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Research progress of Yarlung Zangbo ophiolite

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Abstract: *Ophiolite is a relic of the paleo oceanic crust preserved on the earth continent. It preserves a lot of important evidences in the process of crust-mantle interaction and records information about oceanic lithospheric dynamics and geotectonics. It has always been a research hotspot in the field of geology. Especially in recent years, the ophiolite has made a lot of important progress in the global lithospheric evolution, ocean-continent transition history in different geological periods and geodynamics, which has aroused great research enthusiasm in the field of geology. The Yarlung Zangbo ophiolite is the most important ophiolite in China.However, the tectonic setting, rock composition and genesis of the Yarlung Zangbo ophiolite are still controversial. This paper expounds the Yarlung Zangbo ophiolite from three aspects: brief history, characteristics and existing problems, so as to promote the Yarlung Zangbo ophiolite to the international academic circles.*

Keywords: *Ophiolite, Yarlung Zangbo, Tectonic setting, Forming age, Emplacement age*

1. Introduction

French mineralogist Alexandre brongniart first proposed the concept of ophiolite [1]. Later, Gustav Steinmann called peridotite (serpentinite), gabbro, diabase and basalt together as ophiolite in his field work [2]. Bailey and McCallien [3,4] developed it into the classic Steinmann Trinity Model. In the 1960s, the birth of the theory of plate tectonics brought a new dawn to the study of the origin of ophiolites [5], and made ophiolites become a petrological term that has attracted much attention since the theory of plate tectonics was put forward. According to this theory, ophiolites may represent fragments of oceanic lithosphere formed at plate spreading, including mantle peridotite in the lower part, cumulate gabbro in the middle, and diabase and basalt in the upper part, and have been widely used to identify traces of palaeo-ocean closure [6,7]. Influenced by the theory of plate tectonics, the Geological Society of America held the Penrose Conference on ophiolite in the western United States in 1972, which defined ophiolite as a set of rocks composed of metamorphic ultramafic rocks, gabbro, mafic sheeted dike and mafic volcanic rocks [6]. The 1972 definition stresses that the term does not imply a genetic meaning.

In the past 30 years, geologists have studied the representative Ophiolites in typical areas by using the theories of mineral petrology, geochemistry and geophysics, and found that only a few ophiolites were formed in the mid ocean ridge environment, and most of the lava above the ophiolites had similar formation environment with the volcanic rocks in the modern ocean subduction zone. Therefore, there are many problems about the tectonic environment, emplacement mode and geodynamics of ophiolites. Taking the Troodos ophiolite in Cyprus as an example, the sequence of the upper lava is different from that of the ophiolite formed in the normal mid ocean ridge environment, but more consistent with that of the volcanic rocks in the subduction zone environment. Many scholars believe that the ophiolite sequence does not directly represent the oceanic lithosphere, but is formed in the tectonic environment of the subduction zone (SSZ).In 1984, Pearce J.A. established and improved the theoretical system of mid ocean ridge (MOR) type and subduction zone (SSZ) type ophiolites, and combined with mantle dynamics, explained the diversity of ophiolites [8].

Dilek and Fumes (2011) [9] redefined ophiolites: ophiolites are the residual products of rocks in the upper mantle and crust of the oceanic lithosphere. Due to the convergence between plates, ophiolites are emplaced in plate suture zones, where a set of related ultramafic rocks to felsic rocks are usually developed, and sheeted dikes are not absolutely developed. According to the research of Dilek and Fumes, it can be seen that: ① sheet dykes are not a specific criterion for ophiolites [10]; ② Because of the tectonic emplacement of ophiolites, the rock units are exposed intermittently; ③ In some specific tectonic environments, each rock unit of ophiolites experienced different stages of melting and magmatic evolution.

It can be seen that there are still controversies on the tectonic setting, rock composition and genesis of ophiolites. Taking the Yarlung Zangbo ophiolite as an example, this paper expounds the research history, characteristics and existing problems, and further discusses the problems of ophiolites. At the same time, it hopes to promote the Yarlung Zangbo ophiolite to the international academic circles.

2. Brief research history

The first person to conduct scientific research on the Yarlung Zangbo ophiolite is a foreign scholar, who is A.Gansser, a Swiss geologist known as the father of the Himalayas [11]. The concept of Yarlung Zangbo ophiolite was first proposed by Chinese scholars Chang Chengfa and Zheng Xilan [12]. They described in the article that roughly along the Yarlung Zangbo River Valley, a belt of ultrabasic and basic rocks emerges intermittantly. The ultrabasic rocks include peridotite, harzburgite, olive-pyroxenite and pyroxenite; The basic rocks include gabbro, pegmatite gabbro and hornblende gabbro.Moreover, in addition to gabbro bearing ultrabasic rocks, basic dikes, basalts and tuffs, red and green siliceous rocks and siliceous limestones with foraminifera are also widely developed. They together form the so-called ophiolite suite.

The large-scale study of the Yarlung Zangbo ophiolite in China started from the geological prospecting work in the 1960s. The focus of the study in this period is the ultramafic rock mass containing chromite. In the late 1970s, with the introduction of plate tectonics theory into China, and the concept of Yarlung Zangbo ophiolite proposed by Chang Chengfa and Zheng Xilan [12], domestic scholars began to pay attention to the properties of a series of mafic-ultramafic rocks distributed along the Yarlung Zangbo River [13-15], accompanied by radiolarian siliceous rocks and deep-sea flysch sedimentary intercalations [16]. In 1979, the U.S. plate tectonic delegation made a field investigation on the Xialu ophiolite in the Yarlung Zangbo zone, and obtained several understandings: ① the ophiolite in the belt is not complete, and may have been destroyed by later tectonism;② There are many lherzolites in the mantle peridotite unit of ophiolite;③ The thickness of gabbro in ophiolite is relatively thin, which indicates that the magma supply of magma chamber was limited at that time, which may be the background of slow spreading ocean ridge.

In the 1980s, Sino French cooperation pushed the study of the Yarlung Zangbo ophiolite to a new peak. The most representative achievement is the article published by Nicolas et al in nature, which takes the ophiolite in Xigaze area as the main research object, and deepens the understanding of the Yarlung Zangbo ophiolite [17]: ① Compared with the ophiolites in other parts of the world, the mafic units in the Yarlung Zangbo ophiolites lack plutonite;② Diabase occurs not as dyke, but as diabase sheet; ③ The peridotite in the upper part of the ophiolite was intruded by a large number of diabase sheets;④ The thickness of mafic unit in ophiolite is relatively thin;⑤ Chromite diopside often exists in harzburgite; ⑥ There is no low temperature plastic shear deformation in ultramafic rocks. After the end of Sino French cooperation, the study of the Yarlung Zangbo ophiolite fell into a low period.Until the end of last century, the cooperation between China and Canada pushed the study of the Yarlung Zangbo ophiolite to a new height [18-22].

In recent years, scholars at home and abroad continue to pay close attention to the Yarlung Zangbo ophiolite, and have done a lot of work on rock mineralogy, rock geochemistry and geochronology, which will be mentioned in the following chapters.

3. Overview features

Located in the east of the Tethys orogenic belt, the Qinghai-Tibet Plateau is composed of several terrains, including the Kunlun-Qilian terrains, Songpan-Garze terrains, Qiangtang terrains, and Lhasa terrains [23]. From Late Cretaceous to early Paleocene, during the closure of the Neotethys ocean, the Indian plate drifted northward and the Eurasian plate converged, resulting in the largest and youngest Yarlung Zangbo Suture Zone on the Qinghai-Tibet Plateau.The Yarlung Zangbo River ophiolite is exposed in this narrow suture zone on a large scale along the east-west direction. From east to west, there are Luobusa, Zedang, Xgaze, Saga, Zhongba, Xiugugabu, Pulan and Dongbo. According to the characteristics of ophiolite occurrence, the ophiolite can be divided into three parts: the eastern segment (Qushui-Motuo), the middle segment (Renbu-Sangsang) and the western segment (saga to the Sino Indian border).The northern part of the ophiolite belt is the Xigaze fore-arc basin and the Gangdise island arc, and the southern part is the ophiolite melange, sedimentary melange, flystite sedimentary rock and the Tethyan Himalayan terrane [24, 25].

The ophiolite in the eastern section is distributed between the flysch strata of Late Triassic Langjiexue group in the South and Gangdise island arc, J3-K1 volcanic rocks and Tertiary conglomerate in the north, including Zedang, Luobusa and Nang County rock bodies [26]. The eastern section is characterized by a large amount of mantle peridotite and developed chromite deposits. The Zedang pluton is composed of mantle peridotite and a set of mafic complexes.The REE distribution pattern of Zedang mantle peridotite is "U" or "V" type, and the total REE content is low. It has undergone the transformation process from MOR to SSZ environment [27-30]. The Luobusa pluton is mainly composed of mantle peridotite, gabbro-diabase and basalt.Diabase and gabbro extend in large scale and are located in the north of mantle peridotite. Basalt is not developed and a small amount of basalt is located in the north of mantle peridotite.The distribution pattern of rare earth elements is flat type with LREE slightly depleted, and its formation environment is MOR and SSZ [31-33]. Luobusa chromite includes Luobusa, Xiangkashan and Kangjinla mining areas, where disseminated, podiform and massive chromite are widely developed. The former two are generally associated with the olives, while the surrounding rock of massive chromite is harzburgite [34].

The middle ophiolite is located in Angren to Renbu area, including Angren, Jiding, Luqu, Xialu, Chongdui, Qunrang, Deji, Bailang, Dazhuqu and Renbu rocks from west to east, collectively known as Xigaze ophiolite.Xigaze ophiolite is the most typical ophiolite with the highest degree of research.From south to north, the ophiolites in this area show the lithologic variation from mantle peridotite, gabbro-diabase to basalt.In the south of the ophiolite, there is a set of Mesozoic gaxue group mixed accumulation, and the siliceous rocks are mainly dated from Late Jurassic to early Cretaceous. The chongdui formation of late Early Cretaceous-early Late Cretaceous can be seen in the northern part of the area, which is covered by the ophiolite, but most of the ophiolite is covered by the Xigaze fore-arc basin of Late Cretaceous.Fresh mantle peridotites are mainly distributed in the Luqu and Dazhuqu plutons, which are mainly composed of harzburgite, a small amount of lherzolite and dunite, while the mantle peridotites of other plutons have been serpentinized to varying degrees.The Jiding, Bailang and Dazhuqu plutons of the Xigaze ophiolite have developed oceanic crust, which is mainly composed of layered gabbro, massive gabbro, diabase sheet and pillow lava.The Angren, Luqu, Xialu, Chongdui, Qunrang, Deji and Renbu plutons are devoid of gabbros, only containing relatively thin diabase sheets and pillow lavas.Some diabase and gabbro dikes intrude into the underlying mantle peridotite in the crust-mantle transition zone [35,36]. The REE distribution pattern of mantle peridotite in Xigaze is "U" type, and most researchers believe that it was formed in a SSZ type tectonic environment.Xiong et al. [41] found a massive chromite deposit in the Xialu pluton of the eastern Xigaze ophiolite. She Yuwei discovered a new chromite deposit in Dazhuqu pluton [42].

The ophiolites in the western segment include Dongbo, Pulan, Xiugugabu, Zhongba, Saga and other plutons, which are characterized by a large amount of mantle peridotite and a small amount of mafic rocks [43]. The mantle peridotites of Dongbo, Pulan, Xiugugabu and Zhongba plutons are mainly fresh harzburgite with a small amount of lherzolite and dunite.The Dongbo, Pulan and Xiugugabu ophiolites are locally exposed with small-scale podiform chromite mineralization. The orebodies are generally 2-5m in length and 0.5-3m in thickness, and are distributed in lenticular form in harzburgite.The mantle peridotite of Saga pluton is strongly serpentinized.The mantle peridotites of these plutons are generally intruded by gabbros and diabase dikes of different sizes, and a small amount of basalts are exposed locally.Dongbo harzburgite and dunite have "U" or "V" REE patterns and LREE are enriched. However, lherzolites are depleted in LREE and enriched in Hree [44]. Dongbo mantle peridotite was formed in MOR environment, and later was modified by SSZ environment [44-45]. The REE distribution pattern of mantle peridotite in Pulan is similar to that of "U" type [46], which was formed in MOR environment and was modified by SSZ environment during emplacement [47-48].

4. Existing problems

4.1 Definition

According to the definition of the Pengrose conference in 1970s, a complete ophiolite profile from bottom to top should include ultrabasic peridotite, basic gabbro / diabase and basalt with pillow structure in the upper part.This complete ophiolite profile is similar to the oceanic lithospheric profile formed by the rapid spreading oceanic ridge (such as the mid Pacific ridge) on the earth.Therefore, the traditional study of ophiolite is mainly focused on the ancient and modern comparison with the rapidly expanding mid-ocean ridge. However, complete ophiolite profiles are rare on land.Most of the ophiolites preserved in the orogenic belt do not have such a complete structure, which makes the comparative study of phiolites in some difficulties. In addition, the study of ophiolite in China often considers that there are ophiolites in some areas without detailed petrological, mineralogical and geochemical work on ultramafic rocks and cumulates. This conclusion is not reliable, thus affecting the positive recognition of the tectonic setting in some areas. There is little positive evidence;On the contrary, there is a lot of evidence that they may not be ophiolites. For example, some basalts in Xiugugabu have the characteristics of OIB, which is not a member of ophiolite [49].

The research results of Deep Sea Drilling Program and Ocean Drilling Program of the United States enrich and perfect the theoretical system of MOR type and SSZ type ophiolites, and reasonably explain the diversity of ophiolites and their differences with the oceanic lithosphere.

The theoretical system of MOR type and SSZ type ophiolites has been enriched and improved by the research results of Deep Sea Drilling Program and Ocean Drilling Program of the United States, which reasonably explain the diversity of ophiolites and the difference between them and the oceanic lithosphere. The latest research found that in the slow and ultra-slow spreading mid ocean ridge, due to the lack of magma supply, a complete new oceanic crust can not be formed in time, and the spreading of the ridge is mainly realized by "detachment fault". The study of slow and ultra-slow spreading ridges has become a new driving force for the study of ophiolites. Therefore, further field investigation and detailed indoor work are needed to determine the properties of ophiolite.

4.2 Tectonic setting

The tectonic setting and genetic types of the Yarlung Zangbo ophiolite are also controversial.Some scholars believe that the Yarlung Zangbo ophiolite is formed in the center of slow spreading of mid ocean ridge [17,35,36,50-53]. However, many scholars believe that the Yarlung Zangbo ophiolite was formed in the subduction zone environment [19, 25, 54-56].At present, the mainstream view is that the Yarlung Zangbo ophiolite was formed in the tectonic setting related to island arc and belongs to SSZ type ophiolite. Traditionally, ophiolites have been judged to be formed in subduction zone (SSZ) environment mainly based on the geochemical characteristics of mafic rocks in ophiolites sequence without other direct geological evidence [8, 57-58]. If the Yarlung Zangbo ophiolite is really classified as SSZ ophiolite, then we must first make clear where the arc is.Although McDermid et al. [59] identified a Jurassic intraoceanic island arc in Zedang area, it is proved that the island arc is actually only a part of the active continental margin of Gangdise [60], not an intraoceanic island arc.Therefore, at present, we are not sure that there is an intraoceanic island arc in the Neotethys ocean in the Yarlung Zangbo area.Furthermore, even if we assume that the intraoceanic island arc may have disappeared in the later subduction process, we must find evidence of its existence. Because as a researcher, if we cannot find solid geological evidence, we cannot admit its existence, let alone use it as a starting point for subsequent relevant hypotheses.

According to the tectonic position, ophiolites can be divided into mid ocean ridge type, fore arc type and back arc type [17, 25, 61, 62]; According to the spreading rate of ocean basin, ophiolite can be formed in fast spreading ridge, slow spreading ridge and ultra-slow spreading ridge [17, 61]. Obviously, the tectonic setting and genetic type of the Yarlung Zangbo ophiolite have not been determined at present, so it needs to be further determined by field and experiment.

4.3 Forming age and emplacement age

Nowadays, with the rapid development of science and technology, geologists continue to carry out the dating of the Yarlung Zangbo ophiolite.At present, the research results on the age of each segment of ophiolite body show differences. The ages of different ophiolite bodies are quite different, but the age of ophiolite in the middle and east segments is earlier than that in the west segment [47]. Zhou Su et al. (2001) [63] determined the isochron age of gabbro-diabase in the eastern Luobsha pluton as 177±31Ma by isotope Sm-Nd method; Zhong Lifeng et al. (2006) [64] used SHRIMP zircon U-Pb method to determine the age of the diabase zircon in the Luobsha ophiolite as 162.9±2.8Ma. The ages of gabbro, rodingite and diabase in Dazhuka and Jiding ophiolites in the middle section are 124.0±1.6Ma-131.8±3 Ma [56, 62]. The U-Pb age of zircon in diabase of Sangsang ophiolite is 125.2±3.4Ma. In the west section, the age of gabbro in Zhongba pluton is 125.7±0.9Ma [55]. Wei Zhenquan et al. (2006) [65] used SHRIMP zircon U-Pb method to date diabase dike in the Xiugugabu ophiolite in Tibet, and obtained an age of 122.3±2.4Ma; Xu Deming et al. (2008) [66] measured the isochron age of the whole rock and minerals of gabbro in the Xiugugabu ophiolite as(126±1.5)Ma. The latest data show that the age of Dangqiong diabase is 126.7±4 Ma and 123±0.8Ma [67]. The zircon SHRIMP U-Pb dating of diabase dyke in Pulan ophiolite by Li Jianfeng et al. (2008) [68] shows that the weighted mean age is 120.2Ma±2.3Ma; Miller et al(2003) [69] reported that the Sm-Nd isochron age of the tholeiite in the Pulan ophiolite is 147±25Ma, which is different from the ^{40}Ar-^{39}Ar age of 152±33Ma;Liu Zhao et al. (2011) [47] used LA-ICP-MS zircon dating to indicate that the Pulan ophiolite was formed in 130±3Ma.Xiong et al. (2011) [70] reported that LA-ICP-MS ages of gabbro and pyroxenite in Dongbo ophiolite are 128±1.1Ma and 130±0.5Ma, respectively..Therefore, a series of age data statistics show that the formation age of the Yarlung Zangbo ophiolite is heterogeneous.

On the issue of the emplacement age of the Yarlung Zangbo ophiolite, there is not much work done by predecessors. Traditionally, the direct means to determine the age of emplacement is to determine the relationship between the upper and lower coverage of the strata, but this means is difficult to give an accurate age limit. Therefore, the high-pressure metamorphic rocks generated by tectonism around the ophiolite become an important indicator for us to determine the emplacement age.At present, the high-pressure metamorphic rocks identified in Zhongba, Sangsang, Lhatse, Saga and Bailang in the Yarlung Zangbo Suture Zone include chloritoid schist , black chlorite schist, lawsonite schist and blueschist [71,72]. In the 1980s, Wang Xibin et al. (1987) [73] obtained the age of metamorphic basalt in the ophiolite melange is 81 Ma, which makes people believe that these ophiolites were emplaced in the late Cretaceous.However, Li Cai et al. (2007)[72] conducted Ar-Ar analysis on chlorite schist-blueschist in northeast of Bailang county, and the geochronological data is 59 Ma. Another means of determining the emplacement age of ophiolites is the study of the metamorphic floor associated with the upthrusting of ophiolite. Up to now, the metamorphic floor has a relatively complete definition, which is located under the ophiolite and in fault contact with the ophiolite. The lithology is metamorphic basalt (such as garnet amphibolite, clinopyroxene amphibolite and amphibolite) and metamorphic sedimentary rock (such as metamorphic radiolarite, metamorphic mudstone and quartzite), and the thickness is generally not more than 500m. The degree of metamorphism gradually decreases with the distance from the overlying ultramafic rocks, and changes from high-grade granulite facies to greenschist facies [74]. Malpas et al. (2003) [75] conducted Ar-Ar dating of amphibole and biotite in Luobusa plagioclase amphibolite, and obtained the age is 88-81 Ma. The Ar-Ar dating of garnet amphibolites in saga, Bailang and Sangsang areas by China Canada Cooperation shows that the age is 123-129Ma [20-22], which is very close to the age of ophiolite itself, indicating that the tectonic emplacement occurred shortly after ophiolite formation. In fact, this phenomenon widely exists in ophiolites in other regions of the world, and is considered to be an important indicator of the formation of ophiolites in the initial stage of subduction [76]. At present, there is no comprehensive study on the emplacement age of the Yarlung Zangbo ophiolite, so it is difficult to understand the emplacement situation in the whole region.

5. Conclusion

Since last century, ophiolite has been a hot topic and difficult point in the field of geology.At present, we still have a lot of deficiencies in the field and indoor identification of the Yarlung Zangbo ophiolite, and even some basic questions can not be answered positively. For example, is it ophiolite? What is its tectonic background and genetic mechanism? What is the age of its formation? What is the age of its emplacement? These problems are unavoidable. Therefore, we should start from the field geology, combined with indoor petrology, mineralogy, geochemistry, isotope dating and other means for systematic analysis and judgment, in order to promote the Yarlung Zangbo ophiolite to the international academic community.

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