Effects of the core-shell structure on the magnetic properties of partially oxidized magnetite grains: Experimental and micromagnetic investigations

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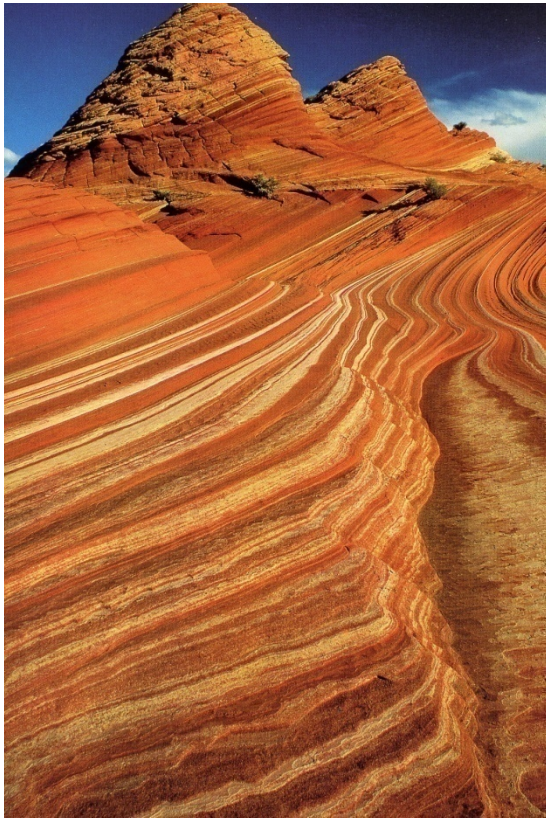
Outline

- Introduction
- Experiment
- Micromagnetic modeling
- Results and Discussion
- Conclusions

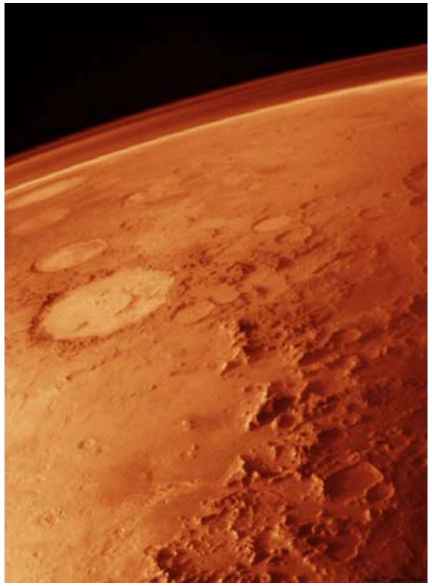
Introduction

- Low-temperature oxidation of magnetites or titanomagnetites are common in nature



Weathering on Earth surface

Oxidation under the Ocean



Weathering on Mars

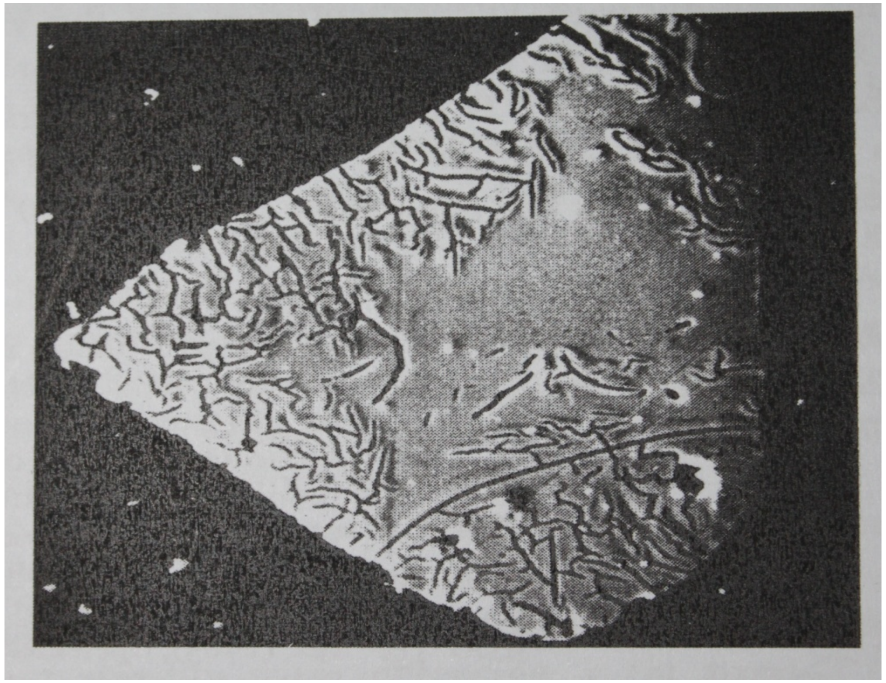
Introduction

- Can palaeomagnetic recordings survive low-temperature oxidation process?

- Why? Or why not?

Introduction

- Maghemitization

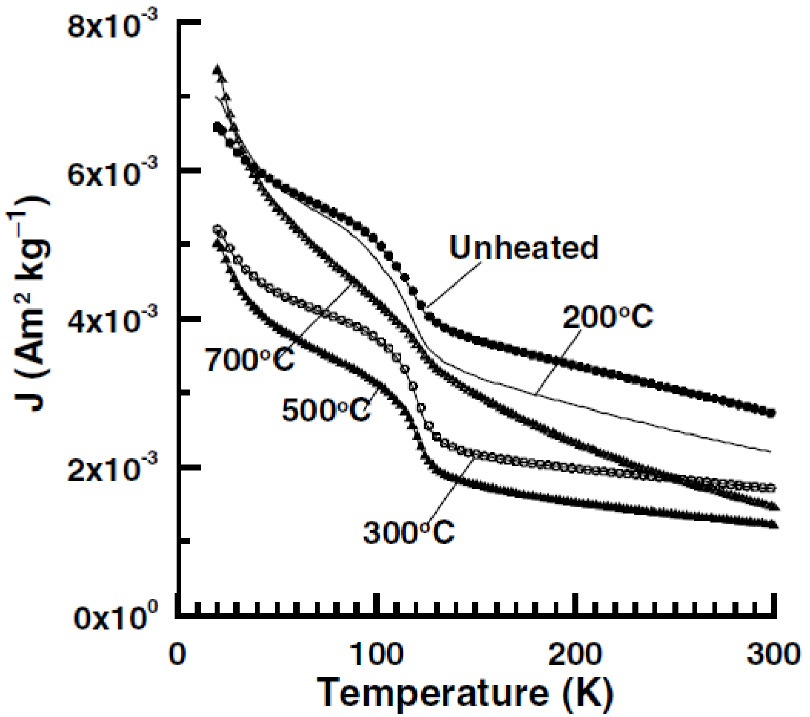


Maghemitization in a magnetite crystal
(Gapeyev and Tsel'movich, 1988)

The oxidation process starts at its surface, where Fe^{2+} is oxidized to Fe^{3+}.

An oxidized shell is formed around an unoxidized core (core-shell structure)

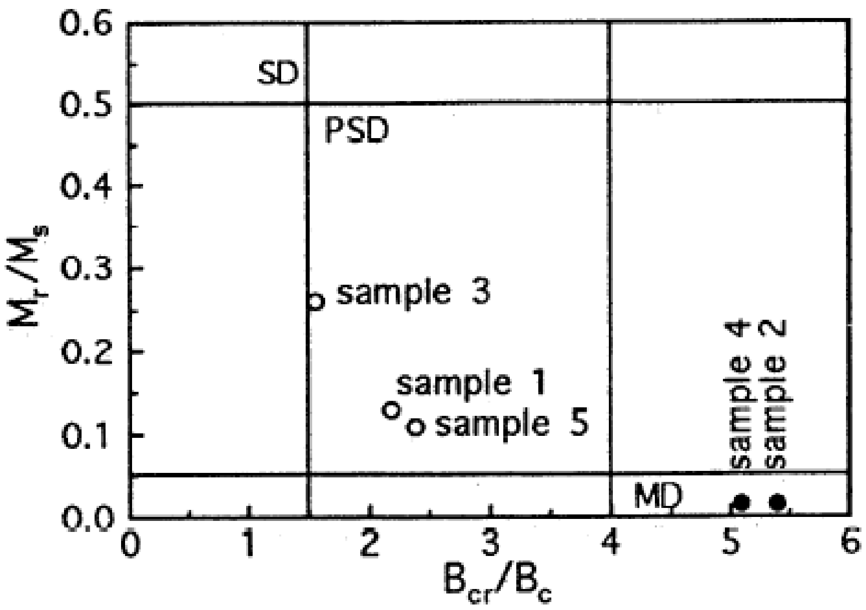
Introduction



LT-SIRM measurements for Chinese loess
（Liu et al., 2004）

Magnetite core still remains stoichiometric even after being heated to 700 °C

Introduction



Day plot of MD magnetite particles
（Cui et al., 1994）

Three possible explanations:

(1) PSD core dominate

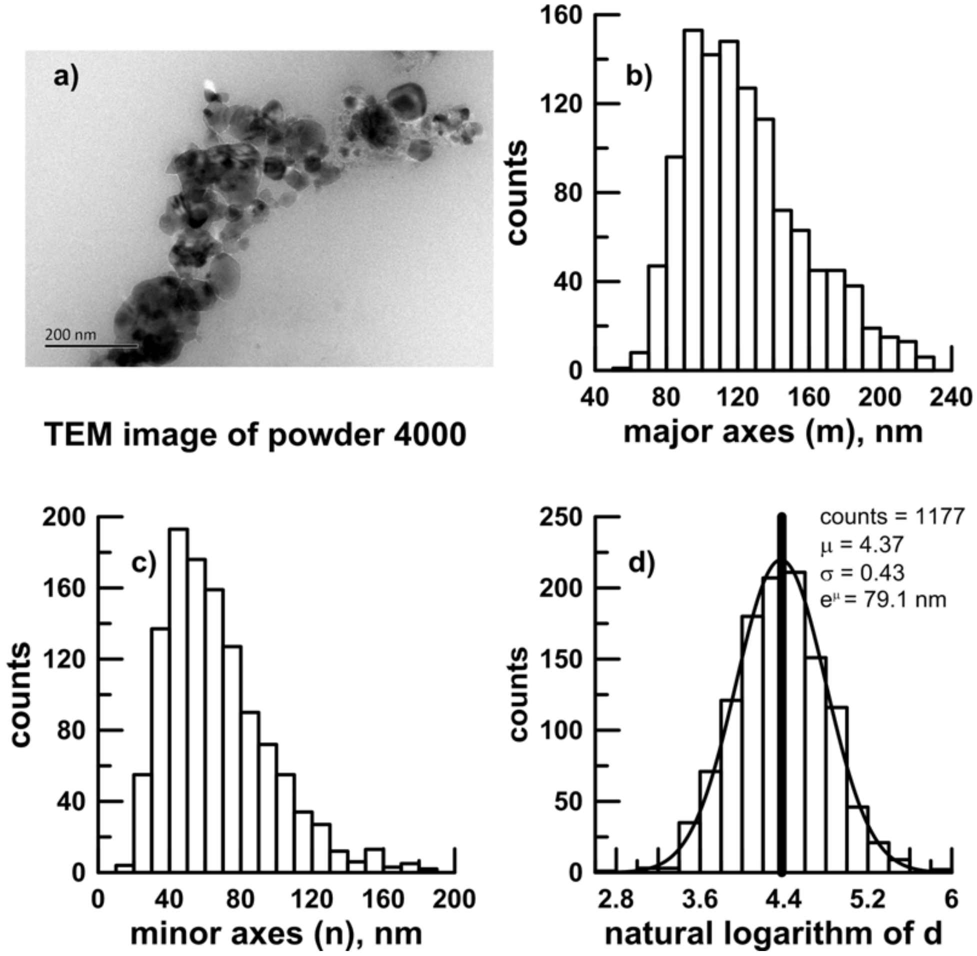
(2) core-shell coupling favors the PSD-like behavior

(3) mixed behavior of SD maghemite and MD magnetite

Introduction

- Examine maghemitization in SD and PSD grains
  - Experimental observations as a function of oxidation
  - Numerical modeling using a core-shell structure

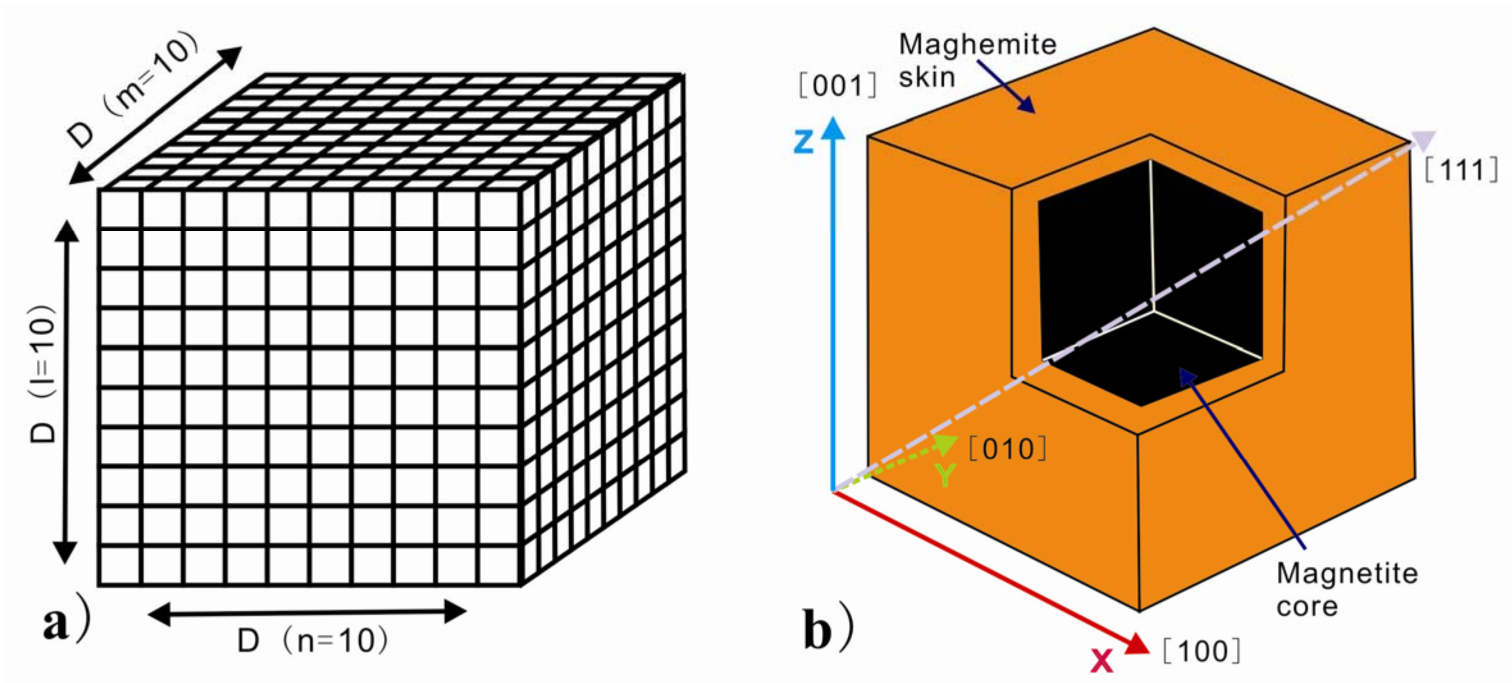
Experiment



TEM image and statistical results of magnetite powder

- Samples were initially heated in a mixture of 80% CO_2 and 20% CO at 395 °C for 74 hours
- Oxidized by heating to 5 different temperatures and 5 different heating periods.
- Total of 26 samples produced with oxidation parameter *Z* obtained from XRD cell edge measurements.

Micromagnetic modeling



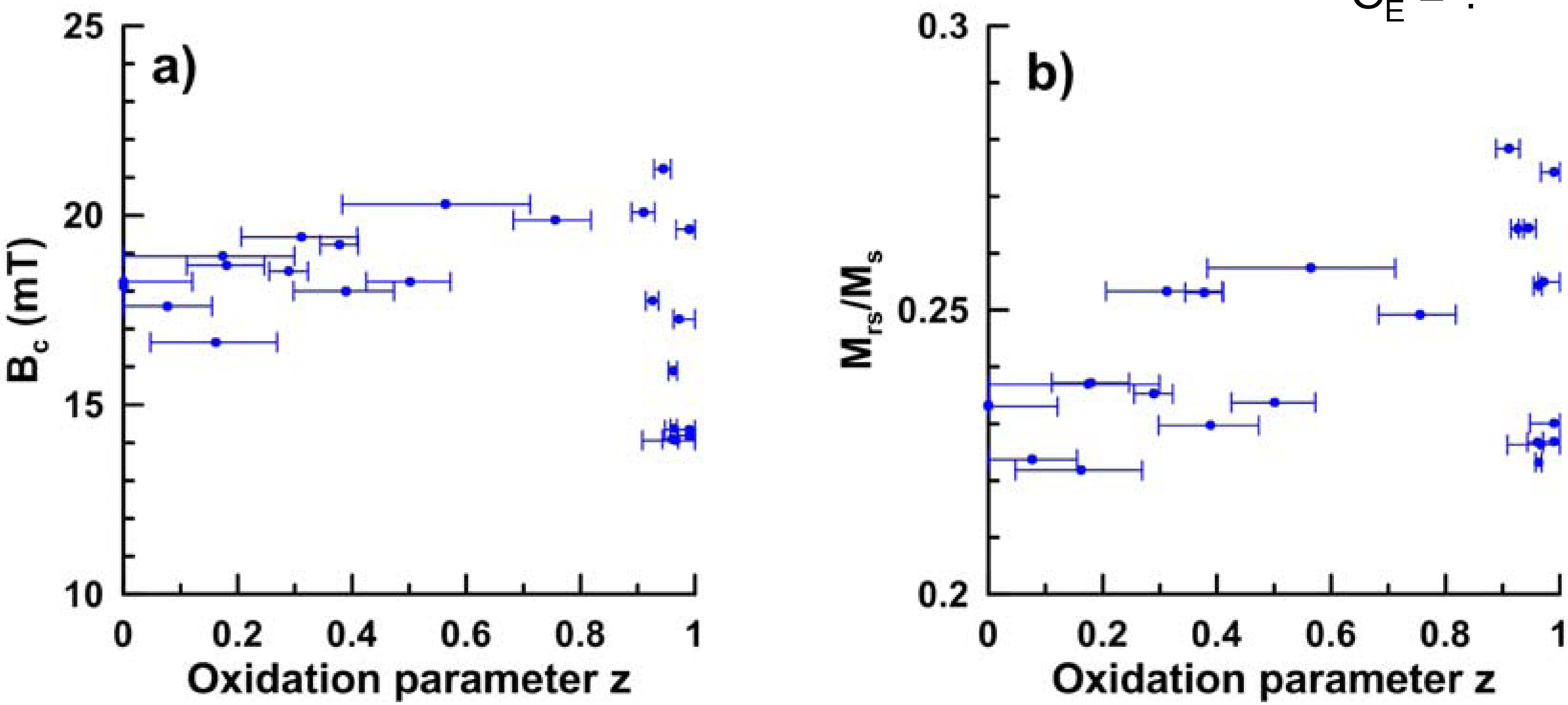
Frame of reference for micromagnetic modeling

Micromagnetic modeling

- Exchange coupling at the interface
  - $C_E = 0$
    (magnetostatic coupling only)
  - $C_E = 0.5 \times 10^{-11}$ J/m
    (weak coupling)
  - $C_E = 1.17 \times 10^{-11}$ J/m
    (an average of magnetite and maghemite)

Results and Discussion

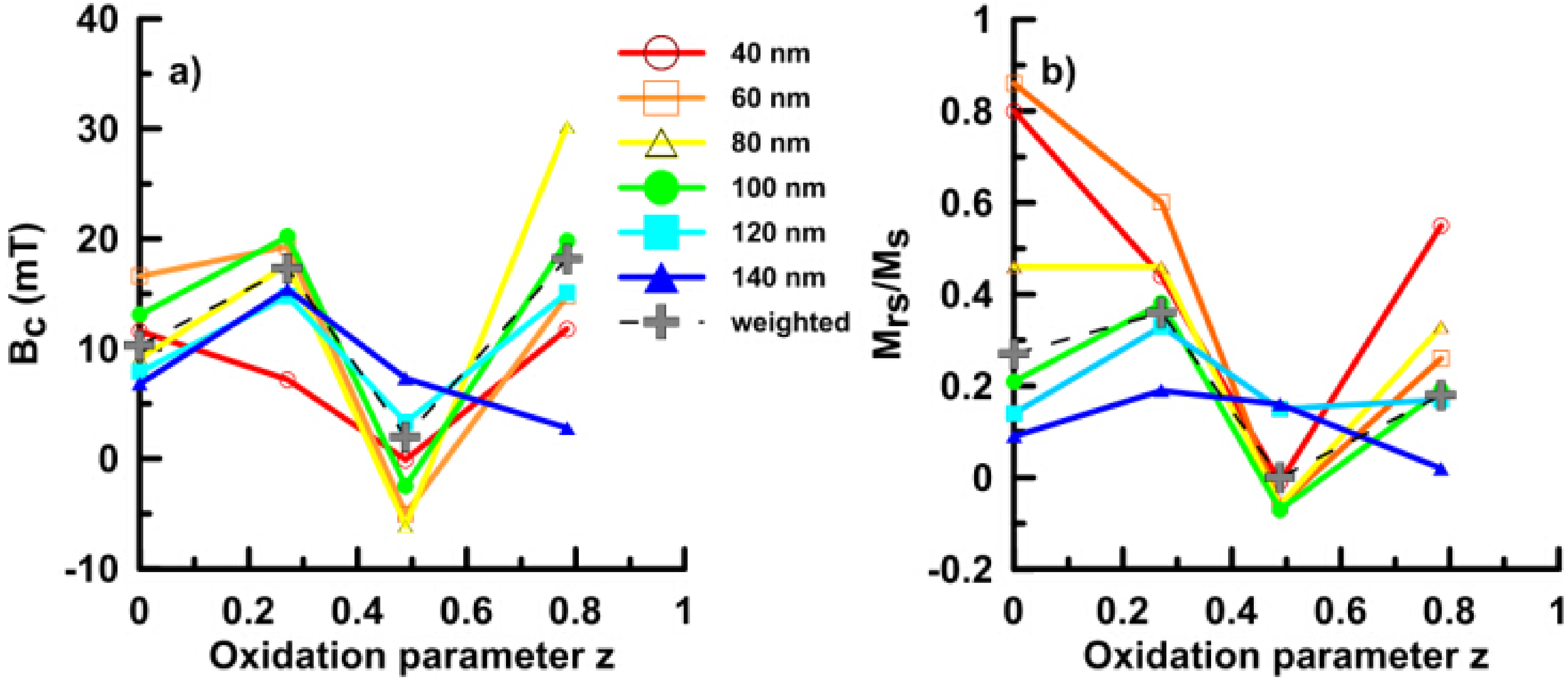
C_E = ?



Experimental results of B_c and M_{rs}/M_s versus oxidation parameter z

Results and Discussion

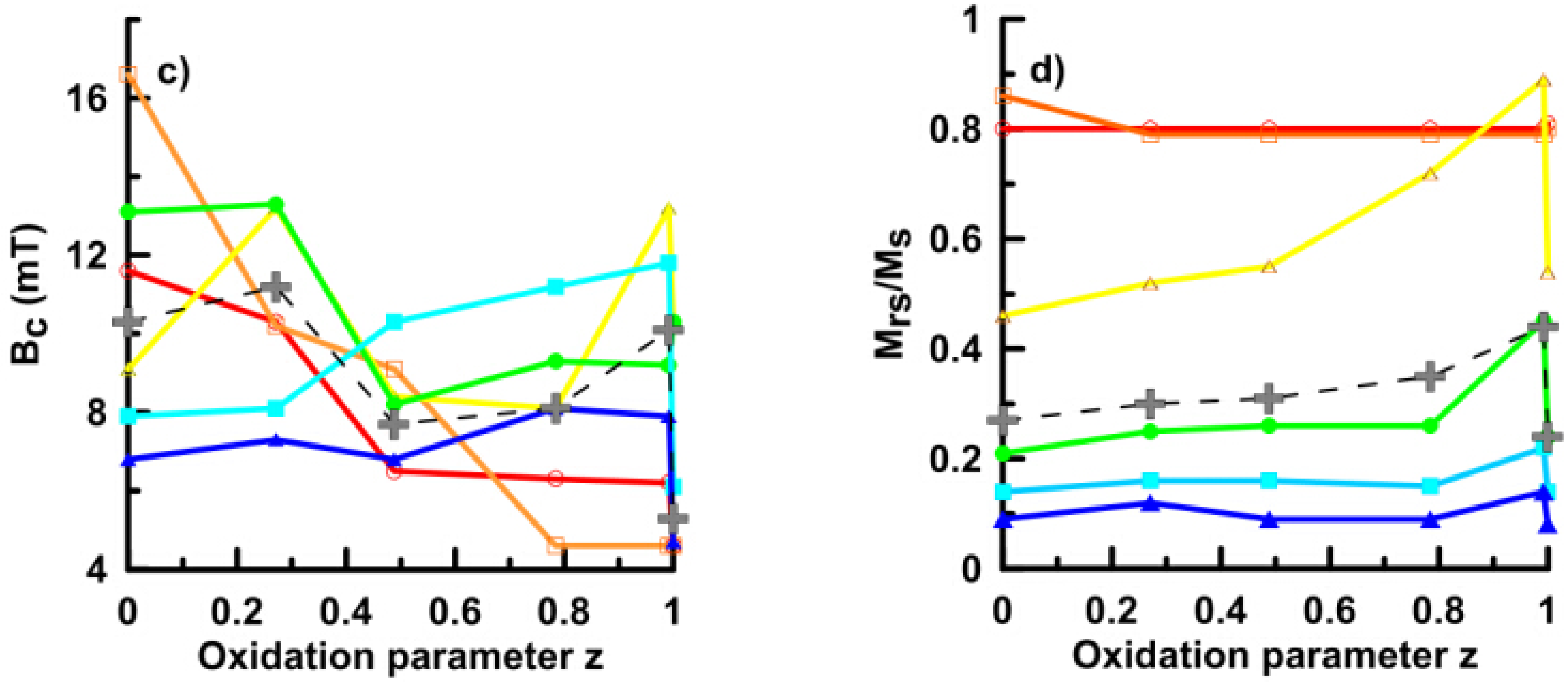
$C_E = 0$



Micromagnetic results of B_c and M_{rs}/M_s versus oxidation parameter z

Results and Discussion

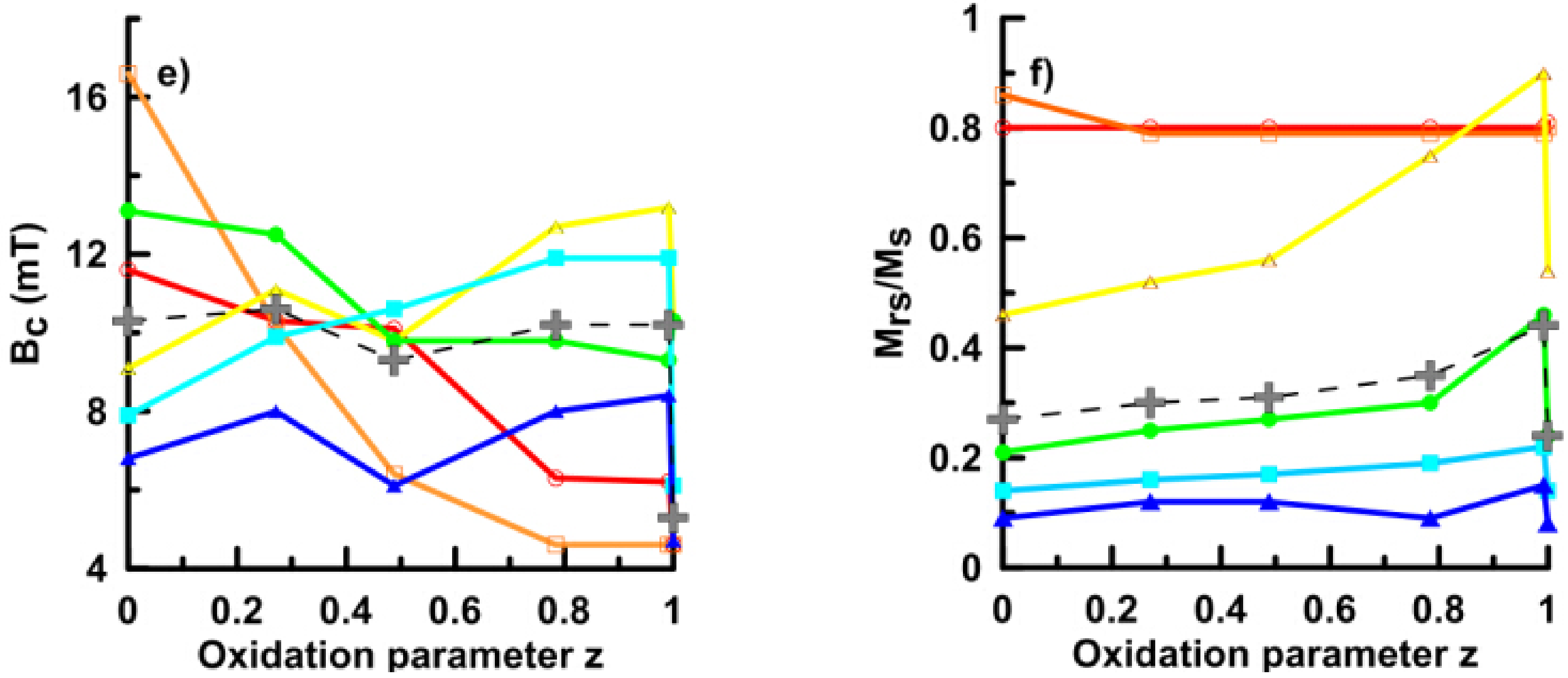
C_E = 0.5 x 10-11 J/m



Micromagnetic results of B_c and M_{rs}/M_s versus oxidation parameter z

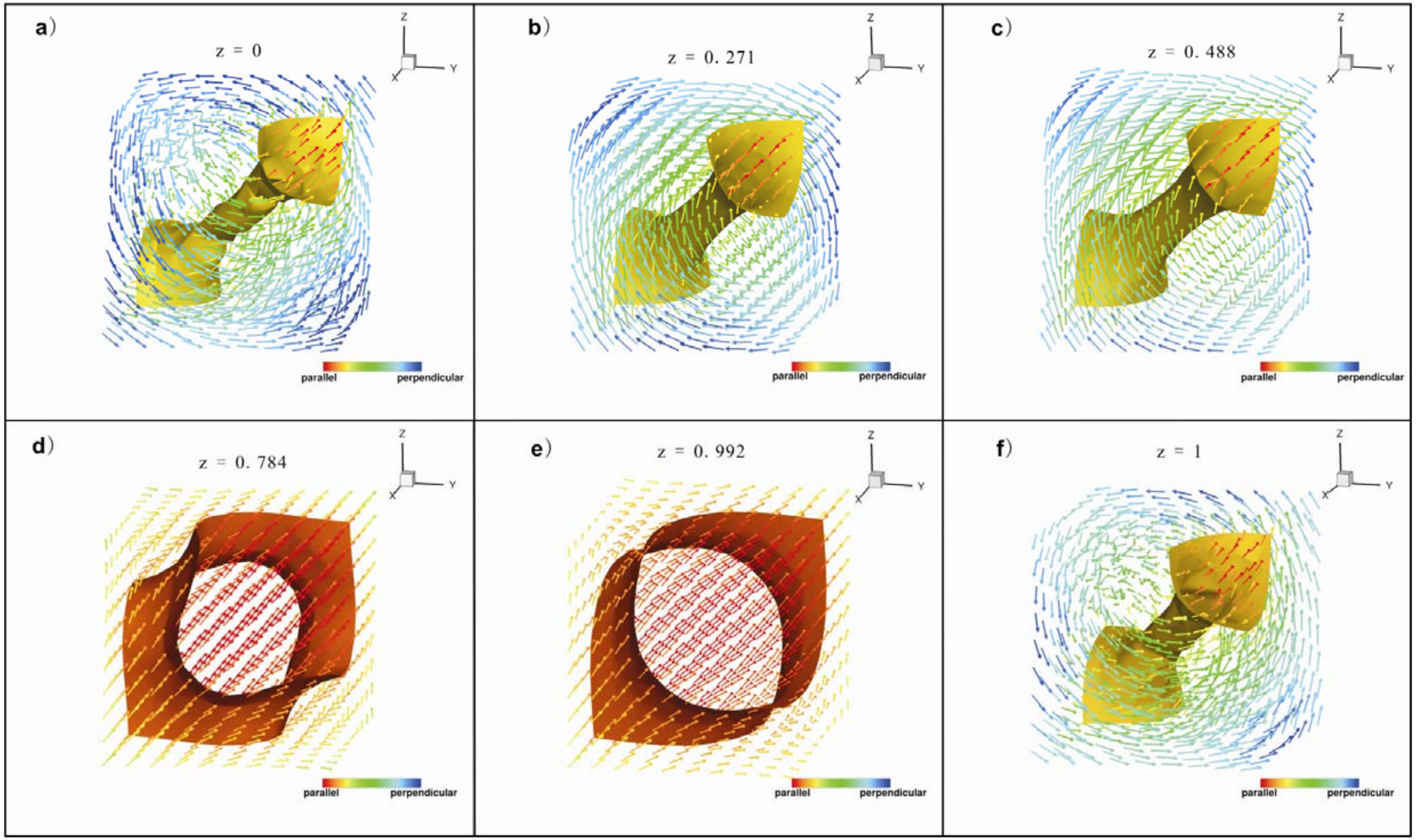
Results and Discussion

C_E = 1.17 x 10-11 J/m



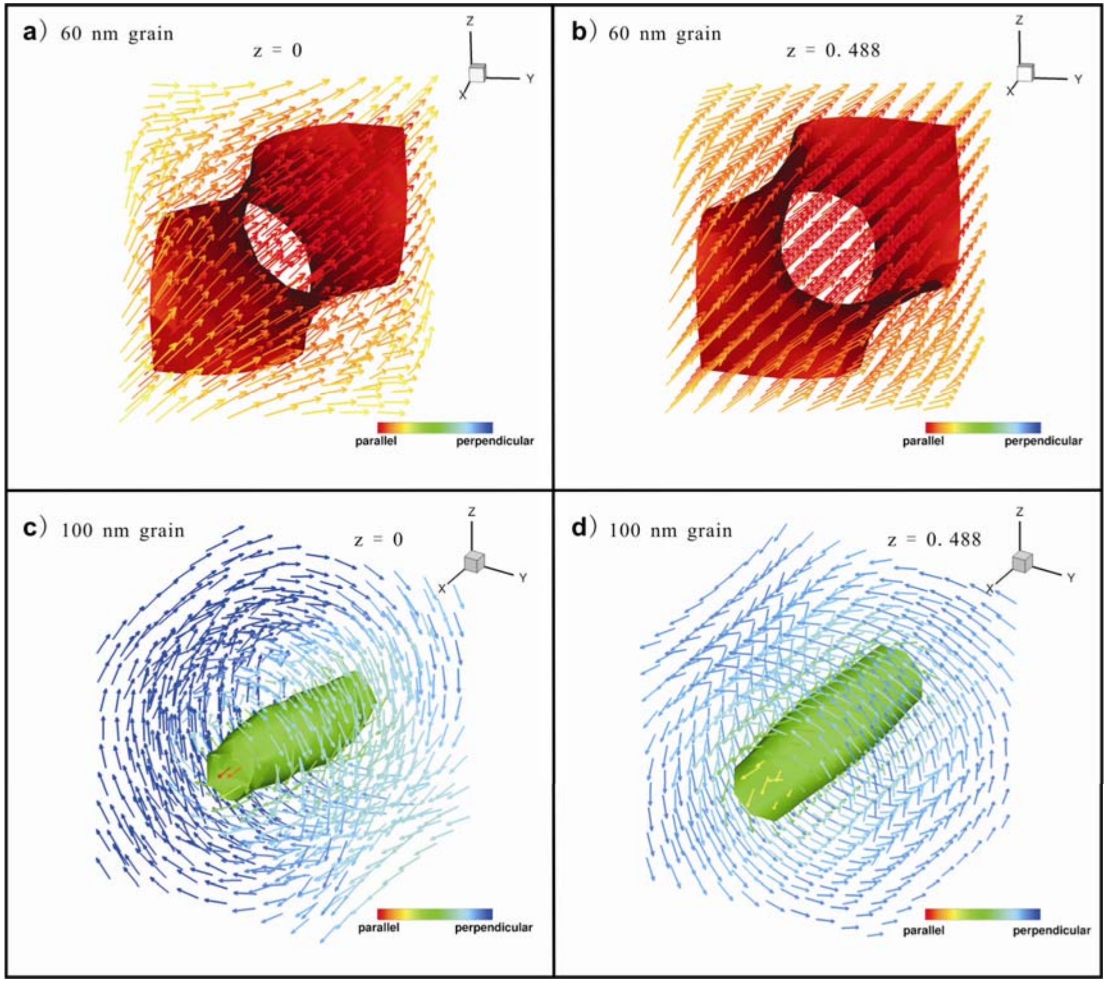
Micromagnetic results of B_c and M_{rs}/M_s versus oxidation parameter z

Results and Discussion



Zero-field micromagnetic domain structures for grain size of 80 nm with oxidation parameter

Results and Discussion



Zero-field micromagnetic domain structures for core-shell model with grain size of (a and b) 60 nm and (c and d) 100 nm

For SD particles (< 70 nm), the domain states remain in a largely uniform domain state for all values of z.

For larger PSD particles (> 110 nm), the grains will remain in a vortex state throughout the oxidation process.

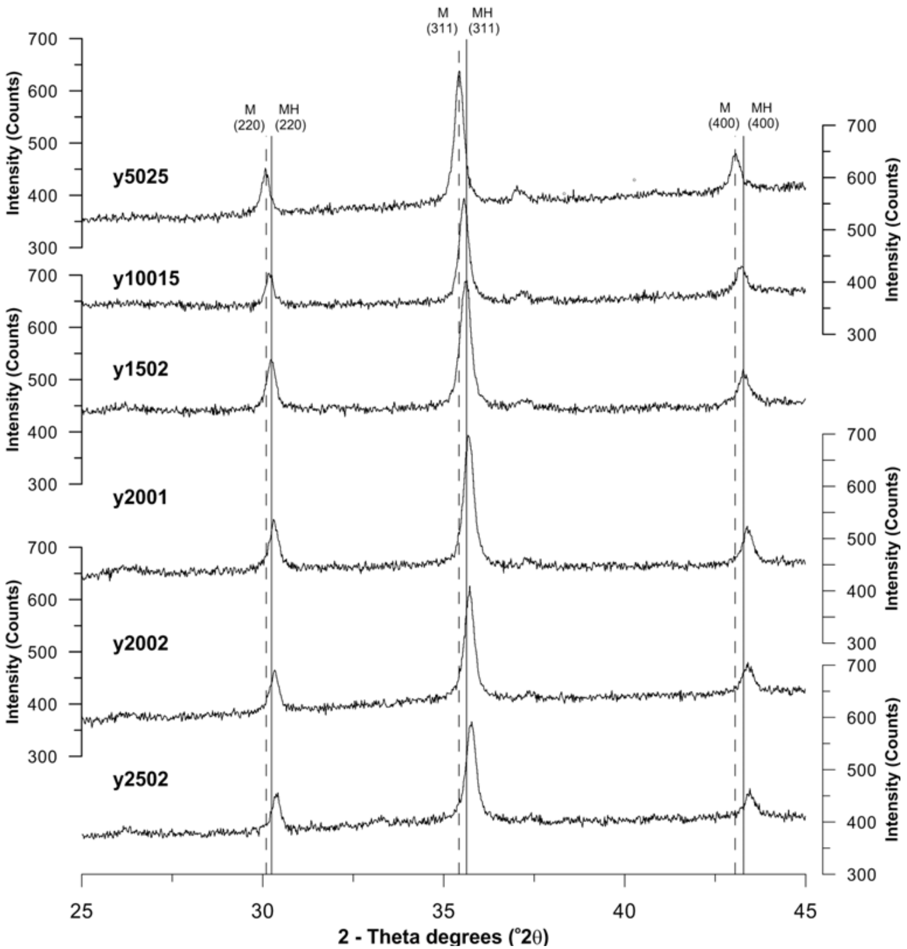
Conclusions

- Micromagnetic results of core-shell structrue are in good agreement with the experimental observation.
- Magnetic properties of surface oxidized magnetite are dominated by exchange coupling at the core-shell interface.
- The low-temperature oxidized magnetite in SD-PSD range can reliably record palaeomagnetic signals.

Thank you for your attention~

FIFA WORLD CUP
Brasil

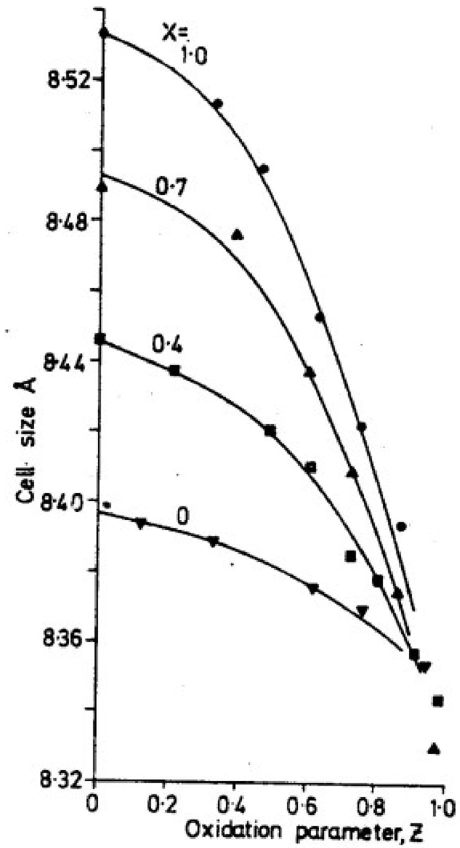
Experiment



典型部分氧化磁铁矿的X 射线衍射（XRD）图像

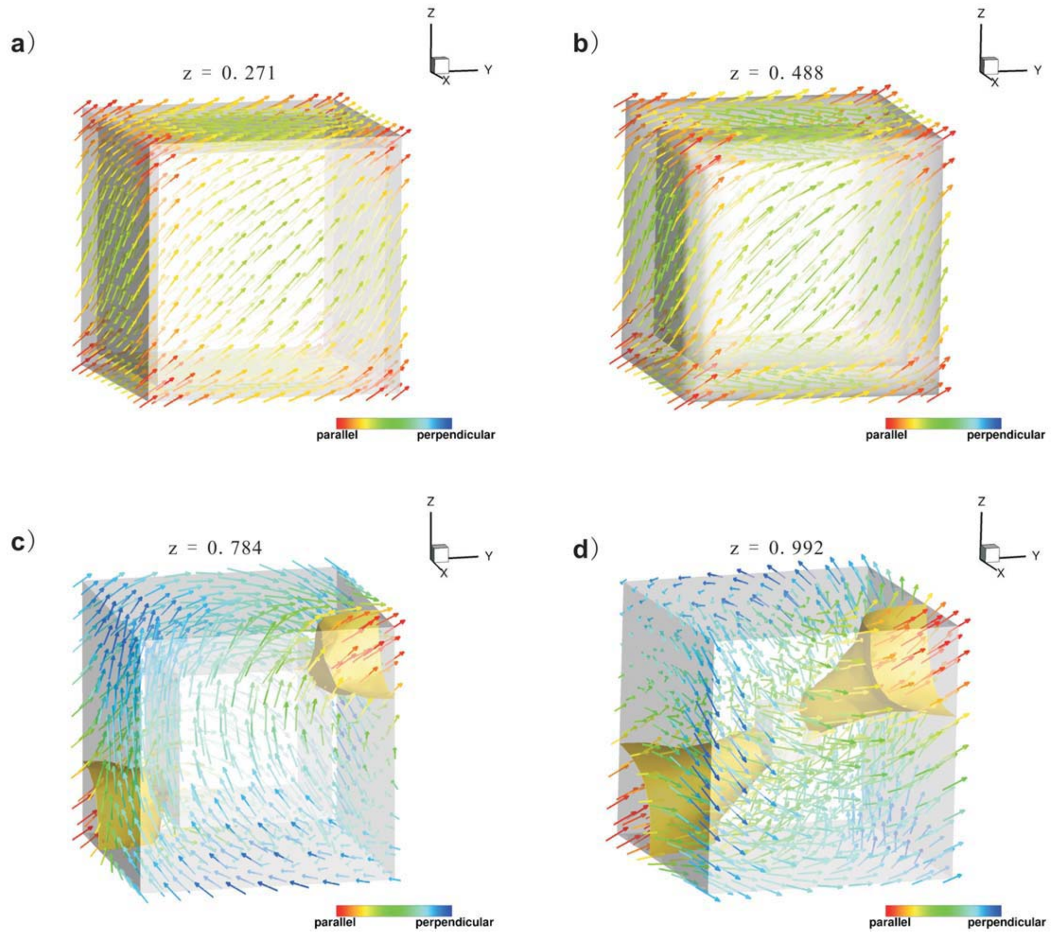
8.3967 Å

8.337 Å



（钛）磁铁矿晶格参数与氧化程度关系图 (Readman and O’Reilly, 1972)

Micromagnetic modeling



Zero-field micromagnetic domain structures for shell-only model with grain size of 80 nm for different oxidation parameter