years in age (Ricker et al. 2014). Although the crust of the Earth (Oceanic + Continental) constitutes only ~0.6% of the mass of the present-day silicate Earth, it contains between 20% and 70% of the highly incompatible[14] trace element budget (Rudnick & Fountain 1995). Hence, this explains the elevated Al_2O_3, CaO, Na_2O, TiO_2, and K_2O values when comparing the crustal to the other melts in Table 1. For such crustal melts to co-exist, plate tectonics is likely required (Rudnick & Gao 2014). The presence of Earth-like pla ssitate the presence of a weaker interio es can move, and liquid water is a lik uch a weak layer (e.g. Mierdel et al. 2007).

background information

Observed ating with these compositions could i question has had a recent history of plate presence of liquid water. The fact that ely well mixed with the mantle (Kite et al. 2016) means that the melting of the crust must have occurred very recently due to, for example, a recent giant impact or the host star entering the red giant phase. Therefore it is unlikely that such signatures will be found on targets that are believed to have a long-lived lava ocean. Alternatively, if such signatures are fou ication that the upper layers of the melt n such a way that they resemble crustal anet has a mantle with a unique bulk composition.

gap/need of the study

what is in the paper

4.3. Limitations of 1D equilibrium models

There are obvious predictive limitations of 1D equilibrium models. This is especially true for lava planets where the atmosphere is likely to be confined to the permanently irradiated dayside. Away from the sub-stellar point, the sharp drop in temperature will induce an enormous pressure gradient, causing strong horizontal winds towards the nightside (Castan & Menou 2011; Kite et al. 2016; Nguyen et al. 2020). Material removed via winds is bound to condense at cooler regions, settling down onto the surface, where it may or may not be reincorporated into the outgassing cycle via surface and interior transport. In this study, we have mimicked this effect to some extent using fractional vaporisation, but this is a very simplistic assumption. For a more accurate assessment of observability, 2D circulation models combined with simplified outgassed chemistry and radiative transfer may prove t tep.

Use of equilibriu ignores the potential effects of photo ixing. Photochemical destruction/ioni s, e.g., SiO or Na, may cause substanti ucture and observability of the specific species. Decrease in shortwave absorption will result in weaker thermal inversions. This effect is apparent with evolved cases, where Na is removed from the system while SiO abundance is slightly reduced (Fig. 8). Approximations of SiO photochemistry done by Ito et al. (2015) show that only pressures below 10^{-5} bar would be strongly affected, however, the significance is unclear without employing full kinetic photochemistry networks. The possibility of photochemical haze formation is also not considered.

key results with evaluative comments

5. Conclusions

Characterisation of lava worlds is exciting new frontier to be explored in the imminent future. Decade old studies have predicted formation of silicate-rich atmospheres, outgassed from the molten surface of irradiated planets (Schaefer & Fegley 2009; Miguel et al. 2011). With the launch of JWST, the topic has received more interest than ever, including many predictive and observational studies (Ito et al. 2015; Kite et al. 2016; Dai et al. 2019; Nguyen et al. 2020; Ito & Ikoma 2021; Zieba et al. 2022). Several lava planets have been confirmed for the initial observers programme of JWST, which may lead to first evidence of silicate atmospheres on exoplanets (Hu et al. 2021; Brandeker et al. 2021; Dang et al. 2021; Espinoza et al. 2021).

As current theory predicts, these atmospheres should be depleted in highly volatile material. Thus characterisation with low resolution spectroscopy is likely to be only feasible via infrared emission coming from the dayside of the planet. In this work we have modelled 1D outgassed equilibrium chemistry consistently with radiative-transfer for all currently confirmed short period rocky exoplanets. We have considered a large number of possible species, including ions, as well as all up to date opacities. Finally, we have assessed observability of the best targets with the MIRI LRS instrument. Our results indicate the following:

1. Thermal inversions may not be as dominant in silicate atmospheres as previously thought. We find that inversions extend all the way to the surface only for planets with sub-stellar temperatures below 2000 K. With larger surface temperature, due to increasing IR dominance over shortwave opacity inversions weaken and become confined to the upper atmospheric regions. Inversion strength also decreases with decreasing stellar temperature, implying that lava planets around M and K dwarfs may show only slightly increased emission flux, if any at all. This severely impacts characterisation of silicate atmospheres;
2. The dominant opacity sources for non-evolved silicate atmospheres with sub-stellar temperatures >2500 K are SiO, SiO_2, MgO, Na and TiO. Excluding these absorbers from models may result in inaccurate temperature–pressure profiles;
3. The best observable features come from silicon oxides, specifically 7 µm SiO_2 and 9 µm SiO bands. SiO_2 is confined to the lower, cooler regions, manifesting as absorption features. SiO is highly abundant in the low pressure, inversion dominated regions. While our temperature result in relatively small atmospheric features, we find that for the best targets, observations of only a few eclipses with MIRI LRS are needed for a detection;
4. The composition of the melt and possible volatile removal from the system will impact observability. Fractionally evolved atmospheres will have reduced SiO and SiO_2 features and will prove much more difficult to characterise. Large flux from TiO (<1 µm) could suggest atmospheres outgassed from melts resembling the Earth's Continental or Oceanic crust. Detection 11-16 µm SiO_2 features imply depletion of MgO, which is also characteristic of crust-like compositions. Detection of certain atmospheric abundances may allow us to constrain melt compositions, surface activity and even interior dynamics;
5. The recommended targets for silicate atmosphere characterisation with low resolution infrared spectroscopy are lava planets with sub-stellar temperatures of at least 2500 K that ideally orbit cooler K dwarfs. Some of the currently confirmed planets to keep an eye on include: TOI-1807 b, 55 Cnc e, TOI-2431 b, K2-141 b, HD 3167 b, TOI-561 b, HD 213885 b. 55 Cnc e and K2-141 b are confirmed for the JWST Cycle 1 GO programme.

[14] (In)compatibility is a geochemical term used to describe how easily a minor or trace element is able to replace major elements in a mineral.

limitations, potential directions of future research

We stress the fact that 1D equilibrium models are limited in their predictability. The large temperature contrast between the day and the night side, circulation and interior effects, photochemistry and kinetics are all likely to influence the thermal structure and atmospheric abundances. There is also a need for more accurate modelling of opacities, accounting for pressure broadening effects and the high temperatures of silicate atmospheres.

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