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Reply to the comment on “Ti-poor high-Al chromitites of the Moa-Baracoa ophiolitic massif (eastern Cuba) formed in a nascent forearc mantle” by Rui et al. [Ore Geol. Rev., 104847]

Hui-Chao Rui[a], Jing-Sui Yang[b,c,*], Angélica I. Llanes Castro[d], Jian-Ping Zheng[a], Dong-Yang Lian[b], Wei-Wei Wu[b], Yurisley Valdes Mariño[e]

[a] School of Earth Sciences, China University of Geosciences, Wuhan 430074, China
[b] School of Earth Sciences and Engineering, Nanjing University, Nanjing 210023, China
[c] Center for Advanced Research on the Mantle (CARMA), Chinese Academy of Geological Sciences, Beijing 100037, China
[d] Department of Petrology and Mineralogy, Institute of Geology and Paleontology, Havana 10200, Cuba
[e] High Mining Metallurgic Institute of Moa “Dr. Antonio Nunez Jimenez”, Moa 83310, Cuba

1. Introduction

We appreciate Pujol-Solà et al. (2022) for their important comments and the opportunity to further discuss the formation of podiform chromite deposit in the Moa-Baracoa Ophiolitic Massif (MBOM). The comments mainly include two points of discussion about our paper (Rui et al., 2022a). They question (1) definition of a new type of Ti-poor high-Al chromitite, and (2) proposal of ultrahigh-pressure (UHP) Cr-spinel in the studied chromitites. Our reply is given below.

2. Ti-poor high-Al chromitite

The Cayo Guam deposit is not a single chromite orebody. As Rui et al. (2022a) described in text and shown in Fig. 1c and d, the Cayo Guam chromite deposit “contains dozens of orebodies”. The term “Ti-poor high-Al” was used to describe the chemical features of studied Cayo Guam chromitites of the MBOM (Rui et al., 2022a). We all agreed that our samples could not reflect all chemical and structural characteristics of a large number of MBOM chromitites. In fact, Ti-rich chromitites containing Cr-spinel with TiO_2 contents up to 0.5 wt% (our unpublished data) are also observed in the Cayo Guam chromitites. However, these samples are closely contacted with gabbro dykes in the field. Most Cr-spinel grains from these Ti-rich chromitites commonly have lamellar exsolutions of ilmenite and/or rutile. Similar features were also reported in the Mercedita and Potosí chromite deposit of MBOM (Proenza et al., 2001; Pujol-Solà et al., 2018; 2020a). We preliminarily infer that Ti-rich chromitites are resulted from metasomatism of parental magma of the gabbro dykes. Therefore, these Ti-rich chromitites subject to metasomatism are not included in Rui et al. (2022a), because this paper aims to discuss the magmatic process in the origin of Cayo Guam chromitites. As to the Ti-poor chromitites, Rui et al. (2022a) have also noticed that “A few occurrences of such Ti-poor high-Al chromitites have been reported, such as the Zambales ophiolite in Philippines (TiO_2 = 0.05–0.22 wt%, Zhang et al., 2020) and the Dongbo ophiolite in Tibet (TiO_2 < 0.15 wt%, Xiong et al., 2017)”, but they have never defined these “Ti-poor high-Al” samples as a new type of chromitite.

3. High-pressure (HP) fingerprints in the massive chromitites

3.1. Diamonds in the MBOM

We noted that Pujol-Solà et al. (2020b) reported *in situ* diamond hosted below the polished surface of olivine in chromitite and gabbro at the deposit of Potosí of MBOM, which was already quoted in the Introduction part of Rui et al. (2022a). However, we also noted that Pujol-Solà et al. (2020b) proposed that these diamonds were formed at low pressure (<200 MPa) based on thermodynamic modelling of the solid and fluid assemblage in diamond-bearing inclusions. We value this interpretation from Pujol-Solà et al. (2020b), however, since we have already made comments on the same idea of “A shallow origin for diamonds in ophiolitic chromitites” (Yang et al., 2019), it is not appropriate to discuss this issue again in this new paper.

3.2. Genetic connection between gabbros and chromitites

In the Moa-Baracoa district, gabbro sills and dykes commonly occur

* Corresponding author at: Qixia District, Nanjing, Jiangsu Province, China.
E-mail address: yangjsui@163.com (J.-S. Yang).

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in or nearby the chromitite bodies of MBOM, and different opinions have been proposed for their genesis (e.g., Proenza et al., 1999; Marchesi et al., 2006; Pujol-Solà et al., 2018; González-Jiménez et al., 2020; Rui et al., 2022b). We all agree that gabbros show no evidence of HP or UHP metamorphism, however, the genetic connection between gabbros and chromitites is still unclear. In fact, these gabbros mostly are not syngenetic with the massive chromitites (see details in 3.3), thus it is obviously unreasonable to deny HP fingerprints in massive chromitite by the existence of unmetamorphosed gabbros. Rui et al. (2022a) identified both HP and Low-pressure (LP) Cr-spinel grains in the massive chromitites based on microstructural observations, and proposed that the HP Cr-spinel traveled upward with parental melt, deposited together with the LP Cr-spinel to form massive chromitites in the shallow mantle (Fig. 16, Rui et al., 2022a). To be brief, the massive chromitites may remain some HP Cr-spinel grains when they were rising from relatively deep mantle and recrystallized with ambient P-T environments. This model also fits well with field and petrological observations of gabbro sills and dykes.

3.3. Silicate exsolution lamellae in Cr-spinel

Pujol-Solà et al. (2018) argued that the chromite grains containing clinopyroxene lamellae were not derived from UHP conditions, according to (i) gabbro sills contacted with chromite orebodies show no evidence of HP/UHP metamorphism; and (ii) chromite grains yielded Raman spectra similar to the low-pressure chromite.

Gabbros are intimately associated with orebodies in the region. Abundant interstitial clinopyroxene, plagioclase inclusions, and ilmenite and/or rutile lamellae within chromite can be traced in the proximities to the gabbros (Pujol-Solà et al., 2022), convincingly suggesting that these chromites were strongly metasomatized by the parental magma of gabbros. Similar occurrences were documented in Potosí of MBOM and discussed in detail by Pujol-Solà et al. (2020a) and González-Jiménez et al. (2020). It should be not difficult to conclude that this metasomatism event has no directly genetic relationship with chromite deposit.

Origin of silicate exsolution lamellae in Cr-spinel is still in debate (e.g., Chen et al., 2019; Liu et al., 2020; Yamamoto et al., 2009; Pujol-Solà et al., 2018). Pujol-Solà et al. (2022) provided an example that Liu et al. (2020) documented clinopyroxene lamellae coexisted with apatite in chromite grains from the Stillwater Complex, a typical type of stratiform chromite deposit, and proposed that the silicate lamellae represent trapped melt inclusions, with a conclusion that "clinopyroxene exsolution in chromite grains do not necessarily involve exsolution from a UHP phase". We have no question for this, because as far as we known, similar lamellae composed of clinopyroxene + apatite has never been reported in Cr-spinel of podiform chromitites.

As for the Raman spectra patterns of chromite grains are different

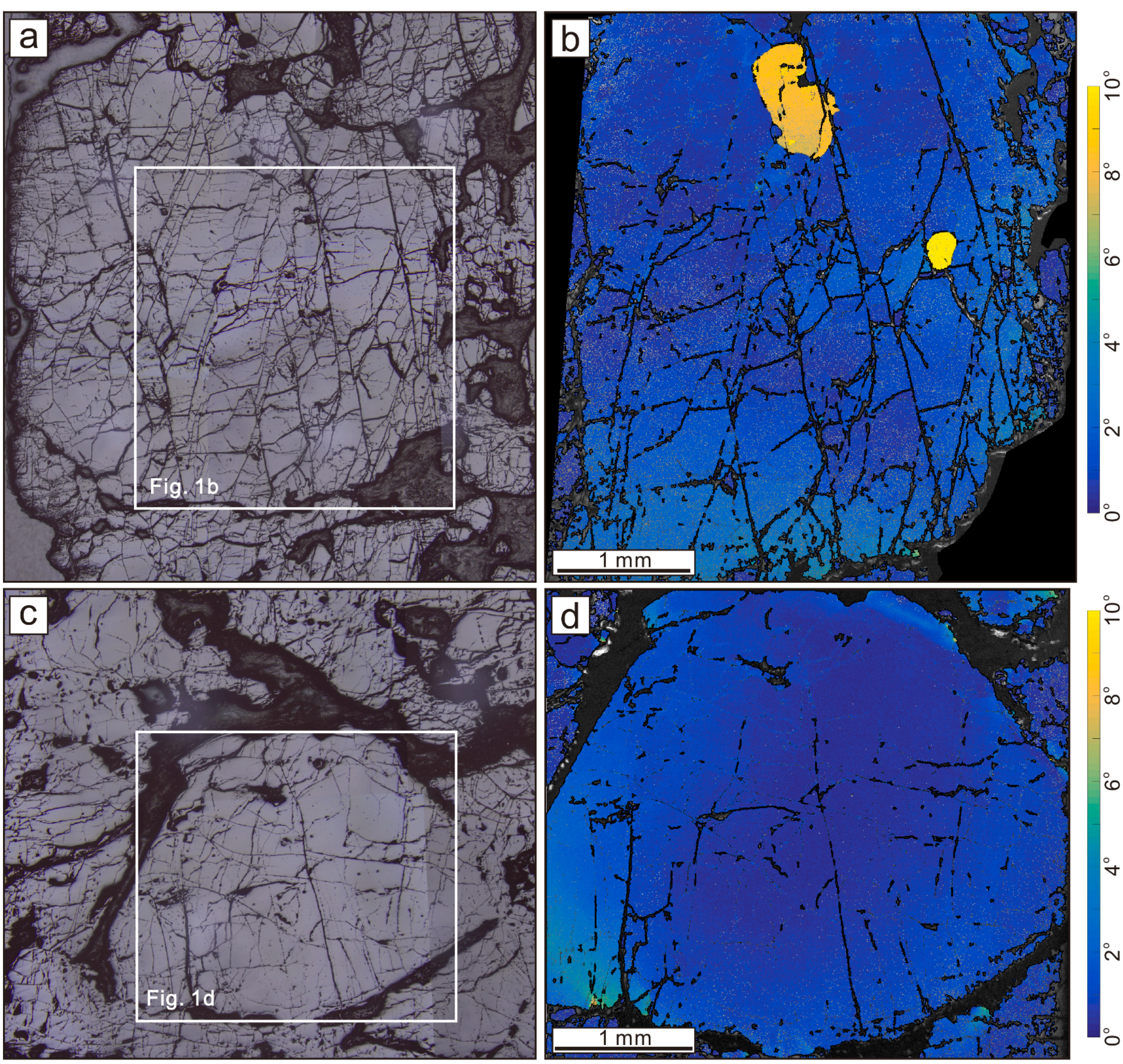

Fig. 1. EBSD misorientation mapping of representative Cr-spinel grains in massive chromitites from the Cayo Guam area.

from UHP chromite (12 GPa) observed by Pujol-Solà et al. (2018), it is not unusual because the coesite-bearing chromite (>3 GPa) also display Raman spectra similar to the low-pressure chromite (Yamamoto et al., 2009). Thus, integrated considerations of quantity of silicate lamellae, microstructure of chromite, and other evidence is necessary to discriminate LP from (U)HP chromite. Generally, dense lamellae of clinopyroxene in chromite is still considered as result of exsolution upon exhumation from HP to UHP conditions (e.g., Colás et al., 2020; González-Jiménez et al., 2017; Xiong et al., 2022).

3.4. Olivine chemistry

In an individual chromite deposit, olivine grains in chromitites usually have higher Fo values and NiO concentrations than those from surrounding peridotites, which is generally attributed to subsolidus re-equilibration between olivine and Cr-spinel (e.g., Leblanc et al. 1984; Proenza et al., 1999; Yang et al., 2015; Arai and Miura, 2016; Xiao et al., 2016; Xiong et al., 2022). Rui et al. (2022a) also interpreted that the high Fo and NiO contents of the olivines from the Cayo Guam chromitites are resulted from cation exchange and/or redistribution during subsolidus re-equilibration. It should be noticed that some olivine inclusions from the massive chromitites have extremely higher Fo (up to 97.2) and NiO (up to 1.12 wt%) than olivine inclusions and matrix from the semi-massive samples (Fig. 5a, Rui et al., 2022a). Since the diffusion coefficients of Mg and Ni in olivine are generally positively correlated with temperature (Jollands et al., 2016; Chakraborty, 1997), significantly high Fo values and NiO contents indicate Mg and Ni redistribution into olivine in the massive chromitites during high-temperature or long-time re-equilibration. In addition, such high Fo values and NiO contents are also documented in olivine from UHP chromitites in Tibet (Fig. 5a, Rui et al., 2022a).

3.5. Microstructural characteristics of overgrowth

To further check the microstructural characteristics of chromitite, EBSD analysis for additional two massive chromitite samples from the Cayo Guam area were performed at CAGS. The detailed analytical processes are same as those described by Rui et al. (2022a). Since the working area of EBSD detector in polished section is limited, it is difficult to obtain complete mapping for very large Cr-spinel grains. For the chromite, edge effects and polishing artifacts were only caused by broad ion beam polishing, resulting in small misorientations (<2°) (Vukmanovic et al., 2013). Our thin sections were mechanically polished by abrasive materials, and they would not be obviously affected by edge effects or polishing artifacts.

EBSD mapping for additional two samples are present in Fig. 1. To avoid effect of cherry-picking of the coordination point for measuring the deviation angle, misorientation of Cr-spinel was displayed relative to crystal average orientation. EBSD mapping reveals that Cr-spinel grains suffered weak to strong crystal-plastic deformation and one large Cr-spinel crystal contains at least two small Cr-spinel grains (Fig. 1a–b). Combined with healed fractures, relict Cr-spinel subgrains (Rui et al., 2022a), and small Cr-spinel inclusions (Fig. 1a–b), our EBSD data suggested the overgrowth of large Cr-spinel crystal on pre-existing Cr-spinel grains during HP/high-temperature conditions (e.g., Xiong et al., 2017). Pujol-Solà et al. (2022) noticed similar misorientation of chromite grains from un-(U)HP metamorphosed Bushveld chromitites (e.g., Vukmanovic et al., 2013) and ophiolitic chromitites (e.g., Prichard et al., 2015). However, the chromite grains in their samples are usually small in size and have not experienced obviously overgrowth on pre-existing chromite crystal (Prichard et al., 2015; Vukmanovic et al., 2013).

4. Concluding remarks

The term "Ti-poor high-Al" was used to describe the chemical features of studied Cayo Guam chromitites of the MBOM, which has never been defined as a new type of chromitite. After integrated considerations of microstructural and mineralogical features, Rui et al. (2022a) found that some Cr-spinel grains in the massive chromitites show HP characteristics, and inferred that these grains start to crystallize at relatively deep mantle. UHP Cr-spinel was not identified or proposed in our study.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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