incrassatus* de la Harpe (Mid Eocene-Oligocene) and *N. bouillei* de la Harpe (Upper Eocene-Oligocene).

Discussion: Formation of the pyroclastic rocks and succession of the volcanic events

The main features of the pyroclastic rocks from the lower packet make us consider that they have been deposited from dense, pyroclastic pumice flows, generated by high plinian column collapse (Fisher, Schmincke, 1984; Cas, Wright, 1988; Sparks, 1978, 1986; Sparks et al., 1973). A large part of the finest ash from downwind plume must have been deposited far away from now studied field. The only fall-out deposits, which have been found there, are finegrained diffusely layered pumice beds alternating with the rocks of the sedimentary unit to the southeast of Malko-Gradishte village. Pumice flow deposits (i.e. ignimbrites) are thick, ungraded, poorly sorted, and massive. The rhyolite fragments in them are probably vent-derived. In separate outcrops sharp smooth surfaces can be seen between levels showing different proportion and grainsize distribution of the particles, which probably separate the individual emplacement units. The thin layers consisting essentially of glass shards and finegrained pumice must have been deposited from ash clouds billowing above and behind a moving pyroclastic flow (Fisher, 1979; Cas, Wright, 1988).

The presence of thin lenses of epiclastic rocks, and especially of reef limestones is evidence of normal sedimentary processes operating during repose periods between eruptions.

Some of the features of the pumice tuffs, such as low grade of welding (resulted in some flattening of larger pumice clasts) and complete zeolitization of the volcanic glass are also indicative of their deposition in marine environment.

No ignimbrite source area has been localized in the studied field. Eastward increase of the maximum size of lithic clasts might be indicative of the vent region proximity (Sparks, 1975). But it should be noted that the pyroclastic flow may transport very large, metres-sized lithic fragments significant distances from source (Davies et al. 1978; Allen, Cas, 1998). Therefore, we can only suppose that the vent region of Sheinovets caldera ignimbrites presumably lay to the east of the studied field, maybe out of the exposed part of the caldera, in an area now occupied by younger deposits.

The rocks from the upper, lithic breccia packet could have been vent-derived lithic products or/and deposited from hot or cold rock avalanches, formed during emplacement and growth of rhyolite domes, by directed blasts, explosive or gravitational dome collapses (Cas, Wright, 1988).

It is common knowledge that volcanic eruptions are short-lived compared to others geological processes, such as the sedimentation, but during them vast volumes of pyroclastic material can be deposited. Therefore, in the absence of significant sedimentary layers in the upper parts of the pyroclastic sequence, we can conclude that there were not appreciable breaks of the volcanic activity. The deposition of these rocks might have taken short time after the formation of the lower, paleontologically dated parts of the intracaldera units. For example, more than 100 m thick valley-filling ignimbrites were deposited during only 11 to 16 hours lasting episode I of 1912 eruption at Novarupta (VTTS, Alaska) (Fiersten, Hildreth, 1992).

Obtained field evidence shows that volcanic activity in the studied field began with several plinian phases, during which large volumes of pumice were ejected. The initial, relatively low energetic stages might have been phreatomagmatic because of the unrestricted access of water to the vent(s). Gradually eruptions became highly energetic, with an off chance of water/magma interaction, and the activity became dominantly dry-explosive. These violent eruptions resulted in creation (subsidence) of the Sheinovets caldera. Volcanic activity continued and terminated with dome formation (Peléan-type activity). There are no indications of the time-position of dome formation in regard to the caldera collapse. The rhyolite dykes intruded along the south margin of this part of the Ibredjeck horst are considered by Lilov et al. (1987) to have been produced by another, probably Upper Oligocene magmatic event.

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References

Aleksiev, B., E. Djourova. 1995. Mordenite zeolites to the west of the town of Svilengrad in the NE Rhodopes, Bulgaria. - *In: Sofia Zeolite Meeting'95. Intern. Symp., Abstracts*, p. 3.

Allen, S. R., R. A. F. Cas. 1998. Lateral variations within carse co-ignimbrite lithic breccias of the Kos Plateau Tuff, Greece. - *Bull. Volcanol*., **59**, 356-377.

Berggren, W. A., D. V. Kent, C. C. Swisher, III, M.-P. Aubry. 1995. A revised Cenozoic geochronology and chronostratigraphy. - In: *Geochronology, Time Scales and Global Stratigraphic Correlation*. Soc. Sedim. Geol., Spec. Publ., **54**, 129-212.

Boyanov, I., B. Mavroudchiev, I. Vaptsarov. 1963. On the structural and formational peculiarities of part of the Eastern Rhodopes. - *Izvestia Geol. Inst*., **12**, 125-186 (in Bulgarian with an English abstract).

Cas, R. A. F., J. V. Wright. 1988. *Volcanic Successions; Modern and Ancient*. London, Chapman & Hall, 528 p.

Davies, D. K., M. W. Quearry, S. B. Bonis. 1978. Glowing avalanches from the 1974 eruption of volcan Fuego, Guatemala. - *Geol. Soc. Am. Bull*., **89**, 369-384.

Fiersten, Y., W. Hildreth. 1992. The plinian erup-

tions of 1912 at Novarupta, Katmai National Park, Alaska. - *Bull. Volcanol***.**, **54**, 646-684.
Filippidis, A., A. Kassoli-Fournaraki, A. Tsirambides. 1995. The zeolites of Petrota and Metaxades (Thrace) and the kaolins of Leucogia (Macedonia), Greece. - In*: Sofia Zeolite Meeting'95. Intern. Symp., Guide Post-meeting Field Trip,* 49-62.
Fisher, R. V. 1961. Proposed classification of volcanoclastic sediments and rocks. - *Geol. Soc. Am. Bull*., **72**, 1409-1414.
Fisher, R. V. 1979. Models for pyroclastic surges and pyroclastic flows. - *J. Volcanol. & Geotherm. Res*., **6**, 305-318.
Fisher, R. V., H.-U. Schmincke. 1984. *Pyroclastic Rocks.* Berlin, Springer-Verlag, 472 p.
Harkovska, A., Y. Yanev, P. Dikova. 1976. Acid volcanism of Upper Eocene (Priabonian) age in the Eastern Rhodopes Paleogene depression. - *C. R. Acad. bulg. Sci.*, **29***,* 4, 579-582 (in Russian).
Harkovska, A., Y. Yanev, P. Marchev. 1989. General features of the Paleogene orogenic magmatism in Bulgaria. - *Geologica Balc.*, **19***,* 1, 37-72.
Ivanov, R., 1960. Magmatism in the Eastern Rhodopes Paleogene depression. Part I - Geology. – *Trudove Geol. Bulg., Ser. Geochim., Pol. Izkop.*, **1***,* 311-387 (in Bulgarian with a German abstract).
Kirov, G. N., A. Filippidis, A. Tsirambidis, R. G. Tzvetanov, A. Kassoli-Fournaraki. 1990. Zeolite-bearing rocks in Petrota area (Eastern Rhodope massif, Greece). - *Geol. Rhodopica*, **2***,* 500-511.
Kozhoukharov, D., I. Boyanov, E. Kozhoukharova, A. Goranov, S. Savov, G. Shilyafov. 1995. *Explanatory Note and The Geological Map of Bulgaria on Scale 1:100 000; Svilengrad Map Sheet*. Com. Geol. and Min. Res., Geology & Geophysics Corp., 67 p.
Lilov, P., Y. Yanev, P. Marchev. 1987. K/Ar dating of the Eastern Rhodopes Paleogene magmatism. - *Geologica Balc.,* **17**, 6, 49-58.
Martini, E. 1971. Standard Tertiary and Quaternary calcareous nannoplankton zonation. – In: *2-nd Planktonic Conf., Rome, Proc.,* 739-785.
Sparks, R. S. J. 1975. Stratigraphy and geology of the ignimbrites of Vulsini volcano, Central Italy. - *Geol. Rundsch*., **64**, 497-523.
Sparks, R. S. J. 1978. Gas release rates from pyroclastic flows: an assessment of the role of fluidisation in their emplacement. - *Bull. Volcanol.,* **41**, 1-9.
Sparks, R. S. J. 1986. The dimensions and dynamics of volcanic eruption columns. - *Bull. Volcanol.,* **48**, 3-15.
Sparks, R. S. J., S. Self, G. P. L. Walker. 1973. Products of ignimbrite eruptions. - *Geology,* **1**, 115-118.
Tzvetanov, R. G., G. N. Kirov, I. T. Topolova. 1983. Zeolite mineralizations in the tuffs of the Malko-Gradishte and Efrem volcanoes, Eastern Rhodopes. - *Ann. Univ. Sofia, Geol.-Geogr. Fac*., **77***,* 1-geol., 71-79 (in Bulgarian with an English abstract).
Yanev, Y. 1995. General characteristics of the Late Paleogene collision volcanism in the Rhodopes. - In: *Sofia Zeolite Meeting'95. Intern. Symp.,Guide Post-meeting Field Trip*, 3-19.
Yanev, Y. 1998. Petrology of the Eastern Rhodopes Paleogene acid volcanics, Bulgaria. - *Acta Vulcanol.,* **10**, 2, 265-277.
Yanev, Y., B. Karadjova, A. Andreev. 1983. Distribution of alcalies and genesis of the acid effusives in part of East Rhodopes Paleogene depression. - *Geologica Balc*., **13***,* 3, 15-44 (in Russian with an English abstract).
Yanev, Y., Y. Yordanov, R. Boyadjieva, P. Lilov, A. Andreev. 1990. Geochemistry of the collision-related acid Paleogene volcanism in the Eastern Rhodopes, Bulgaria. - *Geol. Rhodopica*, **2**, 241-250.

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