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PHENOMENON OF MUD VOLCANOES IN WESTERN ROMANIA AS A GEOTURISM OBJECT

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Abstract: The biggest mud volcanoes in Europe are located in eastern Romania, in the center of the Carpathian Foredeep, in the anticline structure called Berca-Arbanasi extending for 20 km north-southward. The volcanoes are located there in four zones: Beciu, Paclele Mici (PMI), Paclele Mari (PMA) and Fierbatori at a distance about 20 km northwest from Buzau. In 1924 the volcanoes PMI and PMA received the status of geological reserve, and nowadays are one of the major geotourism attractions in the country. The volcanoes in both regions are either cone- or pie- shaped. In the mud samples drawn from both regions the separation of fractions was carried out. It indicates that the muddy substance is composed mainly of grain fraction of 0.5-0.18mm and 1.0-0.5mm. The mineral composition, determined by means of polarizing microscope on fraction 0,5-0,18mm in both regions, indicates that prevailing, however distinct in percentage share, minerals are the following: quartz grains, claystones and mudstone fragments. This identification was confirmed by X-ray pattern, which showed the mud volcanoes transport mostly mud composed of clay minerals represented by illite-smectite. Chemical analyses performed using ICP method showed that volcano waters are composed of mud mixed with salty waters. Moreover, chemistry of these waters collected from the two separate volcanoes are different too, and the main elements are the following: B, Ba, Br, Ca, I, K, Li, Na, Mg and Sr. Results of chemical analyses confirm various sources of salty waters as well as their migration across various evaporites present below volcanoes. The research shows significant differences between these two apparently identical objects, making them even more attractive as far as geotourism values are concerned. Establishing an appropriate geotourism infrastructure would serve at least three purposes: enriching the aesthetic impressions after visiting the region, allowing tourists to get to know the differences and enhancing the educational offer of the reserves.

Keywords: Romania, Carpathian Foredeep, mud volcanoes, mineral composition, geoturism

1. Introduction

1.1 General information about mud volcanoes

Mud volcanoes are defined as geological features through which agrillaceous material is altered and transported from the Earth’s interior and expelled onto its surface. Mud volcanoes can be found almost everywhere on Earth. They are commonly associated with compressional tectonics at convergent margins (Higgins and Saunders, 1974; Barber et al., 1986; Kopf et al., 1998 cited in Kopf, 2003). Their density shows a positive correlation with (1) thick, rapidly deposited sediments consisting of high clay mineral component as (Yassir, 1989 cited in Kopf, 2003), (2) sediment overpressuring due to hydrocarbon formation (Hedberg, 1974; Lavrushin et al., 1996 cited in Kopf, 2003), (3) a structural association with tectonic shortening dehydration (Moore and Vrolijk, 1992 cited in Kopf, 2003) and/or earthquake activity (Sondhi, 1947 cited in Kopf, 2003), (4) fluid emission such as gas, brines, water from mineral dehydration (Moore and Vrolijk, 1992 cited in Kopf, 2003) and gas hydrate dissociation (Milkov, 2000 cited in Kopf, 2003), and (5) polymictic assemblages of the surrounding rock present in the ejected argillaceous matrix (Robertson and Scientific Party of ODP Leg 160, 1996; Kopf et al., 1998 cited in Kopf, 2003).

There are about 700 mud volcanoes known in the world, and almost half of them can be found in

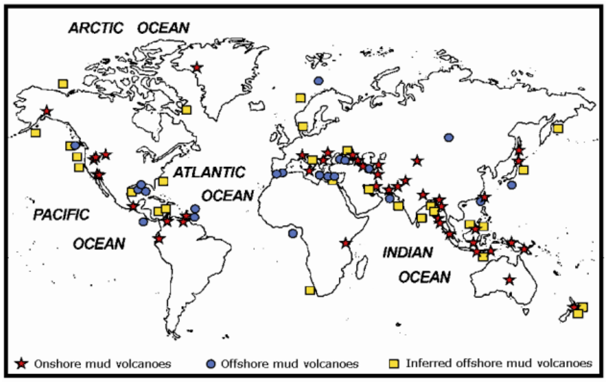


Fig. 1. Distribution of mud volcanoes worldwide (modified from Milkov 2003).

Azerbaijan. The other ones were also discovered in Turkmenistan and in the south-Caspian region, in Australia, Taiwan, China, Pakistan and Iran. Only a few are found in Europe: in the south-west of Ukraine, in Southern Italy and Sicily, and in Romania. It is also worth noticing that mud volcanoes can form both onshore and offshore (Fig. 1) (http://azer.com/aiweb/categories/magazine/ai151_folder/151_articles/151_mud_volcanoes.html).

The size of mud volcanoes ranges from a few centimeters to several meters of width, and from a few centimeters to 500-700 meters of height, whereas the biggest offshore mud volcano reaches the diameter of 30 km and about 2 km of relative height (Kopf, 2002).

Generally, mud volcanoes have the shape of cones (Fig. 2) or pies (Fig. 3). The former, depending on the viscosity of the muddy substance, exhibit various inclinations from 35 - 40˚, and sometimes are characterized by the presence of parasitic cones on the slopes. The latter, are characterized by slight inclination of slopes - <5˚, and become cylindrical or irregular in shape. Both forms may occur in active or fossil form (Kopf, 2002).


Fig. 2 Example of cones in Paclele Mici region (Madeja 2009).

The substance flowing out of mud volcanoes can be both watery, thus such outflows are constant and accompanied by characteristic bubbling, however, at times they can be viscid, sticky and therefore, more spectacular eruptions of discarding fireballs can take place. Frequently, slight traces of oil accompany the discard (http://azer.com/aiweb/categories/magazine/ai151_folder/151_articles/151_mud_volcanoes.html).


Fig. 3 Example of pie in Paclele Mari region (Mrowczyk 2009).

Interestingly, mud volcanoes due to their specificity are not long-lasting objects (in a geological time), and are susceptible to erosive factors. At the same time, new cones or pies begin to form, and therefore the landscape, where mud volcanoes occur, changes constantly, creating more and more fascinating forms.

1.2 The outline of the geological structure of Romania

There are three main tectonic units in Romania: the south-western part of the East European Plate (EEP) called Moldavian Platform, Moesian microplate (MP) and Intra-Alpine micro-plate (IAP). IAP is a core component of the Alpine orogen, which includes the Eastern Carpathians, the Southern Carpathians and the Apuseni Mountains. Besides, IAP also includes depressions such as Pannonia and Transylvania. The boundaries draw between the major tectonic units: TT zone (Teisseyre-Tornquist), extending NW-SE separating EEP and IAP, as well as major crustal faults separating MP from EEP and IAP. The area where all three boundaries of tectonic units meet is called Vrancea Region, and is characterized by high seismic and geodynamic activity (Baciu, 2007) (Fig.4).

There is the Carpathian Foredeep filled by thick Neogene molassic sediments located in the outer part of the Eastern and Southern Carpathians. On the basis of geologic and tectonic features, three sedimentary basins were distinguished there: Moldavian Basin, Focsani Basin and Getic Basin. The biggest thickness of sediments reaching 8000m is observed in Focsani Basin, on the other two indexes reach 3000m (Baciu, 2007).

Romania is a country characterized by moderate tectonic activity, and receives earthquakes at depths of 5 to 30 km. However, within its borders, there is one of the most tectonically active areas in Europe, where magnitudes of earthquakes reach

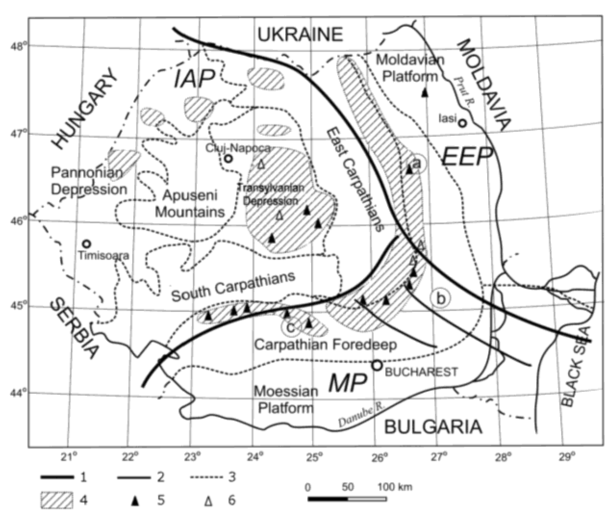


Fig. 4. Geotectonic units in Romania and distribution of mud volcanoes and hydrocarbon seeps in Romania. 1-limits between lithosperic plates (microplates); 2- major faults; 3- limits between main structural units; 4- hydrocarbon seepage areas; 5- mud volcanoes; 6- Dry macroseeps; EEP - East European Plate; IAP - Intra-Alpine Microplate; MP – Moessian Microplate; a - Moldavian Basin; b - Focsani Basin; c - Getic Basin (modified from Baciu, 2007).

7.7, and their hypocenters are located at 70 to 180km underground. It is in already mentioned Vrancea Region (Baciu, Etiope, 2005).

Romania also possesses is well-stocked in deposits of hydrocarbons (Fig. 4). Two of the richest regions are the Flysch Carpathians and the Carpathian Foredeep, where almost 110 deposits are located, and where the majority of mining has been taking place for the last 150 years. Research indicate that the age of these deposits dates back to Paleogene-Pliocene. Moreover, the hydrocarbons deposits are known from Moesian Platform, where over 125 structures, rich in natural gas and oil, were found at depths of 350 to 4900m, and exhibit a large age span: from the Devonian to the Pliocene (Paraschiv, 1979 cited in Baciu, 2007). Other, less important, Miocene gas deposits, were discovered in the western part of the Moldavian Platform. Furthermore, Transylvanian Depression is regarded as the biggest provider of natural gas for the Central and Eastern Europe (Baciu, 2007).

In Romania mud volcanoes are located in Carpathian Foredeep, Transylvanian Depression and Moesian Platform. The main aim of this paper is to describe mud volcanoes located in Carpathian Foredeep as a geoturism object.

1.3 Mud Volcanoes in Romania

The largest mud volcanoes in Romania are those located in the center of the Carpathian Foredeep, more precisely in the anticline structure called Berca-Arbanasi, of north-south orientation and 20 km long. Numerous faults occur in the anticline intersecting impermeable salt formations drawing on hydrocarbon deposits, enabling natural gas and mud to expel onto the surface (Etiope, 2004, Baciu, 2007).

Volcanoes are located there in four zones: Beciu, Paclele Mici (45°21’29.08”N, 26°42’44.47”E), Paclele Mari (45°20’22.17”N, 26°42’25.65”E) and Fierbatori, 20km North-West of Buzau (Fig.5). The distances, in straight line from specific zones, can be illustrated in the following way: Beciu-Paclele Mici - 3km, Paclele Mici - Paclele Mari - 2km; Paclele Mari - Fierbatori - 5km (Fig. 5). Two regions: Paclele Mici (PMI) and Paclele Mari (PMA) received the status of geological reserve in 1924 and they will be the subject of subsequent discussion (Etiope, 2004).

Paclele Mari and Paclele Mici regions are located in the central part of anticline, where strike-slip fault intersects the axis of this anticline (Fig. 5). Paclele Mari (Fig. 6) region is a plateau 1.8km long and 3km wide and 80m high, whereas Paclele Mici (Fig. 7) is a slightly smaller plateau: 1.3km long, 1km wide, and 60m high. The surface of 1.62km^2 is covered by products originating from Paclele Mari volcanic activity, whereas the surface of Paclele Mici has only 0.62km^2. The active volcanoes in Paclele Mari cover 0.22km^2 while in Paclele Mici 0.16km^2 (Baciu, 2007). In both regions over 60 holes emit methane: 62 holes in Paclele Mari expels 300 tons of methane to the atmosphere yearly, while 65 holes in Paclele Mici emit 255 ton/year. Methane comes out onto the surface through pores in ground in the following amounts: Paclele Mari 430 ton/year Paclele Mici 128 ton/year (Etiope, 2004). In both regions the volcanoes have cone shapes, and are 10m high, some of them have parasitic cone shapes, too. Furthermore, muddy substance reaches the surface through pies of 3 to 10m in diameter (Baciu, 2007).

In Fierbatori region (Fig. 5), located in the southern part of the discussed anticline feature, the surface, covered by products of volcanic activity, has 0,09km^2. Mud coming out to the surface is relatively watery there and has the shape of pies, and few small, rather flat cones (Baciu, 2007). What is more, large emission of methane through pores in ground is also noticed there. The first recorded eruption of muddy substance there took place in 1881 (Cobalcescu, 1883 cited in Etiope, 2004).

The smallest surface area, less than 0.01 km^2, covered by deposits from mud volcanoes (in form of pies), is located in the northern part of anticline, in the area of Beciu (Fig. 5). However, it was in this region that the biggest outflows took place in the past. A significant eruption occurred in November 1976, and 1 meter-"pillar" of mud eruption was seen for 24hours, and during 30 days of volcanic activity there 5000 tons of muddy material got out to the surface (Sencu, 1985 cited in Etiope, 2004). Slightly smaller, but also well- remembered event took place a year later when the local earthquake, which reached the magnitude of 7.2, was accompanied by 6h -mud eruption (Sencu, 1985 cited in Etiope, 2004).

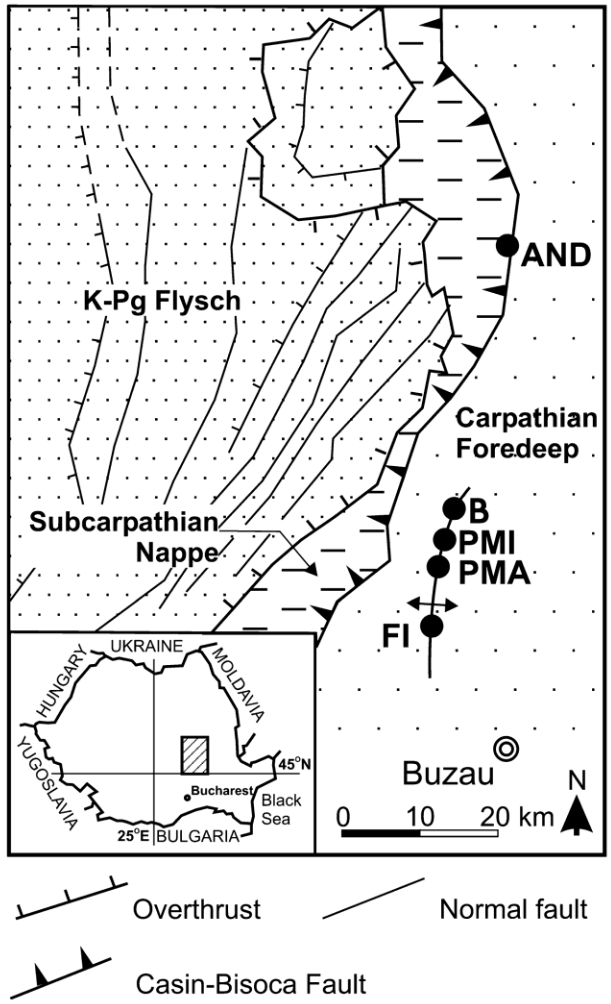


Fig. 5. Sketch map of the geostructural setting of the study area. AND-Andreiasu, B–Beciu, PMI-Paclele Mici, PMA-Paclele Mari, FI-Fierbatori (modified from Etiope 2004).

The total surface of the four discussed areas, covered by products of volcanic activity, is estimated for 2,5km^2, whereas the total methane emission, according to research data, accounts for 1200 ton/year (Etiope, 2004 cited in Baciu, 2007).


Fig. 6. Paclele Mari region (Madeja 2009).

Fig. 7. Paclele Mici region (Mrowczyk, 2009).

Furthermore, in the north-east of Beciu, there is a small village Andreiasu (Fig. 5) which is a natural reserve for the self-burning exhalations of gas-known as “Focul viu” (live fire). These fires burn all the time, and their columns can reach 1m high. The occurrence of fire is connected with a fault Casin-Bisoca located there (Etiope, 2004; Baciu, 2007). Geology of ground: hard marl, sandstones and volcanic tuffs do not favor mud formation, and therefore only natural gas (mostly methane), around 50 ton/year, is emitted to the surface of 400m^2 , and small amount of water (Baciu, 2007).

In the table 1 it is shown the composition of gas emitted in percentage terms in the discussed areas.

Table 1. Gas composition and He isotopes of the macro-seeps in Romania (PMI-Paclele Mici, PMA-Paclele Mari, FB-Fierbatori, AND-Andreiasu) (Baciu 2007).

	He (ppmv)	N_2 (%V)	CH_4 (%V)	CO_2 (%V)	3He/4He
PMI	24	2.8	94.9	2.3	$6.1x10^{-8}$
PMA	25.1	15.3	82.7	2	$6.1x10^{-8}$
FB	14.3	6.2	91.2	2.5	$2.1x10^{-8}$
AND	10.3	2.2	95.8	2	$4.3x10^{-8}$

2. Materials and methods

The material for investigation was collected to glass containers as samples of mud coming from the volcano. The samples were spread at laboratory using following sieves: 2mm, 1mm, 0,5mm, 0,18mm. Each fraction was then dried and prepared for analysis.

Coarse fractions were tested using digital as well as polarizing light microscope. Mineral composition of fractions was determined after counting of 500 grains at each sample. Results were collected in tables and illustrated in the form of diagrams.

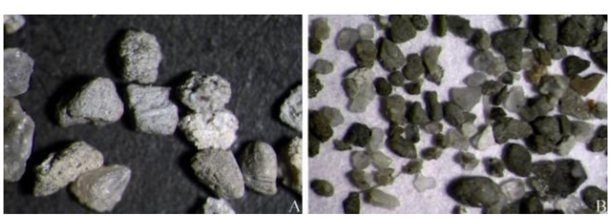


Fig. 8. Coarse grains separated from sample PMI. A–rounded fragments of rocks, B–fragments of rocks (dark grey) mixed with sharp grey and milky quartz . Digital microscope, magnification 20x.

Table 2 Separation of fractions in samples PMI and PMA.

	<0,18mm	0,5-0,18mm	1-0,5mm	1-2mm
PMI	99,33%	0,62%	0,04%	0,01%
PMA	99,63%	0,32%	0,05%	0%

Fine, clay fraction was observed under Jeol 540 SEM and examined using X-ray diffraction method.

3. Results and Discussion

3.1 Sample PMI

Natural sample represented clayey mud of grey color. Separation of fractions showed that sample was composed mostly of grains 0,5-0,18mm and 1.0-0,5mm (Tab. 2). Microscopic observation performed by digital microscope showed the presence of rock fragments as well as sharp grains of gray and milky quartz (Fig. 8, 9). However, it did not answer question concerning petrological character of rocks fragments, therefore further investigation was performed by use of polarizing light microscope.

Further investigation showed that fragments of rocks as well as quartz are main components of

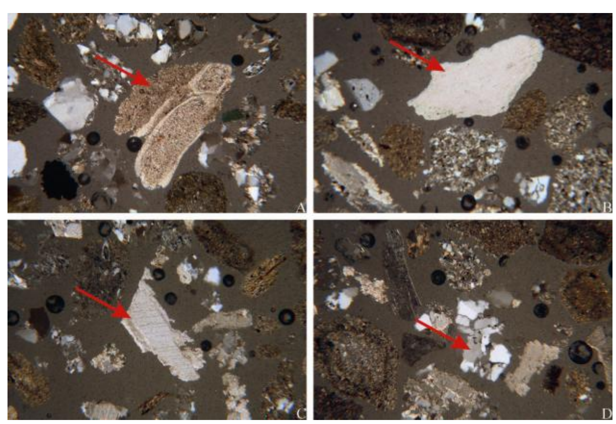


Fig. 9. Microscopic picture of coarse fractions separated from sample PMI. A–grain of limestone containing foraminifera, B–fragment of cortex bone, C-fragment of calcite monocrystal, D-fragments of fine sandstone and claystones. Polarizing light microscope, polaroides X, magnification 80 x.

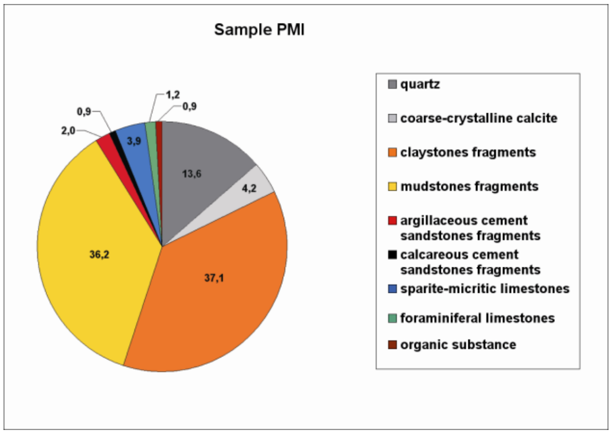


Fig. 10. The diagram showing mineral composition of fraction 0,5-0,18mm selected from sample PMI.

this fraction (Fig. 9, Tab. 3, Fig. 10).

Investigation of fine fractions performed using SEM microscope showed that they were composed of clay flakes mixed with fine quartz (Fig. 11). This identification was confirmed by X-ray pattern. X-ray examination of natural orientated sample showed the illite and mixed smectite-illite minerals as main clay components of sample (Fig. 12). On the other hand, detrital material was represented mainly by quartz, calcite and traces of feldspars. The value d_{hkl} = 7.6A confirms the presence of gypsum, however this mineral was present most probably in fraction < 0.18mm because in coarser fractions tested using polarizing light microscope gypsum was not identified.

The presence of mixed illite-smectite clay minerals was confirmed additionally by X-ray examination

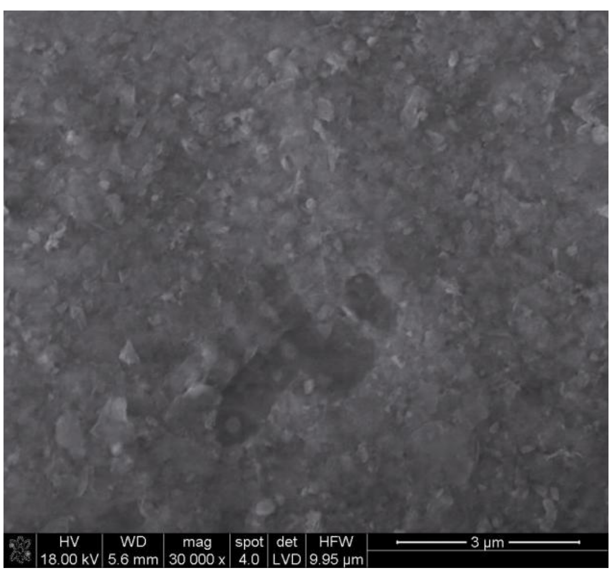


Fig. 11. Microscopic picture of fine fraction selected from sample PMI. One can see small flakes of clay minerals present together with fine grains of quartz. SEM. Magnification 30 000x.

of sample after glycole (Fig. 13) where two small peaks showing values d_{hkl} about 13.8 and 14.2A can be perceived.

Chemical analyses performed using ICP method showed that volcano waters are composed of mud mixed with salty waters. Moreover, chemistry of these waters collected from the two separate volcanoes were different (Tab. 4, 5). Differences concerned major as well as minor components of salty waters suggesting two various wags of water mineralization. Waters of sample PMI contained more Na whereas sample PMA contained more Ca. These differences suggest that PMI mud volcanoes were supplied by waters penetrating salt layers and waters from PMA volcanoes were connected with limestones ore rock containing higher amount of calcium. Waters from the PMA volcanoes contained additionally more Mg, Sr and K but the content of Br and J was at both waters similar confirming the connection of volcanoes waters with evaporate systems (Fig. 14).

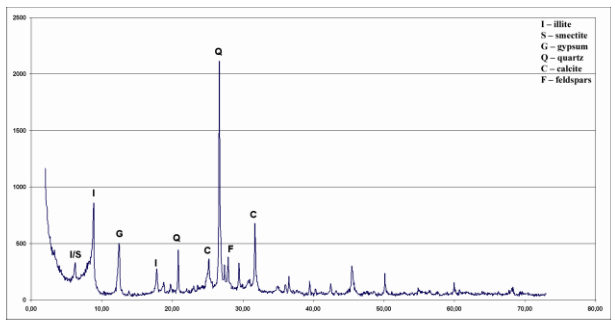


Fig. 12. X-ray pattern of fine clay fraction selected from sample PMI.

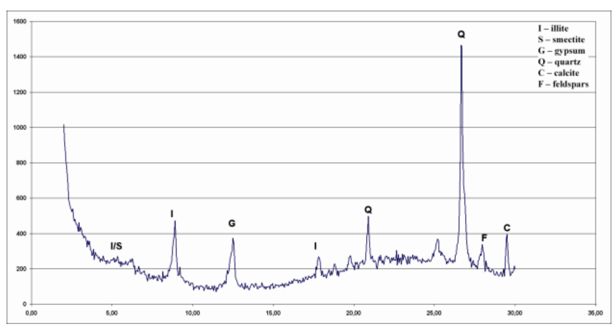


Fig. 13. X-ray examination of sample PMI after glycole.

3.2 Sample PMA

Sample represented soft, gray clay with admixture of fine mud fraction (Tab. 2). Investigation confirmed that tested sample did not contain grains bigger than 1mm. Finer material was of similar character as observed in sample PMI however, more quartz and less fragments of rocks could not be perceived (Fig. 15).

Table 3. Mineral composition of fraction 0,5-0,18mm selected from sample PMI and PMA.

		PMI	PMA
minerals			
	quartz	13,6	45,0
	coarse-crystalline calcite	4,2	1,7
clastic rocks fragments			
	claystones fragments	37,1	23,3
	mudstones fragments	36,2	19,4
	argillaceous cement sandstones fragments	2,0	3,8
	calcareous cement sandstones fragments	0,9	2,6
limestones fragments			
	sparite-micritic limestones	3,9	1,2
	foraminiferal limestones	1,2	1,8
evaporites fragments			
	fine-crystalline gypsum	0,0	0,5
igneous rocks fragments			
	rhyolite character effusive rock framents	0,0	0,3
organic substance	organic substance	0,9	0,4

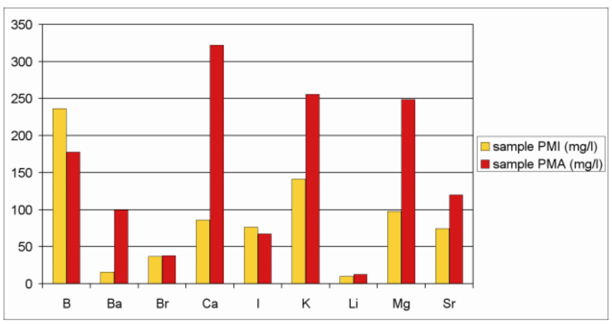


Fig. 14. Diagram showing content of main elements at tested waters from mud volcanoes.

A more detailed observation performed by polarizing light microscope confirmed quartz and rocks fragments as the main components in this fraction (Fig. 16, Tab. 3, Fig. 17).

X-ray pattern of natural sample showed a general mineral composition similar to composition of sample PMI, however, it contained slightly more clay minerals represented mostly by illite (Fig. 18, d_{hkl} = 10.1A). The content of other identified minerals such as quartz and feldspars was similar to a sample PMI, but it contained less carbonates represented by calcite (Fig. 18, d_{hkl} = 3,85A, 3.03A). Gypsum was present in this sample at fraction > 0.18mm and was identified under microscope observation. The amount of coarse grains was small (Tab. 3). This fact confirmed that gypsum was also present in fine fraction.

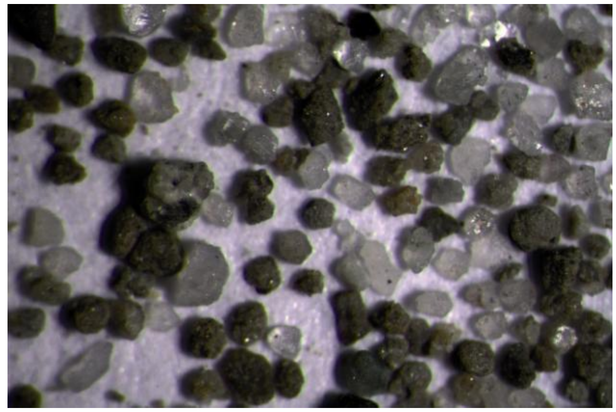


Fig. 15. Fraction 0,5-0,18 mm selected from sample PMA. Digital microscope, magnification 20x.

X-ray pattern of orientated natural (Fig. 18) and not orientated sample (Fig. 19) confirmed quartz and clay minerals to be the main component.

4. Conclusions

Examination showed that the mud volcanoes transports mostly mud composed of clay minerals represented by illite-smectite. Together with clay minerals one can determine quartz and rocks fragments, present at various proportions, in volcanoes mud. Salty waters transported by mud volcanoes are chemically differentiated too.

Obtained data i.e. results of chemical analyses confirm various sources of salty waters as well as their migration across various evaporites present below volcanoes.

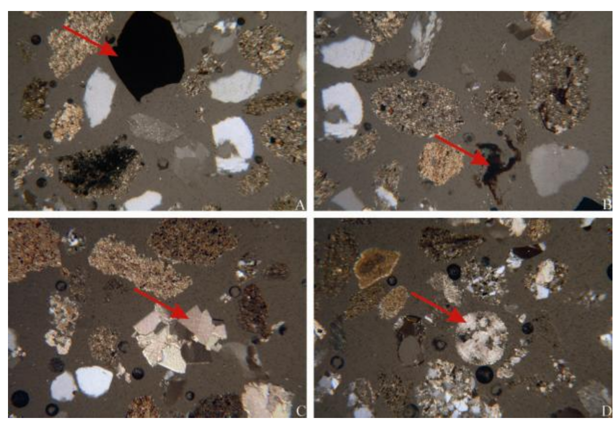


Fig. 16 Microscopic picture of coarse fractions separated from sample PMA. A-black fragment of organic matter (charcoal?), B-fragments of claystones and mudstones together with irregular fragment of organic matter, C-aggregates of calcite crystals grains of quartz and fragments of claystones, D-skeleton of foraminifera mineralized with calcite between grains of mudstones and claystones. Polarizing light microscope, polaroides X, magnification 80x.

Table 4 Chemical composition (mg/l) of waters from mud volcanoes.

	PMI	PMA		PMI	PMA
Ag	0.003139	0.002056	**Mn**	0.019799	0.051006
Al	0.112184	0.480066	**Mo**	0.060520	0.017069
As	0.071971	0.090101	**Na**	15430.000	17810.000
B	236.2961	178.0153	**Ni**	0.015888	0.016025
Ba	15.734322	99.995579	**P**	1.470154	0.894768
Be	0.000181	0.000271	**Pb**	0.004990	0.031456
Bi	0.000757	0.000682	**Rb**	0.145275	0.336015
Br	36.986726	37.823335	**Sb**	0.006419	0.002936
Ca	86.265110	322.38698	**Se**	0.148906	0.100473
Cd	0.000324	0.000898	**Si**	12.500321	10.206566
Co	0.002561	0.002570	**Sn**	0.001077	0.000754
Cr	0.270529	0.345542	**Sr**	74.236739	120.285076
Cs	0.000355	0.001520	**Te**	0.000640	0.001001
Cu	0.239583	0.285641	**Tl**	0.000381	0.000197
Fe	0.541477	1.864679	**U**	0.000283	0.000872
Ga	0.308273	1.265757	**V**	0.075059	0.092024
Hg	0.031424	0.022678	**W**	0.228601	0.000628
I	76.716075	67.336015	**Y**	0.000474	0.001355
K	141.148990	255.560988	**Zn**	0.073695	0.136326
Li	10.252115	12.687268	**Zr**	0.001215	0.000334
Mg	97.786107	248.445632			

Mineral composition of volcanoes mud as well as chemical composition of their salty waters suggest their good features for utilization. Because of this there is necessity to continue investigation of mud volcano region as potential area for balneology and recreation.

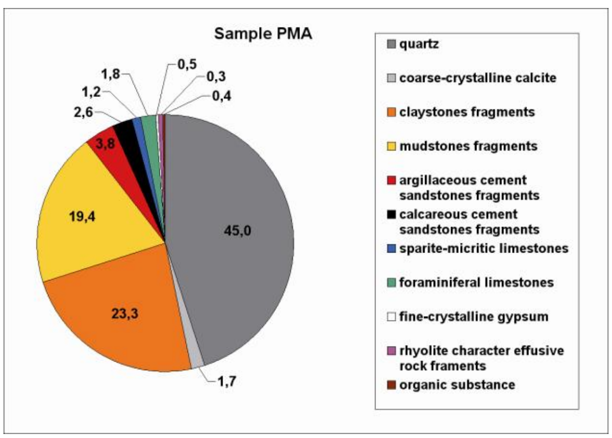


Fig. 17. The diagram showing mineral composition of fraction 0,5–018mm selected from sample PMA.

5. Current state of geoturism development

The observations made in July, 2009 clearly indicate that touristic infrastructure in the region of mud volcanoes is rather underdeveloped. The marking of access roads to the volcano areas is virtually non-existent. Occasional signposts, only in Romanian language, often force tourists to guess where to go. Although the way to Paclele Mici is relatively easy to decipher, it is difficult to get to Paclele Mari on the other hand. The roads to Beciu or Fierbatoni are not labeled at all. Reaching Beciu requires several hours marching, or possessing off-road vehicle as the road is a very low quality. However, getting to Fierbatoni seems almost impossible for an average tourist, as even the locals do not know the way.

Table 5 Anions containing in sample PMI and PMA.

	Cl (mg/l)	HCO_3 (mg/l)
PMI	25094,84	2249,314
PMA	32054,67	917,318

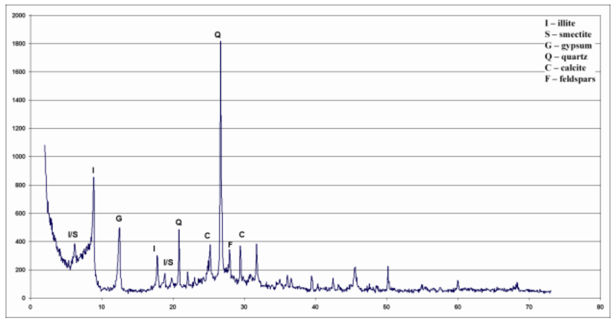


Fig. 18. X-ray pattern of fine clay fraction selected from sample PMA.

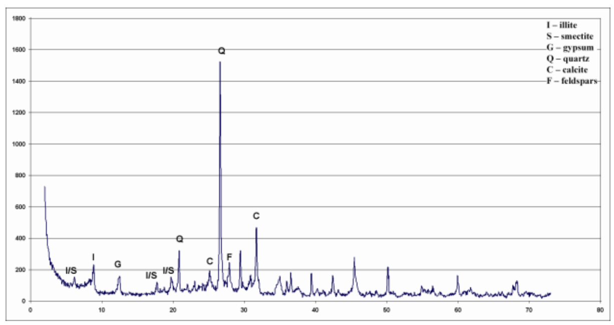


Fig. 19. X-ray pattern of not orientated sample PMA.

There is a guest house with restaurant nearby the reserve PMI, but the quality of rooms and bathrooms does not meet the Europeans standards, although the establishment is relatively new. Berca offers more possibilities of accommodation and catering.

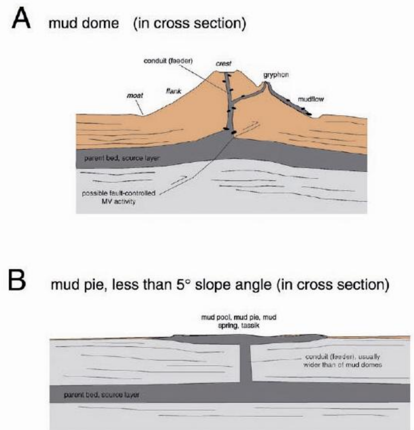
Tourists must pay to enter PMI and PMA reserves. PMI volcanoes are located next to access road, and there is also a small car park there. The only English source of information can be purchased in a form of a brochure, however the books about volcanoes and souvenirs from the region are available only in Romanian language. Right behind the entrance gate, there are two information boards, one concerns terms of use of the reserve, in the other there is a map of attractions in nearby localities. However, the problem arises here as well, as both boards are in Romanian language.

General information about mud volcanoes

Mud volcanoes are defined as geological features through which agrillaceous material is altered and transported from the Earth's interior and expelled onto its surface. The size of mud volcanoes ranges from a few centimeters to several meters of width, and from a few centimeters to 500-700 meters of height, whereas the biggest offshore mud volcano reach the diameters of 30 km and about 2 km of relative height (Kopf 2002).

Generally, mud volcanoes have the shape of cones or pies. The former, depending on the viscosity of the muddy substance, exhibit various inclinations from 35 - 40°, and sometimes are characterized by the presence of parasitic cones on the slopes. The latter, are characterized by slight inclination of slopes <5°, and become cylindrical or irregular in shape. Both forms may occur in active or fossil form (Kopf 2002).

The substance flowing out of mud volcanoes can be both watery, thus such outflows are constant and accompanied by characteristic bubling, however, at times they can be viscid, sticky and therefore, more spectacular eruptions of discarding fireballs can take place. Frequently, slight traces of oil accompany the discard.

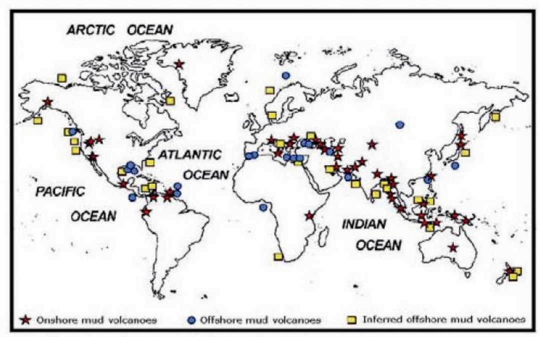


Significance of mud volcanism (Kopf, 2002)

Mud volcanoes in the world

There are about 700 mud volcanoes known in the world, and almost half of them can be found in Azerbaijan. The other ones were also discovered in Turkmenistan and in the south-Caspian region, in Australia, Taiwan, China, Pakistan and Iran. Only a few are found in Europe: in the south-west of Ukraine, in Southern Italy and Sicily, and in Romania. It is also worth noticing that mud volcanoes can form both onshore and offshore.

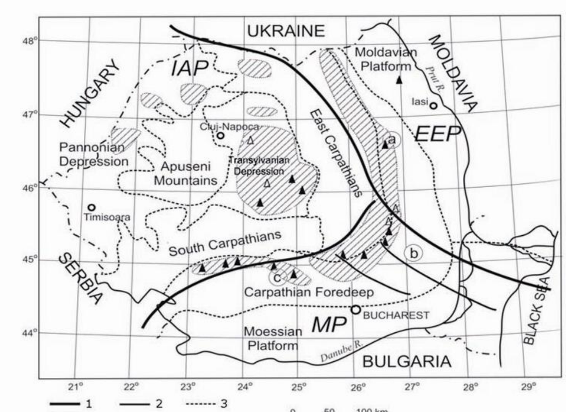
Mud volcanoes are commonly associated with compressional tectonics at convergent margins (Higgins and Saunders 1974; Barberet al. 1986; Kopf et al. 1998 cited in Kopf 2003). Their density shows a positive correlation with (1) thick, rapidly deposited sediments consisting of high clay mineral component (Yassir 1989 cited in Kopf 2003), (2) sediment overpressuring due to hydrocarbon formation (Hedberg 1974; Lavrushin et al. 1996 cited in Kopf 2003), (3) a structural association with tectonic shortening dehydration (Moore and Vrolijk 1992 cited in Kopf 2003) and/or earthquake activity (Sondhi 1947 cited in Kopf 2003), (4) fluid emission such as gas, brines, water from mineral dehydration (Moore and Vrolijk 1992 cited in Kopf 2003) and gas hydrate dissociation (Milkov 2000 cited in Kopf 2003), and (5) polymictic assemblages of the surrounding rock present in the ejected argillaceous matrix (Robertson and Scientific Party of ODP Leg 160 1996; Kopf et al. 1998 cited in Kopf 2003).



Worldwide distribution of mud volcanoes (modified from Milkov, 2003)

Mud volcanoes in Romania

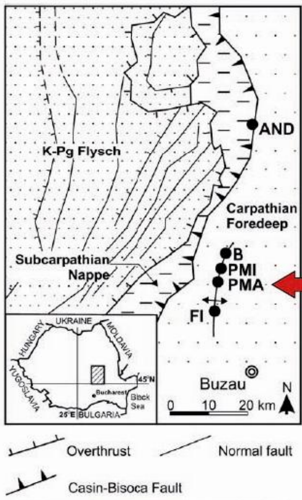
In Romania mud volcanoes are located in Carpathian Foredeep, Transylvanian Depression and Moesian Platform. The largest mud volcanoes in Romania are those located in the center of the Carpathian Foredeep, more precisely in the anticline structure called Berca-Arbanasi, of north-south orientation and 20 km long. Volcanoes are located there in four zones: Beciu, Paclele Mici (45°21'29.08" N, 26°42'44.47" E), Paclele Mari (45°20'22.17" N, 26°42'25.65" E) and Fierbatori, 20km North-West of Buzau. The distances, in straight line from specific zones, can be illustrated in the following way: Beciu-Paclele Mici - 3km, Paclele Mici – Paclele Mari – 2km; Paclele Mari – Fierbatori – 5km. Two regions: Paclele Mici and Paclele Mari received the status of geological reserve in 1924.



Geotectonic units in Romania and distribution of mud volcanoes and hydrocarbon seeps in Romania. 1 - limits between lithosperic plates (microplates); 2 - major faults; 3 - limits between main structural units; 4 - hydrocarbon seepage areas; 5 - mud volcanoes; 6 - Dry macroseeps; EEP - East European Plate; IAP - Intra-Alpine Microplate; MP – Moessian Microplate; a - Moldavian Basin; b - Focsani Basin; c - Getic Basin (modified from Baciu 2007).

Fig. 20. Information board proposition "General information about mud volcanoes" (Mrowczyk and Madeja, 2009).

Mud volcanoes in Paclele Mari region

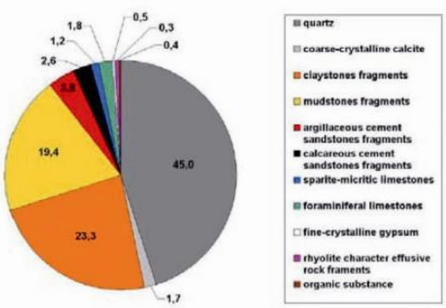


Sketch map of the geostructural setting of the study area. AND-Andreiasu, B–Beciu, PMI-Paclele Mici, PMA-Paclele Mari, FI-Fierbatori (modified from Etiope 2004).

YOU ARE HERE

Paclele Mari and Paclele Mici regions are located in the central part of anticline, where strike-slip fault intersects the axis of this anticline. Paclele Mari region is a plateau 1.8km long and 3km wide and 80m high. The surface of 1.62 km^2 is covered by products originating from Paclele Mari volcanic activity. The active volcanoes in Paclele Mari cover 0.22km^2 (Baciu 2007). The volcanoes have cone shapes, and are 10m high, some of them have parasitic cone shapes, too. Furthermore, muddy substance reaches the surface through pies of 3 to 10m in diameter (Baciu 2007). 62 holes in Paclele Mari expels 300 tons of methane to the atmosphere yearly. Methane comes out onto the surface also through pores in ground in the amounts 430 ton/year. The composition of gas emitted in PMA are: CH_4 (82,7%), N_2 (15,3%), CO_2 (2%) and sprinkling He (Etiope 2004).

Natural sample represented soft, gray clay with admixture of fine mud fraction: grains 0,5-0,18mm (99,63%) and 1.0-0,5mm (0,32%). Main components of fraction 0,5-0,18mm are quartz (45%), fragments of claystones (23,3%) and mudstones (19,4%). Volcanoes waters are composed of mud mixed with salty waters. Main elements at tested waters from mud volcanoes are: Ca, K, Mg, B, Sr,Ba, I, Br and Li. So great amount of Ca suggesting that waters from PMA volcanoes are connected with limestones ore rock containing higher amount of calcium.



The diagram showing mineral composition of fraction 0,5 - 0,18mm

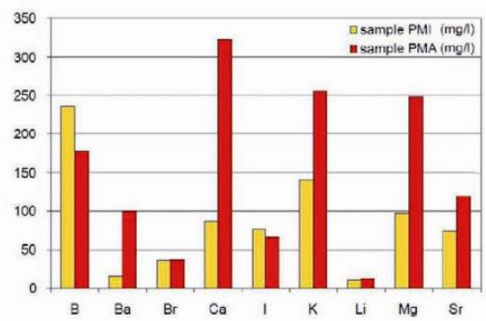
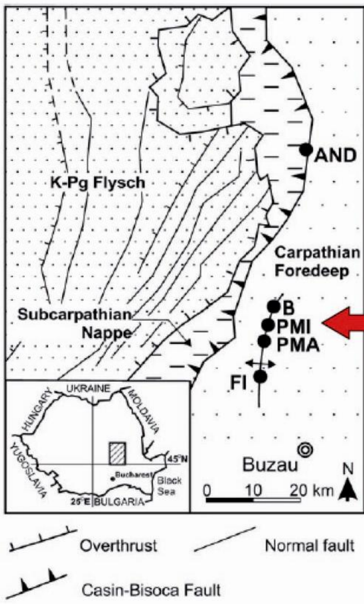


Diagram showing content of main elements at tested waters from mud volcanoes

Fig. 21. Information board proposition "Mud volcanoes in Paclele Mari region" (Mrowczyk and Madeja, 2009).

Mud volcanoes in Paclele Mici region

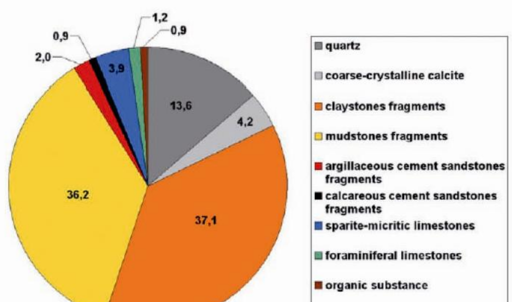


Sketch map of the geostructural setting of the study area. AND-Andreiasu, B–Beciu, PMI-Paclele Mici, PMA-Paclele Mari, FI-Fierbatori (modified from Etiope, 2004).

YOU ARE HERE

Paclele Mari and Paclele Mici regions are located in the central part of anticline, where strike-slip fault intersects the axis of this anticline. Paclele Mici region is a plateau 1.3km long, 1km wide, and 60m high. The surface of 0.62km^2 is covered by products originating from Paclele Mici volcanic activity. The active volcanoes in Paclele Mici cover 0.16km^2. The volcanoes have cone shapes, and are 10m high, some of them have parasitic cone shapes, too. Furthermore, muddy substance reaches the surface through pies of 3 to 10m in diameter (Baciu 2007). 65 holes in Paclele Mici expels 255 tons of methane to the atmosphere yearly. Methane comes out onto the surface also through pores in ground in the amounts 128 ton/year. The composition of gas emitted in PMA are: CH_4 (94,9%), N_2 (2,8%), CO_2 (2,4%) and sprinkling He (Etiope 2004).

Natural sample represented clayey mud of grey color, composed mostly of grains in fractions 0,5-0,18mm (99,33%) and 1.0- 0,5mm (0,62%). Main components of fraction 0,5-0,18mm are fragments of claystones (37,1%) and mudstones (36,2%) as well as quartz (13,6%). Volcanoes waters are composed of mud mixed with salty waters. Main elements at tested waters from mud volcanoes are: Na, B, K, Mg, Ca, Sr, Br, Ba, Li. So great amount of Na suggesting that PMI mud volcanoes are supplied by waters penetrating salt layers.



The diagram showing mineral composition of fraction 0,5-0,18mm

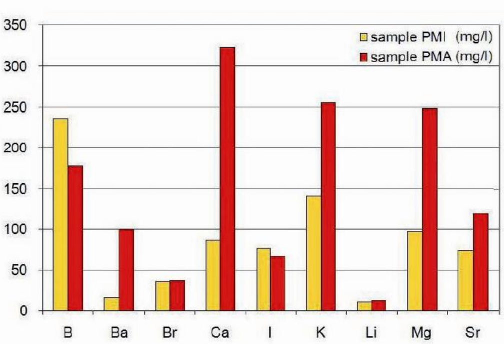


Diagram showing content of main elements at tested waters from mud volcanoes

Fig. 22. Information board proposition "Mud volcanoes in Paclele Mici region" (Mrowczyk and Madeja, 2009).

It is advisable to ask for access road to PMA while visiting PMI, as the only existing sign can be missed easily, which is confirmed by a small number of visitors there. After reaching a small booth, located on a peripheral road, it is necessary to take a 20-minute walk still along an unmarked path to get to the volcanoes. Nevertheless, things are going to be changed in a near future, as some part of the path has already been lined with stones which makes it easier to move around. There are neither information boards, nor souvenirs in PMI.

Geotourism infrastructure in the discussed region is almost non-existent. It is a great pity as this type and class of object that belongs to major geotourism attractions in Romania, and whose values have been appreciated for 86 years, should possess such infrastructure. According to the definition a geotourism object can or/and may become an object of touristic interest if well promoted and easily accessed (Słomka and Kicińska-Świderska, 2004). Undoubtedly, PMA and PMI volcanoes fit the definition. Development of geotourism infrastructure in MV region would certainly broaden visitors' knowledge about the earth and processes present in its nature. More and more often tourists ask themselves when, why and how such geological object was created, thus an appropriate infrastructure even in the form of information boards and folders would provide them with the answers and thereby elevate the importance of the object.

In the discussed region, it would be enough to put up one or two information boards upon entrance to the reserve, providing a comprehensive geo-information for an average tourist, without causing any damage to the landscape. To achieve as smallest interference into the landscape as possible, the boards should be two-sided and contain the same information in both languages (Romanian and English), so that every tourist has an equal opportunity to know their content. Well-selected information, photos and drawings would enrich aesthetic experience obtained from the visit to this extraordinary place.

Although there are many publications about mud volcanoes, they are not available to public. Therefore, the next step of development in PMI and PMA zones should concern the creation of a folder, including geological information about mechanisms of formation and activity of mud volcanoes, their correlation with occurrence of earthquakes, and some pieces of information about regional geology. Furthermore, it should contain data concerning: hydrocarbon migration, diversified mineral composition of mud from PMI and PMA, as well as water chemistry. The following figures show examples of information boards (Fig. 20, 21, 22).

Establishing an appropriate geotourism infrastructure in PMI and PMA mud volcanoes areas, enabling tourists to know the differences between the two presented herein regions would not only enrich the aesthetic impressions remaining after visiting these fascinating places, but also would enhance the educational offer of the reserves.

Acknowledgments

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