Southern Ocean controls of marine $\Delta\delta^{13}C$ – a modelling study

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1. Introduction

$\Delta\delta^{13}C$ is the surface-to-deep gradient of $\delta^{13}C$, the standardized ^{13}C isotope. ^{13}C is slightly heavier than the ^{12}C isotope, which causes a fractionation effect during air-sea gas exchange and photosynthesis. The result is a $\delta^{13}C$ enriched surface ocean and a $\delta^{13}C$ depleted deep ocean, thus creating a gradient ($\Delta\delta^{13}C$).

This study aims to better understand the controlling mechanisms and sensitivity of marine $\delta^{13}C$ and $\Delta\delta^{13}C$. The focus on the Southern Ocean (SO) is because of its important role in regulating atmospheric CO_2 [Broecker et al., 2013] and the challenge to understand the SO importance of circulation vs. biogeochemistry for the SO&global carbon cycle.

$\delta^{13}C$ and $\Delta\delta^{13}C$ are used to study the carbon cycle (pCO_2, biological pump, etc.) as well as ocean circulation.

2. Methods

All experiments are done using HAMOCC2 [Heinze et al., 2016], a ocean biogeochemistry general circulation model with fixed ocean circulation, a free box atmosphere and an annual time step.

Sensitivity experiments:

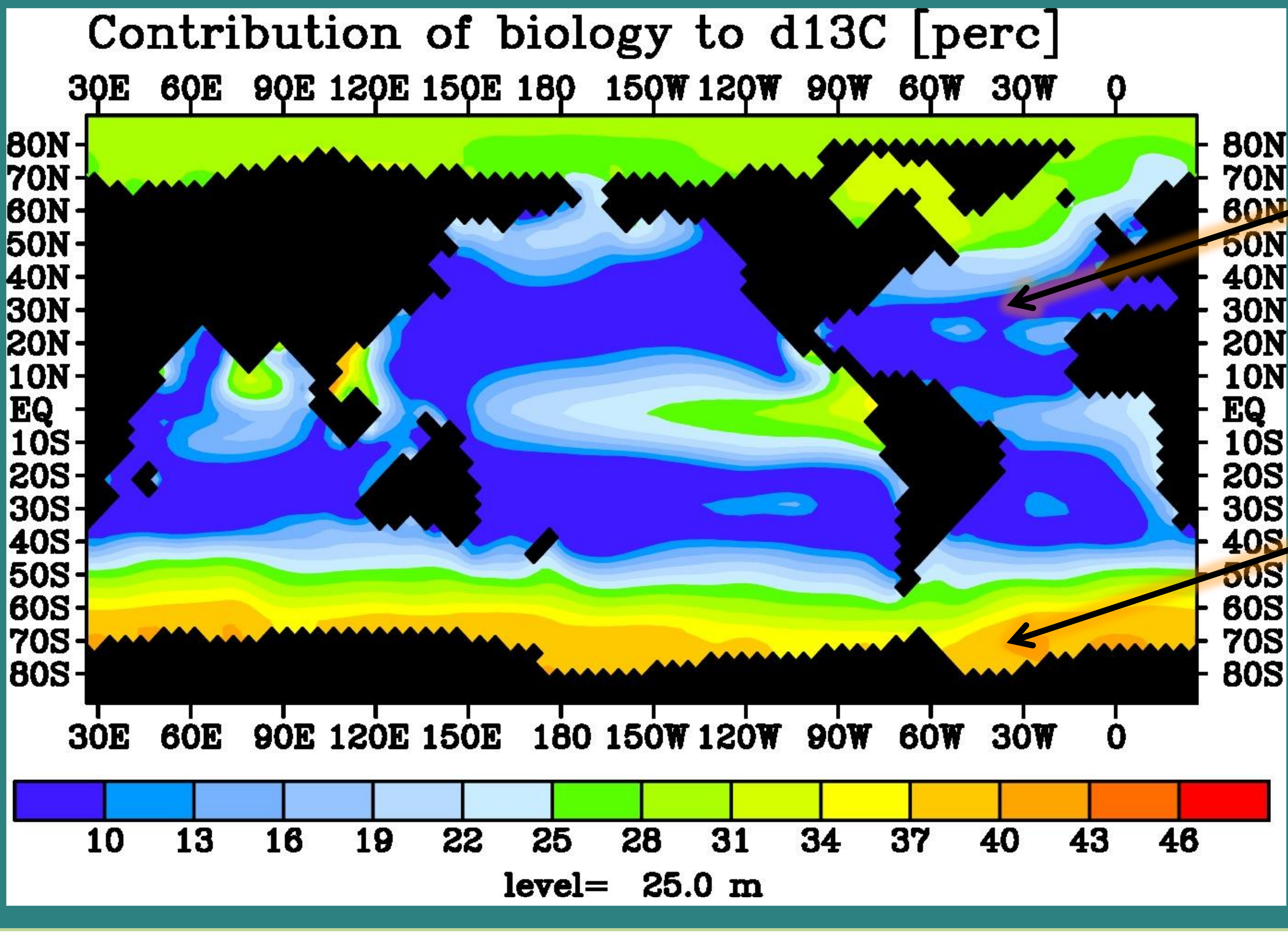
- **CO_2 air-sea gas exchange rate** ('wind speed') high/low
- **POC sinking rate** ('biological pump') fast/slow
- **Ice cover** (glacial-interglacial change) big/small

Done twice: 1. whole ocean and 2. Southern Ocean only

The standardized ^{13}C isotope:

$$\delta^{13}C = (\frac{^{13}C_{model}/(DIC_{model} - {}^{13}C_{model})}{R} - 1) * 1000‰$$

Want to know more?
Take one of these!



Mid- and low-latitude $\delta^{13}C$ controlled by **air-sea gas exchange** at the surface

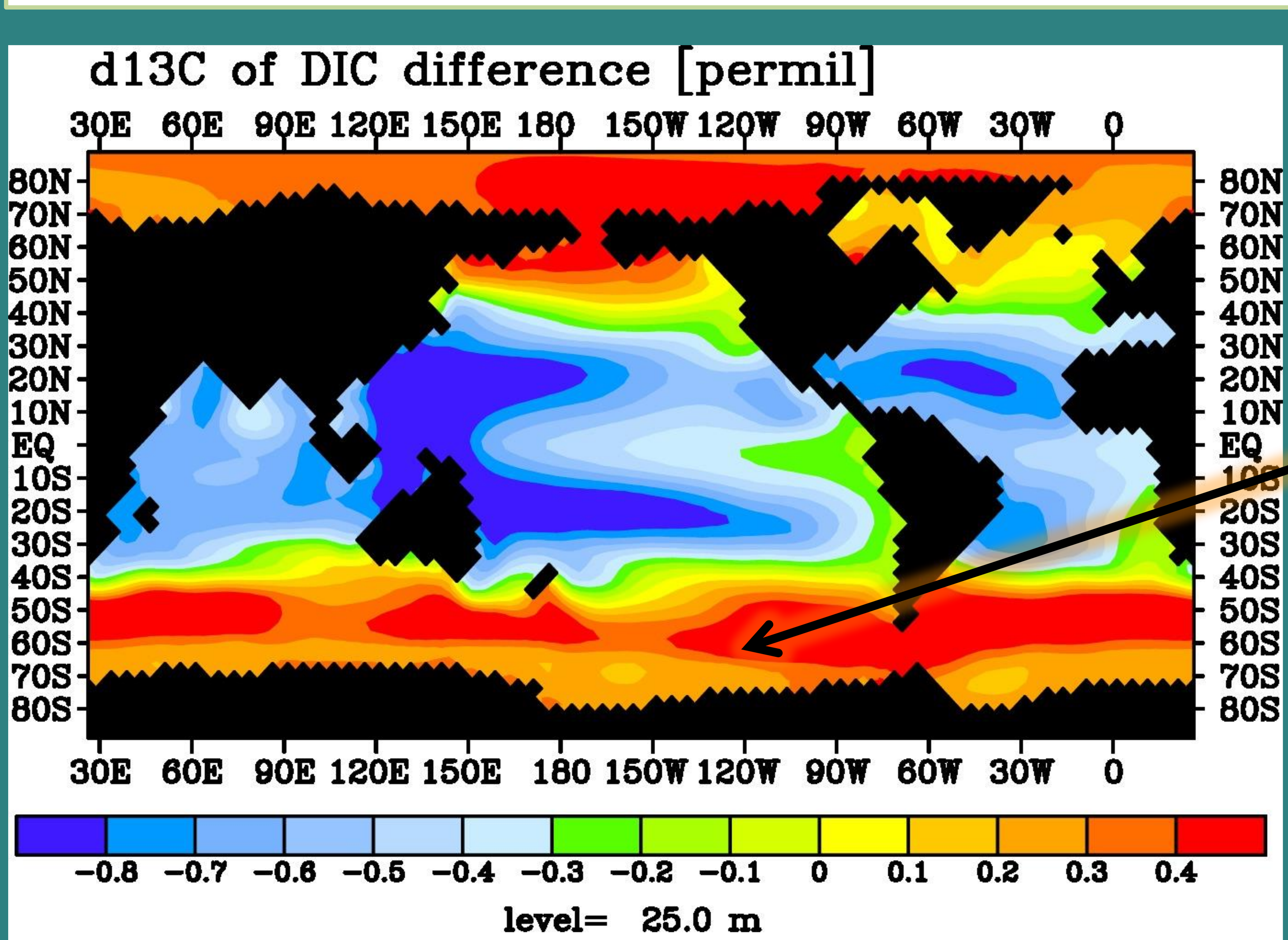
Deep ocean and SO $\delta^{13}C$ for **~40%** determined by **biological** processes

3. Results & Conclusions

- $\delta^{13}C$ and $\Delta\delta^{13}C$ are controlled by different processes depending on **depth, longitude and latitude**;
- The **SO contributes disproportionally large amounts** to the global $\delta^{13}C$ & $\Delta\delta^{13}C$ sensitivity

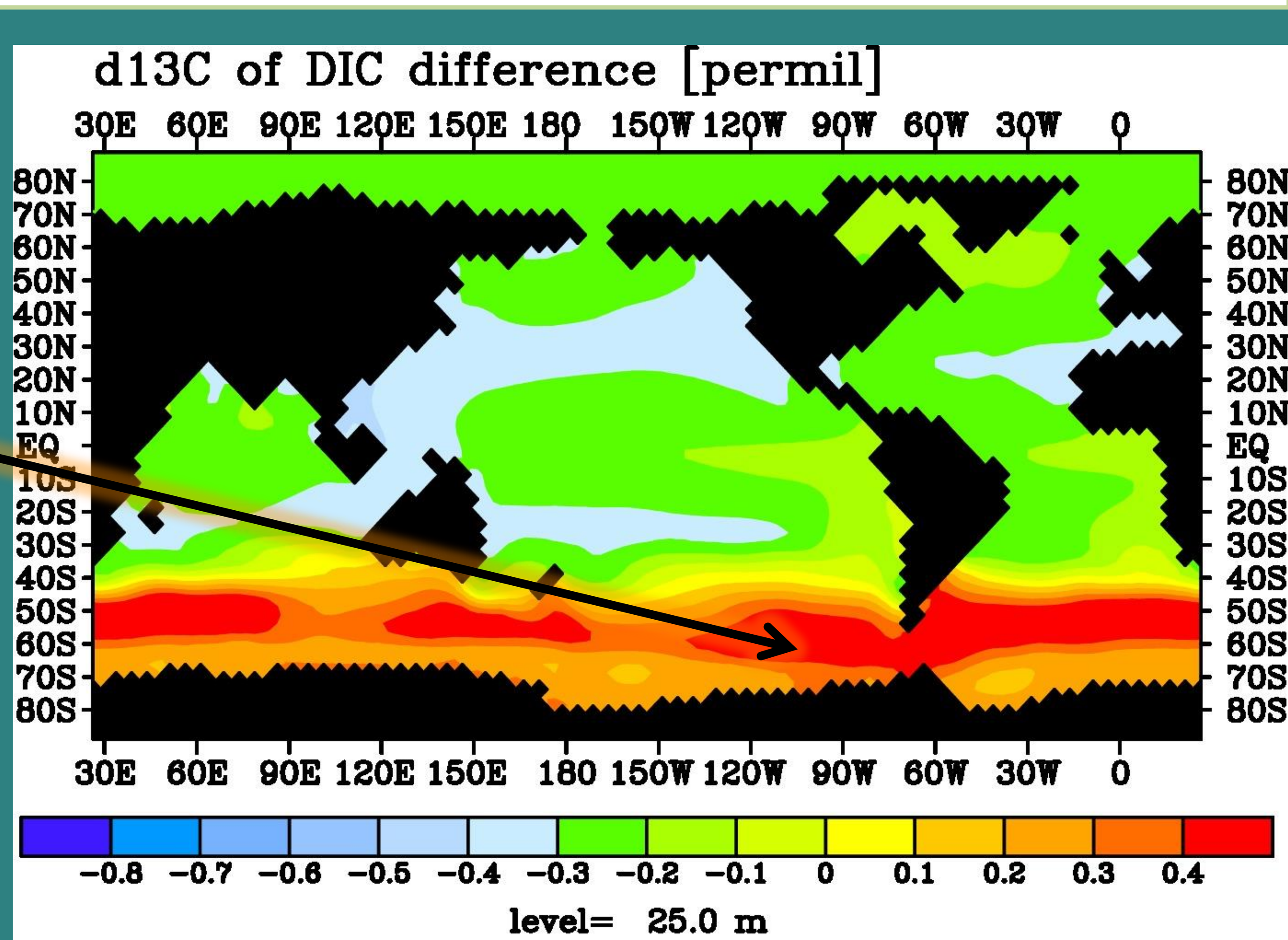
4. What's next?

- Explore correlation between $\delta^{13}C_{atm}$, $\Delta\delta^{13}C$ and pCO_2
- SO nutrient depletion experiment
- Constrain (SO) effects on $\delta^{13}C$ & $\Delta\delta^{13}C$



Fast gas exchange in the Global Ocean

Fast Gas exchange
Change compared to the control run:
Southern Ocean controls major part of global $\delta^{13}C$ and $\Delta\delta^{13}C$ change



Fast gas exchange in the SO only

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Broecker, W. S., and E. Maier-Reimer (1992), Global Biogeochem. Cycles, 6(3), 315–320, doi:10.1029/92GB01672
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Want to know more? Read this! And/or send an email to anne.moree@uib.no.

The sensitivity experiments

Sensitivity experiment	Global Ocean	Southern Ocean-only
Gas fast	CO2 exchange rate * 4	CO2 exchange rate * 4, only south of 40°S
Gas slow	CO2 exchange rate / 4	CO2 exchange rate / 4, only south of 40°S
POC fast	POC sinking rate increased to 30m/d (control*10)	POC sinking rate increased to 30m/d, only south of 40°S
POC slow	POC sinking rate decreased to 0.3m/d (control/10)	POC sinking rate decreased to 0.3m/d, only south of 40°S
Ice big	Southern Ocean ice cover (no CO2 gas exchange) south of 50°S [50°S is about winter extreme during the Last Glacial Maximum]	
Ice small	Southern Ocean ice cover (no CO2 gas exchange) only south of 70°S	

More on Methods

$$\delta^{13}C_{bio}\ [\%\ of\ \delta^{13}C] = \frac{\varepsilon_{photo}}{\overline{DIC}} * r_{c:p} * (PO_4 - \overline{PO_4}) + \overline{\delta^{13}C}$$

$\varepsilon_{photo} = -19‰$, $\overline{DIC} = 2308.793$ μmol/kg, $r_{c:p} = 128$, $\overline{PO_4} = 2.399$ μmol/kg, $\overline{\delta^{13}C} = 0.742‰$

For the control model run [adjusted from Broecker and Maier-Reimer, 1992].

More info on Results & Conclusions

- The **POC sinking** rate experiments show that $\Delta\delta^{13}C$ is weakened and Southern Ocean $\Delta\delta^{13}C$ is less sensitive to changes in POC sinking rate than the rest of the ocean. Also, the global average ocean d13C is less sensitive to a reduced POC sinking rate than to an increased POC sinking rate. The SO explains 35-75% of global change of different carbon cycle tracers for 'POC Fast', but only 0-20% for 'POC Slow';

- The sensitivity of the ocean $\delta^{13}C$ & $\Delta\delta^{13}C$ to slower **CO_2 gas exchange** is opposite of faster CO_2 gas exchange, and the changes are less pronounced. The Southern ocean is an important region for these effects: 40-60% of the change in surface ocean $\delta^{13}C$, $\Delta\delta^{13}C$, pCO_2(atm), and net air-sea C flux is explained by the SO;

- A **large sea-ice cover (50S)** causes relative depletion of d13C under the ice (~-0.2‰) as compared to the control and relative enrichment of d13C (~+0.2‰) in the rest of the surface ocean. Since changes in the deep ocean are small (the average d13C changes -0.01‰), $\Delta\delta^{13}C$ weakens in the ice covered ocean and becomes stronger elsewhere. A strongly **reduced ice cover** (70S) results in opposed effect, with SO enrichment (~0-3‰) and a small depletion (~-0.1‰) in the rest of the ocean.

References

W.S. Broecker, D. McGee, The 13C record for atmospheric CO2: What is it trying to tell us?, Earth and Planetary Science Letters, Volume 368, 2013, Pages 175-182, ISSN 0012-821X, http://dx.doi.org/10.1016/j.epsl.2013.02.029.