БЪЛГАРСКА АКАДЕМИЯ НА НАУКИТЕ • BULGARIAN ACADEMY OF SCIENCES

ГЕОХИМИЯ, МИНЕРАЛОГИЯ И ПЕТРОЛОГИЯ • 39 • СОФИЯ • 2002
GEOCHEMISTRY, MINERALOGY AND PETROLOGY • 39 • SOFIA • 2002

Geological structure and petrology of the Late Cretaceous Chelopech volcano, Srednogorie magmatic zone

Stanislav Stoykov, Yotzo Yanev, Robert Moritz, Ildiko Katona

Abstract. The Chelopech volcano is the host of one of the largest Au-Cu deposits in Europe. The volcano, part of the Srednogorie Late Cretaceous island arc includes three phases: dome-like bodies (andesites and latites to trachydacites), lava to agglomerate flows (andesites, latites, dacites to trachydacites) and a lava breccia neck (andesites to shoshonites and latites). The age of the volcano is probably Turonian. The volcanic rocks are porphyric with plagioclase and amphibole phenocrysts, rarely quartz (in the dome-like bodies) and biotite. The groundmass is microlitic. The lava flows contain fully crystallized fine grained inclusions with more basic compositions indicating mingling between two parental magmas. The chemical evolution from more acid to more basic lavas, and the absence of an Eu anomaly probably indicate a chemically zoned magmatic chamber. The trace element content is similar to that of the active continental margin (Andean type). Sr isotopic compositions display a small range between 0.7049 and 0.7054 (corrected for 90 Ma).

Keywords: Late Cretaceous subduction volcanism, Chelopech volcano, Chelopech Au-Cu deposit, Sr isotopes, trace elements
Addresses: S. Stoykov, Y. Yanev - Geological Institute, Bulgarian Academy of Sciences, 1113 Sofia, Bulgaria; E-mail: stenly@geology.bas.bg; R. Moritz - Earth Science Section of the University of Geneva, 1211 Geneva, Switzerland; I. Katona - Laboratory of Geology, Catholic University of Louvain-la-Neuve, 1348 Louvain-la-Neuve, Belgium

Стойков, С., Й. Янев, Р. Мориц, И. Катона. 2002. Геоложки строеж и петрология на къснокредния Челопешки вулкан, Средногорска магмена зона. - *Геохим., минерал. и петрол.,* **39**, 27-38.

Резюме. Челопешкият вулкан вмества едно от най-големите Au-Cu находище в Европа. Вулканът е част от Средногорската къснокредна островна дъга и е изграден от продуктите на три фази: куполоподобни тела (андезити, латити до трахидацити), лавови, преминаващи в агломератни потоци (състав, вариращ между андезити, латити, дацити и трахидацити) и нек от лавобрекчи (андезити до шошонити и латити). Възрастта на вулкана е вероятно туронска. Вулканитите са порфирни с впръслеци от плагиоклаз и амфибол, рядко кварц (в куполоподобните тела) и биотит. Основната маса е микролитова. Лавовите потоци съдържат напълно кристализирали, финнозърнести включения с по-базичен състав, сочещи за смесване (минглинг) на две родоначални магми. Еволюцията на химизма на вулканските продукти (от по-кисели към по-базични лави) и липсата на Eu аномалия вероятно се дължат на химично зонирана магмена камера. Микрохимичният състав на изследваните вулканити е подобен на този, характерен за активните континентални окрайнини от Андийски тип. Изотопният състав на Sr варира в тесни граници между 0.7049 и 0.7054 (коригирано за 90 млн. г.).

Introduction

The Chelopech volcano is the host of one of the largest Au-Cu deposits in Europe, containing well in excess of 5.5 million ounces of Au and >10 million ounces Au equivalent (Andrew, 1997). It is situated about 65 km east of Sofia at the foot of the Stara Planina Mountain. This deposit has been an object of many investigations connected to its geology and structures (Popov, Mutafchiev, 1980; Popov et al., 2000, 2002), hydrothermal alteration (Mutafchiev, Chipchakova, 1969), mineralogy, stratigraphy of the Late Creta-ceous sequences (Moev, Antonov, 1978a; Dimitrova et al., 1984), structures in the region (Moev, Antonov, 1978b; Popov et al., 2000, 2002), and radiogenic age (Lilov, Chip-chakova, 1999), because of its large econo-mical interest. The petrographic and age characteristics of the surrounding area of the Chelopech deposit have received less attention (Mutafchiev, Chipchakova, 1969; Moev, Antonov, 1978a). The aim of present paper is to complete this information and to show new data about the geological structure, petro-chemical, mineralogical and age characteris-tics of the magmatic rocks, which form the Chelopech volcano and its structure.

Geological setting of the Chelopech volcano

The Chelopech volcano (Popov et al., 2000) is located in the Central Srednogorie volcano-intrusive area, part of the Srednogorie Late Cretaceous island arc (Dabovski et al., 1991). The area is characterized by development of volcano-plutonic complexes consisting mainly of andesites, dacites, granodiorites and quartz-monzodiorites grouped in 4 successive phases with ages in Ma according to Lilov and Chipchakova (1999), as follows: 1st >91, 2nd 91-88, 3^{d} 88-86 and 4th 67-65. According to these authors the products of the 1st, 2nd and 4th phases are developed in the Chelopech region.

The region of the Chelopech volcano (Fig. 1) is built up by metamorphic basement rocks and a Upper Cretaceous volcanic and sedimentary rock succession. The basement appears in the northeastern part of the region and it is composed of the metamorphic rocks of the Pirdop and the Bercovitza Groups in tectonic contact with each other. The Pirdop Group consists of two-mica migmatites with thin intercalations of amphibolites, hornblende-biotite and biotite gneisses (Dabovski, 1988). The Bercovitza Group is a Late Precambrian-Cambrian sedimentary-volcanic complex of island-arc association (Haydoutov, 2001). It consists of equal parts of sedimentary and volcanic rocks (spilites, keratophyres and their pyroclastic rocks) metamorphosed under greenschist facies conditions. This basement is transgressively overlained by Late Cretaceous (Turonian - Maastrichtian) sedimentary and volcanic rocks, more than 2000 m in thickness. The basement is also cut by east-west oriented andesitic dykes which are not discussed in the present paper.

The Late Cretaceous sedimentation starts with conglomerates and coarse sandstones with coal-bearing interbeds (coal-bearing formation, according to Moev and Antonov, 1978a) covered by polymictic, argillaceous and arcose sandstones to siltstones (sandstone formation) with up to 500 m thickness. Both formations are probably of Turonian age (Nikolaev, 1947; Moev, Antonov, 1978a) as confirmed by the new pollen data of Stoykov and Pavlishina (2003). These sedimentary rocks are cut by volcanic bodies and overlaid by the sedimentary and volcanic rocks of the Chelopech Formation according to Moev and Antonov (1978a) or the Tuff formation according to Dimitrova et al. (1984). The products of the Chelopech volcano participate in this Formation (Vozdol Member). After the Subhercinian tectonic deformations (Popov et al., 2002) the rocks of this Member have been eroded and transgressively covered by the

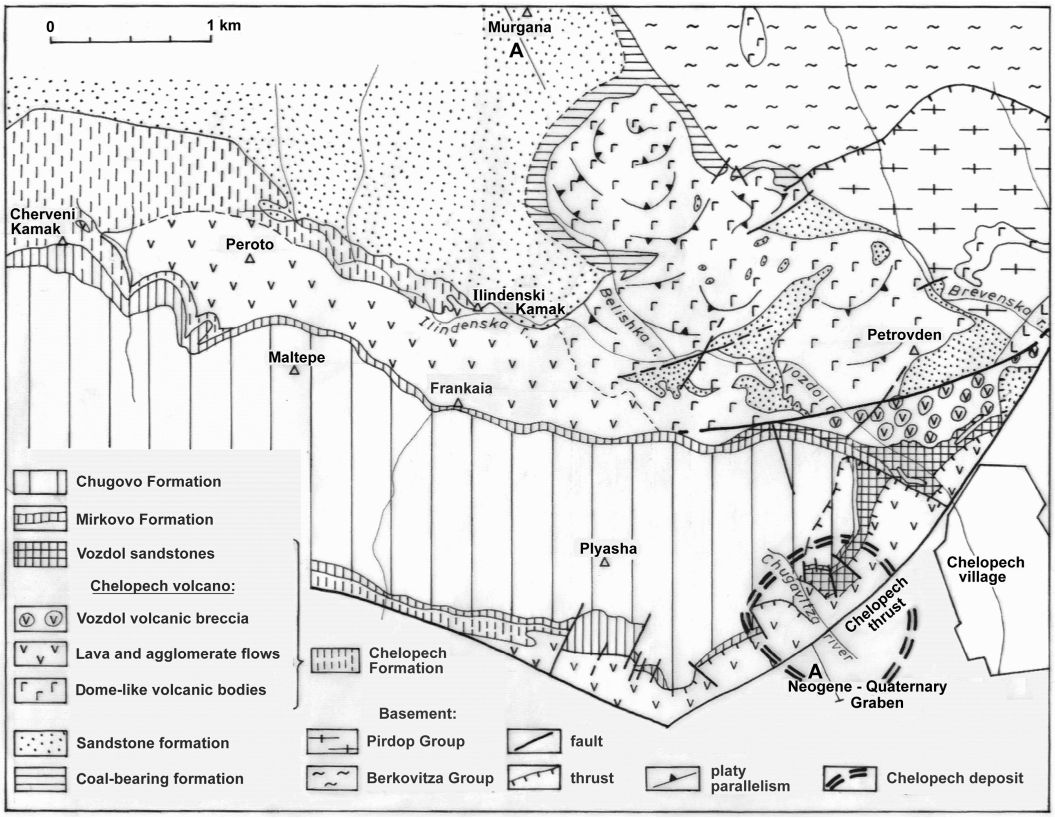


Fig. 1. Geological map of the Chelopech volcano, according to Moev and Antonov (1978a, b) with additions of the authors. A-A, line of the geological section presented on Fig. 2

Фиг. 1. Геоложка карта на Челопешкия вулкан по Моев и Антонов (1978a, b), допълнена от авторите. A-A, линия на геоложкия разрез, показан на фиг. 2

sedimentary rocks of the Mirkovo Formation - reddish limestones and marls (Moev, Antonov, 1978a) or the limestone-marls formation after Dimitrova et al. (1984). They are covered by the flysch of the Chugovo Formation (Moev, Antonov, 1978a) or the flysch formation after Dimitrova et al. (1984). The rocks of the last two Formations build up the Chelopech syncline (Moev, Antonov, 1978b). The size of this structure is 10 × 2 km. The volcanic rocks preserved by erosion form the limbs of this syncline that is cut and covered in the eastern part (Fig. 2) by the Chelopech thrust (Moev, Antonov, 1978b). The later structure is recovered by the Neogene-Quaternary Zlatitsa graben

The geophysical data show the presence of a positive anomaly 20 km in diameter, which is located between the Chelopech volcano and the Elatsite pluton to the North (Popov et al., 2002). This magnetic anomaly is interpreted as a large magnetic-active body corresponding to a shallow magmatic cham-ber. These autors proposed that the Chelopech volcano and the Elatsite pluton are part of the same volcano-plutonic complex and one ore-magmatic system.

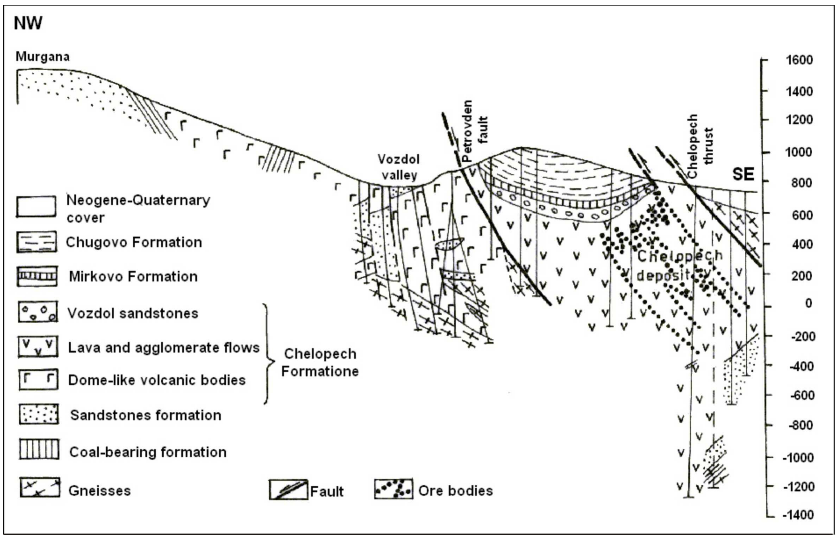


Fig. 2. Geological section A-A of the Chelopech volcano according to the borehole data (the dashed line indicates the borehole situated about 300 m to the SW of the section line). For the location of the section see Fig. 1

Фиг. 2. Геоложки разрез А-А на Челопешкия вулкан по сондажни данни (прекъснатата линия маркира сондаж, намиращ се на около 300 m ЮЗ от профилната линия, обозначена на фиг. 1)

Geological structure of the Chelopech volcano

The basement of the volcano

The basement is not exposed on the surface, but is cut by the boreholes in the Chelopech deposit (Fig. 2). It is composed of the rocks of the sandstone formation, with a thickness between 300 and 450 m (Moev, Antonov, 1978a). According to Popov et al. (2002), in the northern part of the Vozdol river, the basement of the volcano is built up by an olistrostrome unit with a limited development according to borehole data. These data can be interpreted in terms of blocks of metamorphic basement with a sedimentary rock cover, cut by volcanic bodies (Fig. 2).

The volcano

The Chelopech volcano (stratovolcano according to Popov et al., 2002) consists of the products of 3 phases: (1) dome-like volcanic bodies, (2) lava and agglomerate flows and (3) a neck, locally known as the Vozdol neck (Popov et al., 2002).

Dome-like volcanic bodies. In the Murgana area (Fig. 1) the dome-like volcanic bodies are exposed on the surface without clear relationships with the lava and agglomerate flows. These bodies are intruded in the Turonian sediments where the bedding of the hosting rocks close to their contact is subvertical (e.g. in the Belishka river). The largest body is about 2 × 1 km in size. It has a complicated morphology probably reflecting its composite character. Some parts of the bodies (to the south of the Murgana summit) have a dome-like morphology (according to the data of Moev and Antonov, 1978a), corresponding to their volcanic petrographic characteristics (see below). Popov and Mutafchiev (1980) described these bodies as subvolcanic, and later, as subvolcanic intrusions (Popov et al., 2000). These authors distinguished an early and a late group of subvolcanic bodies. Lilov and Chipchakova (1999) attributed a 65-67 Ma age according to K-Ar dating of some of the bodies, which probably reflects a younger, overprinting geological event (see below).

The lava and agglomerate flow. The lava flows grade into agglomerate flows in the upper levels. The agglomerates have the fragments up to 30 cm in size. Subvertical columnar jointing is observed in the lava flows in some places (e.g. in the Ilindenska river). The total thickness of these volcanic products is up to 1200 m according to the drilling data (Popov et al., 2002). K-Ar data of non-altered andesite indicate a Turonian age (91 Ma according to Lilov and Chipchakova, 1999). The location of the volcanic center is not clear. It is probably situated in the area of the Chelopech deposit (respectively in the area of the Chugovitza river) where two boreholes (Fig. 2) cut a very thick volcanic succession (1700-2000 m). The other boreholes in the deposit cut a 700-800 m thick succession of volcanic rocks only. This difference in thickness is too large to be connected to a caldera subsidence. There are also no geological and geophysical evidences for concentric faults related to caldera subsidence, as proposed by Popov et al. (2000, 2002). The volcanic breccia and tuffs in the deposit (Mutafchiev, Chipchakova, 1969; Popov, Mutafchiev, 1980) are strongly hydrothermally altered and probably more of them are epiclastic rocks.

In the western part of the volcano, nearby the Chervenia Kamak summit the upper levels of the agglomerate flows are intercalated with psephitic and psamitic epiclastic rocks, the latter are interbedded with the sandstones and marls of the Chelopech Formation.

The Vozdol neck. In the eastern part of the Vozdol valley (Fig. 1), to the northeast of the Petrovden fault a volcanic breccia is outcroping with a surface of 1.5 × 0.250 km. It is interpreted as the youngest neck of the Chelopech volcano, and is called Vozdol monovolcano by Popov et al. (2000, 2002). One $^{40}Ar/^{39}Ar$ age of biotite from this breccia gives a Turonian age of about 90 Ma (Velichkova et al., 2001). The former K-Ar age of 65 Ma obtained by Lilov and Chipchakova (1999) for samples from the same locality likely represents the age of a younger overprinting thermal event than the real magmatic crystallization age of the Vozdol volcanics. The Vozdol neck consists of clasts-supported lava-breccia with 20 to about 80 cm-sized fragments in a lavic matrix. In the eastern periphery of the body, sedimentary material occurs in the matrix (sandstones to gravelites), which increases volumetrically to the border of the body, where they form a small lens and layers. These features show sedimentation during the formation of this volcanic body and the beginning of its destruction and redeposition in the younger sandstones of the Vozdol area.

The cover of the volcano

The cover represented by the Vozdol sandstones (in the eastern part), the muddy limestones of the Mirkovo Formation (in the central part) and the sedimentary rocks of the Chelopech Formation (in the western part).

The Vozdol sandstones, which have not been described as a single litostratigraphic unit in previous contributions, are only locally developed. They are exposed on a surface of about 2.5 × 1 km and are partly covered by the Chelopech syncline. These sandstones have a variable thickness, with the largest one (up to 250 m) being located in the syncline and on the Vozdol river. They are probably of fluvial or coastal origin (Stoykov, Pavlishina, 2003) and of Turonian age (Nikolaev, 1947) confirmed by the new pollen data of Stoykov and Pavlishina (2003). The sandstones are coarse, thick bedded, and they show cross-bedding. Small coal lenses are present and two conglomerate layers can be recognised (described previously as tuff layers by Moev and Antonov, 1978a, and Popov and Mutafchiev, 1980) with fragments of different volcanic rocks (including from the Vozdol neck) and variable sizes up to 1 m. They can be interpreted as products of mud flows. In comparison to the sandstones of the Chelopech Formation, they also contain muscovite (Popov et al., 2002) which corresponds to another source of terrigeneous material probably derived from the Pirdop Formation to the north.

The partly eroded Chelopech volcano (in the central part of the region) and the Vozdol sandstones (in the eastern part of the region) are transgressively covered by reddish clayey limestones of the Mirkovo Formation (Moev, Antonov, 1978a). These limestones, with a thickness up to 30-40 m, comprise fragments up to 25 cm in size of different volcanic rocks and the Vozdol sandstones. Calcareous nannofossils from the limestones, mostly in the base of this sedimentary unit, indicate a Latest Santonian to Campanian age (unpublished data of K. Stoykova, Geological Institute). They are concordantly covered by flysch sedimentary rocks of the Chugovo Formation (Late Campanian - Early Maastrichtian according to K. Stoykova). The latter consist of an interbedding of calcareous sandstone, siltstone and argillite with a thickness up to 500 m. Volcanoclastic layers are not present in the region of the Chelopech volcano, which is in contrast with other parts of the Central Srednogorie area (Velichkova et al., 2001). The sedimentary rocks of these two Forma-tions form the Chelopech syncline.

Petrology of the Chelopech volcanic rocks

Methods

The major and trace elements were analyzed by X-ray fluorescence (XRF) at the University of Lausanne (Switzerland). The rare earth elements (REE) were analysed by ICP-atomic emission spectrometry following the procedure of Voldet (1993). The representative analyses of the compositional variation of the rock recovered from the Chelopech volcanics are given in Tables 1 and 2. Trace elements (Table 2) were analyzed also by XRF at the University of Geneva. The petrological study was carried out on fresh samples. Mineral analyses on 10 samples of the different phases were carried out at University of Lausanne (Switzerland) on a CAMEBAX SX-50 electron microprobe.

Petrography

The Chelopech volcanic rocks are shoshonites, andesites, latites to dacites and trachydacites (Fig. 3). The magma evolved from more acid volcanic rocks with 61-64 wt. % SiO_2 of the earlier products (dome-like bodies and lava - agglomerate flows) to the more basic ones with 55.5-58 wt. % SiO_2 of the Vozdol volcanic rocks (Table 1).

The composition of the lava flows is mostly latitic. Subsidiary andesites, dacites and

Table 1. *Major elements composition of representative volcanic samples*
Таблица 1. *Химичен състав (главни елементи) на представителни проби от вулканити*

Oxides wt. %	Lava flows	Dome-like body	Vozdol breccia
	MR.1. 2002.2	MR.1. 2002.3	MR.1. 2002.1
SiO_2	63.01	61.22	57.11
TiO_2	0.51	0.54	0.65
Al_2O_3	16.36	17.98	18.35
Fe_2O_3	4.94	5.01	7.03
MnO	0.12	0.14	0.12
MgO	1.63	1.44	1.75
CaO	4.91	3.38	4.87
Na_2O	3.39	5.32	4.19
K_2O	2.74	2.70	3.27
P_2O_5	0.23	0.25	0.26
LOI	1.16	1.73	1.55
Total	99.00	99.71	99.15

MR.1.2002.1 (2, 3) - collection numbers, Geological Institute
MR.1.2002.1 (2, 3) - № в колекцията на Геологическия институт

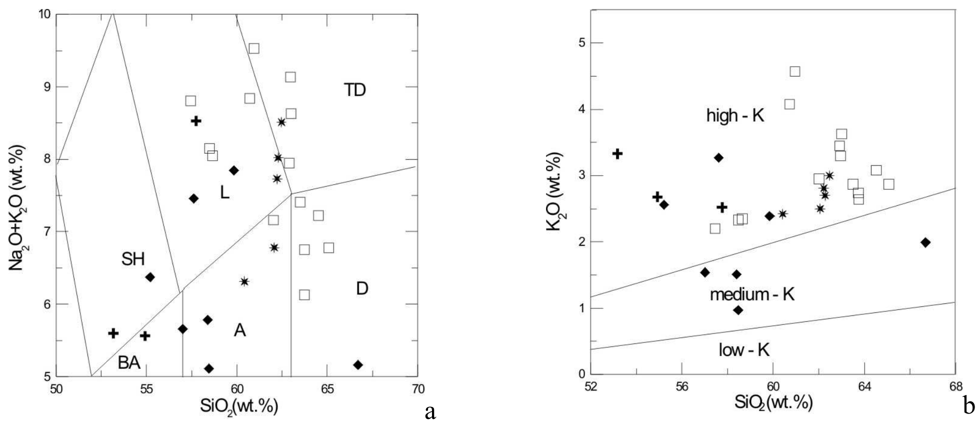


Fig. 3. TAS diagram (a) and SiO_2 vs. K_2O diagram (b) after Le Maitre (1989) for representative Chelopech volcanic rocks (B - basalt; BA - basaltic andesite; A - andesite; D - dacite; SH - shoshonite; L - latite; TD - trachydacite). Stars, Murgana dome-like body; squares, lava flows; diamonds, Vozdol lava breccia; crosses, mafic inclusions in the lava flows (some of the analyses of the inclusions are altered with LOI >2 wt. %)
Фиг. 3. TAS диаграма (а) и SiO_2 към K_2O (б), по Le Maitre (1989), на представителни анализи от Челопешките вулканити (B - базалт; BA - базалтоандезит; A - андезит; D - дацит; SH - шошонит; L - латит; TD - трахидацит). Звезди - Мурганско куполоподобно тяло; квадрати - лавови потоци; ромбове - Воздолски лавови брекчи; кръстове - мафични включения (някои от анализите на включенията са променени със ЗПН>2 тегл. %)

trachydacites are also present in minor amount. These volcanic rocks are highly porphyric with microlitic groundmass. The phenocrysts (> 40 volume %) consist of plagioclase, zoned amphibole, minor biotite, and titanite; whereas the microlites consist of plagioclase and amphibole only. The accessory minerals are apatite, zircon, and Ti-magnetite. The lava flows contain fine-grained, fully crystallized inclusions consisting of the same minerals (plagioclase, amphibole and minor biotite) which comprise phenocrysts of different chemistry. The margins of the inclusions are marked by fine-grained quartz zone which is interpreted as evidence of magma mingling.

The dome-like bodies are also porphyric with a microlitic groundmass and an andesitic, latitic to trachydacitic chemistry. These volcanic rocks consist of the same phenocrysts, microlites and accessory minerals as the lava flows but they contain also rare corroded quartz crystals as a minor phase.

Table 2. *Composition of plagioclase phenocrysts*
Таблица 2. *Състав на плагиоклазови порфири*

Volcanic rocks	Lava flows		Vozdol breccia	
Pheno-cryst	center	periphery	center	periphery
SiO_2	58.31	59.76	58.03	59.14
Al_2O_3	26.19	25.22	26.36	25.63
Fe_2O_3	0.22	0.28	0.26	0.23
CaO	7.68	6.75	8.24	7.79
BaO	0.01	0.02	0.05	0.02
Na_2O	6.68	7.37	6.39	6.62
K_2O	0.70	0.70	0.65	0.71
Sum	99.80	100.10	99.99	100.14
Si	2.62	2.67	2.60	2.64
Al	1.39	1.33	1.39	1.35
Fe^{3+}	0.01	0.01	0.01	0.01
Ca	0.37	0.32	0.40	0.37
Na	0.58	0.64	0.56	0.57
K	0.04	0.04	0.04	0.04
Sum	5.00	5.00	4.99	4.99
Ab	58.64	63.75	56.15	58.13
An	37.31	32.24	40.01	37.77
Or	4.03	3.97	3.75	4.07

Table 3. *Representative analyses of amphibole phenocrysts*

Таблица 3. *Представителни анализи на амфиболови порфири*

Volcanic rocks	Lava flows		Vozdol breccia	
Phenocryst	center	periphery	center	periphery
SiO_2	43.13	43.23	42.91	43.39
TiO_2	1.53	1.59	1.74	1.74
Al_2O_3	10.00	9.64	10.27	9.25
Fe_2O_3(calc)	3.39	2.65	2.61	3.67
FeO(calc.)	14.87	14.96	15.31	13.94
MnO	0.68	0.61	0.75	0.67
MgO	9.84	10.26	9.67	10.63
CaO	11.8	11.98	11.81	11.84
Na_2O	1.55	1.57	1.58	1.52
K_2O	1.24	1.22	1.29	1.25
Cl	0.14	0.15	0.14	0.16
H_2O(calc.)	1.96	1.95	1.95	1.95
Sum	100.11	99.75	100.01	99.97
Si	6.496	6.527	6.475	6.527
Ti	0.174	0.180	0.198	0.196
^{IV}Al	1.504	1.473	1.525	1.473
^{VI}Al	0.272	0.244	0.303	0.166
Fe^{3+}	0.384	0.301	0.297	0.415
Fe^{2+}	1.873	1.889	1.932	1.754
Mn^{2+}	0.087	0.077	0.095	0.085
Mg	2.210	2.309	2.175	2.384
Ca	1.905	1.938	1.909	1.908
Na	0.452	0.459	0.462	0.443
K	0.239	0.235	0.249	0.240
Cl	0.035	0.038	0.036	0.040
OH	1.965	1.962	1.964	1.960
Sum	17.595	17.631	17.62	17.592
Mg #	0.54	0.55	0.53	0.58

The Vozdol andesites and latites to shoshonites display similar petrographic characteristics but their phenocrysts (plagioclase, amphibole, minor biotite, and titanite) are less abundant compared to the other magmatic rocks of the Chelopech volcano. The groundmass is composed of the microlites of the same minerals. K-feldspar is present as microlites only in the Vozdol andesitic rocks.

Table 4. *Trace elements composition of representative volcanic samples*

Таблица 4. *Елементи-следи в представителни проби от вулкански скали*

Elements ppm	Lava flows	Dome-like body	Vozdol breccia
	MR.1. 2002.2	MR.1. 2002.3	MR.1. 2002.1
Nb	7	7	6
Zr	98	121	127
Y	20	23	18
Sr	781	1430	871
Rb	63	72	46
Th	3	4	3
Pb	16	17	15
Ga	19	18	18
Zn	72	46	137
Cu	26	25	35
Ni	2	3	4
Co	10	50	13
Cr	14	10	15
V	127	96	139
Ba	1441	870	768
S	113	12	29
Hf	6	7	6
Sc	10	6	9
As	6	11	3
La	22.9	-	21
Ce	49.3	-	44.7
Pr	5.3	-	5.2
Nd	24	-	22.8
Sm	4.9	-	4.6
Eu	1.26	-	1.27
Gd	3.3	-	3
Dy	3.1	-	3
Ho	0.66	-	0.64
Er	1.8	-	1.7
Tm	0.26	-	0.24
Yb	1.5	-	1.4
Lu	0.22	-	0.18

Mineral chemistry

The composition of plagioclase phenocrysts (Table 2) of the Murgana volcanic rocks varies from $An_{38.5-42.2}$ (core) to $An_{38.7-46.2}$ (rim); those of the lava flows - from $An_{42.5-48.2}$ (core) to $An_{30.1-53.9}$ (rim) and the Vozdol volcanic rocks phenocrysts display range from center $An_{50.8}$ to $An_{36.2}$ in the periphery. The rims are variable in composition and substantially overlap the field of the phenocryst cores (Fig. 4). The composition of plagioclase microlites vary from An_{31} to An_{48}. K-feldspar microlites (Or_{86-93}) where only analyzed in the Vozdol volcanic rocks. The amphiboles (Fig. 4, Table 3) for all volcanic rocks display Mg # between 0.48 and 0.67. The contents of Si *ap.fu.* range between 6.40 and 6.55 and they plot on the limit of the magnesiohastingsite, pargasite, ferropargasite, hastingsite and Fe-edenite field of Leake et al. (1997). The composition of the amphibole crystals of the inclusions is different to those of the volcanic rocks. It displays higher values of Mg # between 0.70 and 0.83 and is classified as magnesiohastingsite. The contents of Si *apfu.* of the amphiboles from the inclusions range between 5.90 and 6.10.

Trace elements.

The MORB normalized patterns for the Chelopech volcanic rocks (Table 4, Fig. 5) indicate enrichment of LILE and in lesser degree of some HFSE (Ce, Zr, P and Hf) with a strong negative Nb anomaly and a depletion of the Fe-Mg elements. All these features are typical for subduction-related magmatic sequences due to the melting of sedimentary material of the subducted slab. In comparison to the volcanic rocks of an Andean-type active continental margin, the Chelopech magmatic rocks show small K_2O, Ba and Hf enrichments and depletions of Nb, TiO_2, Zr and P_2O_5.

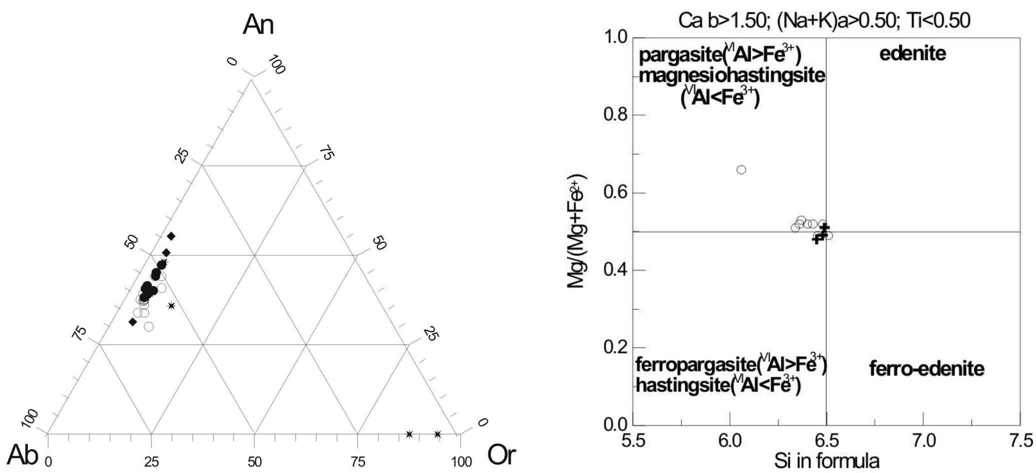


Fig. 4. Left, Ab-An-Or ternary diagram of feldspars: filled circles, phenocrysts core; open circles, phenocrysts rim; filled diamonds, first generation phenocrysts; stars, groundmass microlites. Right, classification of amphibole phenocrysts (after Leake et al., 1997): circles, amphiboles with $^{VI}Al > Fe^{3+}$; crosses, amphiboles with $^{VI}Al < Fe^{3+}$

Фиг. 4. Ляво - Ab-An-Or триъгълна диаграма на фелдшпати: запълнени кръгове - ядра на порфирите; празни кръгове - периферия на порфирите; запълнени ромбове - първа генерация порфири; звезди - микролити. Дясно - класификация на амфиболови порфири (по Leake et al., 1997): кръгове - амфиболи с $^{VI}Al > Fe^{3+}$; кръстове - амфиболи с $^{VI}Al < Fe^{3+}$

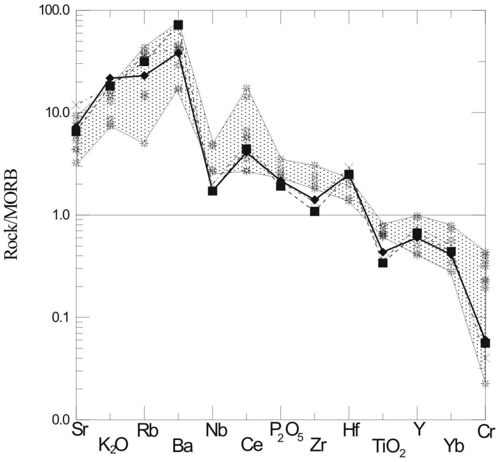
All rocks have fractionated LREE and relatively flat HREE patterns (Fig. 5), as typically found in subduction related volcanic rocks. The LREE enrichment ranges from 33 to 105 times chondritic, whereas La_n/Yb_n ratios vary from 10 to 13. Middle and heavy REE show relatively flat patterns, generally within 5-30 times that of chondritic ones. An Eu anomaly is not observed, which suggests that there was no plagioclase fractionation involved in genesis of the studied andesitic rocks. The data can be interpreted in terms of a chemically zoned magmatic chamber (according to the model of Hildreth, 1981). The rocks from the Murgana dome-like body show slightly enriched values of the LREE compared to the lava flows and the Vozdol volcanic rocks.

Sr isotopes

The Sr isotope ratios of the magmatic rocks from the Chelopech volcano display a small range between 0.7049 and 0.7054 after a 90 Ma correction (Stoykov et at., 2002). Generally $^{87}Sr/^{86}Sr$ ratios fall within the field previously defined by Kouzmanov et al. (2001) values from 0.7046 to 0.7061 (after 80 Ma correction) for the volcanic (andesite and dacite) and plutonic (granodiorite and granite) rocks from the southern part of the Central Srednogorie volcano-intrusive area.

Conclusions

The Upper Cretaceous Chelopech volcanic rocks are located in the central part of the



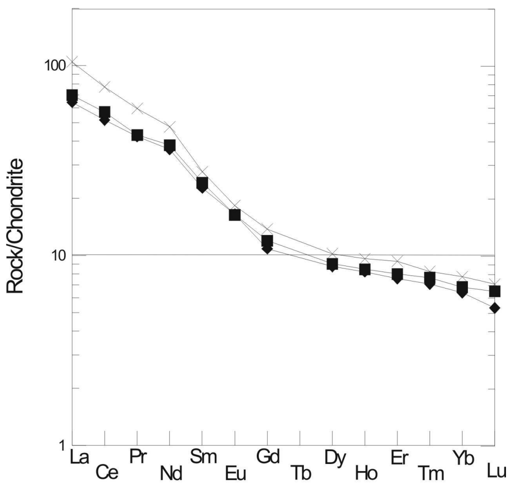


Fig. 5. Left, MORB (Mid-ocean ridge basalt) - normalized trace and major element patterns for average analyses of Chelopech volcanic rocks (crosses, Murgana dome-like body; squares, lava flows; diamonds, Vozdol lava breccia) and some active continental margins andesites (Antisona volcano - Ecuador, data from Bourdon et al., 2002; South Sister volcano, Oregon, USA, data from Brophy and Dreher, 2000; Western USA - eastern zone and South America - Andes, data from Erwart, 1982, and Mexico data from Robin, 1982). Normalization values after Pearce (1982). Right, chondrite-normalized REE patterns for Chelopech volcanic rocks

Фиг. 5. Ляво - MORB (базалти от срединноокеанските хребети) - нормализирана спайдерграма за някои редки и главни елементи за средни състави на Челопешките вулканити (кръстове - Мурганско куполоподобно тяло; квадрати - лавови потоци; ромбове - Воздолски лавови брекчи) и андезити от активни континентални окрайнини (вулкана Антисона - Еквадор, данни от Bourdon et al., 2002; вулкана Саут Систер, Орегон, САЩ, данни от Brophy and Dreher, 2000; Западни САЩ - източна зона и Южна Америка - Анди, данни от Erwart, 1982 и Мексико, данни от Robin, 1982). Нормализационите фактори са по Pearce (1982). Дясно - хондрит-нормализирана крива на редкоземните елементи от Челопешките вулканити

Srednogorie island arc. The products of this magmatic activity have a Ca-alkaline to shoshonitic affinity and are probably of Turonian age. The magma evolved from more acid volcanic rocks with 61-64 wt. % SiO_2 of the earlier products (dome-like bodies and lava – agglomerate flows) to the to more basic ones with 55.5-58 wt. % SiO_2 of the laters (Vozdol lava breccia neck). This chemical evolution and the absence of an Eu anomaly probably indicate a chemically zoned magmatic chamber. Magma mingling was a ubiquitous process and together with fractional crystallization controlled the evolution of the andesitic magmas of the Chelopech volcano. The behaviour of the trace elements is similar to the andesitic rocks formed at an active continental margin. The Sr isotope signature suggests derivation of melts generated in a mantle source modified by the addition of crustal material.

Acknowledgements: This work is supported by the Swiss National Science Foundation through the SCOPES Joint Research Project 7BUPJ062276 and research grant 21-59041.99. This is a contribution to the ABCD-GEODE research program supported by the European Science Foundation. The authors would like to thank G. Morris and P. Voldet (University of Geneva) for their help with microprobe and REE data acquisition and L. Heskia from Geological Institute (Bulgarian Academy of Sciences) for the technical help.

References

Andrew, C. 1997. The geology and genesis of the Chelopech Au-Cu deposit, Bulgaria: Europe's largest gold recourse. - In: *Europe's Major Gold Deposits.* Abstracts Vol., 68-72.

Bourdon, E., J.P. Eissen, M. Monzier, C. Robin, H. Martin, J. Cotten, M. Hall. 2002. Adakite-like lavas from Antisana volcano (Ecuador): Evidence for slab melt metasomatism beneath the Andean Northern Volcanic Zone. - *J. Petrol.,* **43**, 199-217.

Brophy, J., S. Dreher. 2000. The origin of composition gaps at South Sister volcano, central Oregon: Implication for fractional crystallization processes beneath active calc-alkaline volcanoes. - *J. Volcanol. Geotherm. Res.,* **102**, 287-307.

Dabovski, Ch. 1988. Precambrian in the Srednogorie zone (Bulgaria). - In: Cogne, J., D. Kozhoukharov, H.G. Krautner (eds.) *Precambrian in Younger Fold Belts*. Essex, 841-847.

Dabovski, Ch., A. Harkovska, B. Kamenov, B. Mavrudchiev, G. Stanisheva-Vasileva, Y. Yanev. 1991. A geodynamic model of the Alpine magmatism in Bulgaria. - *Geol. Balcanica*, **21**, 4, 3-15.

Dimitrova, E., I. Nachev, I. Slavov. 1984. Stratigraphy of the Upper Cretaceous in Panagyurishte region. - *Paleont. Stratigr. Lithol.,* Sofia, **19,** 65-84. (in Bulgarian).

Ewart, A. 1982. The mineralogy and petrology of Tertiary: Recent orogenic volcanic rocks, with special reference to the andesitic-basaltic compositional range. - In: Trope, R.S. (ed.) *Andesites.* Chichester, Wiley, 25-98.

Haydoutov, I. 2001. The Balkan island-arc association in West Bulgaria. - *Geol. Balcanica*, **31,** 1/2, 109-110.

Hildreth, W. 1981. Gradients in silicic magma chambers: Implications for lithospheric magmatism. - *J. Geophys. Res.,* **86**, 10153-10192.

Kouzmanov, K., R. Moritz, M. Chiaradia, C. Ramboz. 2001. Sr and Pb isotope study of Au-Cu epithermal and porphyry-Cu deposits from the southern part of the Panagyurishte district, Sredna Gora zone, Bulgaria. - In: A. Piestrzynski et al. (eds.) *Mineral Deposits at the Beginning of the 21st Century*. Lisse, Swets & Zeitlinger Publ., 539-542.

Leake, B.E., A.R. Woolley, C.E.S. Arps, W.D. Birch, M.C. Gilbert, J.D. Grice, F.C. Hawthorne, A. Kato, H.J. Kisch, V.G. Krivovichev, K. Linthout, J. Laird, J. Mandariano, W.V. Maresch, E.H. Nickel, N.M.S. Rock, J.C. Schumacher, D.C. Smith, N.C.N. Stephenson, L. Ungaretti, E.J.W. Whittaker, G. Youzhi. 1997. Nomenclature of amphiboles. Report of the Subcommittee on amphiboles in the IMA Commission on new minerals and minerals names. - *Eur. J. Mineral*., **9**, 623-651.

Le Maitre, R.W. 1989. *A Classification of Igneous Rocks and Glossary of Terms*. Oxford, Blackwell, 193 p.

Lilov, P., S. Chipchakova. 1999. K-Ar dating of the Late Cretaceous magmatic rocks and hydrothermal metasomatic rocks from Central Srednogorie. - *Geochem. Mineral. Petrol.,* Sofia, **36**, 77-91 (in Bulgarian).

Moev, M., M. Antonov. 1978a. Stratigraphy of the Upper Cretaceous in the eastern part of Strelcha-Chelopech line. - *Ann. de l'École sup. mines et géol.,* **23**, Fas. II - Géol., 7-27 (in Bulgarian).

Moev, M., M. Antonov. 1978b. Structure of the eastern part of Sturgel-Chelopech line. - *Ann. de l'École sup. mines et géol.,* **23**, Fas. II - Géol., 31-49 (in Bulgarian).

Mutafchiev, I., S. Chipchakova. 1969. Hydrothermal alterations of the rocks of the Senonian volcanic complex at the gold-copper-pyrite deposit of Chelopech (Pirdop district). - *Bull. Geol. Inst., Ser. Metal., Non-Metal. Mineral Deposits,* **18**, 125-142 (in Bulgarian).

Nikolaev, G. 1947. Contributions to the geology of the south slobs of the Stara planina mountain, between Botevgrad and Zlatiza pass. - *Rev. Bulg. Geol. Soc.,* **15/19**, 1-18 (in Bulgarian).

Pearce, J.A. 1982. Chemical and isotope characteristics of destructive margin magmas. - In: Trope, R.S. (ed.) *Andesites*. Chichester, Wiley, 525-548.

Popov, P., I. Mutafchiev. 1980. The structure of the Chelopech Cu-ore field. - *Ann. de l'École sup. mines et géol.,* **25**, Fas. II - Géol., 25-41 (in Bulgarian).

Popov, P., R. Petrunov, S. Strashimirov, M. Kanazirski. 2000. Elatsite-Chelopech ore fielld. - In: *Guide to Excursions A and C,* ABCD-GEODE 2000 Workshop, Borovets, 8-18.

Popov, P., R. Radichev, S. Dimovski. 2002. Geology and evolution of the Elatzite-Chelopech porphyry-copper - massive sulfide ore field. - *Ann. Univ. Mining and Geol.,* **43/44**, part 1 - Geol., 31-44 (in Bulgarian).

Robin, C. 1982. Regional distribution and character of active andesite volcanism - Mexico. - In: Trope, R.S. (ed.) *Andesites*. Chichester, Wiley, 137-148.

Stoykov, S., Y. Yanev, R. Moritz, D. Fontignié. 2002. Late Cretaceous magmatism of Chelopech region, Central Srednogorie volcanic-intrusive zone (Bulgaria). - *Geol. Carpat. Special Issue*, **53** (*electronic version).*

Stoykov, S., P. Pavlishina. 2003. New data for Turonian age of the sedimentary and volcanic succession in the southeastern part of Etropole Stara Planina Mountain, Bulgaria. - *C. R. Acad. bulg. Sci.* (in print).

Velichkova, S., R. Handler, F. Neubauer, J. Ivanov. 2001. Preliminary $^{40}Ar/^{39}Ar$ mineral ages from the Central Srednogorie Zone, Bulgaria: Implication for the Cretaceous geodynamics. - *Romanian J. Mineral Deposits,* **79**, 112-113.

Voldet, P. 1993. From neutron activation to inductively coupled plasma-atomic emission spectrometry in the determination of rare-earth elements in rocks. - *Trends Anal. Chem.,* **12,** 8.

Accepted December 28, 2002
Приета на 28. 12. 2002