ISSN 1069-3513, Izvestiya, Physics of the Solid Earth, 2017, Vol. 53, No. 5, pp. 645–657. © Pleiades Publishing, Ltd., 2017.
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Experimental and Numerical Simulation of the Acquisition of Chemical Remanent Magnetization and the Thellier Procedure

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Received October 17, 2016

Abstract—The results of the Thellier–Coe experiments on paleointensity determination on the samples which contain chemical remanent magnetization (CRM) created by thermal annealing of titanomagnetites are reported. The results of the experiments are compared with the theoretical notions. For this purpose, Monte Carlo simulation of the process of CRM acquisition in the system of single-domain interacting particles was carried out; the paleointensity determination method based on the Thellier–Coe procedure was modeled; and the degree of paleointensity underestimation was quantitatively estimated based on the experimental data and on the numerical results. Both the experimental investigations and computer modeling suggest the following main conclusion: all the Arai–Nagata diagrams for CRM in the high-temperature area (in some cases up to the Curie temperature T_c) contain a relatively long quasi-linear interval on which it is possible to estimate the slope coefficient k and, therefore, the paleointensity. Hence, if chemical magnetization (or remagnetization) took place in the course of the magnetomineralogical transformations of titanomagnetite-bearing igneous rocks during long-lasting cooling or during repeated heatings, it can lead to incorrect results in determining the intensity of the geomagnetic field in the geological past.

DOI: 10.1134/S1069351317040085

INTRODUCTION

The problems of paleomagnetism are solved by the interpretation of the information about the characteristics of the geomagnetic field recorded in ancient rocks, which is only possible subject to the preservation of the primary magnetization of the studied rock samples. Besides the primary origin and good preservation of the natural remanent magnetization (NRM), for the purpose of determining paleointensity of volcanics, it is also required to prove that NRM is thermoremanent (TRM). At the same time, it is known that stable magnetization of a significant magnitude can also be created due to the chemical transformations of magnetic minerals in high temperatures. Following Draeger et al. (2006), the magnetization that develops under the lengthy treatment of a sample at a high temperature T_{CRM} is referred to as chemical remanent magnetization (CRM). However, the rocks can also acquire a different type of chemical magnetization—the so-called thermochemical remanent magnetization (TCRM), which is understood as the magnetization that develops under chemical transformations during the primary cooling of the rock (Geissman and Van der Voo, 1980) from its Curie temperature T_c. The influence of CRM and TCRM on the results of paleointensity determination (B_{anc}) is still unclear. In (Smirnov and Tarduno, 2005; Draeger et al., 2006) the authors hypothesized that TRM can have similar temperature stability with TCRM and CRM; i.e., they have close spectra of the blocking temperature (T_b). Hence, they will be barely distinguishable from each other by the Thellier or Wilson–Burakov experiments, which will eventually yield misleading B_{anc} determinations. Validating or refuting this hypothesis is critically important for assessing the reliability of the data of the World Paleointensity Database (WDB). This requires further research both in the field of experimental investigations and in the theory and numerical modeling of CRM and TCRM.

According to the existing theoretical models, TCRM and CRM can be created due to the growth of the volume of fine superparamagnetic (SPM) grains when under thermal treatment at a certain temperature T and in the presence of the external magnetic field **B** their volume increases to the blocking volume v_b (Kobayashi, 1962). Although this scenario is fairly common, it has been poorly studied both in the experiments and theoretically. The existing works in this field cite the inconsistent data about the similarity of the thermal stability of TRM and TCRM (Gendler et al., 2005, Drager et al., 2006). In the present work, we describe the results of the experiments on determining "paleointensity" B_{anc} by the Thellier–Coe procedure on the samples containing CRM which was