Sedimentary-volcanic tuffs formed during the early Middle Triassic volcanic event in Guizhou Province and their stratigraphic significance *

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Abstract The sedimentary-volcanic tuff (locally called "green-bean rock") formed during the early Middle Triassic volcanic event in Guizhou Province is characterized as being thin, stable, widespread, short in forming time and predominantly green in color. The green-bean rock is a perfect indicator for stratigraphic division. Its petrographic and geochemical features are unique, and it is composed mainly of glassy fragments and subordinately of crystal fragments and volcanic ash balls. Analysis of the major and trace elements and rare-earth elements (REE), as well as the related diagrams, permits us to believe that the green-bean rock is acidic volcanic material of the calc-alkaline series formed in the Indosinian orogenic belt on the Sino-Vietnam border, which was atmospherically transported to the tectonically stable areas and then deposited as sedimentary-volcanic rocks there. According to the age of green-bean rock, it is deduced that the boundary age of the Middle-Lower Triassic overlain by the sedimentary-volcanic tuff is about 247 Ma.

Key words volcanic event; boundary age; early Middle Triassic; Guizhou

1 Introduction

The early Middle Triassic volcanic ash-falling event in Guizhou Province resulted in the formation of a thin but very stable sedimentary-volcanic tuff layer in the strata. Such sedimentary-volcanic tuff is grayish-green in color and usually contains small SiO_2-bearing beans and, therefore, is locally called "green-bean rock". This rock is widespread in Sichuan, Chongqing, Hubei, Guangxi and eastern Yunnan, covering a total distribution area of (8×10^5) km^2 (Wu Yinglin et al., 1994). In the long past the rock has been regarded as an indicator for Middle/Lower Triassic stratigraphic division. Green-bean rock is usually absent along the platform margin-uplift zone, about 1 – 2 km wide, from Nidang of Xingyi, Pojiao of Anshun, Longgong of Anshun, Yangchanghe of Pingba, and Qingyan of Guiyang to Machangping of Fuquan. With this exception, green-bean rock is widespread in other vast areas, either in shallow-water carbonate areas in the northwest of the uplift zone or in the deep-water basin areas, where clastic rocks are dominant, on the southern (eastern) flank of the uplift zone (Fig. 1). The green-bean rock played an important role in lithologic and stratigraphic division of either platform areas or basin areas. Although there can sometimes be observed 3 – 5 layers of volcanic tuff, there is only one most stable and thickest layer, called the "green-bean rock". The green-bean rock is the object of this study.

In the platform-phase region green-bean rock is generally one meter thick or so, with the maximal thickness of 4.3 m (at Sanqiao, Guiyang). The overlying and underlying strata are all thin-moderate thick micritic dolomites and argillaceous dolomites. Their $\delta^{13}C$ values are $-5‰ - 0‰$ and $-3‰ - 0‰$, respectively (Zhu Zhongfa and Wang Guangxin, 1986), showing a Sabkha environment with salinity anomalies. In the basin region the rock is less thick, usually less than one meter, with the maximal thickness of 3.7 m (at Leyuan, Wangmo). It is normally sandwiched between thin-layered siliceous rocks and thin-layered mudstones, the $\delta^{13}C$ values of the hanging-wall and foot-wall rocks are $0‰ - 3‰$ and $0‰ - 2‰$, respectively (Zhu Zhongfa and Wang Guangxin, 1986), indicating that the rock was formed in a normal open marine environment. The forming time of green-bean rock is very short and during its deposition there prevailed an arid hot environment (Xu Jinghua et al., 1983). Moreover, the bio-assemblages are different from the upper part downwards. The region studied is characterized by a great thickness of green-bean rock and inconsistent accumulating environments, so it has been regarded as an ideal area for the investigation of such

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green-bean rock. On the basis of the detailed description of the characteristics of green-bean rock, this paper explored the properties of volcano-eruptive materials and their tectonic settings and deciphered the stratigraphic significance of green-bean rock in Middle-Lower Triassic boundary division.

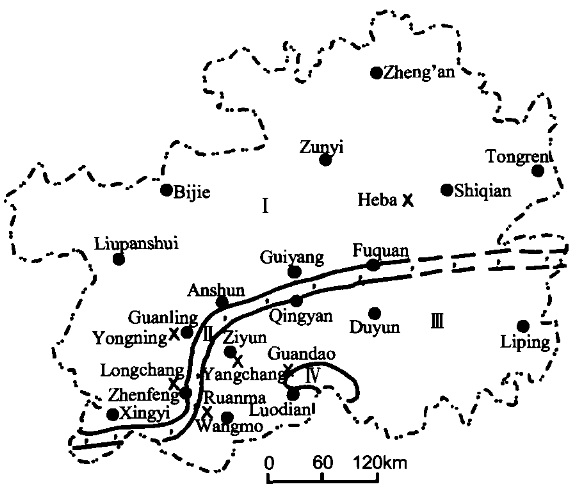

Fig. 1. Sketch map of early Middle Triassic paleogeography of Guizhou and sample localities. Ⅰ. Carbonate platform; Ⅱ. platform margin; Ⅲ. basin; Ⅳ. isolated platform; ×. sampling location.

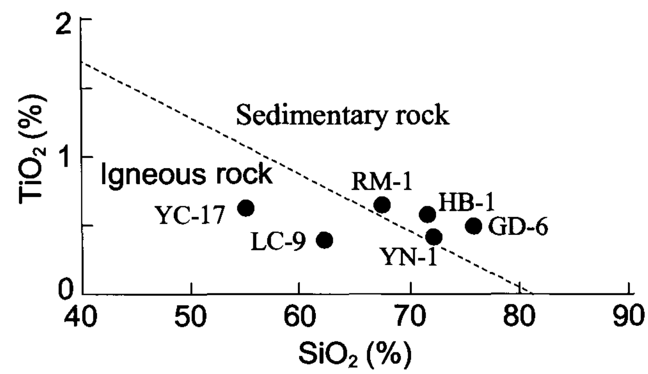

Fig. 2. TiO_2-SiO_2 diagram.

2 Petrological characteristics

In the region studied there have been recognized three types of volcanic tuffs, i. e. , vitric fragment tuff, crystal fragment tuff and volcanic ash-ball tuff. Their formation is followed mainly by montmorillonization and silicification. They exhibit micro-laminated structures and textures (Wu Yinglin et al. , 1994).

The tuffs are composed mainly of pyroclastics, which account for more than 90%. Vitric fragments are dominant with minor amounts of crystal fragments and extremely small amounts of volcanic ash balls.

(1) Vitric fragments: These fragments have been basically devitrified and decomposed into clay minerals (dominated by montmorillonite, followed by illite) and replaced by cryptocrystal siliceous material. Residual vitric fragments are diverse in form (e. g. bow-, eyebow-, flying bird-, chicken bone- and spearhead-shaped).

(2) Crystal fragments: There have been recognized quartz crystal fragments, sanidine crystal fragments, albite crystal fragments and biotite crystal fragments. The residual crystal fragments in the tuffs are dominated by sanidine and quartz, indicating that the components of primary magma were mainly of the acidic tuffaceous rock type.

(3) Volcanic ash balls: They are simply rounded, elliptic and flat-elliptic in shape and significantly different in size.

3 Mineralogical characteristics

In the green-bean rock clay minerals are dominant, including montmorillonite, illute and kaolinite, in addition to quartz (Zhu Lijun, 1995; Guizhou Provincial Bureau of Geology, 1987). The main clay minerals generally account for more than 80%. Due to differences in petrogenesis and mineral assemblage, illite is dominant around northern and central Guizhou, montmorillonite is dominant in western Guizhou, and kaolinite is dominant in southwestern Guizhou.

The heavy minerals in the green-bean rock are mainly zircon, apatite, manozite, etc.

4 Geochemical characteristics

4.1 Major elements

The chemical composition of the green-bean rock is listed in Table 1. As can be seen from this table, the contents of SiO_2 are highest, ranging from 54.84% – 75.44%; those of Al_2O_3 are relatively high, within the range of 11.12% – 23.51%; those of FeO, CaO and Na_2O are relatively low; and those of MgO and

K_2O are relatively high. The green-bean rock has much similarity in chemical composition with acid magmatic rocks, indicating that its source material is the acid volcanic ash.

Table 1. Chemical composition of the early Middel Triassic green-bean rock in Guizhou Province

Sample No.	Sample locality	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	LOI
RM-1	Ruanma, Zhenfeng	68.21	0.63	16.42	0.30	0.10	0.34	1.61	0.73	1.90	3.50	0.40	5.35
YC-1	Yangchang, Ziyun	54.86	0.70	23.51	0.66	0.68	0.48	1.72	0.74	0.46	3.71	0.20	11.80
GD-6	Guandao, Luodian	75.44	0.50	11.12	0.50	0.23	0.68	1.11	0.72	3.14	1.70	0.33	4.32
LC-9	Longchang, Zhenfeng	62.33	0.43	13.24	0.52	0.15	0.76	4.62	1.88	0.16	1.78	0.32	13.25
YN-1	Yongning, Guanling	71.88	0.43	12.59	1.60	0.19	0.71	2.99	1.67	0.47	2.56	0.27	3.97
HB-1	Heba, Shiqian	71.60	0.58	11.65	0.33	0.11	0.34	3.11	0.84	0.19	3.83	0.30	6.74

Note: Samples were analyzed at the Institute of Geochemistry, Chinese Academy of Sciences.

By making use of the methods described by Tarney (1976), Jensen (1976), Wright (1969) and Rittman (1973), the major element analysis data for the green-bean rock and the corresponding parameters (Table 2) were diagramed.

(1) The TiO_2 and SiO_2 data were plotted onto Tarney's TiO_2-SiO_2 diagram (Fig. 2). It can be seen in the diagram that all these samples are near the boundary line between the area of volcanic rocks and that of sedimentary rocks. This indicates that the green-bean rock stemmed from volcanic eruptives and was accumulated in the form of sediments. So, it exhibits obviously the features of clastic rocks.

(2) As can be seen in the Al_2O_3-MgO-Fe_2O_3 + FeO + TiO_2 diagram (Jensen, 1976), all the samples fall within the area of dacite, indicating that the green-bean rock came from acidic volcanic eruptives.

(3) The Rittman index σ for the green-bean rock varies between 0.29 to 1.57, all being less than 4, belonging to the calc-alkaline series (Qiu Jiaxiang, 1985). The data points of the samples were plotted onto the SiO_2-AR (alkalinity) diagram of Wright (Fig. 4), and it can be seen from the figure that all the data points fall within the area of calc-alkaline series. This indicates that the green-bean rock is the product of calc-alkaline volcanic eruption, and calc-alkaline volcanic rocks are mainly distributed in island arcs and on active continental margins.

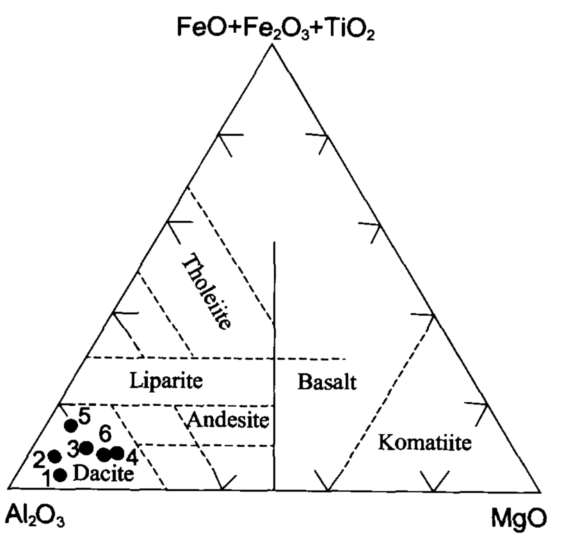

Fig. 3. Jensen's diagram (after Jensen, 1976). 1. RM-1; 2. YC-17; 3. GD-6; 4. LC-9; 5. YN-1; 6. HB-1.

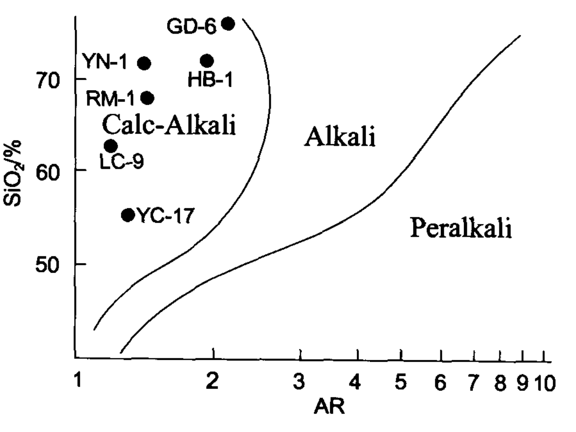

Fig. 4. Diagram of SiO_2 vs. AR (alkalinity).

(4) The logarithmic values of Rittman indices (σ) and Gottni indices (τ) are plotted onto Fig. 5 and all the data points fall within area B, i.e., the orogenic belt area (island-arc and active continental margin areas). This demonstrates that the green-bean rock stemmed from volcanic eruptives in the orogenic belt.

4.2 REE characteristics

The REE contents of and the parameters for the green-bean rock (Table 3) indicate that its total REE amount ($\sum$REE) is relatively high, ranging from 160.56 to 415.22, with the ratios of LRRE to HREE ranging from 2.04 to 4.40 and $Ce_N/Yb_N > 1$, indicating an LREE-enrichment type. There is little difference in REE contents from one sample to another. The δCe values are within the range of 0.37 - 0.90, displaying weak negative Ce anomalies. The REE distribution patterns tend to incline from left to right, and the curves for LREE are rather steep (Fig. 6), while those for HREE are smooth. With the exception of sample YC-17 whose curve shows a slight difference, the curves for the rest samples are generally in parallel with one another. The REE contents and distribution curves of the green-bean rock show similarities to those of acid volcanic rocks (Wang Zhonggang et al., 1989), and their obvious common characteristics also reflect that they should be the product of cognate magmas. Some similarities have been recognized in REE contents between the green-bean rock and sedimentary rocks (Xie Guiqing et al., 2001; Yu Bingsong et al., 1998).

Table 2. Parameters lgσ, lgτ and AR for the green-bean rock

Parameter	RM-1	YC-17	GD-6	LC-9	YN-1	HB-1
lgσ	0.2	0.17	-0.14	-0.54	-0.49	-0.20
lgτ	1.36	1.52	1.20	1.48	1.45	1.29
AR	1.57	1.42	2.31	1.29	1.56	1.95

Table 3. REE contents ($\times 10^{-6}$) of and related parameters for the Early Triassic green-bean rock in Guizhou Province

Sample No.	Sample locality	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy
RM-1	Ruanma, Zhenfeng	35.10	64.50	8.02	32.70	7.37	0.46	5.51	1.07	7.61
YC-17	Yangchang, Ziyun	93.10	132.00	18.00	81.00	12.20	1.97	8.14	1.48	10.00
GD-6	Guandao, Luodian	56.99	113.68	13.21	47.65	10.00	0.65	10.17	1.75	10.02
LC-9	Longchang, Zhenfeng	31.70	47.20	6.920	27.00	6.19	0.42	5.64	1.18	8.08
YN-1	Yongning, Guanling	26.20	46.90	6.46	24.6	5.43	0.39	4.75	0.92	6.92
HB-1	Heba, Shiqian	32.60	57.80	6.93	24.60	5.38	0.34	4.89	0.93	6.86

Sample No.	Ho	Er	Tm	Yb	Lu	Y	ΣREE	LREE/HREE	δEu	δCe
RM-1	1.45	4.42	0.64	3.81	0.44	28.30	201.40	2.78	0.21	0.90
YC-17	2.04	5.68	0.74	4.17	0.50	44.20	415.22	4.40	0.57	0.73
GD-6	2.27	6.08	0.88	4.66	0.72	64.97	343.70	2.39	0.19	0.97
LC-9	1.59	4.59	0.63	3.76	0.36	32.8	178.06	2.04	0.21	0.74
YN-1	1.34	4.12	0.60	3.33	0.40	28.20	160.56	2.17	0.23	0.85
HB-1	1.31	4.04	0.59	3.51	0.39	27.90	178.07	2.53	0.20	0.89

Note: Samples were analyzed at the Experiment and Test Center of the Yichang Institute of Geology and Mineral Resources. Chondrite-normalized values from McDonough (1995).

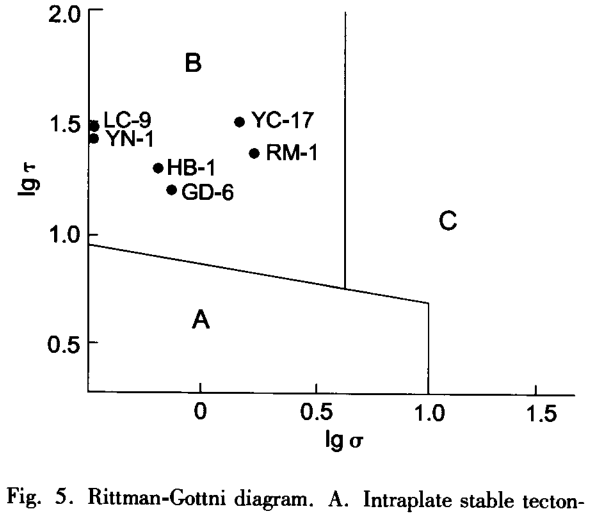

Fig. 5. Rittman-Gottni diagram. A. Intraplate stable tectonic zone; B. orogenic belt area (island-arc and active continental margin areas); C. alkaline rock area.

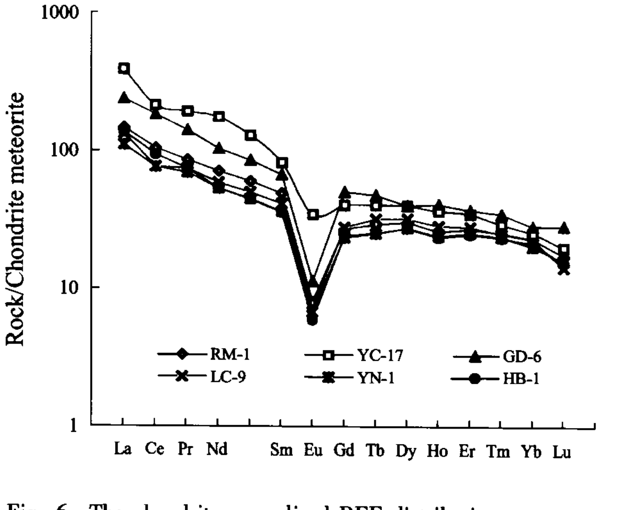

Fig. 6. The chondrite-normalized REE distribution patterns of the green-bean rock.

4.3 Trace element characteristics

As viewed from the contents of trace elements in the green-bean rock (Table 4), the rock is characterized by enrichment in LILE such as Rb and radiogenic elements such as Th, with Th/Ta ratios varying from 10.76 to 28.19. It is commonly accepted that Th > Ta is a characteristic feature of continental environment including island-arc and active continental margin. According to the Rb-(Yb + Ta) diagram of volcanic rock tectonic environment (Fig. 7), with the exception of sample YC-17 which falls within the intraplate tectonic environment, the rest samples all fall within the island-arc environment. The spider diagram of trace element ratios (Fig. 8) shows that Rb_N/Yb_N ratios are greater than unity, displaying a strong incompatible element enrichment type. Remarkable negative Ba and Nb, especially Sr, anomalies are recognized against obvious positive Rb, Th, La and Nd anomalies. Their patterns are similar to those shown in the spider diagrams charted by Sivell et al. for volcanic arc dacites and tuffs in New Zealand (Li Changnian, 1992).

The above characteristics indicate that the green-bean rock in the region studied is the product of deposition of acid volcanic ashes of orogenic calc-alkaline series, which had fallen in a stable region.

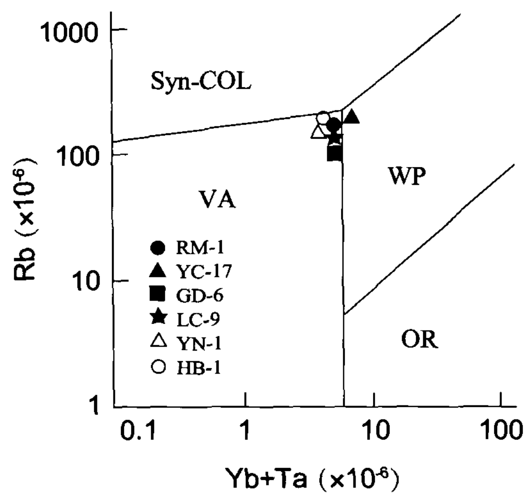

Fig. 7. Rb-(Yb + Ta) diagram. Syn-COL. syncollisional volcanic rock; WP. intraplate volcanic rock; OR. mid-ocean ridge volcanic rock; VA. volcanic arc.

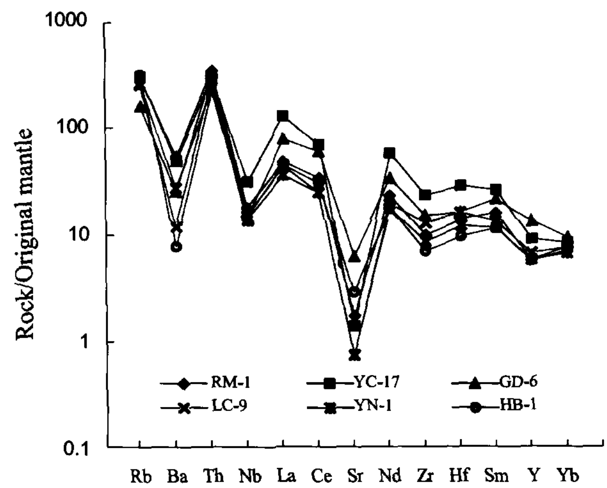

Fig. 8. Spider diagram of trace element ratios in the green-bean rock. The primary mantle-normalized values are after McDonough and Sun (1985).

5 The tectonic environment of volcanic eruption in the source region of the green-bean rock

According to the study on the tectonic settling of the Youjiang Basin during the Triassic, the basin had experienced a large-scale settlement during the early Middle Triassic. Such tectonic settlement may be attributed to the superimposition of a folded thrust fault, which resulted from collision between the Indosinian Plate and the South China Plate in northern Vietnam (Qin Jianhua et al., 1996), on the South China Plate, thus leading to bending of the South China Plate. It is the plate collision event that the Indosinian orogene was formed in the border area between China and Vietnam and that large-scale volcanic eruption was induced. Around the Songzuo-Dongxing area of southwestern Guangxi the Middle Triassic strata contain tuffaceous volcanic rocks (Yang Lizhen, 1997), belonging to the K-high calc-alkaline series tuff assemblage. It is seen that the volcanic source region of the green-bean rock should be around the area from southwestern Guangxi to northern Vietnam, belonging to a continental eruption environment. The tectonic setting of volcanic eruption should be the folded thrust fault. So, the tectonic setting of volcanic eruption in the source region of the green-bean rock should be the Indosinian orogenic belt in the border area between China and Vietnam. From the Sino-Vietnam border to the inland of Guizhou there is a distance over several hundreds of kilometers, more than one thousand kilometers away from Sichuan and Hubei. Can volcanic ashes drift so far? The answer is positive. The available data on recent volcanic activities indicate that intensively erupted volcanic ashes may fly in the air at an altitude of over more than 3000 km and cover an area of about several thousand kilometers. From this it can be seen that the volcanic eruption that took place during the early Middle Triassic is relatively intensive.

6 Geostratigraphic implication for the green-bean rock

In the long past green-bean rock has been regarded as the Middle/Lower Triassic boundary. That is because the macroscopic bio-fossil assemblages are different in the strata bellow and above the Middle/Lower Triassic boundary. In the overlying strata are contained the Triassic double-shell *Costatoria goldfussi mansuyi-Leptochondria* assemblage and the *Leirolites-Hollandites* assemblage, while in the lower strata are contained the Early Triassic double-shell *Entolium discites microtis-Pteria murchisni* assemblage and the *Tirolites-Procarmites* assemblage (Guizhou Provincial Bureau of Geology, 1987). Such fossils are usually absent in several meters or several tens of meters of the strata underlying the green-bean rock. Therefore, it is doubt to regard the green-bean rock as the Middle/Lower Triassic boundary. The current scheme of division of the Middle and Lower Triassic series is mainly based on the geological facts that the first emergence of conodont *Chiosella timorensis* is regarded as the mark of the beginning of the Middle Triassic series (Yin Hongfu et al., 2000; Yin Hongfu and Tong Jinnan, 2002). Great progress has been made in the studies of conodonts in recent years. In the strata underlying the green-bean rock the fossil *C. timorensis* has been found, which marks the beginning of the Middle Triassic series (Wang Zhihao and Zhong Rui, 1990; Yang Shouren and Chu Qingchun, 1992; Qin Dianxi et al., 1993; Wei Jiayong et al. ①, 2004). All this indicates that the stratigraphic position of green-bean rock is higher than that of the Middle/Lower Triassic boundary, so the green-bean rock can only be used as a supplementary mark of the Middle/Lower Triassic boundary.

Although the green-bean rock cannot be used as a direct marker of the Middle/Lower Triassic boundary, it is an isochron geological body, widely distributed and stable. In light of its absolute age data, the boundary age value can be indirectly determined with *C. timorensis as* the marker of the Middle/Lower Triassic boundary. Martin et al. (2001) used the U-Pb method to determine the zircon age of green-bean rock in the Guandao section at Luodian, which is 247.2 ± 0.4 Ma; Wei Jiayong et al. ① (2004) found that the location where *C. timorensis* emerged first in the Guandao section is only 3.6 m beneath the green-bean rock. According to the thickness (238 m) and timing of formation of the Luolou Formation (4.4 Ma), the sedimentation rate of the Luolou Formation was estimated to be about 56 m/ Ma. It is deduced from a comprehensive analysis of the age of green-bean rock and the sedimentation rate of the Luolou Formation that the Middle/Lower Triassic boundary age is about 247 Ma.

7 Conclusions

(1) Petrological and geochemical characteristics of the green-bean rock indicate that its source material—volcanic ashes which are composed mainly of glassy fragments with relatively high SiO_2. According to its major elements, trace elements and REEs, as well as the diagrams concerned, it can be judged that the green-bean rock was formed in such a way that acidic volcanic materials of calc-alkaline series had been transported via atmosphere and settled down in a tectonically stable area.

(2) The eruptive tectonic environment of volcanic source region of the green-bean rock is the Indosinian orogenic belt in the border area between China and Vietnam, and its dynamic mechanism is the collision between the Indosinian Plate and the South China Plate.

(3) In light of the age values of the green-bean rock, it is deduced that the Middle/Lower Triassic boundary age is about 247 Ma.

References

Guizhou Provincial Bureau of Geology (1987) *Regional Geology of Guizhou Province* [M]. pp. 436 – 438. Geological Publishing House, Beijing (in Chinese).

Li Changnian (1992) *Trace Element Petrology of Volcanic Rocks* [M]. pp. 108 – 109. China University of Geosciences Press, Wuhan (in Chinese).

Martin M. W., Lehrmann D. J., Bowring S. A., Enos P., Ramezani J., Wei Jiayong, and Zhang Jiyan (2001) *Timing of Lower Triassic Carbonate Bank Buildup and Biotic Recovery Following the End-Permian Extinction Across the Nanpanjiang Basin, South China* [A]. Geological Society of America, Abstracts with Programs. **33**, A – 201.

McDonough W. F. and Sun S. S. (1985) Isotopic and geochemical systematics in Tertiary-recent basalts from southeastern Australia and implication for the sub-continental lithosphere [J]. *Geochim. Cosmochim. Acta.* **49**, 2051 – 2067.

McDonough W. F. and Sun S. S. (1995) The composition of the Earth [J]. *Chemical Geology.* **120**, 222 – 253.

Qin Dianxi, Yan Chengxi, and Xiong Jianfei (1993) New development in bio-stratigraphic research on Middle Triassic conodonts [J]. *Geology of Guizhou.* **10**, 120 – 130 (in Chinese with English ab-

① Wei Jiayong et al. (2004) Research on China's Qingyanian and Middle/Lower Triassic boundary age.

stract).

Qin Jianhua, Wu Yinglin, Yan Yangji et al. (1996) Tectonic evolution of Hercynian-Indosinian sediments in the Nanpanjiang Basin [J]. *Acta Geologica Sinica*. **70**, 99 - 106 (in Chinese with English abstract).

Qiu Jiaxiang (1985) *Petrology of Magmatic Rocks* [M]. pp.35. Geological Publishing House, Beijing (in Chinese).

Wang Zhihao and Zhong Rui (1990) The Triassic conodont bio-strata in different phase areas of eastern Yunnan, western Guizhou and northern Guangxi [J]. *Journal of Stratigraphy*. **14**, 15 - 35 (in Chinese with English abstract).

Wang Zhonggang, Yu Xueyuan, Zhao Zhenhua et al. (1989) *REE Geochemistry* [M]. pp. 212 - 225. Science Press, Beijing (in Chinese).

Wu Yinglin, Zhu Hongfa, Zhu Zhongfa et al. (1994) *Triassic Petrography- Paleogeography and Diagenesis in Southern China* [M]. pp.59 - 61. Geological Publishing House, Beijing (in Chinese).

Xie Guiqing, Hu Ruizhong, Fang Weixuan, and Qi Liang (2001) Geological and geochemical characteristics of the cherts in the Mojiang gold deposit and their implications [J]. *Chinese Journal of Geochemistry*. **20**, 249 - 257.

Xu Jinghua, He Qixiang, Wu Yinglin et al. (1983) Carbon and oxygen stable isotope geochemistry of upper and lower parts of the isochroneous surface of "green bean rock" between the Early and Middle Triassic series in southwestern China [J]. *Bulletin of Chengdu Institute of Geology and Mineral Resources, Chinese Academy of Geosciences*. **4**, 1 - 12 (in Chinese with English abstract).

Yang Lizhen (1997) Cycle division of Mesozoic volcanic activities in southeastern and southwestern Guangxi [J]. *Geology of Guangxi*. **10**, 9 - 12 (in Chinese with English abstract).

Yang Shouren and Chu Qingchun (1992) Research on conodonts from the Triassic Yongning Formation in southwestern Guizhou and the Lower/Middle Triassic boundary [J]. *Bulletin of Peking University*. **28**, 722 - 732 (in Chinese with English abstract).

Yin Hongfu and Tong Jinnan (2002) On China''s marine Triassic stages and Lower Triassic stage boundary [J]. *Earth Science—Journal of China University of Geosciences*. **27**, 490 - 497 (in Chinese with English abstract).

Yin Hongfu, Yang Zhunyi, and Tong Jinnan (2000) The status quo of international research on the Triassic system [J]. *Journal of Stratigraphy*. **24**, 109 - 113 (in Chinese with English abstract).

Yu Bingsong, QiuYuzhuo, and Li Juan (1998) Geochemistry of sedimentary rocks and its relation to crustal evolution and mineralization in Southwest Yangtze massif, China [J]. *Chinese Journal of Geochemistry*. **17**, 265 - 273.

Zhu Lijun (1995) A preliminary study on the characteristics and origin of clay minerals in green-bean rocks in Guizhou [J]. *Acta Mineralogica Sinica*. **15**, 75 - 81 (in Chinese with English abstract).

Zhu Zhongfa and Wang Guangxin (1986) Paleogeography during pre- and post-sedimentation of green-bean rocks between the Early and Middle Triassic in the Upper Yangtze platform and its vicinities [J]. *Geology of Oil and Natural Gas*. **7**, 344 - 355 (in Chinese with English abstract).