

This looks like a great paper and more data-driven methods can definitely benefit the relative young science of exproation targeting for REE deposits, particularly those related to alkaline and carbonatite complexes. Looking forward to reading it when it is published! I do have some minor comments and corrections regarding the geochemical and petrological aspects of this paper.

We are very grateful for the encouraging remarks and welcome the constructive comments. Please see our responses to the comments in blue below-

line 32: Although IUPAC includes this entire list, Pm is an unstable element and for practical reasons in geology does not exist. It is better to remove it. Scandium also probably does not belong here, as it is not an element that is generally associated with the other REEs, and it not sourced from carbonatites and alkaline complexes.

Response: We appreciate your suggestion and agree that Pm is an unstable element, not found in nature and that Sc is generally not associated with other REEs sourced from carbonatites and alkaline complexes. However, they were included in the list as the IUPAC recognised list was being quoted. To implement this aspect, we will, however, add the statement in the revised version: "However, since Pm is an unstable element and Sc is not an element sourced from carbonatites-alkaline complexes, this study does not claim to have these elements as part of the targeting outputs." in line 94 to make the reader aware of this.

line 45: Placers are the major source in India, but not globally. The largest operating REE mine is Bayan Obo, which is indeed a high temperature carbonatite.

Response: We acknowledge the error and thank you for pointing it out, we intend to rephrase the sentence in line 44 and 45 to "Although the majority of **Indian** production of REEs comes from low-temperature deposits such as regolith-hosted and heavy-mineral placer (IBM yearbook 2018, 2019), the bulk of geological resources are in high-temperature magmatic deposits, particularly those associated with carbonatites (e.g., Bayan Obo, Inner Mongolia, China; Mount Weld, Western Australia; Maoniuping, South China; Mountain Pass, USA etc.; Gonzalez-Alvarez et al., 2021 and references therein)."

lines 62-73: Is a list of all approaches necessary? If yes, then I think it would look better in a table. It is challenging to read as it is now, in paragraph text.

Response: We agree with your suggestion and plan to remove the paragraph in the next revision.

line 91: You're saying that "no deposit has been identified in the province so far", but in Table 1 you're showing Kamthai, which has a delineated resource estimate?

Response: You are very right. Thank you for flagging this. During the next revision, the sentence in line 91 will be rephrased as "Although a well-established carbonatite province that is widely considered prospective for REE deposits, **just a single** deposit has been identified in the province so far."

line 165: Reactions between carbonatites and country rocks are very common in carbonatites, and it is correct that these reaction remove CO₂. However, it has very little to do with the enrichment in REE. If anything, it allows REE to be deposited into REE-rich silicate minerals, essentially removing REE from the melt. This has been discussed in detail in our own work (Anenburg & Mavrogenes 2018, available <https://doi.org/10.2475/03.2018.03> or open access at <http://hdl.handle.net/1885/143148>)

REE are enriched in carbonatites primarily because they are incompatible elements, and Na+K in the melt allow them to be soluble all the way down to the final stages of magmatic fractionation, causing their enrichment in the last batches of carbonatite melt. See our work (Anenburg et al 2020 available open access at <https://doi.org/10.1126/sciadv.abb6570>)

Response: We thank you for the suggestions and new references provided. This input has greatly improved the model. The paragraph (lines 165 – 175) will be modified as follows in the upcoming revision to adapt the new references –

“The crystallisation of carbonatites and alkaline complexes along with reactions with the country-rock to form Ca and Mg silicates is accompanied by the removal of CO₂, dissolved P and F (Skirrow et al., 2013; Jaireth et al., 2014). The above reactions may **cause REEs to deposit in silicate minerals along the country rock interface (Anenburg & Mavrogenes 2018; Anenburg et al., 2020). eEnrichment of incompatible elements such as REEs, U, Th, Nb, Ba, Sr, Zr, Mn, Fe, Ti in the fluids occur due to liquid immiscibility, especially in liquids rich in alkalis which promote REE solubility** (#10, 13, 14, 15, 16, 17, 18, 19 in Fig. 3 and Table 3; Cordeiro et al., 2010; Skirrow et al., 2013; Jaireth et al., 2014; Pirajno, 2015; Mitchell, 2015; Chakhmouradian et al., 2015; Stoppa et al., 2016; Poletti et al., 2016; Giovannini et al., 2017; Simandl and Paradis, 2018; Spandler et al., 2020; **Anenburg et al., 2020**). Carbonatite-alkaline complexes are often enriched in ferromagnesian minerals that cause well-defined magnetic and gravity anomalies (#9 in Fig. 3 and Table 3; Gunn and Dentith, 1997; Thomas et al., 2016). Fenitisation often enriches country rocks in K and Na (#12 in Fig. 3 and Table 3; Le Bas, 2008; Elliott et al., 2018). **In alkali rich intrusions, LREEs are retained in the primary carbonatite while HREEs tend to concentrate in Fenites, particularly K-Fenites; whereas in silica-rich or alkali-poor intrusions, HREEs remain in the carbonatite (Anenburg et al., 2020). Size and HREE/LREE concentration of the fenites halo are a major proxy.**”

line 175: These late stage minerals are often in-situ replacement of two minerals: burbankite and carbocernaite, which are probably the two most important primary REE minerals in carbonatites, but because of their solubility, they are rarely preserved. Typically, currently observed REE minerals don't precipitate from hydrothermal fluids as you stage in your line 173, rather they are the result of local redistribution of REE after burbankite and carbocernaite are dissolved, and their REE component remain immobile. See for example the Anenburg et al 2020 paper I referred to earlier, and these two relevant papers by Kozlov et al (<https://doi.org/10.3390/min10010073>) and Andersen et al (<https://doi.org/10.1016/j.oregeorev.2017.06.025>)
Also please correct mineral name from "parasite" to "parisite".

Response: The added information and references have greatly improved the model and we are very grateful for your insightful inputs. We also thank you for pointing out the spelling error. It will be corrected in the next revision. The paragraph (lines 176 – 183) will also be modified as follows –

“Rare earth element mineralisation in the carbonatites can be in the form of primary REE-bearing minerals (e.g., Mountain Pass, Mariano, 1989; Castor, 2008; Verplanck and Van Gosen, 2011; Van Gosen et al., 2017) **or by secondary hydrothermal activity, including in-situ replacement, or from late magmatic fluid phases expelled from the carbonatite magmas** (Verplanck and Van Gosen, 2011; Skirrow et al., 2013; Jaireth et al., 2014; Van Gosen et al., 2017). Primary REE-bearing cumulates include perovskite, pyrochlore, apatite and calcite, while late-stage REE-bearing minerals include bastnäsite, **parisite, and synchysite that form from the redistribution of soluble primary phases such as ancylite, burbankite and carbocernaite** (#24 in Table 3; Verplanck and Van Gosen, 2011; Skirrow et al., 2013; Van Gosen et al., 2017; **Andersen et al., 2017; Anenburg et al., 2020; Kozlov et al., 2020**).”

line 185: Something which should be highly relevant for your modelling is the decoupling between LREE and HREE in carbonatites and fenites. Our experimental study (Anenburg et al 2020 above) demonstrated that LREE are retained inside the carbonatite, whereas HREE tend to be mobilised outwards into fenites. This is also observed in nature: see example papers by Andersen et al and Broom-Fendley et al:

<https://doi.org/10.2138/am-2016-5532>

<https://doi.org/10.1016/j.oregeorev.2016.10.019>

<https://doi.org/10.2138/am-2016-5502CCBY>

Response: Thank you very much for your valuable suggestions. We have included it in the model and we think it has greatly benefitted from your suggestion. We now have an

added vector towards mineralised zones which would be very relevant for camp scale exploration studies.