学位論文要旨

Integrated petrogenesis of podiform chromitites

（ポディフォーム・クロミタイトの統合的成因論）

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要約

Podiform chromitites are well known as one of key rocks in ophiolites to interpret the genesis of ophiolite, although their abundance is very low. They have been interpreted as shallow magmatic products at the uppermost mantle. However, they still remain some serious problems such as the existence of UHP (=ultrahigh-pressure) minerals in some chromitites from Tibet and the Polar Urals. In this study, I re-examined and compared some chromitite pods from the Oman, Tibet and Polar Ural ophiolites with chromitite xenoliths from the Takashima alkali basalt in terms of petrographycal characteristics to constrain the genesis of podiform chromitite. Ophiolitic chromitites are classified into two types, LP (low-pressure) and UHP, based on the presence or absence of UHP minerals. The two types are also quite different in petrographycal characteristics, such as inclusion in spinel. Furthermore, the LP chromitites from Oman are divided into two types in terms of differences in their involved magma and tectonic setting of the formation. I propose a new classification of ophiolitic podiform chromitites based on geological and petrographical characteristics, and revealed the relationships between chromitite formation and mantle dynamics.

学位論文要旨

The genesis of podiform chromitites from the Oman ophiolite

Podiform chromitites in ophiolites are classified into two types, discordant and concordant, in terms of structural relatiohship with foliation of surrounding harzburgite (Cassard et al., 1981). I selected three discordant pods along Wadi Hilti, Rajmi and Fizh, two concordant pods along Wadi Hilti and Rajmi, and one MTZ chromitite pod from Wadi Rajmi for this study. Discordant chromitite pods in the mantle section along Wadi Hilti, Rajmi and Fizh, have some arc-related features. Numerous inclusions of primary hydrous mineral, e.g., pargasite and Na phlogopite (Figs. 1a, b & c), in spinel from discordant pods suggest that hydrous magma was involved in formation of chromitites. Chromian spinels from discordant pods and dunites are characterized by high Cr#s (around 0.65 to 0.78) and low TiO_2 (up to 0.2 wt%) contents, an arc-related feature (Arai et al., 2011) (Fig. 2). Harzburgites adjacent to discordant pods also show high depletion of magmatic components, i.e. high Cr#s and low TiO_2 contents of spinel and low HREE contents in clinopyroxene (Fig. 2). Trace element characteristics of clinopyroxene in dunites enveloping Hilti and Fizh discordant pods suggest that high-Mg andesitic, such as boninitic, melts were involved in their formation (Fig. 3). Their characteristics are actually similar to those of boninite found in the northern Oman ophiolite (Ishikawa et al., 2005), as well as of the boninitic melt expected to be in equilibrium with the harzburgite-dunite-orthopyroxenite suite, from the northern Oman ophiolite (Tamura and Arai

2006) (Fig. 3b). Such arc-related magmas were probably generated by flux melting of depleted harzburgite, based on LREE enrichment in spinel and clinopyroxene from the harzburgites adjacent to discordant pods (Fig. 3a). In the case of the harzburgite surrounding the discordant pod along Wadi Hilti, we can see the transition from sub-arc mantle to sub-oceanic mantle peridotite within several meters, in terms of spinel chemistry and clinopyroxene trace-element chemistry. These observations from the surrounding peridotites of Hilti discordant pod suggest that the melt/harzburgite reaction plays an important role in the evolution or formation of boninitic magma and chromitite in the sub-arc uppermost mantle.

Concordant pods along Wadi Hilti and Rajmi are distinctly different from the discordant pods in mineral chemistry and in micro-inclusions in spinel. Spinels from the concordant pods and surrounding peridotites show low Cr#s, around 0.5 to 0.65, possibly showing a sub-oceanic feature (e.g., Arai et al., 2011) (Fig. 2). They contain primary hydrous mineral inclusions as in the discordant pods, although they are far less abundant and smaller in size than in the latter (Fig. 2f). Numerous pyroxene lamellae are typically available only from the concordant pods (Figs. d & e). In addition, olivines in the dunite enveloping a concordant pod along Wadi Hilti, are extraordinarily high in Ni content, suggesting Ni diffusion from the chromitite. Exsolution of silicate lamellae in spinel and subsolidus Ni diffusion in olivine from dunite envelope were probably due to longer duration of subsolidus cooling.

Coexistence of the two contrasted types of chromitites in the Oman ophiolite reflects the switch of tectonic setting from oceanic mantle to sub-arc mantle. The involved melt was clearly different between the two types of chromitite. The concordant chromitite and surrounding peridotites have a sub-oceanic affinity, and the discordant pods and surrounding rocks show an arc-related feature. The former have probably experienced longer duration of subsolidus cooling, which facilitated the exsolution of silicate lamellae in spinel and Ni diffusion in olivine from the dunite envelope. The longer duration of cooling was due to transportation and deformation of the pod by horizontal mantle flow after chromitite formation at a spreading ridge. The discordant chromitites, dunites and surrounding highly depleted harzburgites were probably formed by arc-related magmatism at the supra-subduction zone environment before ophiolite obduction. In addition, both the concordant and discordant chromitites are of low-P origin because of the existence of primary amphibole mineral inclusion in spinel and the lack of UHP minerals.

The Takashima chromitite xenoliths and their implications

The Takashima chromitite xenoliths were compared with a discordant chromitite from the Oman ophiolite. The Takashima chromitites are characterized by various textures, e.g., massive, layered, anti-nodular and nodular (Arai and Abe 1994). Chromian spinels from the Takashima chromitite and dunite xenoliths show high Cr#s and low TiO_2 contents, suggesting an arc-related feature (e.g., Arai et al., 2011) (Fig. 4a). Laurites, one of typical PGMs in ophiolitic chromitite (e.g., Ahmed and Arai 2002), were found as minute (up to 5 μm diameter) soliary grains of euhedral to subhedral shape in spinel from the Takashima chromitites. Chemical characteristics of laurite grains in the Takashima chromitites are analogous to those in ophiolitic chromitites. Silicate inclusions, showing a concentric distribution in spinel, are mainly composed of pyroxenes and olivine. Hydrous minerals, such as pargasite and Na phlogopite, are not found from the Takashima chromitites. The chondrite-normalized PGE patterns of the Takashima chromitite xenoliths show slightly negative slopes from Ru to Pt, and low Pd/Ir ratios (0.08 to 0.25), similar to those of typical ophiolitic chromitites (Fig. 4b). The Takashima chromitites are quite similar in their textural variations, spinel chemistry and PGE chemistry to some of discordant chromitite pods from the northern Oman ophiolite, indicating a sub-arc origin for the latter.

The Takashima chromitites possibly occur in a thick MTZ, beneath Takashima because of their PGE chemical characteristics and the lack of associated mantle harzburgite xenoliths (Arai et al., 2001). Some of ophiolitic chromitites, showing similar characteristics to the Takashima chromitite xenoliths, probably are of sub-arc origin. Charactersitics of the Takashima chromitites indicate an origin of ophiolitic chromitites and a tectonic setting for host ophiolite formation.

The origin of UHP chromitites from Luobusa and Ray-Iz ophiolites

UHP chromitites from the two ophiolites are similar to each other. They are mostly concordant to the foliation of surrounding peridotite, suggesting their deformation via mantle convection flow. As the evidence supportive of deformation at high-T condition, spinels from both UHP chromitites are sometimes cut by olivine-filled fracture. Spinels from the two UHP chromitites show high Cr#s (around 0.8 to 0.85) and low TiO_2 contents (up to 0.2 wt%), indicating their arc-related feature (e.g., Arai et al., 2011) (Fig. 5). Olivines in the two UHP chromitites are sometimes characterized by extraordinarily high Mg (Mg#= around 0.98) and Ni contents (up to 1.2 wt%) (Fig. 5), suggesting long duration of subsolidus cooling. This is consistent with the existence of numerous pyroxene exsolution lamellae in spinels (Figs. 1g, h & i). UHP chromitites from both the ophiolites are classified into two types in terms of mineral species as inclusion in spinel. One is characterized by coexistence of coesite lamella (Yamamoto et al., 2009) and primary Na amphibole inclusion in spinel. The other is free of primary Na amphibole inclusions. Coexistence of coesite and Na amphibole in the former spinel indicates their experience of relatively low-T (around 700 to 800 °C) and high-P (around 3 GPa) conditions (e.g., Niida and Green 1999). If we consider geotherms of the upper mantle, the former can be formed by UHP metamorphism in a subduction zone environment rather than deep mantle igneous origin beneath the mid-ocean ridge. On the other hand, the latter are possibly of deeper mantle origin than the former because of the absence of primary Na amphibole inclusion in spinel. Their similarity to chromitites of the Higashi-Akaishi ultramafic complex, which experienced high-P metamorphism in a subduction zone environment, suggests that some of the characteristics of the UHP chromitites can be formed by compression of low-P chromitites, such as deep recycling (cf. Arai 2013).

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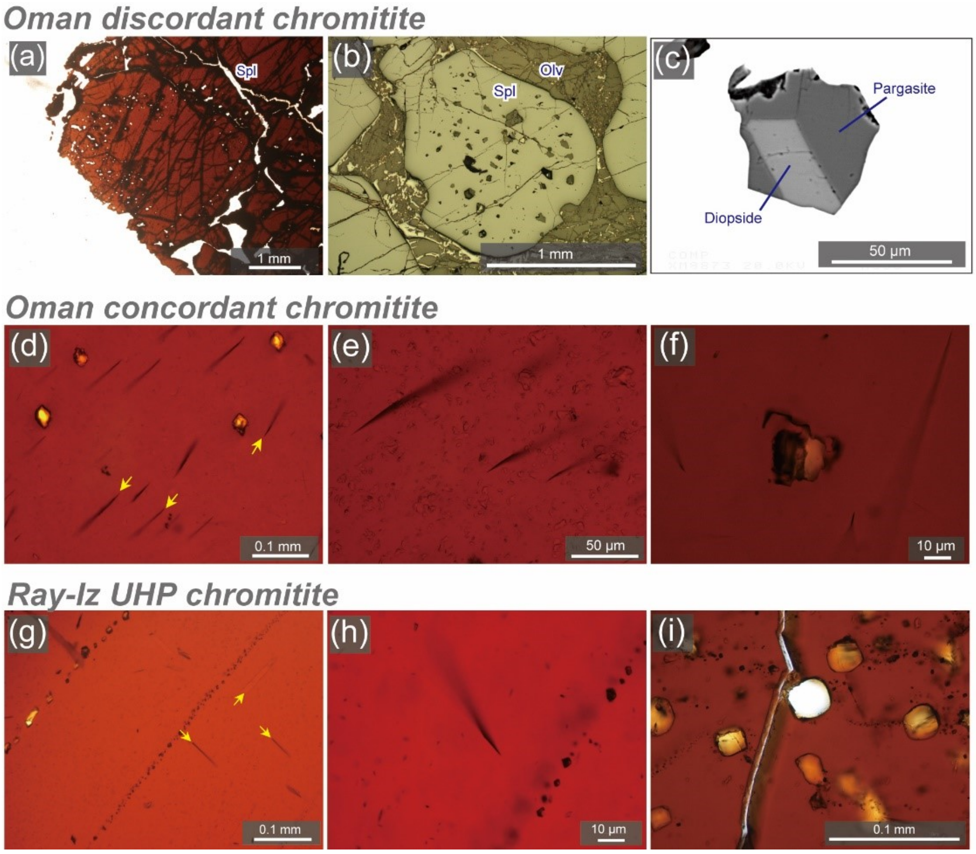
図表

Figure 1. Photomicrographs of inclusions in spinel from the Oman discordant and concordant chromitite, and UHP chromitites from Polar Urals. Silicate globular inclusions in the Oman discordant chromitite (a-c), lamellar inclusions in spinels from the Oman concordant chromitites (d-f) and lamellar and globular inclusions in spinel from the Ray-Iz UHP chromitites (g-i).

Figure 2. Relationships between Cr# (=Cr/(Cr+Al) atomic ratio) and TiO_2 content in spinels from discordant (a) and concordant (b) pods from the northern Oman ophiolite. Abyssal peridotite fields are from Dick and Bullen (1984) and Arai et al. (2011). Arc-related peridotite fields are from Arai et al. (2011).



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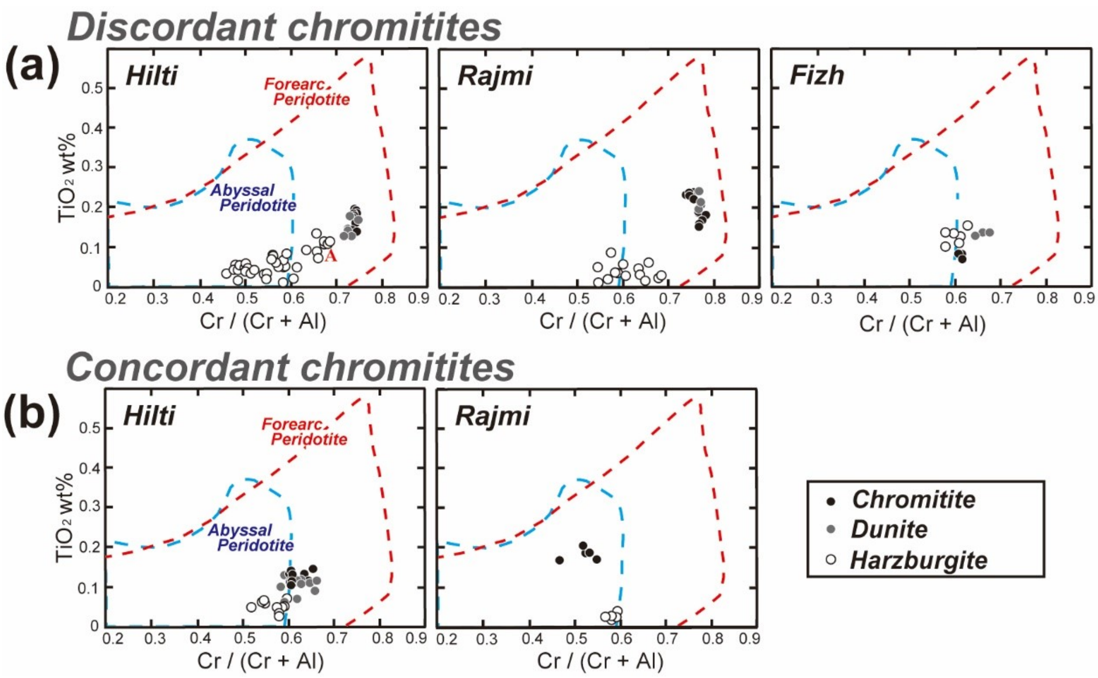

Figure 2.

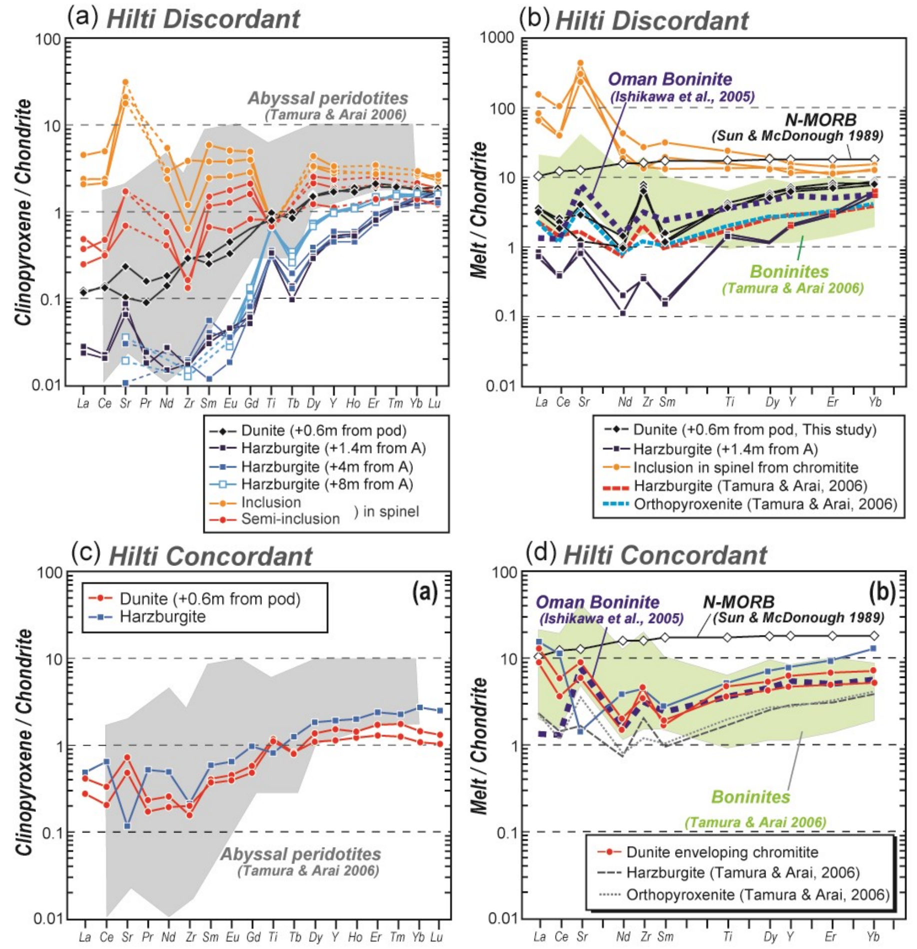

Figure 3. Chondrite-normalized trace element patterns of clinopyroxenes in the Hilti discordant and concordant chromitites, dunites and surrounding harzburgites. Harzburgite, orthopyroxenite and boninite fields are from Tamura and Arai (2006). Abyssal peridotites field is from Tamura et al. (2008). N-MORB pattern is from Sun and McDonough (1989). (a) Clinopyroxenes in the dunite envelope, surrounding harzburgites and chromitite from Wadi Hilti. Note that clinopyroxene show higher contents of LREE, e.g., Ce, in the adjacent harzburgites than in the distant harzburgites. (b) Calculated melt in equilibrium with clinopyroxene from dunite and chromitite. The Oman boninites (Ishikawa et al., 2005) and arc-related ultramafics (Tamura and Arai 2006) are shown for comparison. The partition coefficients of clinopyroxene/melt, reported by Sobolev et al. (1996) were used for the calculation of melt composition.

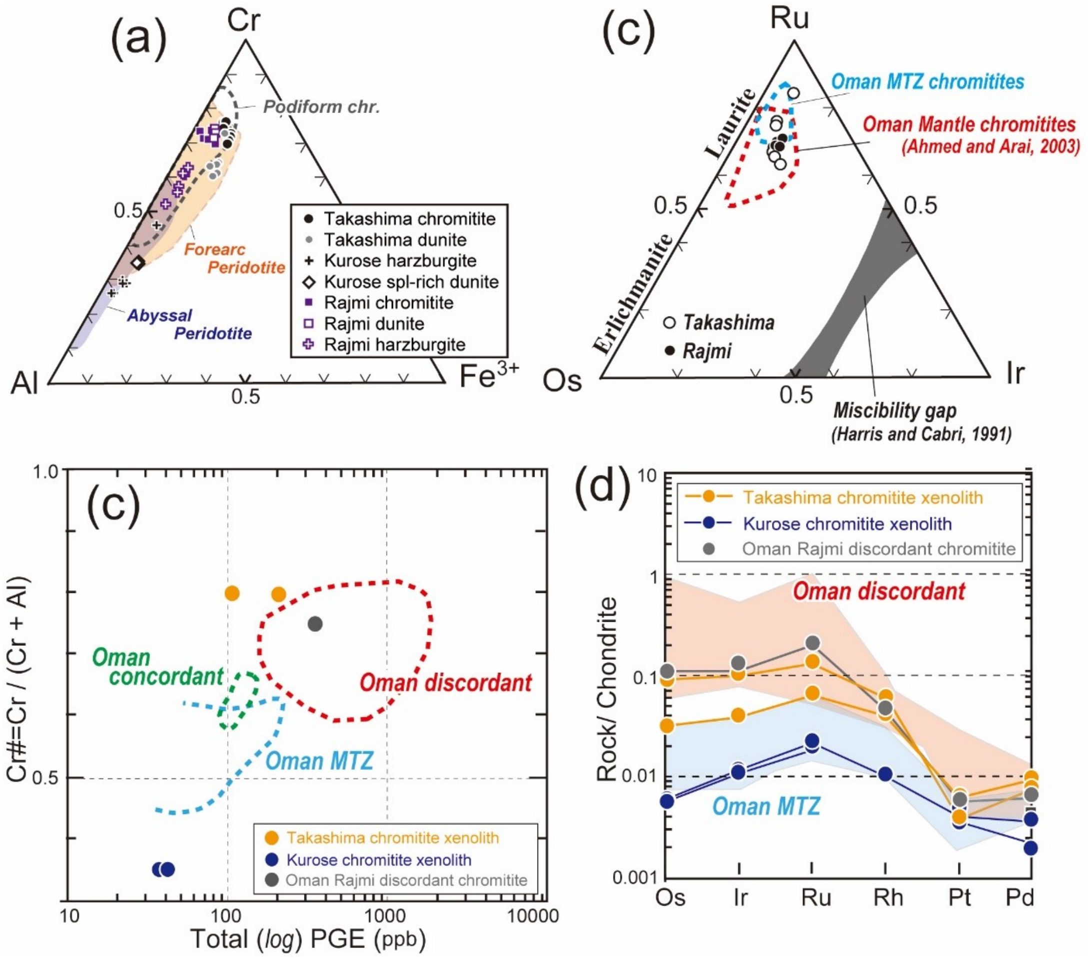

Figure 4. Chemical variations of chromian spinels (a), and PGE characteristics (b-d) of the Takashima, Kurose and Oman Rajmi discordant chromitites. (a) Trivalent cation ratios of chromian spinels. (b) Chemical variations of laurite grains in the Takashima and Oman chromitites in terms of Ru-Os-Ir in the laurite-erichmanite series. (c) Relationships between the spinel Cr# and the total PGE concentrations in the suites of chromitites and dunites. (d) Chondrite-normarized PGE patterns of chromitites and dunites. Oman discordant and MTZ fields are from Ahmed and Arai (2002). Abyssal peridotite fields are from Dick and Bullen (1984) and Arai et al. (2011). Arc-related peridotite fields are from Arai et al. (2011).

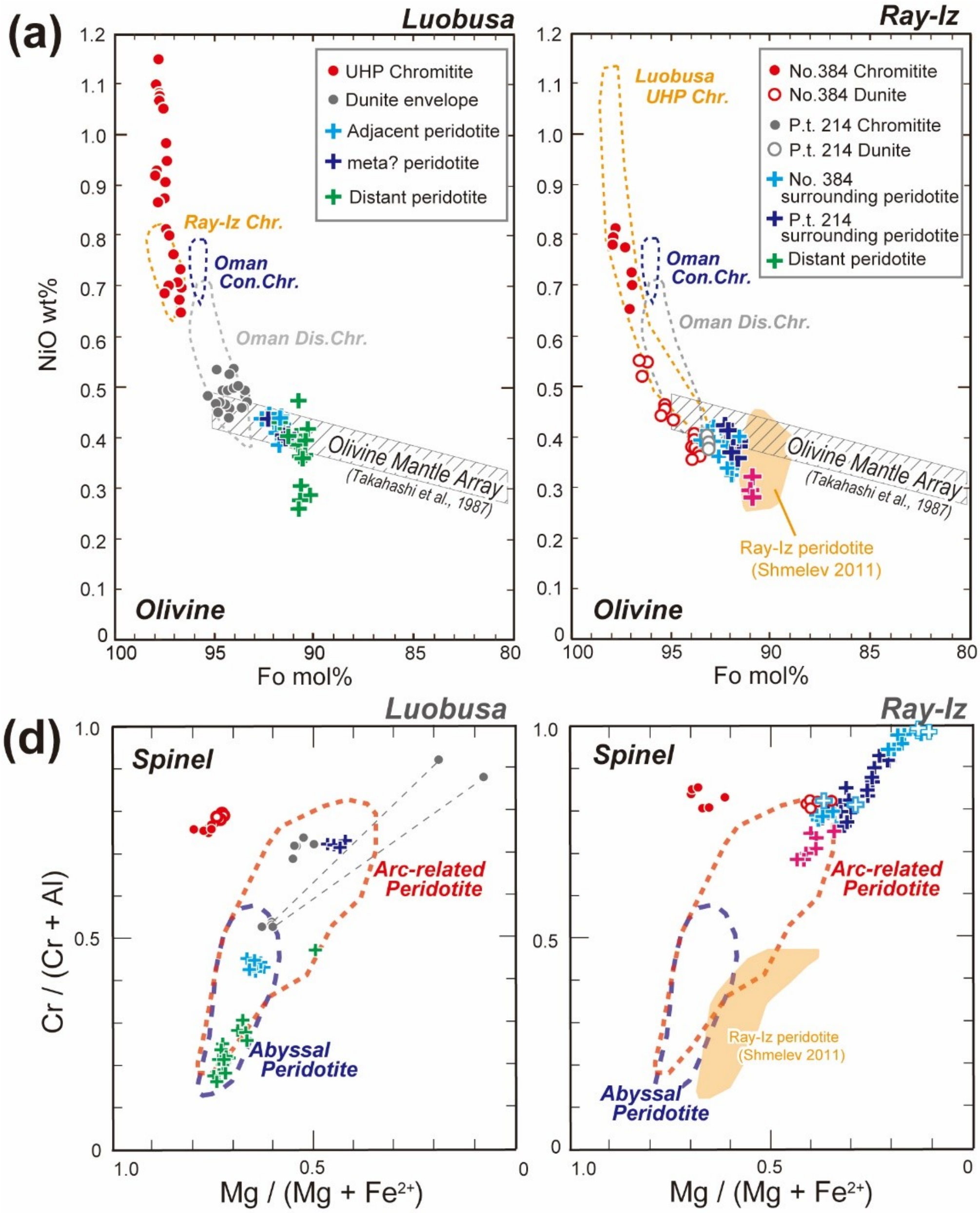

Figure 5. Chemical characteristics of olivines and spinels from the UHP chromitites from the Luobusa and Ray-Iz ophiolites. Abyssal peridotite fields are from Dick and Bullen (1984) and Arai et al. (2011). Arc-related peridotite fields are from Arai et al. (2011). (a) Relationships between Fo and NiO contents in olivine. (b) Relationships between Mg# and Cr# of spinel.

平成２７年　１月２７日

学位論文審査報告書（甲）

1．学位論文題目（外国語の場合は和訳を付けること。）

Integrated petrogenesis of podiform chromitites（ポディフォーム・クロミタイトの統合的成因論）

2．論文提出者　(1) 所　　属　環境科学　　専攻

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3．審査結果の要旨（600～650 字）

三浦真氏は地球深部，マントル中に広く産出するクロミタイト（ポディフォーム・クロミタイトと呼ぶ）の成因を総合的に再構築するために，様々な産状のものを詳細に検討した。野外調査および野外観察を綿密に行い，調査が不可能なものに関しては必要試料を入手した。まず，ある種の海洋底の断片とされるオマーン・オフィオライト北部において調和性，非調和性クロミタイトを詳細に検討し，両者ともに低圧（上部マントル）起源であることを確認した。ただし，調和性クロミタイトに関しては超高圧クロミタイトと一部共通の特徴を有することを明らかにした。また，非調和性クロミタイトについては，日本列島下マントル由来のクロミタイト捕獲岩との比較を行い明瞭な類似点を見いだし，前者の島弧起源を確かなものとした。謎の多い超高圧クロミタイトに関してはチベット（ルオブサ）と北極圏ウラル（ライ・イズ）のものを検討し，それらの地質学的・鉱物化学的特徴がリサイクル成因モデルと整合的であることを示した。特に，それらを，コーサイトを含むもの，ダイヤモンドを含むものに分類できたことはリサイクルの多様性を示し興味深い。クロミタイト（特に超高圧）成因論が混迷を極め，怪しい議論が横行するなかで，三浦氏のきちんとした記載に基づく研究は異彩を放つものであり，大いに評価される。国際誌に既に公表された論文は高く評価され，多くの人に引用され始めている。従って，本委員会は本論文が三浦真氏に博士（理学）の学位を与えるのにふさわしいものと判断する。

4．審査結果　(1) 判　　定（いずれかに○印）　（合格）・　不合格

(2) 授与学位　博　士（　理学　）