Do REE and Ti in lunar zircons reflect temperature and oxygen fugacity of lunar magmas?

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INTRODUCTION & CONTEXT

✱ Rare Earth Elements (REE) and Ti are incorporated in zircons during crystallisation and are routinely used to track the chemistry of their parent rocks and temperature of crystallisation.

✱ Significant information about the Hadean Earth is based exclusively on trace element data measured in detrital zircon, including REE, Ti-in-zircon concentration (and temperature) and oxygen fugacity (calculated from Ce content and T).

✱ These results depict a cool Early Earth, covered by oceans and dominated by modern tectonics, with a granitic continental crust [e.g. 1-5].

✱ Controversy has arisen when studies have shown that REE in zircons may not be completely reliable to identify the chemistry of their parent magma [6,7], hence casting doubt on the cool Early Earth model and the possibility of a modern-like continental crust.

WHAT IS THIS STUDY ABOUT?

✱ REE and Ti in lunar zircons have received little attention compared to terrestrial grains, although the history of lunar zircons is simpler (no metamorphism on the Moon) and they are therefore better candidates to evaluate the usefulness of REE as petrogentic indicators.

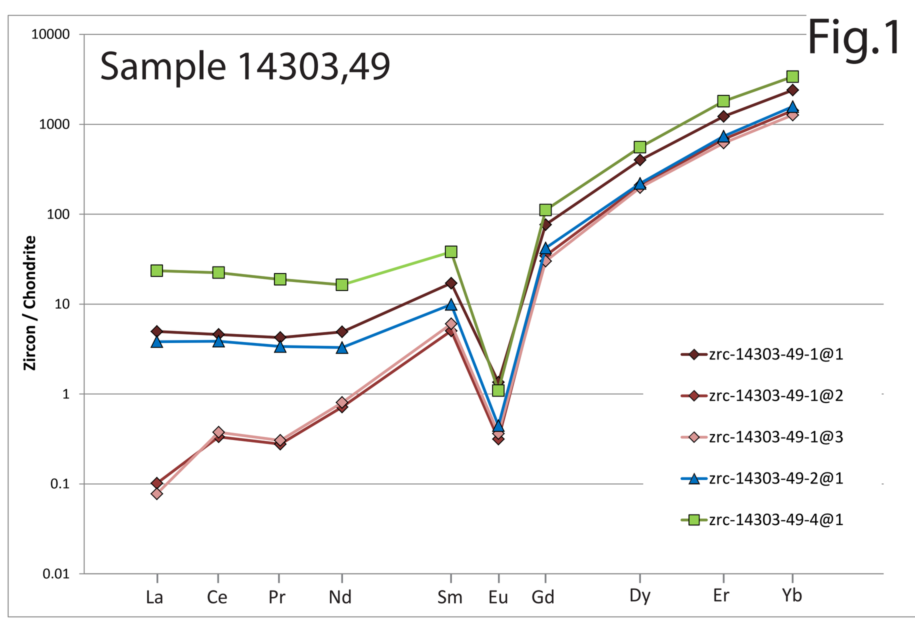
✱ We present new REE and Ti concentrations as well as oxygen fugacity *f*(O_2) on lunar zircons, some of which are enclosed within lithic clasts, so that the parental rock can be identified.

METHODS

✱ REE and Ti were analysed by SIMS (Secondary Ion Mass Spectrometry) on the Cameca 1280 at the NordSIM facility in the Museum of Natural Sciences of Stockholm and on the SHRIMP at the John deLaeter Centre of Curtin University, Perth.

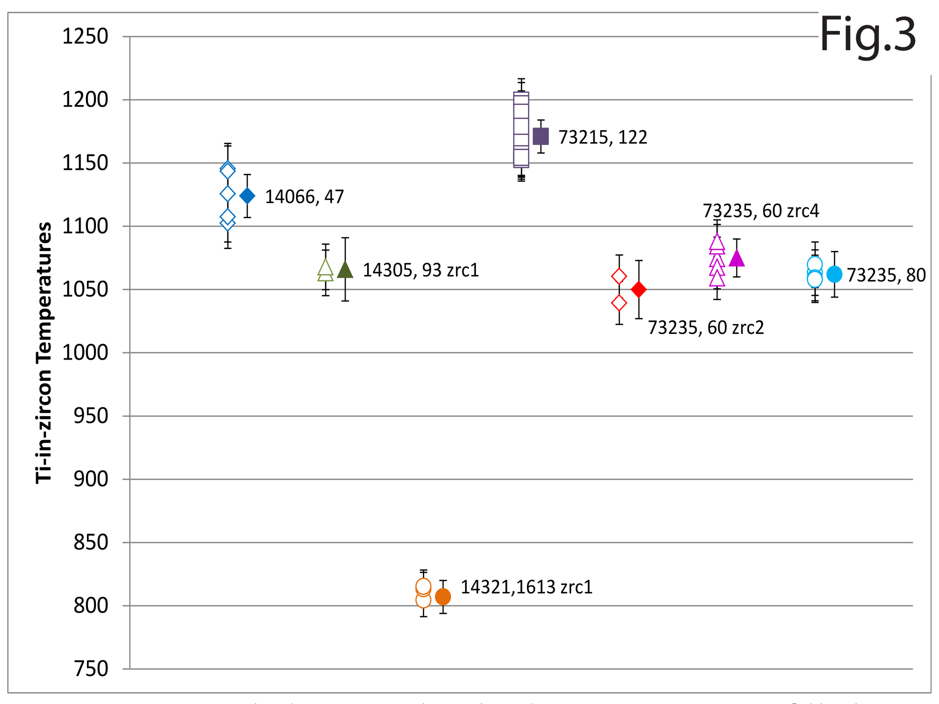
✱ Temperatures were calculated using the thermometer described by [8] and oxygen fugacities using the empirical formula determined by [9].

RESULTS



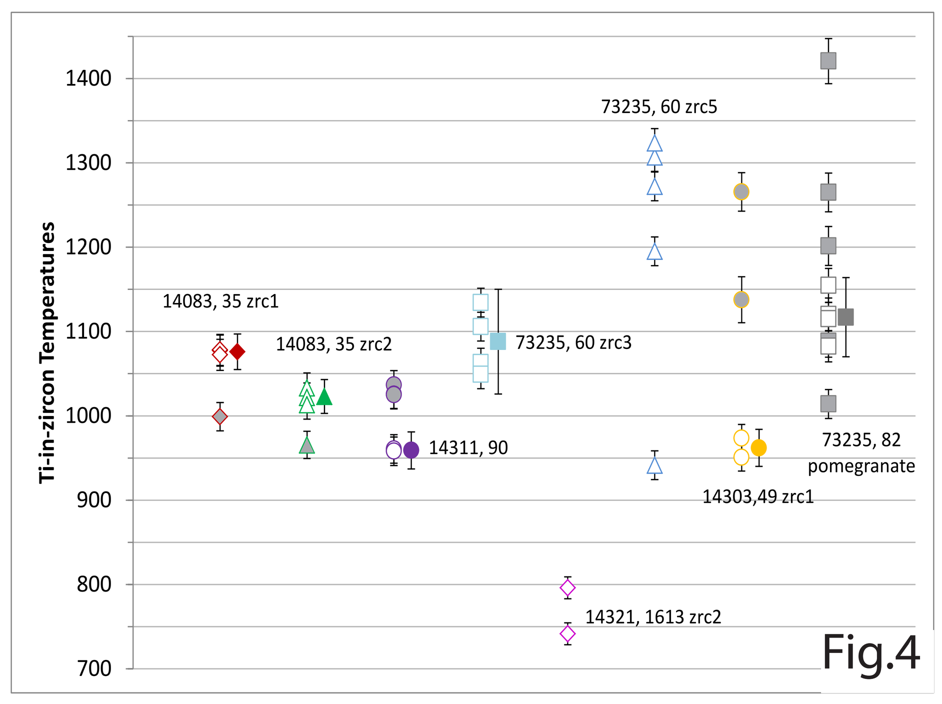
✱ A lot of variability is observed in light REE measured within a single zircon grain (e.g. 14303-49-1 above, in red)

✱ There is no consistency in the REE spectra of zircons located within the same granitic clast (e.g. in 14303, 49)



Empty symbols are individual measurements; filled symbols are weighted averages (2 sigma error)

✱ Some lunar zircon grains show good internal consistency of Ti concentrations which translate into homogenous temperature estimates for individual zircon grains.

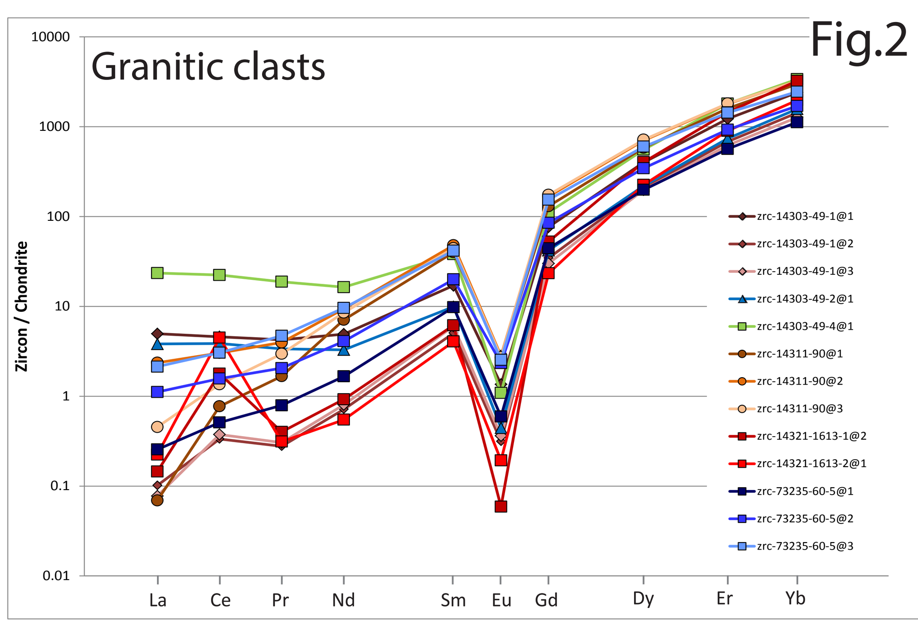


Empty symbols are individual measurements; filled symbols are weighted averages (2 sigma error); grey symbols represent individual data that have been excluded from average calculation. Note that averages cannot be calculated for two zircon grains, given the large spread of data and the absence of solid evidence as to the origin of the spread.

✱ Some zircons have heterogenous distribution of Ti leading to an unrealistic spread of calculated crystallisation temperatures.

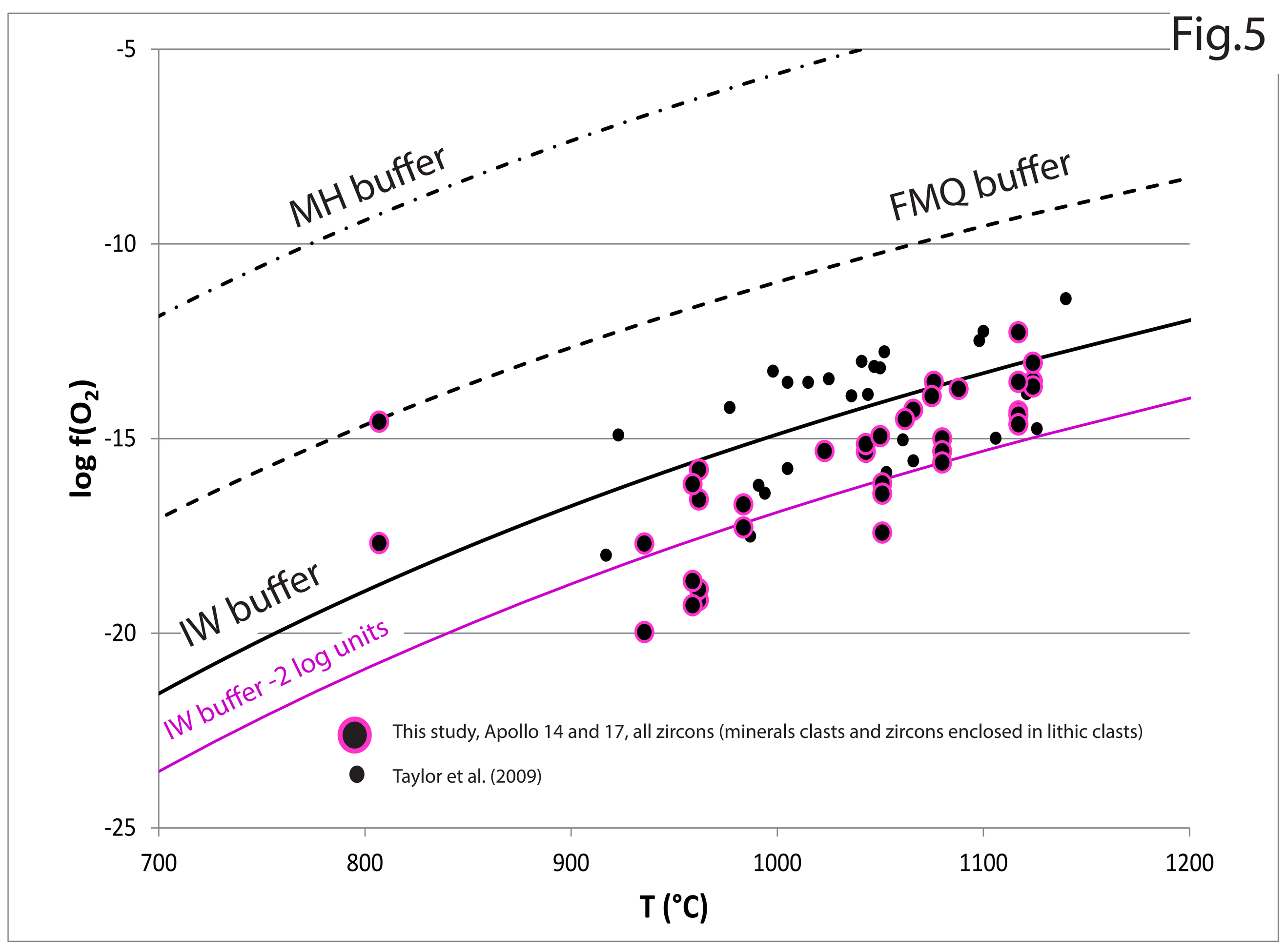
✱ Data show that this can come from foreign Ti filling up micro-cracks of the grains and can be the results of impacts.

✱ However, there seems to be no logical explanation of inhomogeneity in some grains, that show magmatic features and are crack-free.



✱ There is also a lot of variation in REE spectra and concentrations in zircon included within granite clasts from different samples (Fig. 2).

✱ This is also true for other lithic clasts, like QMD and Anorthosite (not shown).



✱ As Ce^{4+} is largely more compatible in zircon than Ce^{3+} and its occurrence is enhanced in oxidising environment, the Ce anomaly in zircon can be correlated to the oxygen fugacity *f*(O_2) of the magma where zircon crystallised.

✱ An empirical formula established by [9] provides a way of calculating *f*(O_2) from Ti-in-zircon temperature and the amplitude of Ce anomaly in the grains.

✱ Results of oxygen fugacity indicate that lunar magmas from which zircons crystallised, are reduced, on or below the Iron-Wüstite buffer curve.

✱ Two grains (sample 14321, 1613) with lower temperature of crystallisation and high Ce anomalies (Fig. 2) indicate noticeable higher *f*(O_2), up to the FMQ buffer.

The fugacity of oxygen measured from all studied zircons plotted against temperature of crystallization as given by Ti-in-zircon. Black dots are data from Taylor et al. [10]

DISCUSSION

REE concentrations measured within single grains and across different grains within the same lithic clasts vary to a larger degree than what is expected for a mineral crystallised from a single batch of magma

➔ REE in zircon may not constitute reliable petrogenetic indicators, as was already pointing out by [6,7].

Variations in Ti concentrations, that translate to variations in T of crystalliation of the zircon, cannot always be correlated to specific physical features of the grains, like micro-cracks or impact features

➔ The distribution of Ti in zircon may be influenced by other, more elusive, parameters such as pressure and TiO_2 activity controlled by the coeval crystallisation of Ti-rich phases.

Although the lunar mantle is characterised by reduced conditions [11] and *f*(O_2) calculated from Ce anomalies in lunar zircons support this result, it is still possible to produce strong positive Ce anomalies in some zircon grains (Fig. 2) that are consistent with oxidising conditions

➔ These anomalies probably reflect very local (sub-mm scale) variations in the melt during crystallisation and cannot be extrapolated to regional conditions within the lunar mantle.

REFERENCES

[1] Wilde et al. (2001) Nature 409:175; **[2]** Valley et al. (2002) Geology 30(4):351; **[3]** Harrison et al. (2005) Science 310:1947; **[4]** Peck et al. (2002) Geochim. Cosmochim. Acta 65(22):4215; **[5]** Harrison (2009) Annu. Rev. Earth Planet. Sci. 37:479; **[6]** Hoskin and Ireland (2001) **[7]** Whitehouse and Kamber (2002) Earth Planet. Sci. Lett. 204:333; **[8]** Ferry and Watson (2007) Contrib. Mineral. Petrol. 154:429; **[9]** Trail et al. (2011) Nature 480:79; **[10]** Taylor et al. (2009) Earth Planet. Sci. Lett. 279:79 **[11]** Wadhwa (2008) Rev. Mineral. Geochem. 68:493.

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