Oxidation-reduction state of lithospheric mantle in northern Xingmeng orogenic belt

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Abstract. Xingmeng orogenic belt is located in the eastern part of East Asian orogenic belt, which is a typical area of superimposition and reconstruction of multiple tectonic systems. Spinel peridotite captives have been found in Nuo Min and Kolo areas in the north of Xingmeng orogenic belt. The olivine Mg# of lherzolite is 0.895 ~ 0.911, which is slightly smaller than that of lherzolite (0.912 ~ 0.928), and the high Mg# of lherzolite also indicates that the upper mantle in the study area is refractory. The lherzolite and lherzolite in the study area show high fO₂ values, FMQ+1.947 ~ 3.145, which is in sharp contrast with the relatively reduced ancient lithospheric mantle facies in general. The fundamental reason may be that the Paleozoic ancient Asian Ocean and the Mesozoic ancient Pacific Ocean successively subducted under the Xingmeng orogenic belt, resulting in the sharp rise of fO₂ in the lithospheric mantle at that time.

1. Introduction

Orogenic belts, as the most active belts in lithosphere and crust, are the key research areas with the most information storage and records of lithosphere formation and evolution. Xingmeng orogenic belt is located between Siberian plate, North China plate and Pacific plate, which belongs to the eastern part of Central Asia orogenic belt, generally refers to northeast China and Russia region affected by Paleozoic tectonics, and is a typical area where many tectonic systems are superimposed and reformed. At present, there are still controversies about the basement attribute of each micro-block in Xingmeng orogenic belt, the assembly history of each micro-block, the reconstruction time of ancient oceanic tectonic system and its influence time and space, and the crustal proliferation and reconstruction. Oxidation-reduction state (fO₂) is an important parameter that restricts the physical–chemical reaction mode between mantle source region and surface, which affects the activity of metal, gas (liquid) phase composition and melt properties, and plays an important role in the process of magmatic rock origin, slurry degassing and metasomatism[1]. The study area is located in the superposition area of several tectonic systems, which has experienced the superposition of the subduction of the ancient Asian Ocean, the Mongolia-Okhotsk tectonic system and the subduction of the ancient Pacific Ocean since Paleozoic. In this paper, the major elements of peridotite captive minerals in Nuo Min and Kolo areas in the northern Xingmeng orogenic belt are tested by electron probe, and the oxygen fugacity in the study area is calculated and analyzed, so as to deepen our understanding of the mantle evolution history in the study area.

2. Regional overview

Xing-Meng orogenic belt has a complex and long evolution history, which is the longest known
orogenic belt with the most complex magmatic activity in China. The tectonic position of Xingmeng orogenic belt lies between Siberian plate, North China plate and Pacific plate, and belongs to the eastern part of Central Asia orogenic belt. Ergun block in the north, Xing'an block in the northwest, Songliao block in the middle and Jiamusi block in the southeast are the main components of Xingmeng orogenic belt. The study area is located in the northern part of Xingmeng orogenic belt (Figure 1). Many oceanic subductions resulted in a large amount of fluid volatiles, fusible components, Fe₂O₃, CO₂ and other oxidizing fluids being released into the upper mantle, which caused partial melting of the mantle and formed a large-scale magmatic activity, resulting in a large number of volcanic and peridotite captives covering the surface of the study area, which also provided direct evidence for the study of lithospheric mantle[2].

![Figure 1 Structural zoning map of Xingmeng orogenic belt. The map modified after Wu et al.,(2011)](image)

3. Method
The samples in this paper were collected from Nuo Min and Kolo areas in the north of Xingmeng orogenic belt. Rock slices of the samples were prepared in geological museum, China, and the determination of major elements in peridotite minerals was completed on JEOL-JXA-8100 electronic probe in Northeast Asia Key Laboratory of Mineral Resources Evaluation, Ministry of Natural Resources, and the implementation standard was GB/T.15074-2008 General Rules for Quantitative Analysis Methods of Electronic Probe. The necessary conditions for analysis include: the diameter of electron beam should be less than 1μm, the beam current of electron beam should be between 10⁻⁴ and 10⁻³ A, and the acceleration voltage should be between 15 kV and 2 kV. ZAF method is used to correct the original data.

4. Discuss
4.1. Partial melting degree
The Mg²⁺ of olivine samples in the study area ranges from 0.895 to 0.928, and most of them are more than Mg²⁺>0.915, showing a high degree of partial melting. In the graph of the relationship between Cr²⁺ and Fo (Figure 2), the mantle range of our samples defined by Arai is inside the trend line of refractory evolution, and most of them are in the range of deep-sea peridotite. There are samples with high Cr²⁺ and high Fo in these throwing points, which indicates a high degree of partial melting[3].
relationship of Fo-Ol content also shows that some samples fall into Proterozoic mantle area defined by Griffin et al, and some samples fall into Archean lithosphere mantle area, which represents ancient craton mantle (Figure 3). Therefore, in terms of composition, some peridotite samples in the study area have high melting degree, and have the properties of ancient craton mantle, while the other part is relatively young.

4.2. Oxidation-reduction state

The fO2 value of lherzolite in Nuo Min area ranges from FMQ+2.127 to 2.375, and that of periclas ranges from FMQ+2.139 to 2.965 (Table 1). fO2 values of lherzolite and lherzolite in Kolo area range from FMQ+2.544 to 3.145 and FMQ+1.947 to 2.374 (Table 1), respectively. The average fO2 in Nuo Min was 2.39 (n=16), which was slightly lower than that in Kolo (2.69, n=8). The global norm fmq of fO2 value in Xingmeng orogenic belt ranges from+1.947 to+3.145, which shows a relatively narrow range.
Table 1. $fO_2$ calculation results of study area

| Sample | KL-3-4 | KL-3-10 | KL-3-13 | NME-3-18 | NME-3-24 | NME-3-25 |
|--------|--------|---------|---------|----------|----------|----------|
| O1     |        |         |         |          |          |          |
| $X_{Fe^{O1}}$ | 0.086  | 0.104   | 0.094   | 0.086    | 0.082    | 0.094    |
| $X_{Mg^{O1}}$ | 0.914  | 0.896   | 0.906   | 0.914    | 0.918    | 0.906    |
| Opx    |        |         |         |          |          |          |
| M1 (Fe) | 0.078  | 0.091   | 0.075   | 0.073    | 0.074    | 0.084    |
| M2 (Fe) | 0.082  | 0.099   | 0.081   | 0.078    | 0.079    | 0.092    |
| Sp     |        |         |         |          |          |          |
| Cr$^+$ | 0.329  | 0.255   | 0.307   | 0.382    | 0.356    | 0.106    |
| Fe$^{3+}/\Sigma$Fe | 0.799  | 0.804   | 0.818   | 0.819    | 0.793    | 0.841    |
| Mg/ (Mg+Fe$^{2+}$) | 0.656  | 0.674   | 0.692   | 0.690    | 0.642    | 0.758    |
| log$_{Fe^{3+}O_4}^{Sp}$ | -0.891 | -0.821  | -0.910  | -1.013   | -0.850   | -0.923   |
| P[Gpar] | 1.500  | 1.500   | 1.500   | 1.500    | 1.500    | 1.500    |
| TBK(90)-2px(℃) | 10.35  | 1150    | 1173    | 1167     | 1007     | 1254     |
| Δlog($fO_2$)FMQ | 2.586  | 2.086   | 1.947   | 2.470    | 2.687    | 2.375    |

Min and Kolo areas, and the results showed that the Re depletion age of some samples was 1.9Ga, indicating that there was an early Proterozoic lithospheric mantle in the study area, but its $fO_2$ was generally high. The study area is located in the northern part of Xingmeng orogenic belt, which is a superposition area of several tectonic systems, and has experienced many stages of plate subduction since Paleozoic: 1) the northward subduction of the ancient Asian Ocean in Paleozoic; 2) Westward subduction of Mesozoic ancient Pacific plate. As the first oceanic subduction in the study area, the ancient Asian Ocean was mainly characterized by the combination of micro-landmasses, and finally closed along the seamline of Xilamulun-Changchun-Yanji during the Late Permian-Middle Triassic[5]. The ancient Pacific plate began to subduct westward in the middle-late Triassic, and the subduction is still continuing so far. Therefore, the subduction of the ancient Asian Ocean and the ancient Pacific Ocean has become the most likely factor causing the increase of $fO_2$ in the study area. From the relationship between spinel Cr$^+$ and $fO_2$ (Figure 4), it can be seen that Cr$^+$ shows a certain positive correlation, and the reason for this phenomenon may be that Fe$_2$O$_3$, CO$_2$ and H$_2$O will be released continuously with the subduction process during the subduction of the ancient Asian Ocean and the ancient Pacific Ocean, and these oxygen-rich substances will enter the upper mantle with the fluid, and some samples with high melting degree will go through multiple metasomatism, resulting in the continuous increase of $fO_2$ value.
5. Conclusion

1) The olivine Mg\# of peridotite captive in lithosphere mantle in the study area ranges from 0.895 to 0.928, and some samples have Mg\#>0.92, which is the residue of ancient lithosphere mantle with high melting degree.

2) The peridotite xenoliths in the study area have high fO\_2, which indicates that the lithospheric mantle beneath the land has been oxidized, and the subduction of the ancient Asian Ocean and the ancient Pacific Ocean provided oxidation materials for the mantle wedge of Xingmeng orogenic belt.

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