Petrogenesis of the basalts from lanjiafan formation

Chapter 5: Petrogenesis of the basalts from Lanjiafan Formation and Evaluation of Tectonic setting

Most trends on variation diagrams are the result of mixing. Below consider some of the more important mixing process.

5. 1Alteration

It is observed from the field evidence as well as petrography that the studied basalts are experienced varying degrees of alteration, which were observed by the presence of the secondary minerals such as calcite and a larger LOI varying from 3. 87wt%-13wt%. Elements which are mobile during alteration include SiO_2 , CaO, Na_2O, K_2O, indicating that these major elements easily migrate with alteration occurs and low strength elements (Humphris et al., 1978). However, the high field strength elements (HFSE, such as Nb, Ta, Zr, Hf, Th, U, and Y) and the rare earth elements (REE) are relatively immobile in all even the most severe hydrothermal alteration (Pearce, 1975). In contrast, large LILE (LILEs, such as Cs, Rb, Sr, Rb, Pb and Ba) show no linear relation with zirconium. For this reason only high field strength elements Ti, Zr, Y, Nb, Ta, Hf, Th and REE have been used in the discussion of the source properties and petrogenesis of these mafic volcanic rocks.

5. 2 Fractional crystallization

Fractional crystallization is a major process in the evolution of many igneous rocks, and is frequently the cause of trends seen on variation diagrams for igneous rocks, especially basalts rocks. However, the basalts from the Lanjiafan Formation have Mg# varying from 46. 2 to 89. 3, slightly higher than those of the primitive mantle derived magmas (about 70-72; Irving and

Green 1976; Frey et al., 1987). Besides, they are relatively low in Cr (0. 68-37. 8) and Ni (14-123), indicating a fractional crystallization to a certain degree in the magmatic chambers or during the ascending processes of the parental magma most likely of plagioclase(Xu et al., (2015). Accordingly, the petro graphical observations show the presence of plagioclase as the dominant mineral. For the alkaline basalts, the weak Eu and Sr anomalies imply a minor fraction crystallization of plagioclase, (Frey et al., 1978). For sub alkaline basalts, the negative Eu (0. 58 Niu et al, 2009, suggest fractionation crystallization. Therefore, in both alkaline and sub alkaline rocks experienced fractional crystallization.

5. 3 Crustal contamination

Generally, the compositional variation of magma is subject to different degrees of contamination by different crustal components during their ascent to the surface through continental crust, which changes the composition of magma (Manikyamba et al., 2014). Although it is difficult to assess crustal contamination without having isotope data, some critical geochemical characters may help to identify possible involvement of crustal material during emplacement of alkaline magmas.

The basalts samples show a depletion in Nb, Ti, and Ta and a positive Pb anomaly, and some samples show an enrichment of LREE, indicating these samples may have been subjected to crustal contamination (Hawkesworth., 1984) or derived from the enriched lithospheric mantle (Wang et al., 2008).

Nb-Ta and neighboring elements (Th, U and La) are not fractionated from each other during partial melting or fractional crystallization (Hofman., 1988), but the enrichment of the mantle source and the crustal contamination can significantly increase LILLE and LREE content and decrease HFSE/LILLE or HFSE/LREE ratios. For alkaline basalts, the higher Nb/Th (11. 43-12. 84), Nb/U (12. 41-54. 58) and Nb/La (1. 28-1. 89) ratios than those of the primitive mantle (Nb/Th= 8. 4; Nb/U= 34; Nb/La= 1. 04; Sun and McDonough, 1989) values reflect the primary signature of the mantle sources with a significant involvement of crustal contamination in the alkaline basalts (fig 5. 3. 1). Thus, the alkaline basalts from Lanjiafan Formation were likely derived from a relatively less depleted mantle, and the alkali basaltic magmas were assimilated with minor crustal components.

However, sub alkaline basalts show crust-like characteristics with obvious enrichment in Th, U, LREE and depletion in Nb, Ta (La/Nb> 1), they have Nb/Th < 8 (Nb/Th: 0. 85 to 11. 60 except one sample having Nb/Th (11. 60 ppm)).

Although, sample D26-11 exhibit no visible HFSE depletion (La/Nb <1) ascribing to less or no contamination (Fig5. 2). The contents of Th and U are suggested to be enriched in the upper continental crust and lithospheric mantle (Rudnick and Gao. 2003). Therefore the high Th content (> 2. 5ppm) and Th-U positive anomaly indicate contamination with upper crustal materials (fig 4. 6 and 5. 3. 1). We consider that the primary magma must have experienced significant crustal contamination.

Indeed, Fig 5. 3. 1 shows a general trend toward more crustal contribution from alkaline basalts. Trace-element ratio-ratio plots (fig 5. 3. 2) for these basalts show a good hyperbolic correlations between Lu/Hf and Hf/Yb, Lu/Hf and Zr/Yb, also indicating crustal contamination in the form of a binary mixing (Wang et al., 2008).

5. 4 Nature of the mantle sources

The basaltic magmas mainly originated in the continental lithospheric mantle or asthenospheric mantle. Turner et al (1995) presented the statistics of the worldwide continental flood basalts, the CaO/Al2O ratios for the basalts from the continental lithospheric mantle are less than 0. 7 while those from the asthenospheric mantle are greater than 0. 7. The basalts from western USA (Fitton et al., 1988) have La/Nb ratios greater than 1. 5 if the basaltic magmas are derived from the lithospheric mantle, whereas those that originated from the asthenospheric mantle have ratios less than 1. 5.

As for the analyzed samples in this study, except for sample D26-7 and D26-8 with lower LOI, all of samples have CaO/Al2O ratios between 0. 13 and 0. 53 with a mean of 0. 34 and La/Nb ratios from 0. 53 to 0. 85, indicating an asthenospheric mantle source. In addition, the La/Ta ratios (> 30 for the lithospheric mantle) may also be considered as the discriminating index for the basaltic magmas (Deng et al., 2013). The La/Ta ratios for all of the analyzed samples from Lanjiafan Formation vary from 11. 89 to 25. 22, with an average of 15. 44, indicating an asthenospheric mantle source as well. Although, differences in the degree of melting of mantle peridotite can lead to variation of TiO_2 content in basal. Ewart et al., (1998) showed the basaltic magma from the asthenosphere has a relatively high Ti content (mean value of TiO_2 in OIB's is 2. 86), while Ti content of basaltic magma from the lithosphere mantle is relatively low. High TiO_2 content in alkali basalts rocks

(2. 46%-3. 66%), mainly comes from the asthenosphere mantle, except for D26-10 sample. For the tholeiitic samples TiO_2 (0. 44%-0. 56%) content is low.

5. 5. Evaluation of Tectonic setting

Basaltic magmas are known to be emplaced in a variety of tectonic settings including intraplate continental or oceanic environments, intraplate rift zone settings, fast and slow spreading mid-oceanic ridges, island arcs, and back-arc basins (Pearce et al., 1973; Manikyamba et al., 2014). It is further demonstrated that, the Dabieshan orogenic belt has a complex evolution history, and different tectonic settings occurred in its southern and northern slopes in the Early Paleozoic (Ma et al., 2005). The enrichment in HFSE and LREE of the alkaline basalts may be directly derived from the asthenospheric mantle such as ocean island basalts (OIB) like source or the small degree partial melting of a normal-type MORB. On the other hand, contents of the basalts from Lanjiafan Formation suggest that the basaltic protoliths might have been derived from an enriched mantle source.

The positive Eu anomaly points to the early plagioclase phenocryst accumulation in the magma chamber, may suggest that they originated from the plagioclase-bearing mantle reservoir and experienced the low degree of partial melting (Frey et al., 1987). As a result, the primary magma of the alkaline suite is possibly generated from the partial melting of the asthenospheric mantle caused by a mantle plume. However, the high contents of HFSE (e. g. Nb, Ti and Ta) relatively high Ti/Y (mostly > 350), except for four samples (D26-7, D26-8, D26-10 and D26-11) and low Hf/Ta (mostly <5), except for D26-7. These ratios make the rocks akin to within-plate basalts (Condie, 1989).

Even, the ratios of Zr/Y (10. 00-12. 47ppm) and Zr/Sm (29. 20-34. 38ppm) are similar to many intra-plate basalts (Zr/Y> 3. 5 and Zr/Sm <20). In the Zr-Zr/Y and Th-Hf-Ta diagrams, most of the basalts samples plot in the within-plate basalt field (Fig5. 5a and 5. 5b); whereas in the Ti (ppm)/1000-V(ppm) diagram (Shervais., 1982) most basalt rocks, especially all alkaline basalts are dropped into the ocean-island and alkali basalts field (fig5. 5c).

So the alkali basalts from Lanjiafan Formation exhibit some characteristics of the within-plate basalts, they may have been derived from ocean floor, ocean plateau or mature back-arc basin basalts, because they have significant positive Nb anomalies (Floyd, 1989) (fig 4. 6a). Most of oceanic island are generally considered to be related ascending plumes of hot mantle (Wilson, 1989).

In conclusion the basalts from Lanjiafan Formation are likely formed in an extension-related within-plate environment probably induced by a mantle plume, rather than the supra-subduction zone.

Chapter 6: Conclusion and Suggestions

6. 1. Conclusion

In summary, the Lanjiafan Formation is widely dominated by basaltic rocks, which are mostly alkaline rocks. These basalts contain basanite, trachyte, and rhyodacite. Through advanced Zircon dating method, we first obtained the ages of the of set of these basalts in the southwest Suizhou tectonic zone

459. 5-464. 4 Ma, which belong to the middle Ordovician, suggesting that a tectono-magma event affected the study area during Paleozoic, which might be the response to occurred of alkaline basalts in the Lanjiafan Formation.

The CL images of zircon show that the zircons from the basaltic rocks are off magmatic type and most of them are euhedral. The basalts contain plagioclase phenocryst altered, magnetite, and calcite and pyroxene minerals. Geochemically, the analyzed basalts, which have a large variation of LOI, indicate that the basalts rocks from Lanjiafan Formation experienced of the strong alteration. These alkaline basalts present a weak Eu and Sr anomalies imply minor fraction crystallization of plagioclase, and suggesting that they undergone significant crustal contamination. Thus, the basalts from Lanjiafan Formation were likely derived from a relatively less depleted mantle, and the alkaline basaltic magmas were assimilated with minor crustal components. For sub alkaline basalts, the high Th content (> 2. 5ppm) and Th-U positive anomaly indicate contamination with upper crustal materials. The basalts from Lanjiafan Formation may be formed in an extension-related within-plate environment probably induced by a mantle plume. Being part of the South Qinling-South Dabieshan Paleozoic alkaline rock belt, the basalts from Lanjiafan Formation result from the Paleozoic extension-initial rifting in the northern margin of the Yangtze Craton.