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Nine month report

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Abstract

It is known from aeromagnetic surveys from Venezuela, China and the U.S. that it is common to find magnetic anomalies over oil fields. It has been suggested that hydrocarbon reservoirs, through upward seepage, create physical and geochemical conditions in soils sitting above them that are conducive to the formation of ferrimagnetic minerals such as magnetite and greigite. From near-surface samples drilled in Venezuela it has been observed that these minerals form aggregates of roughly spherical grains called *framboids*. While the specific physical and geochemical processes involved in the genesis of these minerals is an active research topic, I will focus in studying the domain structure and hysteresis parameters of these minerals via numerical simulation of the *micromagnetic* equations. Solving the micromagnetic problem can be done either by minimising the total Gibbs free energy which is a sum of energies associated with different phenomena in a ferromagnetic material or by solving the dynamical equation for the magnetic moments, that is, the Landau-Lifshitz-Gilbert equation (LLGE). I will use a finite element method based on the general-purpose package collection for automated solutions of partial differential equations *FEniCS* to solve the LLGE as well as an energy minimising routine, specifically a conjugate gradient method. My aim is to find the magnetic signal of these mineral aggregates measured in a given sample by standard rock-magnetic and palaeomagnetic techniques. As a first approach to the problem, before scaling up the simulations, I have conducted simulations of hysteresis loops and zero-field domain structure of octahedral-shaped single grains of greigite and compared these with octahedral grains whose corners have been chopped. These shapes are typical morphologies of greigite and so, these simulations constitute an improvement over previous finite difference models that could only study somewhat unrealistic shapes like cubes and rectangular prisms.

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Chapter 1

Introduction

1.1 Motivation and Objectives

It has been established via airborne magnetic surveys in the U.S.A. (Donovan et al., 1979) that magnetic contrasts—that is, "magnetisation that is different from background magnetisation and which may give rise to mappable magnetic anomalies detectable by conventional magnetometry" (Machel and Burton, 1991)—are a common feature of hydrocarbon reservoir sites. Donovan et al. (1979) suggested that these magnetic anomalies are caused by near-surface magnetic minerals (specifically, magnetite) induced by upward hydrocarbon seepage from the underlying hydrocarbon reservoir. Further studies by Donovan et al. (1984), Reynolds et al. (1993) and Elmore et al. (1993) in the U.S.A., Díaz et al. (2000), Costanzo-Alvarez et al. (2006), Guzmán et al. (2011), González et al. (2002) in Venezuela and Liu and Liu (1999), Liu et al. (2004) and Liu et al. (2006) in China have confirmed the genetic relationship between the magnetic contrasts produced by ferrimagnetic minerals near the surface and the underlying reservoir. These investigations confirm the original hypothesis of Donovan et al. (1979) that the reducing environment caused by the upward seepage from the reservoirs is conducive to the formation of magnetic minerals—such as magnetite and other Fe-oxides, and greigite and other Fe-sulfides—and/or the destruction of minerals such as hematite (Machel and Burton, 1991) and thus further the case for using a combination of aeromagnetic surveying and rock-magnetic measurements of soils for cheap hydrocarbon prospecting as proposed by Donovan et al. (1984).

Though the discussion on the exact mechanism for the formation of these minerals is ongoing, Machel and Burton (1991) have identified two primary agents for the precipitation of magnetic minerals under the influence of hydrocarbon seepage. At higher temperatures and thus higher depths they propose chemical processes as the main factor while at more shallow depths and lower temperatures it is argued that microbial sulfate-reducing processes are playing the larger role. Machel and Burton (1991) also emphasised the difficulty in linking a magnetic anomaly to a process of hydrocarbon seepage because the precipitation of magnetic minerals can cause positive or negative anomalies—that is, peaks or dips in the geomagnetic field and/or the magnetic susceptibility of the soils.

It was recognized by Reynolds et al. (1993) that in some cases iron sulfides may be more important to the magnetic contrasts and thus to the identification of prospective oil-producing fields than iron oxides. Particularly, greigite has been identified as an authigenic mineral of the utmost importance in the Simpson oil field in Alaska. Greigite is an iron sulfide (Fe_3S_4) that can be thought of as the sulfur equivalent of the iron oxide magnetite (Fe_3O_4) as they have the same crystal structure only with sulfur replacing oxygen. Like magnetite, it is highly magnetic. Nevertheless, since it is thought to be unstable, its importance as a palaeomagnetic recorder has not been as readily realized as that of magnetite. Also, its magnetic parameters were poorly understood until the work of Chang et al. (2008) who by synthesising highly pure greigite were able to measure the critical magnetic parameters. Muxworthy et al. (2013) made use of the new accurate measurements of greigite to simulate greigite grains and the effect of intergrain interactions.

Liu et al. (2006) has proposed that magnetic mineral grains that are linked to hydrocarbon seepage have sizes ~25nm and thus generally in the single domain (SD) range. In terms of morphology, it has been repeatedly found (see Aldana et al. (1999) and references therein) that roughly spherical grains of magnetite and/or greigite assemble as raspberry-shaped aggregates called framboids. It is my interest to model these structures via micromagnetics to investigate their domain structure and behaviour in routine rock-magnetic and palaeomagnetic measurements that could also correlate with the size of the aggregates. It is an open question how the intergrain interactions will affect the otherwise simpler problem of modelling single grains. This could aid in developing future oil exploration techniques that are cheaper than more conventional techniques vastly used today.

Chapter 2

Background Theory

2.1 Magnetism and matter

2.1.1 Fundamentals of magnetism

The description of magnetic fields is analogue to that of electrical fields. Although, unlike the situation in electricity, there are no magnetic charges, only magnetic dipoles. A more thorough analysis reveals the origin of magnetism is electrical: a circular electrical current (either a flow of electrons or a single electron) produces an *induction* field $\vec{B}$. As such, the SI magnetic units are represented by electrical and mechanical units. Thus, on a fundamental level it is correct to understand magnetism as an electrical phenomenon.

Chapter 3

Conclusion

3.1 Summary of Thesis Achievements

Summary.

3.2 Applications

Applications.

3.3 Future Work

Future Work.

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