Petrologic and chronological characteristics and formation mechanism of peperite in the Sanjiang Orogenic Belt in western Yunnan, China

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Abstract. Jamda-Weixi continent marginal arc belt is an important component to understand the evolution of Paleotethys. For the first time, the occurrence of peperite is being reported at the bottom of Pantiange Formation in western Yunnan, China. Two types of peperites have been identified, namely fluidal peperite and blocky peperite. LA-ICP-MS U–Pb dating results (253.6±0.7Ma) of dacitic lava showed that the peperite was formed during the late Permian. The peperite was formed during the alternation of active period and quiet period of the volcano in an apparent shallow ocean margin.

1. Introduction
As one of the orogenic belts with the most complex geological structure and most intense igneous activity, the Sanjiang Orogenic Belt is located in eastern and southeastern Tibetan Plateau. The belt keeps a relatively integral record of the tectonic evolution process of Tethys, especially for Paleo-Tethys [1, 2]. Both field survey and geochronological data show that multi-period igneous activities occurred from Late Paleozoic to Early Mesozoic in the Sanjiang region, but their spatial and temporal distribution, tectonic relationship and formation mechanism are still disputed [3, 4].

Recently, peperite with typical peperitic textures were identified in Permian to Early-middle Triassic Pantiange Formation volcanics explored by drill core, which is located in Gepoluo
antimony mining area in Weixi County, western Yunnan, China. Peperite refers to a special rock formed by a mixture of unconsolidated, poorly consolidated or wet sediment and disintegrated magma [5]. Although the distribution of peperite is limited, it has important geological significance: (1) indicator of contemporaneity between volcanism and sedimentation and (2) constraints on the sedimentary environment during volcanism [6].

In this paper, petrologic and chronological characteristics of the peperite were described and formation mechanism was analyzed.

2. Study area, sampling locations and methods

2.1 Study area and sampling location
Pantiange Formation in Weixi County is part of the Permian to Middle Triassic Jamda-Weixi-Madeng-Diancangshan continent marginal arc belt (figure 1-A). Pantiange Formation with the thickness of more than 1200m comprises grey to greyish-green rhyolite and dacite mainly (figure 1-B). The overlying stratum is Cuiyibi Formation, which comprises a volcano-sedimentary succession up to ~5500 m in thickness. The underlayer is Shanglan Formation, which comprises fine sandstone, siltstone, mudstone and limestone. Peperite developed in the lower of Pantiange Formation explored by drill core which is located in Gepoluo antimony mining area. Little outcrop of peperite can be seen.

Samples of fresh peperite were collected from the ZK4802 drill core for zircon U-Pb age dating.

2.2 Analytical techniques
Zircon grains for geochronology were separated by conventional heavy liquid and magnetic techniques and purified by handpicking under a binocular microscope. The zircon grains were mounted in epoxy. The mount was polished to expose the interior of the grains, which were photographed for cathode-luminescence (CL) images to identify internal textures. U-Pb dating was performed at the University of Science and Technology of China, employing an Elan 6100 DRCII Q-ICP-MS coupled to an ArF excimer laser-ablation system.
Figure 1. Geological map showing the locations of the study area and volcano-sedimentary column of the Pantiange Formation showing main lithology (A-modified after [7]; B-modified after [8]).

U-Pb isotope composition of zircon adopts linear drift correction, and standard 91500 was conducted as an external standard. Detailed analysis procedures see [9]. Original data processing was performed by Ladating@Zrn. Common Pb correction adopts ComPb corr#3-18, a method recommended by Anderson in 2002. Weighted average age calculation and concorde plot were made using Isoplot/Ex_ver 4.15, software programmed by Ludwig in 2003.

3. Petrologic feature of the peperite

There is only one outcrop to recognize peperite explored by a new road. The juvenile clast and host sediments make up peperite, and their ratio range from 1:2 to 1:1. The color of fresh juvenile clast is light white, and the size scale ranges from centimeter-level to millimeter-level. Some juvenile clast appears angular, wedge-shaped, polygonal, and the others appear lingulate, flame, irregular and so on (figure 2). Condensation boundary and baking boundary can also be seen. The juvenile
clast shows vitropatic texture mainly. Based on textures mentioned above, the classification of outcrop peperite is fluidal peperite. Host sediments are ash black to dark black, and their composition is tufaceous and carbonaceous.

**Figure 2.** Characteristics of outcrop peperite with structures of condensation boundary and baking boundary combination and sediments fluidization

Concentrated distributions of peperite focus on two drill cores, namely ZK4801 and ZK4802.

In ZK4801 drill core, the peperite has typical features of fluidal peperite. The color of juvenile clast is light white and celandine green, and the size scale is mainly several centimeters. Flowing characteristics of juvenile clast are very obvious, including lingulate, flaming, tearing, angular, wedge-shaped, irregular and so on (figure 3). The ratio between juvenile clast and host sediments ranges from 1:3 to 1:2. The juvenile clast also shows vitropatic texture mainly. Host sediments are dark black, and their composition is tufaceous and carbonaceous.
Figure 3. Characteristics of fluidal peperite in ZK4801 drill core

In ZK4802 drill core, juvenile clast shows straight polygon and irregularly compact accumulation (figure 4). Black host sediments inject fissures of blocky juvenile clast with typical jigsaw-fit texture, indicating that the peperite has typical features of blocky peperite. Blocky peperite is formed in the background of magma producing brittle crackings. When hot magma intrudes cold wet sediments, hot magma generates quenching distortion and forms juvenile clasts. In the process, sediments flow and inject juvenile clasts. The ratio between juvenile clast and host sediments ranges from 3:1 to 2:1. The color of juvenile clast is light white and celandine green, and the size scale is mainly several centimeters. Host sediments are dark black, and their composition is tufaceous and carbonaceous.

Figure 4. Characteristics of blocky peperite with jigsaw-fit texture in ZK4802 drill core

4. Chronology of the peperite

Most of the zircon grains from peperite sample ZK4802 are colorless and transparent, 40-120μm in length with aspect ratios = 1.0-2.0. They are mostly subidiomorphic, and the CL images reveal closely spaced oscillatory zoning. A total of seventy zircon grains were selected for U-Pb analysis. Four analyses yielded $^{206}\text{Pb}/^{238}\text{U}$ ages of $271.6\pm3.6\text{Ma} \sim 755\pm9.5\text{Ma}$. Their CL images show dimgray, developing incomplete oscillating zone and inherited core, which are speculated as the ages of inherited zircon grains. Three analyses have two stages model age, and thirty-five analyses have a low concordance. The remnant twenty-eight concordant analyses form a coherent group with a weighted mean $^{206}\text{Pb}/^{238}\text{U}$ ages of $253.6\pm0.7\text{Ma} (\text{MSWD}=1.3)$, (figure 5).
Figure 5. The cathodoluminescence (CL) images of typical zircons and U-Pb concordia plots

(MSWD—mean square of weighted deviates)

5. The formation mechanism of the peperite and its geological significance

5.1 Formation mechanism

Peperite is a product of magma mingling with wet sediments; however, it is not simple mechanical mixing. The mixing mechanisms are analogous to fuel-coolant interaction (FCI) [10].

There are both fluidal peperite and blocky peperite in Gepoluo mining area that is to say fluidal and blocky juvenile clasts mingling and superpose in the same area. The possible reason is that peperitic processes undergo different mingling periods from plasticity to brittleness. Magma starts to quench after steam episode, while viscosity increment of fluidal magma happened during the cooling process. It results in magma behavior turn into brittleness [11]. In a word, the ratio between fluidal peperite and blocky peperite represents a strong and weak degree of two mechanisms in different stages visually.
5.2 Geological significance
The peperite age of 253.6±0.7Ma shows that the location belongs to Jamda-Weixi continent marginal arc belt, which had continued for more than 40Myr from Permian to Middle Triassic. The belt was formed due to subduction of the Longmu Co-Shuanghu-Changning- Menglian Ocean. Previous data indicate that there are three peak values of the volcanic eruption in Jamda-Weixi continent marginal arc belt, and volcanic erupted intensively per 10Myr [4]. It is consistent with field survey of rock association, namely the formation of continental marginal clastic rocks and carbonate rocks during the interval of magmatic eruption [12], which reveals multiple alternations of active period and quiet period of volcanoes. Therefore, the peperite was formed in an apparent shallow ocean margin.

6. Conclusions
The peperite at the bottom of Pantiange Formation in western Yunnan, China, was formed by the mingling of rhyolitic and dacitic lava with wet, unconsolidated sediments. Two types of peperites were identified based on morphological characteristics of juvenile clast, namely fluidal peperite and blocky peperite, which represent a strong and weak degree of two mechanisms in different stages visually.

LA-ICP-MS U–Pb dating results (253.6±0.7Ma) of dacitic lava showed that the peperite was formed during the late Permian. It was a part of Jamda-Weixi continent marginal arc belt. The peperite was formed during the alternation of the active and quiet period of the volcano in an apparent shallow ocean margin.

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