



A paleomagnetic and paleointensity study on Pleistocene and Pliocene basaltic flows from the Djavakheti Highland (Southern Georgia, Caucasus)

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ABSTRACT

New paleomagnetic, rock-magnetic and paleointensity results obtained on samples from 23 basaltic lava flows belonging to four different flow sequences (Mashavera, Kvemo Orozmani, Zemo Karabulaki and Diliska) of Pleistocene and Pliocene age from the eastern Djavakheti Highland, in southern Georgia, are presented. Radiometric dating of these sequences yields ages between 1.8 and 2.18 Ma for Mashavera, 2.07 and 2.58 Ma for Zemo-Karabulaki and 2.12 and 3.27 for Diliska. No radiometric ages are available for the Kvemo Orozmani sequence, which is considered to be coeval to the Mashavera sequence.

Rock-magnetic experiments including measurement of thermomagnetic, hysteresis and IRM-acquisition curves suggest low-Ti titanomagnetite as main carrier of remanence, although a lower Curie-temperature component was also observed in several cases. Reversible and non-reversible curves were recorded in thermomagnetic experiments.

Paleomagnetic analysis generally indicated the presence of a single component (mainly in the Mashavera sequence), but also two more or less superimposed components in some other cases. In 21 sites a characteristic component could be determined and all except one were characterised by normal-polarity directions. Flows from the Mashavera sequence had a rather steep inclination (73.1°). Nevertheless, a mean paleomagnetic direction of all four sequences is obtained ($D = 8.5^\circ$, $I = 60.8^\circ$, $N = 4$, $\alpha_{95} = 11.7^\circ$, $k = 62.7$) which agrees with the Plio–Quaternary directions obtained in previous studies in Georgia. The paleomagnetic pole obtained (latitude $\phi = 82.1^\circ$, longitude $\lambda = 118.2^\circ$, $A_{95} = 8.0^\circ$, $k = 240.7$) agrees with the pole values of both the 0 Ma and the 5 Ma windows of the synthetic Eurasian polar wander path from Besse and Courtillot (2002). In order to analyse the behaviour of secular variation, the scatter of paleosecular variation of virtual geomagnetic poles of both the Mashavera flow and all 18 studied flows of Pleistocene age was calculated. It could be observed that both data-sets seem to fit well the expected scatter at latitude 41°N.

Paleointensity experiments were carried out with the Coe modification of the Thellier method. Twenty-five out of 84 samples (30%) provided reliable paleointensity results. These successful results were mainly obtained in the Mashavera sequence. Most flows yielded paleointensity results in the 30–45 μT range, in accordance with expected Pliocene to present day intensities. Two flows, however, located near the top of the Mashavera sequence yield high paleointensity values around 60 μT . Anomalous paleointensity results in the upper-lying Mashavera flows together with the steep inclinations observed in that sequence, could perhaps signal the near onset of the Olduvai–Matuyama reversal.

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1. Introduction

The Earth's magnetic field is generated by geodynamo processes in the Earth's liquid outer core and is not static, as its direction and strength vary with time. Knowledge of characteristics of the an-

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cient geomagnetic field can provide important information in order to better understand and constrain the processes related to the evolution of the Earth's deep interior. Sedimentary rocks are able to provide continuous magnetisation records, thus supplying an uninterrupted register of geomagnetic field variations, but the specific characteristics of remanent magnetisation of sedimentary rocks – depositional (DRM) or postdepositional (pDRM) magnetisation – can hamper obtaining a faithful field variation record. In

addition, sedimentary rocks are only able to provide relative paleointensity determinations. Volcanic rocks, on the other hand, allow a reliable and instantaneous record of the Earth's magnetic field by means of the acquisition of thermoremanent magnetisation (TRM). Moreover, they are able to supply absolute paleointensity data. Being tied to volcanic eruptions, the magnetisation record provided by volcanic rocks, however, is discontinuous. Nevertheless, because volcanic rocks are in principle able to provide a more faithful though instantaneous image of the Earth's magnetic field, the study of lava flow sequences emitted in a relatively short period of time is of major interest.

In many paleomagnetic studies, only the directional information provided by declination and inclination of the remanence vector is needed. The need for a better knowledge of the variations of the Earth's magnetic field, however, also demands the determination of the strength of the paleofield vector. Unfortunately, the number of reliable paleointensity data available is still limited. A compilation of paleointensity results from the paleointensity database (Perrin and Schnepf, 2004) shows that available data are still scarce and unevenly distributed: Over a thousand data per Myr for the first million years, 48 determinations per Myr in the 1–20 Ma interval, about 3 determinations per Myr for the 20–400 Ma interval and much less than 0.04 determination per Myr for older time periods. This is related to the fact that paleointensity determinations are experimentally much more difficult than estimations of the direction of the paleofield vector, and the failure rate of these experiments is often large. In addition, the dispersion observed in paleointensity results is much higher than in directional results, often due to the fact that incorrect determinations are considered to reflect a correct paleointensity value (e.g., Calvo et al., 2002).

Despite its unquestionable geological and geophysical interest, reliable paleomagnetic data from the Caucasus are still sparse if compared to other regions of the Alpine fold belt (Bazhenov and Burtman, 2002). Although this region has been the subject of numerous paleomagnetic studies, many of them dating back several decades, methods employed in those studies often do not fulfil the minimum reliability and quality criteria required for present-day paleomagnetic results, as they include, for instance, results based on non-demagnetised samples. In addition, most of those results have only been published in databases (e.g., Khramov, 1984) and in Russian. For these reasons, recent and trustworthy paleomagnetic results from the Caucasus are still limited (Bazhenov et al., 1996; Camps et al., 1996; Gogitchaichvili et al., 1997, 2009; Gogitchaishvili et al., 2000, 2001; Gogitchaichvili and Parès, 2000; Bazhenov and Burtman, 2002; Calvo-Rathert et al., 2008; Shcherbakova et al., 2009).

Because of these reasons, paleomagnetic and paleointensity studies carried out in that region can be of considerable paleomagnetic interest. In this study we present new paleomagnetic and paleointensity results from the Caucasus area, obtained from samples from 23 lava flows belonging to four different volcanic flow sequences from the eastern Dzhavakheti Highland in southern Georgia (Fig. 1).

2. Geologic setting and sampling

The mountain ranges of the Caucasus constitute a segment of the Alpine fold belt. Their formation is related to the convergence between the Arabian and Eurasian plates, which results in compression of the region located between the northern edge of the Arabian block and the Eurasian shelf, with lateral ejection of the Anatolian block westward and the Iranian block eastward (e.g., Jackson and McKenzie, 1984; Philip et al., 1989; Rebaï et al., 1993). The Caucasian region is characterised by the complexity of its active tectonics, showing both N-S compressive (E-W thrusts

and folds) and E-W extensional (N-S normal faults and dykes) structures (Rebaï et al., 1993). Another main characteristic of the Caucasus is the continuous volcanic activity, at least from the Jurassic until present (e.g., Rebaï et al., 1993).

The Neogene-Quaternary magmatism in the Caucasus is also associated with the collision between the Eurasian and Arabian plates (Koronovskii and Demina, 1999) and started in the middle Miocene, lasting until the Holocene, with the last volcanic eruptions taking place in historical times (e.g., Aydar et al., 2003). Milanovskii and Koronovskii (1973) distinguish three stages in the evolution of late magmatism in the Caucasus: (1) late Miocene to early Pliocene, (2) middle Pliocene to Pleistocene, and (3) Quaternary. It should be borne in mind that the International Union of Geological Sciences has confirmed in 2009 the change of the start date of the Pleistocene epoch to 2.588 Ma BP (Gibbard and Head, 2009). Thus the lower boundary of the Pleistocene now coincides with the base of the Matuyama chron.

The present study was carried out in the Dzhavakheti Highland, one of the largest neovolcanic areas of the Lesser Caucasus (Fig. 1). The basement of the Dzhavakheti Highland is composed of Cretaceous and Paleogene volcanogenic sedimentary rocks, which are exposed in many erosion windows. Throughout a greater part of the region, basement rocks are overlain by the Neogene-Quaternary sequence of volcanic rocks, which can have thicknesses of hundreds of metres. Volcanic rocks most widespread in the Dzhavakheti Highland erupted during the middle Pliocene to Pleistocene stage of the late Cenozoic magmatism, and its composition varied from subalkaline basalts of mantle origin to rhyolites of predominantly crustal genesis (Lebedev et al., 2008a). Several radiometric geochronological dates have been published for these lavas, some of them in connection with the discovery of the paleoanthropologic site of Dmanisi (Maisuradze et al., 1991; Schmincke and van den Bogaard, 1995; Camps et al., 1996; Gabunia et al., 2000; Lebedev et al., 2007, 2008a,b). Middle to Pliocene magmatic activity in the Dzhavakheti Highland developed nearly without any important breaks during a period of approximately 2 Myr, from 3.75 to 1.75–1.55 Ma ago (Lebedev et al., 2008a,b).

In the present study, results of paleomagnetic, rock-magnetic and paleointensity experiments carried out on basaltic lava flows of Pleistocene and Pliocene age from the eastern Dzhavakheti Highland, in southern Georgia, are presented. Samples were taken in 2005 from 23 lava flows belonging to four different sequences of volcanic flows (Fig. 1): Mashavera (11 flows), Kvemo Orozmani (4 flows), Zemo Karabulaki (3 flows), and Diliska (5 flows). A portable gasoline-powered core drill was used for sampling, and sample orientation was performed with both a magnetic and a sun compass. Declination anomalies ranged within a few degrees about the expected declination anomaly (5–6°E in 2005), even though in a few cores somewhat larger anomalies were observed. No bedding correction had to be applied. Usually 7–10 cores were sampled per site, although in a few cases some more cores (up to 16 in DM1) were taken.

3. Studied flow sequences

Eleven basaltic flows were sampled in the Mashavera sequence, which is located below the Dmanisi paleoanthropologic site (Fig. 1). Seven of these were sampled in the 80–150 m deep Mashavera gorge, and 4 near the Pinezauri river. The flows have the following order from bottom to top: DM8, DM9, DM10, DM11, DM18, DM17, DM16, DM15, DM14, DM13 and DM12. Their labels reflect the order in which samples were taken in the field. Several K/Ar and ⁴⁰Ar/³⁹Ar ages are available for the upper flow of this sequence (DM12), as it directly underlies the Dmanisi site: 1.8 ± 0.1 Ma (Maisuradze et al., 1991), 1.95 ± 0.22 Ma (Schmincke and van den

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