A Study on the Magma Origin of the Changbai Mountain Volcano Based on Lithological Analysis

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Abstract — Changbai Mountain Volcano is a Cenozoic volcano in the northeastern part of the Asian continental plate. It is located about 1000 km away from the subduction trench, underlain by the stagnant western Pacific slab. The magma origin of the Changbai mountain volcano is obviously different from traditional arc volcanoes. Occurrence of the partial melting due to dehydration of the deep stagnant Pacific slab is one of the most favorite explanations of the Changbai mountain volcano origin. However, the evidence is still lacking or deficient, especially the geological one. In our study in this paper Lithological analysis is implemented to determine the magma origin of the Changbai Mountain Volcano. According to the lithological analysis result, we present a geo-dynamic model of the magma origin of the Changbai Mountain Volcano.

Keywords - lithological analysis; Changbai Mountain Volcano; magma origin

I. INTRODUCTION

Changbai Mountain Volcano is an active volcano with the most potential risk of eruption in China, its active time lasts from Miocene to Holocene, even today, up to 200 times earthquakes can be recorded in this region every year. Generally, arc volcanoes are generated due to mantle partial melting by the dehydration of subducted slab at shallow depth (~100-150 km) [1,2]. Changbai Mountain Volcano is located about 1000 km away from the subduction trench, underlain by the deep western Pacific subducted slab (~600 km), which is obviously different from the arc volcanoes. The origin of the Changbai Mountain Volcano is described by many hypotheses, such as plume, back-arc extension and small scale mantle flow. The morphology of the stagnant Pacific slab in the transition zone can be observed clearly, with the development of high resolution tomography technology[3,4,5]. Therefore, deep subducting slab dehydration is considered as the main mechanism to explain far field intercontinental volcanism/magmatism in
The Changbai mountain volcano experienced a basaltic shield formation process from Pliocene to early Pleistocene, which is mainly composed of trachybasalt. At the late period of early Pleistocene, trachybasalt was transiting to basaltic andesite and trachyte. From middle Pleistocene to Epipleistocene, the volcano experienced a formation stage of trachytic and alkaline lava cone, which is mainly composed of trachyte. And then, at late Epipleistocene, the trachyte was transiting to pantellerite. The mainly magma eruption phase of the Changbai mountain volcano is at Holocene. A number of explosive eruptions occurred at this phase, which mainly generated alkaline pumice and formed the volcanic debris accumulation. The pumice airborne and flow accumulation, which were formed by the explosive eruptions at 2 ka B.P. and 1215 A.D., mat-like override the volcanic cone and shield of the Changbai mountain volcano [10].

III. LITHOLOGICAL ANALYSIS

Deep subducted Pacific slab dehydration is a plausible hypothesis for the magma origin of the Changbai Mountain Volcano [3,6,7]. However, it’s supporting evidence is still lacking or deficient, furthermore, the compositions of the Changbai Mountain Volcano region are still in debate. Nb and Ta are geochemical twins, which are classic high strength field elements, incompatible elements, refractory elements and lithophile elements, with similar geo-chemical behavior in the process of crust-mantle evolution. Nb-Ta are inactive elements in the slab dehydration process with low fluid activity, so Nb-Ta are depleted in the dehydration-induced volcanism compared to the MORB and OIB. The typical Nb/Ta ratios in some environments are listed in the Table 1. In our study, the Nb/Ta ratio is implemented to analyze the origin of the magma in the Changbai Mountain Volcano region. We sampled eight basaltic rock groups in the Changbai Mountain Volcano region. The Nb/Ta ratio is 14.8-15.8 in the Changbai Mountain Volcano region, which is similar to that of basaltic rocks from the Kamchatka deep subduction zone [12,13,14,15]. Furthermore, the Nb/Ta-(Na2O+K2O)wt. % plot (Fig.2) also indicates that the basaltic magma in the Changbai Mountain Volcano region is possibly related to the deep hydration-induced partial melting of the subducted western Pacific slab. The result of lithological analysis indicates that the origin mechanism relates the intra-continental magmatism to the deep subducted slab dehydration. In other words, deep subducted Pacific slab dehydration is a plausible explanation for the development of upwelling hydrous magma and intra-continental volcanism in the Changbai Mountain Volcano region.
TABLE 1. THE TYPICAL Nb/Ta RATIOS IN SOME ENVIRONMENTS

<table>
<thead>
<tr>
<th>Environments</th>
<th>Chondrite</th>
<th>Continental Crust</th>
<th>Morb St. Helens (Mantle Plume)</th>
<th>Kamchatka Deep Subduction Zone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nb/Ta Ratio</td>
<td>18</td>
<td>12-14</td>
<td>16.88</td>
<td>14.7-18.9 And 15.4-18.4*</td>
</tr>
</tbody>
</table>

Reference: [12,13,14,15]

IV. GEO-DYNAMIC MODEL

A dynamic model of the magma origin of Changbai Mountain Volcano is presented (Fig. 3), according to the result of lithological analysis, and this model also references the seismic tomography [3,6,7]. Prior to subduction the oceanic plate begins to bend downward at the subduction trench, and thus the near-surface rocks are placed in tension leading to generation of normal faults. The fluid deeply percolates into the bending oceanic plate along these normal faults, which favors pumping the fluid downward and further reactivation. Another shallow hydration of oceanic plate is that seawater percolate into the porous and permeable basaltic crust. At intermediate-deep depths, plastic behavior is not active. Serpentinization of the slab interior occurs intrinsically in our model controlling by a result of reaction between fluids in excess and the dry rocks through which they migrate. Both porous compaction and dehydration reactions are attributed to expelled water from subducting oceanic plate.

The slab dehydrated at shallow depth, which generates the arc volcanoes. It is assumed that 80% of extracted melt emplace lower depth or underlying the continental plate, forming plutons in the continental crust in areas of highest possible intrusion emplacement. The remaining 20% can propagate upwards to the surface above the extraction zone, influencing the surface topography evolution (e.g. forming volcanoes). High possible local crustal divergence rate is used to predict the location of extracted melt intrusion emplacement, which is the ratio of the effective melt overpressure to the effective viscosity of the crust [2]. The mantle wedge is subjected to fluid-fluxed melting triggered by the water release, above the subducted slab.

Fig.2. Nb/Ta-(Na₂O-K₂O) wt.% plot of early Pleistocene basaltic lavas in the Changbai Mountain Volcano region

Fig.3 The Heating System of Solid Conveying Phase.

The water transports into the deep upper mantle with the hydrated oceanic plate. The stagnant subducted slab releases water, which hydrates the surrounding mantle, and produces wide-distributed melt overlying the slab. Some hydrated partially molten regions start to propagate upwards from the slab due to positively buoyant. The upwelled partially molten hydrated structures form partially molten regions under the far field intra-continental plate. At the surface, broadly distributed intra-continental magmatism can be observed, which produces spatially and temporarily variable clusters of volcanoes.

V. CONCLUSIONS

The Nb/Ta ratio in the Changbai Mountain Volcano region is comparable to that of basaltic rocks from the Kamchatka deep subduction zone. Both the Nb/Ta ratio and the Nb/Ta-(Na₂O-K₂O) wt.% plot indicate that the origin mechanism relates the intra-continental magmatism in the Changbai Mountain Volcano region to the deep subducted slab dehydration. According to the results of lithological analysis and seismic tomography [3,6,7], a geo-dynamic model of the magma origin of Changbai Mountain Volcano is presented. Our study serves as a plausible explanation, also as a certain geochemical evidence, for the development of...
of upwelling hydrous plumes and intercontinental volcanism in the Changbai Mountain Volcano region.

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