# Tectonic Setting and Nature of the Provenance of Sedimentary Rocks in Lanping Mesozoic-Cenozoic Basin: Evidence from Geochemistry of Sandstones *

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**Abstract**: The geochemical composition of sandstones in the sedimentary basin is controlled mainly by the tectonic setting of the provenance, and it is therefore possible to reveal the tectonic setting of the provenance and the nature of source rocks in terms of the geochemical composition of sandstones. The major elements, rare-earth elements and trace elements of the Mesozoic-Cenozoic sandstones in the Lanping Basin are studied in this paper, revealing that the tectonic settings of the provenance for Mesozoic-Cenozoic sedimentary rocks in the Lanping Basin belong to a passive continental margin and a continental island arc. Combined with the data on sedimentary facies and palaeogeography, it is referred that the eastern part of the basin is located mainly at the tectonic setting of the passive continental margin before Mesozoic, whereas the western part may be represented by a continental island arc. This is compatible with the regional geology data. The protoliths of sedimentary rocks should be derived from the upper continental crust, and are composed mainly of felsic rocks, mixed with some andesitic rocks and old sediment components. Therefore, the Lanping Mesozoic-Cenozoic Basin is a typical continental-type basin. This provides strong geochemical evidence for the evolution of the paleo-Tethys and the basin-range transition.

**Key words: geochemistry of sandstone; tectonic setting of provenance; nature of source rock; Lanping Mesozoic-Cenozoic Basin**

## 1 Introduction

The Lanping Mesozoic-Cenozoic Basin in western Yunnan is an important part of the famous "Sanjiang" (Tri-river) tectonic zone in our country, and it is located in the Lanping-Simao microplate between the Lancangjiang fault zone and the Jinshajiang fault zone. It connects with the Yangtze plate in the east, abuts upon the Zangdian plate in the west; in the north is the Changdu Basin, and in the south is the Simao Basin (Yu Qian et al., 2000) (Fig. 1). The formation and evolution of the Lanping Mesozoic-Cenozoic Basin were controlled by the activities of the Lancangjiang and Jinshajiang-Ailaoshan deep faults, the evolution of the Nujiang ocean in the west, and the continu-

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ous subduction of the Indian plate and the Eurasian plate on the basis of collisions between the Lanping-Simao micro-plate and the Yangtze plate, the Zangdian plate and the Baoshan landmass, due to subduction and closeness of the paleo-Tethys Jinshajiang and Lancangjiang ocean during the Late Permian to Early Triassic. It had undergone three different evolution stages, i. e., rifting during the Indosinian stage, depression during the Yanshanian stage, strike-slip and extension during the Himalayan stage (Xue Chunji et al., 2002; Zhu Chuangye et al., 1997; Que Meiying et al., 1998). The Mesozoic-Cenozoic sedimentary rocks in the basin are of great thickness. Studies of sedimentary facies and palaeogeography of the sedimentary rocks (Que Meiying et al., 1998) show that the source rocks of basin sediments came from the paleo-landmass and mountains in the east and west of the basin, but the main provenance of the basin sediments is different during the different sedimentary evolution stages. This provides the basis for studying the tectonic setting and nature of the provenance of sedimentary rocks in terms of the geochemical characteristics of sandstones in the Lanping Basin. The aim of this paper is to disclose the tectonic setting and nature of the provenance and to provide strong geochemical evidence for the evolution of the paleo-Tethys and the basin-range transition developed from the geochemical information about Mesozoic-Cenozoic sandstones in the Lanping Basin.

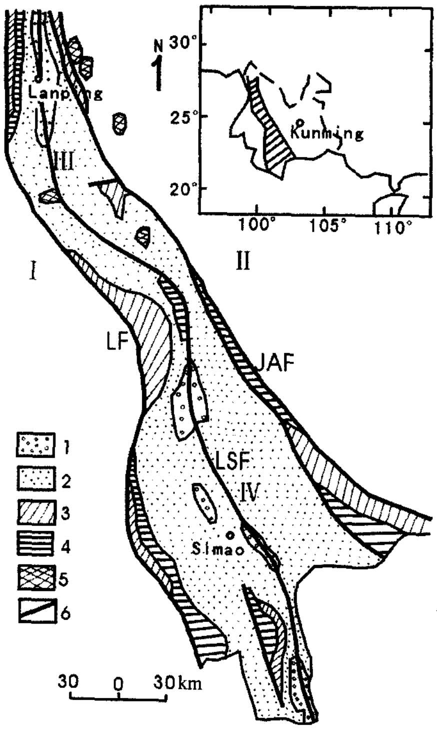


Fig. 1. Geological and tectonic sketch map of the Lanping Mesozoic-Cenozoic Basin (after Xue Chunji et al., 2002). 1. Tertiary; 2. Jurassic; 3. Triassic; 4. Paleozoic; 5. Himalayan alkali rocks; 6. main fault. JAF. Jinshajiang-Ailaoshan fault; LF. Lancangjiang fault; LSF. Lanping-Simao fault; I. Zangdian plate; II. Yangtze plate; III. Lanping Basin; IV. Simao Basin.

## 2 Sampling and analytical methods

Fresh samples of sandstone were collected from four geological profiles in the Lanping Basin. The profiles are located in Huanglianpu of Yongping County, western and northern Yunlong County, and Dongzhiyan and Deshengheke of Hexi Township, respectively. The strata involved in sampling include the Upper Triassic Maichuqing Formation ($T_3m$), the Lower Jurassic Yangjiang Formation ($J_1y$), the Middle Jurassic Huakaizuo Formation ($J_2h$), the Upper Jurassic Bazhulu Formation ($J_3b$), the Lower Cretaceous Jingxing Formation ($K_1j$), and the Eocene Yunlong Formation ($E_1y$) and Guolang Formation ($E_2g$). The sandstones are complicated in lithology including feldspar quartz sandstone, quartz sandstone with lithic fragments, sandstone with feldspar and lithic fragments, and minor graywackes. In order to ensure the samples can represent the geochemical characteristics of sandstones themselves, the mineralization zone and fault zone were avoided when sandstone samples were collected in the field, and the samples were collected as fresh as possible. In laboratory, the samples were washed with water firstly, and dried under the room temperature, then 200 grams of each sample were pulverized to 200 mesh. Analysis of the chemical compositions of sandstones was carried out in the Analysis Center of Resources and Environment, Institute of Geochemistry, Chinese Academy of Sciences. $K_2O$, $Na_2O$, CaO, MgO, MnO and $Fe_2O_3$ were determined by atomic absorption spectrometry; $P_2O_5$ and $TiO_2$ by colorimetry; $Al_2O_3$ and FeO by the volumetric method; $SiO_2$ and volatile components by the gravimetric method; and trace elements and REEs by ICP-MS techniques.

## 3 Analysis of the tectonic setting of the provenance

Although the method of reconstructing the provenance and tectonic setting of the sedimentary basin in the light of the lithologic characters of sandstones has found wide application, it still has some limitations, for instance the precision is only of semi-quantification, and it depends on the experiences of investigators. Furthermore, this method is hard to apply to sandstones, which have undergone strong diagenesis and metamorphism, because the primary lithological characteristics have already been obscured (Li Renwei, 1996). According to Rollinson (1993), the geochemical composition of clastic rocks is still controlled mainly by the provenance in spite of modification during sedimentation. For the bulk chemical characteristics of terrigenous clastic rocks, although some chemical components may have migrated or dissolved and replaced, the bulk chemical composition should not vary significantly because these actions proceeded in the same system (Chen Gang, 1999). Meanwhile, the geochemical study of clastic rocks can provide much better geological information about sediments than the petrological study does (Shao Lei et al., 2001). In this sense, the method of reconstructing the provenance tectonic setting in the light of the chemical composition of sandstones has more advantages. Therefore, many geological scientists have systematically described and summarized the geochemical characteristics of major elements, trace elements and REEs in sandstones formed in different tectonic settings in recent several decades (Bhatia, 1983, 1985a; Bhatia et al., 1986; Roser and Korsch, 1986, 1988). Great progress has been made in discriminating the geotectonic settings in which the rocks were formed in terms of geochemical characteristics of major elements, trace elements and REEs, and so has been in many other countries.

**Table 1. The statistical results of major element composition for the Mesozoic-Cenozoic sandstones in the Lanping Basin (%)**

| Component | $T_3m$ (12) | $J_1y$ (4) | $J_2h$ (17) | $J_3b$ (7) | $K_1j$ (12) | $E_{1-2}$(5) | OIA | CIA | ACM | PCM |
|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 79.80 | 82.61 | 80.37 | 76.10 | 81.79 | 72.74 | 58.83 | 70.69 | 73.86 | 81.95 |
| $TiO_2$ | 0.26 | 0.26 | 0.20 | 0.27 | 0.26 | 0.22 | 1.06 | 0.64 | 0.46 | 0.49 |
| $Al_2O_3$ | 10.70 | 7.86 | 9.08 | 11.61 | 8.42 | 8.91 | 17.11 | 14.04 | 12.89 | 8.41 |
| $Fe_2O_3$ | 2.22 | 2.48 | 2.51 | 2.65 | 1.52 | 2.01 | 1.94 | 1.43 | 1.30 | 1.32 |
| FeO | 1.48 | 0.90 | 1.15 | 1.63 | 1.11 | 0.55 | 5.52 | 3.05 | 1.58 | 1.76 |
| MnO | 0.11 | 0.18 | 0.11 | 0.10 | 0.16 | 0.21 | 0.15 | 0.10 | 0.10 | 0.05 |
| MgO | 0.91 | 1.38 | 1.20 | 1.72 | 1.26 | 2.42 | 3.65 | 1.97 | 1.23 | 1.39 |
| CaO | 0.94 | 2.09 | 2.24 | 1.84 | 2.55 | 9.72 | 5.83 | 2.68 | 2.48 | 1.89 |
| $Na_2O$ | 1.13 | 0.76 | 1.45 | 1.70 | 1.24 | 1.01 | 4.10 | 3.12 | 2.77 | 1.07 |
| $K_2O$ | 1.79 | 0.95 | 1.13 | 1.70 | 1.01 | 1.55 | 1.60 | 1.89 | 2.90 | 1.71 |
| $P_2O_5$ | 0.14 | 0.16 | 0.13 | 0.13 | 0.15 | 0.14 | 0.26 | 0.16 | 0.09 | 0.12 |
| $Fe_2O_3{}^* + MgO$ | 4.77 | 4.86 | 4.99 | 6.18 | 4.01 | 5.04 | 11.73 | 6.79 | 4.63 | 2.89 |
| $Al_2O_3/SiO_2$ | 0.13 | 0.10 | 0.11 | 0.15 | 0.10 | 0.12 | 0.29 | 0.20 | 0.18 | 0.10 |
| $K_2O/Na_2O$ | 1.58 | 1.26 | 0.78 | 1.00 | 0.81 | 1.53 | 0.39 | 0.61 | 0.99 | 1.60 |
| $Al_2O_3/(CaO + Na_2O)$ | 5.17 | 2.76 | 2.46 | 3.28 | 2.22 | 0.83 | 1.27 | 2.42 | 2.56 | 4.15 |

Note: All average values were recalculated on the volatile-free basis. $Fe_2O_3{}^*$ — total iron; OIA. oceanic island arc; CIA. continental island arc; ACM. active continental margin; PCM. passive continental margin. The numbers in the parentheses are the numbers of samples.

In order to clearly reveal the provenance tectonic setting of sandstones hosted in different strata in the Lanping Basin, a formation is taken as a unit and the geochemical compositions of sandstones of each formation are statistically calculated. The statistical results of major elements for sandstones of each formation are listed in Table 1. By comparing the results with those of different tectonic settings summarized by Bhatia (1983), it is shown that the major element composition of sandstones of each formation is characterized by relative enrichment in $Fe_2O_3$ and depletion in $Ti_2O$. This may be related to the oxidation environment of sandstone sedimentation and the primary rocks being dominated by $Ti_2O$-depleted felsic rocks. Nevertheless, the bulk major element composition of sandstones of each formation in the Lanping Basin is obviously different from that of oceanic island arc setting sandstones, but close to that of passive continental margin setting and active continental margin setting sandstones or close to that of the mixture of passive continental margin setting and continental island arc setting sandstones. As a whole, the tectonic setting of the provenance shown by the major element composition of sandstones of each formation varies regularly. The major element composition of sandstones of the Upper Triassic Maichuqing Formation is similar to that of passive continental margin setting sandstones. The major element composition of sandstones of the Lower Jurassic Yangjiang Formation and the Middle Jurassic Huakaizuo Formation is similar to that of both passive continental margin setting sandstones and active continental margin setting sandstones, but by comparing, closer to that of passive continental margin setting sandstones. The major element composition of sandstones of the Upper Jurassic Bazhulu Formation and the Lower Cretaceous Jingxing Formation is close to that of active continental margin setting sandstones or close to that of the mixture of passive continental margin setting sandstones and continental island arc setting sandstones. Although the concentrations of $SiO_2$ are slightly low and those of CaO and MgO are particularly high as the sandstones of the Lower Eocene Yunlong and Guolang formations bear carbonate clastic grains dominated by calcareous cements, their compositional characteristics are still closer to those of passive continental margin setting sandstones. The above situation is more clearly shown in the tectonic setting discrimination plot of $SiO_2$ vs. $K_2O/Na_2O$ for Mesozoic-Cenozoic sandstones in the Lanping Basin (Fig. 2).

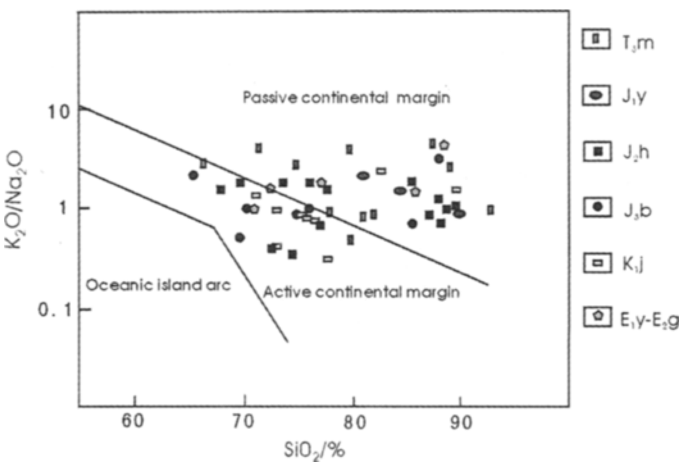


Fig. 2. Tectonic setting discrimination plot of $SiO_2$ vs. $K_2O/Na_2O$ for Mesozoic-Cenozoic sandstones in the Lanping Basin (Boundary lines for different tectonic settings from Roser et al., 1986).

Bhatia and Crook (1986) suggested that trace elements, especially low-mobility trace elements such as La, Th, Y, Zr, Ti, Co and Ni are very useful for provenance tectonic setting discrimination, and they presented several diagrams for discriminating the sandstones formed in oceanic island arc, continental island arc, active continental margin and passive continental margin settings. Plotted in the diagrams of Ti/Zr vs. La/Sc and La/Y vs. Sc/Cr are the analysis results of Mesozoic-Cenozoic sandstones in the Lanping Basin (Fig. 3). On the La/Y vs. Sc/Cr diagram, the sandstones of the Maichuqing, Yangjiang, Huakaizuo, Yunlong and Guolang formations fall mainly in the passive continental margin area, whereas those of the Bazhulu Formation, especially the Jingxing Formation fall in the continental island arc area or in the field between the passive continental margin and the continental island arc. On the Ti/Zr vs. La/Sc diagram, the above characteristics are not so precisely seen, the sandstones of all formations fall mainly in the continental island arc area or in the field between the passive continental margin and the continental island arc, and only a few sandstones fall in the passive continental margin area.

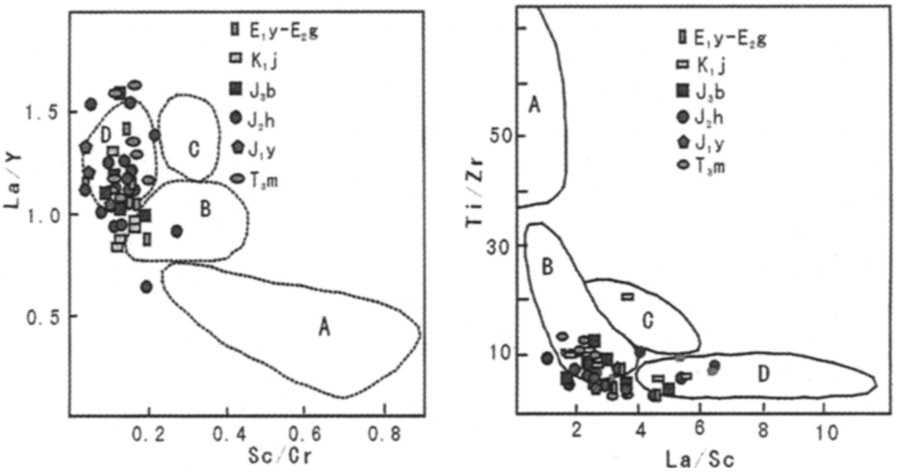


Fig. 3. Tectonic setting discrimination diagrams of Mesozoic-Cenozoic sandstones in the Lanping Basin (Boundary lines for different tectonic settings from Bhatia et al., 1986). A. Oceanic island arc; B. continental island arc; C. active continental margin; D. passive continental margin.

Furthermore, the REE characteristic parameters for Mesozoic-Cenozoic sandstones in the Lanping Basin are presented in Table 2. By comparing the results with those of Bhatia (1985), it is shown that the REE concentrations of the sandstones of each formation are obviously higher than those of oceanic island arc graywackes, and the characteristic parameters are also significantly different. In addition, there are comparabilities with other tectonic setting sandstones. The REE characteristic parameters for the Maichuqing Formation sandstones are most similar to those of the passive continental

**Table 2. Comparison of REE characteristic parameters for the Mesozoic-Cenozoic sandstones in the Lanping Basin with those of the graywacks from various tectonic settings**

| Source | La | Ce | $\sum$REE | La/Yb | $(La/Yb)_N$ | LREE/HREE | Eu/Eu* | Remark |
|---|---|---|---|---|---|---|---|---|
| OIA | 8 | 19 | 58 | 4.2 | 28 | 3.8 | 1.04 | Bhatia, 1985 |
| CIA | 27 | 59 | 146 | 11 | 7.5 | 7.7 | 0.78 | Bhatia, 1985 |
| ACM | 37 | 78 | 186 | 12.5 | 8.5 | 9.1 | 0.6 | Bhatia, 1985 |
| PCM | 39 | 85 | 210 | 15.9 | 10.8 | 8.5 | 0.56 | Bhatia, 1985 |
| $T_3m$ | 24 | 47.31 | 117.64 | 13.84 | 8.96 | 8.17 | 0.64 | 12 samples |
| $J_1y$ | 21.75 | 37.08 | 107.08 | 10.77 | 7.06 | 5.57 | 0.63 | 4 samples |
| $J_2h$ | 22.06 | 42.37 | 105.27 | 12.53 | 8.45 | 7.85 | 0.67 | 17 samples |
| $J_3b$ | 42.78 | 49.59 | 119.91 | 11.63 | 7.81 | 7.89 | 0.64 | 7 samples |
| $K_1j$ | 23.48 | 46.06 | 113.12 | 12.69 | 8.56 | 7.98 | 0.63 | 10 samples |
| $E_{1-2}$ | 21.46 | 45.18 | 110.91 | 10.62 | 7.16 | 7.13 | 0.65 | 5 samples |

margin sandstones, and those of sandstones of other formations are similar to those of the mixture of continental island arc sandstones and passive continental margin sandstones or active continental margin sandstones, but the concentrations of REE in the sandstones of the formations studied are rather low, probably related to the relatively high concentrations of quartz in the sandstones studied.

A comprehensive analysis of the results of tectonic setting discrimination in the light of major elements, trace elements and REEs makes us believe that the tectonic setting of the provenance for Mesozoic-Cenozoic sandstones in the Lanping Basin can be divided into two types, i. e., passive continental margin and continental island arc. Some sandstones possess the geochemical characteristics of active continental margin sandstones due to the mixing of passive continental margin sandstones and continental island arc sandstones. As viewed from the sedimentary facies and palaeogeography data (Que Meiying et al., 1998), the provenance of sediments refers to the palaeo-landmass and mountains in the east of the basin during the period of Late Triassic Maichuqing Formation sedimentation; the provenances of sediments were mainly the mountains in the east of the basin during the Early-Middle Jurassic, and the mountains in the west of the basin were the subordinate provenance of sediments; the provenances of sediments were the mountains in the west and east of the basin during the Late Jurassic to Cretaceous, and the mountains in the west of the basin were the main provenance during the Cretaceous; the source rocks of Lower Tertiary are mainly from the Upper Triassic. So it can be inferred that the sediments derived from the east of the basin were formed in the passive continental margin tectonic setting, whereas those derived from the west of the basin were formed in the continental island arc tectonic setting. This suggests that the eastern part of the Lanping Basin may be mainly in the passive continental margin tectonic setting and the western part mainly in the continental island arc tectonic setting, at least it was in the continental island arc tectonic setting when the source rocks were formed before Mesozoic time. Therefore, the conclusion drawn from the geochemical information about the sandstones is consistent with the geological literature (Que Meiying et al., 1998; Fang Weixuan et al., 2002; Feng Qinglai et al., 1999; He Kezhao et al., 1996).

## 4 Nature of source rocks

REE patterns are the most reliable indicators among those for sediment provenance (Taylor and Mclennan, 1985; Mclennan, 1989; Mclennan et al., 1995). The REEs derived from upper continental crust are characterized by LREE enrichment, uniform HREE concentrations and negative Eu anomalies (Shao Lei et al., 1998, 1999, 2001; Gu Xuexiang et al., 2002). If the parent clastic rocks composed of sandstones derived from upper continental crust, the REE patterns of sandstones should be in agreement with those of the upper continental crust. The chondrite-normalized (Boynton, 1984) REE patterns of sandstones of each formation in the Lanping Basin are characterized by LREE enrichment, uniform HREE concentrations and negative Eu anomalies (Fig. 4), which is almost completely in agreement with the REE patterns of the upper continental crust. In addition, the ratios of weakly mobile elements, such as Th/Sc, La/Sc, Co/Th and Cr/Th, are also very good indicators of source rocks

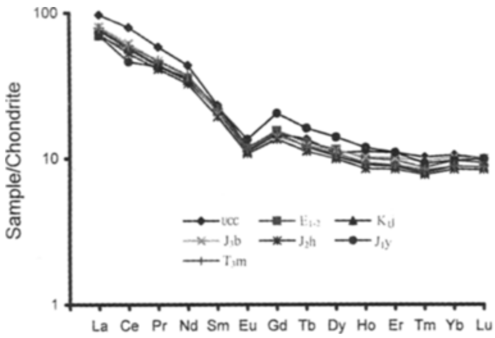

Fig. 4. Chondrite-normalized REE patterns of Mesozoic-Cenozoic sandstones in the Lanping Basin. UCC. Upper continental crust.

( Mclennan and Taylor, 1983). The above ratios of weakly mobile elements in the sandstones of each formation in the Lanping Basin are listed in Table 3. Obviously, they are close to those of the upper continental crust, and significantly different from those of the lower continental crust and oceanic crust. Therefore, the Mesozoic-Cenozoic sedimentary rocks in the Lanping Basin are believed to have been derived from the upper continental crust.

**Table 3. Trace element ratios of Mesozoic-Cenozoic sandstones in the Lanping Basin**

| Ratio | $E_{1-2}$(9) | $K_1j$ (13) | $J_3b$ (9) | $J_2h$ (24) | $J_1y$ (6) | $T_3m$ (20) | UCC | LCC | OC |
|---|---|---|---|---|---|---|---|---|---|
| La/Sc | 2.82 | 2.92 | 2.58 | 2.87 | 2.94 | 2.84 | 2.7 | 0.3 | 0.1 |
| Sc/Th | 1.02 | 0.96 | 1.01 | 1.01 | 0.93 | 1 | 1 | 34 | 1.73 |
| Cr/Th | 6.63 | 6.82 | 6.59 | 6.63 | 8.79 | 6.17 | 3.3 | 222 | 1227 |
| Co/Th | 1.02 | 1.04 | 1.15 | 1.21 | 1.09 | 1.05 | 0.9 | 33 | 214 |
| Eu/Eu* | 0.65 | 0.63 | 0.64 | 0.66 | 0.65 | 0.65 | 0.65 | 1.07 | 1.02 |

Note: UCC. Upper continental crust; LCC. lower continental crust; OC. oceanic crust (from Mclennan et al., 1983).

In order to further reveal the nature of source rocks, the source rock discrimination diagrams of La/Th vs. Hf and La/Sc vs. Co/Th (Gu Xuexiang et al., 2002) are used to analyze the nature of the sandstones studied (Fig. 5). In Fig. 5(A), most of the sandstones fall within the felsic source field and are clustered around the upper continental crust with respect to their average composition; only some sandstones of the Maichuqing Formation fall within the andesitic arc source field; a few sandstones of the Huakaizuo and Maichuqing formations fall within the mixed felsic/basic source field; and a part of the sandstones fall on the right of the felsic source, which suggests there would be incorporated old sediment components. On the plot of La/Sc vs. Co/Th [Fig. 5(B)], the sandstones studied display low and relatively constant Co/Th ratios with an average of 1.09, but high and considerably variable La/Sc ratios, which suggests the source rocks are dominated by felsic rocks, with some andesitic rocks incorporated.

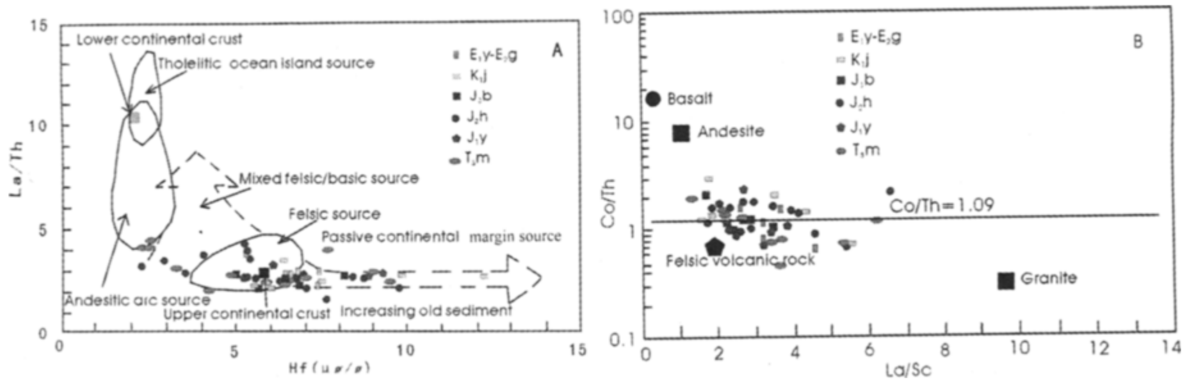


Fig. 5. Source rock discrimination plots of (A) La/Th vs. Hf and (B) La/Sc vs. Co/Th for Mesozoic-Cenozoic sandstones in the Lanping Basin (Boundary lines for different tectonic settings from Gu Xuexiang et al., 2002).

To sum up, the original rocks of Mesozoic-Cenozoic sedimentary rocks in the Lanping Basin should be derived from upper continental crust, with felsic rocks dominant and few andesitic rocks and old sediments incorporated. So the Lanping Basin is the typical continental-type basin.

## 5 Conclusions

The geochemical characteristics of sandstones can provide much information about the provenance tectonic setting and nature of source rocks in the basin. The provenance tectonic settings of sedimentary rocks from the Lanping Basin are represented by passive continental margin and continental island arc. The sediments from the east of the basin were formed in the passive continental margin tectonic setting, and those from the west of the basin were formed in the continental island arc tectonic setting. The original source rocks were all derived from the upper continental crust, with felsic rocks dominant, and few andesitic rocks and old sediments incorporated. Therefore, the Lanping Basin is a typical continental-type basin.

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