Earth and Planetary Science Letters 430 (2015) 54–65

Contents lists available at ScienceDirect

Earth and Planetary Science Letters

www.elsevier.com/locate/epsl

Global equivalent magnetization of the oceanic lithosphere

J. Dyment[a,*], Y. Choi[a], M. Hamoudi[b,1,2], V. Lesur[c,1], E. Thebault[d,3]

[a] Institut de Physique du Globe de Paris, CNRS & Sorbonne Paris Cité, Paris, France
[b] Université des Sciences et de la Technologie Houari Boumediene, Alger, Algérie
[c] GeoForschungsZentrum, Helmholtz-Zentrum, Potsdam, Germany
[d] Laboratoire de Planétologie et Géodynamique, UMR-CNRS 6112, Nantes, France

ARTICLE INFO

Article history:
Received 28 May 2015
Accepted 3 August 2015
Available online 24 August 2015
Editor: B. Buffett

Keywords:
marine magnetic anomalies
magnetization
oceanic lithosphere

ABSTRACT

As a by-product of the construction of a new World Digital Magnetic Anomaly Map over oceanic areas, we use an original approach based on the global forward modeling of seafloor spreading magnetic anomalies and their comparison to the available marine magnetic data to derive the first map of the equivalent magnetization over the World's ocean. This map reveals consistent patterns related to the age of the oceanic lithosphere, the spreading rate at which it was formed, and the presence of mantle thermal anomalies which affects seafloor spreading and the resulting lithosphere. As for the age, the equivalent magnetization decreases significantly during the first 10–15 Myr after its formation, probably due to the alteration of crustal magnetic minerals under pervasive hydrothermal alteration, then increases regularly between 20 and 70 Ma, reflecting variations in the field strength or source effects such as the acquisition of a secondary magnetization. As for the spreading rate, the equivalent magnetization is twice as strong in areas formed at fast rate than in those formed at slow rate, with a threshold at ~40 km/Myr, in agreement with an independent global analysis of the amplitude of Anomaly 25. This result, combined with those from the study of the anomalous skewness of marine magnetic anomalies, allows building a unified model for the magnetic structure of normal oceanic lithosphere as a function of spreading rate. Finally, specific areas affected by thermal mantle anomalies at the time of their formation exhibit peculiar equivalent magnetization signatures, such as the cold Australian–Antarctic Discordance, marked by a lower magnetization, and several hotspots, marked by a high magnetization.

1. Introduction

Marine magnetic anomalies have been mapped in all oceanic basins to determine their age, structure and evolution in the framework of plate tectonics (e.g., Vine and Matthews, 1963; Dyment, 1993, 1998; among many others). In such studies, the magnetic anomalies are used to access geomagnetic polarity reversal sequences recorded by the magmatic oceanic crust in order to date the seafloor by comparison to a Geomagnetic Polarity Time Scale (GPTS; e.g., Cande and Kent, 1995; Ogg, 2012). However, the marine magnetic anomalies represent a geophysical signal whose phase (Cande, 1976, 1978; Cande and Kent, 1976; Petronotis et al., 1992; Roest et al., 1992; Dyment et al., 1994; Koivisto et al., 2011) and amplitude (Irving, 1970; Vogt and Johnson, 1973; Vogt, 1979; Geiss et al., 1989; Sayanagi and Tamaki, 1992) provide useful geological information. The magnetization – direction and amplitude – is indeed the physical property that relates to geological processes, and is therefore the parameter to determine.

Many local or regional studies have inverted marine magnetic anomalies to equivalent magnetization on profiles (Parker and Huestis, 1974; Wittpenn et al., 1989; Ravilly et al., 1998) or grids (Macdonald et al., 1980; Carbotte and Macdonald, 1992; Sayanagi and Tamaki, 1992, among many others). However, different hypotheses (which are not always explicitly stated) on the thickness of the magnetic layer, the way the reduction to the pole is applied (in phase only or in amplitude as well), or the band-pass filter applied to warrant the convergence of the Parker and Huestis (1974) algorithm, make the resulting equivalent magnetization profiles or maps difficult to compare among the different study areas.

Moreover, the Parker and Huestis (1974) technique results in the polarity being part of the resulting equivalent magnetization, i.e. seafloor formed during normal or reverse geomagnetic polarity

* Corresponding author.
E-mail address: jdy@ipgp.fr (J. Dyment).
[1] Also at Institut de Physique du Globe, Paris, France.
[2] Also at GeoForschungsZentrum, Potsdam, Germany.
[3] Formerly at Institut de Physique du Globe, Paris, France.

http://dx.doi.org/10.1016/j.epsl.2015.08.002

displays a positive or negative equivalent magnetization. As a consequence, the areas where a reversal is recorded show a weak equivalent magnetization that may not be representative of the physical properties of the oceanic crust but, instead, reflect the alternation of polarity. It would be preferable to obtain an unsigned value of the equivalent magnetization that does not take into account this alternation but only the rock magnetic properties.

So far there has been no attempt to obtain a global equivalent magnetization map of the oceanic lithosphere from marine magnetics. Attempts to do so from satellite magnetic data have only given access to the long wavelengths associated with the Cretaceous Quiet Zones (CQZs) and the main oceanic plateaus. Whereas the first efforts considered the magnetization to be parallel to the present geomagnetic field (Cohen and Achache, 1994), later efforts adopted magnetization vectors parallel to the paleomagnetic field, taking into account plate motion and true polar wander (Dyment and Arkani-Hamed, 1998a; Hemant and Maus, 2005; Masterton et al., 2012). Dyment and Arkani-Hamed (1998a) estimated the Thermo-Remanent Magnetization (TRM) of the layers constituting the oceanic lithosphere by comparing the amplitudes of satellite anomalies with those of modeled anomalies. The relative contribution of each layer was constrained by their results on the skewness of sea-surface magnetic anomalies (Dyment et al., 1994; Dyment and Arkani-Hamed, 1995). Conversely, Hemant and Maus (2005) and Masterton et al. (2012) adopt a different approach in adjusting the Chemical Remanent Magnetization (CRM) acquisition model of Raymond and LaBrecque (1987) to fit the observed satellite anomalies over the CQZs. However, the CRM model is inadequate, because the acquisition of normal CRM during the long Cretaceous Superchron would overcome the reverse TRM of anomaly M0 predating the superchron, which is not observed on oceanic basalt samples of this age (Verhoef and Arkani-Hamed, 1990).

In this paper we present the first global equivalent magnetization map of the oceanic lithosphere derived from marine magnetic anomaly data. Unlike previous regional and local analyses (see above) that attempted to invert the data to equivalent magnetization using the Parker and Huestis (1974) and Macdonald et al. (1980) algorithm, we adopt quite a different approach based on the comparison of the observed data to a global model of the marine magnetic anomalies computed for a constant magnetization but geomagnetic polarities alternating as a function of the age of the oceanic lithosphere. Such a result is actually a piggy-back result from our attempt to improve the World Digital Magnetic Anomaly Map (WDMAM) over the oceanic areas.

Many aeromagnetic, marine and satellite magnetic measurements have been collected Worldwide but are not readily available. The WDMAM project, launched by IAGA (International Association of Geomagnetic and Aeronomy) in 2003 and joined by the CGMW (Commission for the Geological Map of the World) in 2004, aims to gather these data and build the best achievable map of magnetic anomalies at the Earth surface. A call issued by IAGA in 2003 received several candidate compilations for WDMAM (Hamoudi et al., 2007; Hemant et al., 2007; Maus et al., 2007) that were evaluated and combined to build the first version of the map, released in 2007 (Korhonen et al., 2007). This map gathers the product grids of existing marine and aero-magnetic regional compilations (e.g., Verhoef et al., 1996, for the Arctic and North Atlantic oceans; Bankey et al., 2002, for North America; Golynsky et al., 2001, for Antarctica; Milligan et al., 2010, for Australia; Ishihara and Kisimoto, 1996, for East Asia; Wonik et al., 2001, for Europe) complemented by individual national data sets on land where available. In the oceans, the existing marine data are too few to be efficiently gridded. The data are complemented by modeled anomalies computed from the age of the ocean floor as determined by the few available data and a plate reconstruction model based upon these data. Among the limitations of WDMAM version 1B (Korhonen et al., 2007) is the fact that the magnetization vectors used in this model are parallel to the present day field, as if the plate have not moved or the magnetization is purely induced. In addition, a constant magnetization intensity is adopted and no attempt is made to adjust the model to the available data. Another global magnetic anomaly map, EMAG 2 (Maus et al., 2009), proposes a different approach in the oceans: in areas devoid of data, the existing data are extrapolated along the direction of seafloor spreading isochrons predicted by the plate reconstruction model. Such an approach, however, results in expanding the effect of local anomalies unrelated to seafloor spreading, for instance associated with volcanic seamounts, over wide areas.

A call for a second version of WDMAM was issued in 2010, and the new map adopted in 2015 (Lesur et al., 2015; Dyment et al., 2015). Among improvements of the new map in the oceans are the determination of realistic magnetization vectors based on a plate reconstruction model and true polar wander path of Africa and the adjustment of the complementary magnetic anomaly model to the available data.

In this paper we briefly present the method used to build the new WDMAM over the oceanic areas. We show that adjusting modeled anomalies to the observed ones allows determining equivalent magnetization at a global scale. We describe the resulting equivalent magnetization map and analyze its variations in term of age of the oceanic lithosphere, spreading rate at which it was formed, and other influential factors such as mantle thermal anomalies. We show that oceanic lithosphere younger than 10 Ma bears a significantly stronger equivalent magnetization. The oceanic lithosphere created at the fast and/or hotter spreading centers bears a stronger equivalent magnetization than that formed at the slow and/or colder ones.

2. Method

Our initial goal is to complement the existing marine magnetic anomaly data by a model based on the age of the ocean floor, as determined by the identification of isochrons (built from the same magnetic anomaly data) and plate reconstructions through the geological time. We distinguish three steps in building the WDMAM over the oceans. First we build our initial forward model; second we estimate a function that adjusts this model to the data; and third we multiply the initial model by this function and obtain our final model, to which we superimpose the available marine magnetic data for completion of the WDMAM over the oceans.

In the first step, we use classic point-source forward modeling on a spherical Earth (e.g., von Frese et al., 1981, corrected by Dyment and Arkani-Hamed, 1998b) to build a forward model of the marine magnetic anomalies at sea level. We estimate magnetization vectors using the age map of the ocean floor (Müller et al., 2008), the relative plate motions given by finite rotation poles and angles (Royer et al., 1992), the apparent polar wander path for Africa (Beck, 1994), and a geomagnetic polarity time scale (Cande and Kent, 1995; Kent and Gradstein, 1985). By doing so we improve the approach used to build WDMAM version 1B (Korhonen et al., 2007), which restricted the magnetization to be parallel to the present-day field, i.e. similar to induced magnetization, an hypothesis only valid for recent oceanic floor. We follow the approach adopted by Dyment and Arkani-Hamed (1998a) to model magnetic anomalies of remanent origin at satellite altitude and consider the past motion of plates. As a result, the paleoinclination does not depend on the present latitude but the paleolatitude instead. An amplitude coefficient varying with the paleolatitude is also considered to account for the latitudinal dependence of the paleofield strength, hence the magnetization. Both the paleoinclination and amplitude coefficient are determined assuming a strictly geocentric