Monitoring the resonant properties of the magmatic structures of Elbrus volcano based on observation of lithospheric deformations by the Baksan laser interferometer-strainmeter

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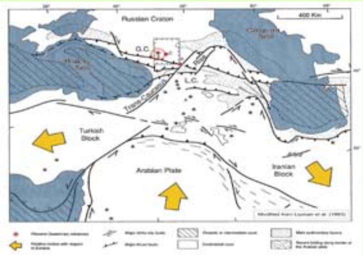

Fig.1. Geodynamic model of Caucasian part of Meditiranian belt (Sobisecich, 2009)

1. Geodynamic characteristic of the region

The Northern Caucasus is one of the most geodynamically active regions of Russia. It is a part of the complex Alpine-Himalaya tectonic belt, associated with the interactions of huge tectonic formations: the Eurasian, Arabian and African lithospheric plates. This collision zone is characterized by higher crust fragmentation, fold tectonics, slips, etc (**Fig.1**).

The Elbrus volcanic center is located on the northern slope of the main ridge of the Greater Caucasus. It includes Mount Elbrus, a double-peaked, polygenetic, strato-volcano, and a number of minor volcanic centers that are con-centrated on its western slope. Elbrus is classified as an active volcano with clearly dated historical eruptions in the Holocene. According to present understandings, the Elbrus volcano falls into the category of the so-called dormant volcanoes that become reactivated. It is a typical volcano of a continental type. (**Fig.2**).

Fig. 2. The Elbrus volcano is the highest point of Europe. The altitude of the west top is 5643 m, the altitude of the east top is 5620 m.

2. Baksan laser interferometer-strainmeter

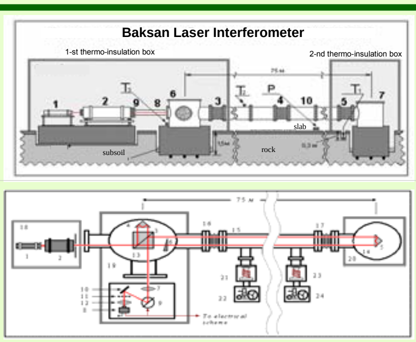

Fig. 3. 1. He-Ne laser. 2. Telescopic system. 3. Beam-splitter. 4,5. Corner reflectors. 6.Optical vedge. 8. Photodiode. 9. Galvanometer. 7,12. Focusing lenses. 10. Turn mirror. 11. Raster. 13,14. Vacuum chamber. 15. Vacuum tubes. 16,17. Bellows. 18,19,20. Concrete foundations. 21,22,23,24. Vacuum pumps.

The SAI's Baksan observatory is located in the Baksan gorge 18 km apart from Mount Elbrus. The interferometer is mounted at a level of 650 m and at a depth of 400 m inside the main gallery of the Baksan Neutrino Observatory, Institute of Nuclear Research, Russia Academy of Sciences.

The Baksan laser interferometer is a Michelson two-beam unequal-arm interferometer operating in the regime of separated beams. The length of its larger (measuring) arm is $L = 75$ m. The instrumental resolution of the interferomter is 2.3×10^{-13} for crustal strain measurement. The design and technical layout of the Baksan interferometer are described in detail in [Milyukov et al., 2005]. (**Fig. 3**).

3.Resonant method for monitoring the state of magamtic structures

The idea of the method (Milyukov, 2006):
Upon the incidence of a broadband powerful seismic signal (**Fig. 4**), magmatic structures, being a resonator, generate secondary seismic waves, having a set of resonant modes and containing information about physical and mechanical properties of structural inhomogeneities.

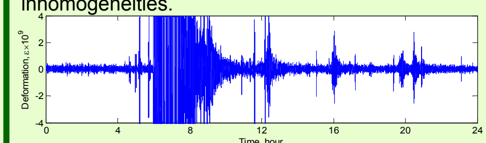

Fig. 4. Registration of Japan EQ (11.03. 2011, M 9.0) by Baksan laser interferometer.

These resonant modes are determined by the geometrical parameters and elastic properties of the magma chamber as well as by magma properties. The frequency of the lowest (fundamental) mode is determined by the largest size of the resonator; the Q-factor is determined by the acoustic properties of magmatic fluids.

4. Data analysis

We analysed the teleseismic signals excited by a large number of global earthquakes (more than 350) and recorded by the Baksan laser interferometer-strainmeter over a period of several years (2000–2011). According to theoretical assumptions, the parameters of resonant modes in the frequency band of 0.006–0.03 Hz (30 -150 s) were estimated and analysed. Parts of modes are identified with high-frequency modes of free oscillations of the Earth (FOE); others can be identified with resonant modes of regional inhomogeneous structures. The revealed resonant modes (period estimations) are presented in bar graph (**Fig. 5a**).

The estimated values of the Q-factors for revealed modes are 200–300. Meanwhile, the Q-factors of the rock matrix are characterised by lower values of 100–150. The Q-factors of the revealed regional modes indicate that these modes relate to structures with liquid and gas components. Therefore, there is a high probability that these resonant modes are generated by the magmatic structures of the Elbrus volcano. The parameters of regional resonant modes are summarized in **Table**.

Regional modes	1	2	3	4	5	6	7	8	9	10
Period, s	55.5	59.6	62.1	64.3	64.5	67.9	86.4	101.5	129.1	132.5
STD, s	0.06	0.06	0.04	0.06	0.04	0.05	0.4	0.2	0.2	0.4
Repeatability	0.86	0.71	1.0	1.0	0.86	1.0	0.71	0.57	0.57	0.57
Q-factor	292	300	275	248	277	255	100	100	100	100
STD	17	14	14	40	16	18	50	45	63	48

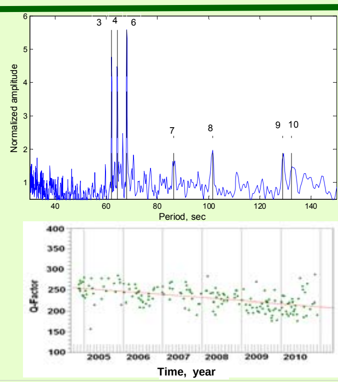

Fig. 5. (a)The spectrum of regional resonant modes, obtained by averaging over an ensemble of normalized spectra, The numbers are indicated the modes pointed in the table.

(b) Changing Q-factor of the resonant modes over time

A small variation of the Q-factor over time was discovered. The value of the Q-factor is slightly decreased. This effect can indicate a changing magma state, particularly a change in the pressure or gas volume fraction (**Fig. 5b**).

5. Acoustic properties of fluids and estimation of parameters of the Elbrus magmatic chamber

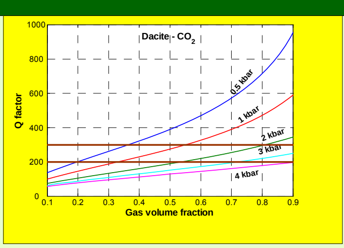

Fig. 6. Modelling Q –factor values for pressure of 0.5-4 kbar versus gas-volume fraction, and experimental estimation of Q-factors of regional modes (solid thick lines).

Modelling the acoustic properties of Elbrus volcanic fluids and estimation of the parameters of the magmatic chamber has been carried out in the frame of the "fluid-filled crack model" (Kumagai, 2000), with the assumptions that the magmatic chamber is filled with magma consisting of dacite with carbon dioxide (CO_2) dissolved in it and that it is in a granite rock matrix at a temperature of the order 1200 ^{o}C. According to this model, the dependence of the Q-factor on a gas component of a magmatic fluid for various pressure values is shown in **Fig.6**.

6. Conclusion

•The new method for the control of dynamic processes and the state of the volcanic magmatic structures is based on an estimation of resonant parameters of the free oscillations of these structures exited upon incidence of broadband seismic signals from teleseismic earthquakes.

•The shallow magmatic chamber with the characteristic size about 9 km, 1-7 km settling down on depths is revealed in the structure of the Elbrus volcanic center. Acoustic properties of magmatic fluids of the magmatic chamber are defined by the rich gas components, the order of 30-70 %, i.e. magma is gas-liquid foam with density 1500-2000 kg/m3. The sound speed of such magma is 150-250 km/s.

•Revealed dynamics of pressure increasing in the magmatic chamber can testify to receipt of new portions of hot lavas from the deep sources.