Tectonophysics 717 (2017) 242–252

Contents lists available at ScienceDirect

Tectonophysics

journal homepage: www.elsevier.com/locate/tecto

New Early and Late Carboniferous paleomagnetic results from the Qaidam Block, NW China: Implications for the paleogeography of Central Asia

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ARTICLE INFO

Keywords:
Central Asia
The Qaidam Block
Carboniferous
Paleomagnetism
Paleogeographic reconstruction

ABSTRACT

There is an ongoing debate regarding the paleogeographic evolution of the Qaidam Block (37.3 °N/96.4 °E) in northwest China during the late Paleozoic. To provide a reliable constraint on the paleogeographic reconstruction and to determine the relationship with the adjacent area, we performed a paleomagnetic investigation of Early and Late Carboniferous sediments from the Qaidam Block. Stepwise thermal demagnetization successfully isolated high unblocking-temperature characteristic directions from the samples. The tilt-corrected mean direction of the Early Carboniferous sediments is $Ds/Is = 298.6°/-46.4°$ with $\alpha_{95} = 4.7°$ and $N = 15$ sites, corresponding to a paleopole at -3.2 °N, 147.5 °E with $A_{95} = 4.8°$. The Late Carboniferous paleomagnetic direction is $Ds/Is = 320.1°/-46.1°$ with $\alpha_{95} = 5.3°$ and $N = 8$ sites, corresponding to a paleopole at -15.1 °N, 132.2 °E with $A_{95} = 5.4°$. A positive fold test for the Early Carboniferous paleomagnetic directions, and consistency with the Kiaman reversed superchron for the Late Carboniferous paleomagnetic directions, indicates the primary origin of the characteristic remanence of the studied section. The new paleomagnetic results suggest that the Qaidam Block was located at about 27 °N and did not undergo significant N-S movement during the Carboniferous. However, the Qaidam Block experienced a counter-clockwise rotation of about 21° during this period. Comparisons of the paleomagnetic results from the major blocks of Central Asia suggest that the Qaidam Block may have experienced a relatively rapid northward movement and collided with the Tarim Block after the Late Permian. Based on the paleomagnetic poles of the Qaidam Block and adjacent blocks, we present a tentative paleogeographic reconstruction for central Asia during the Early and Late Carboniferous.

1. Introduction

Central Asia comprises and was formed by the collision and amalgamation of several continents/blocks (Siberia, North China, Tarim and several microcontinents). The closure of ancient oceans and subsequent collisions of the major blocks of Central Asia formed the Central Asian Orogenic Belt (CAOB, Şengör et al., 1993; Jahn et al., 2004; Xiao et al., 2004, 2009, 2014, 2015; Windley et al., 2007; Zheng et al., 2013; Dong et al., 2016). The Qaidam Block is the major block in the southern part of Central Asia. It has been proposed that the paleo-position of the Qaidam Block was in close proximity to the Tarim Block since the Middle Devonian (Heubeck, 2001) and that it may have originally formed a part of the Tarim Block (Metcalfe, 2006, 2013). In terms of tectonic affinity, several workers have considered that the Qaidam and Tarim Blocks belong to a unique craton (Ge and Liu, 2000; Duan and Ge, 2005; Ge et al., 2009). However, Late Permian paleomagnetic results indicated that the Qaidam Block was amalgamated with the Tarim Block after the Carboniferous (Xu et al., 2011). Moreover, Cocks and Torsvik (2007, 2013) considered that the Qaidam Block formed the southwestern part of the North China Block. The principal features of Central Asia were formed by the end of the Paleozoic (Metelkin et al., 2010). Hence, the Carboniferous is an important interval for deciphering the paleogeography, tectonic transition and evolution of the Qaidam Block.

Paleomagnetism is the one of the most effective methods for reconstructing the paleo-latitudinal displacement of tectonic blocks.

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http://dx.doi.org/10.1016/j.tecto.2017.08.014
Received 25 January 2017; Received in revised form 13 August 2017; Accepted 14 August 2017
Available online 15 August 2017
0040-1951/

Previous Carboniferous paleomagnetic studies for the Siberia continent (Kravchinsky et al., 2002), the Tarim Block (Bai et al., 1987; Fang et al., 1996; Gilder et al., 1996), the Mongolia Block (Zhao et al., 1990; Zhao et al., 2013), the Hexi Corridor-Alashan Block (Wu et al., 1993; Huang et al., 2001; Yuan and Yang, 2015), the Junggar Block (Yi et al., 2015) and the Yili Block (Wang et al., 2007) have provided important constraints on the paleogeography and tectonic evolution of Central Asia. The Qaidam Block is a key area connecting the Tarim, North China Blocks and the Tibetan Plateau in Central Asia. However, previous paleomagnetic studies of the Qaidam Block have focused mainly on the Cenozoic tectonic evolution and tectonic deformation resulting from the India-Asia collision (Halim et al., 1998; Cogné et al., 1999; Li et al., 2001; Chen et al., 2002; Dupont-Nivet et al., 2002, 2003; Sun et al., 2005, 2006, 2012; Fang et al., 2007; Lu et al., 2012; Zhang et al., 2013; Yu et al., 2014a, 2014b). Very little reliable Carboniferous paleomagnetic data is available from the Qaidam Block. Paleomagnetic results from only 25 samples yielded a paleolatitude of 26 °N for the Qaidam Block during the Late Carboniferous (Li et al., 1989). The Qaidam Block was considered to have been a part of the Tarim Block during the Late Carboniferous and it constituted the southern margin of Angaraland. Wu et al. (1997) considered that the Qaidam Block was located at a paleolatitude of about 12 °N and it was farther south than the Tarim Block during the late Paleozoic. However, based on the paleomagnetic results from 17 samples, Yang et al. (1992) suggested that the Qaidam Block was located at a low latitude (4.4 °N) near the equator during the Carboniferous. Recent paleomagnetic results from 56 limestone samples indicated that the Qaidam Block was located at ~13.5 °N during the Early Carboniferous (Wang et al., 2016). The foregoing review demonstrates that the earlier paleomagnetic research was hampered by an insufficient number of samples and by the lack of stability tests, such as fold test and reversal test. Hence, there are significant limitations in discussing the paleolatitude position and tectonic affinity of the Qaidam Block during the Carboniferous based on these earlier paleomagnetic studies.

In this study, we present paleomagnetic results from Early and Late Carboniferous limestones of the Qaidam Block. Our intention was to address the problem of the lack of reliable Carboniferous paleomagnetic data and thereby to provide a reliable constraint on the paleolatitude of the Qaidam Block; and to provide accurate paleomagnetic constraints on its paleogeographic reconstruction, tectonic affinity and relationship with adjacent blocks during the Carboniferous.

2. Geologic setting and sampling

The Qaidam Basin is a Cenozoic sedimentary basin underlain mainly by Precambrian crystalline basement and a Paleozoic fold belt (Wang and Coward, 1990; Zhang et al., 2008). It lies to the southeast of the Tarim Block, southwest of the Hexi Corridor-Alashan Block, and north of the Kunlun and Songpan-Ganze Blocks. It is separated from the Tarim Block by the Altyn Tagh fault zone to the north, from the Songpan-Ganze Block by the East Kunlun fault zone to the southeast, and from the Kunlun Block by the Qimen Tagh fault zone to the south (Fig. 1b). Strata outcrops in the Qaidam Basin are mainly Cenozoic sediments. Outcrops of Pre-Cenozoic strata are limited to the western and northern margins, and outcrops of Carboniferous strata are limited to the basin margin. Major Upper Carboniferous deposits in the Qaidam Basin include the Zhongwunongshan Group (C_{2zh}), the Zhabusagaxiu Formation (C_{2z}) and Keluke Formation (C_{2k}). Lower Carboniferous deposits include the Huaitoutala Formation (C_{1h}) and Chengqianggou Formation (C_{1c}). In the study area, outcropping rocks consist mainly of Paleozoic and Proterozoic strata (Fig. 1c). Examples are the Cambrian Oulongbuluke Formation, Ordovician Duoquanshan Formation, Lower Carboniferous Huaitoutala Formation, Upper Carboniferous Keluke Formation and Upper Carboniferous Zhabusagaxiu Formation. There are several NW-SE faults and left-lateral strike-slip faults in the study area (Fig. 1c).

The sampled locality lies at the northern margin of the Qaidam Block (Fig. 1). Paleomagnetic samples were collected from two different sections. A simplified geological map of the Shihuigou and Oulongbuluke sections is shown in Fig. 2. Sites MC1–MC11 from the Early Carboniferous Huaitoutala Formation and sites MC12–MC20 from the Late Carboniferous Keluke Formation were collected in the Shihuigou section (Fig. 2a). Sites TC23–TC31 from the Early Carboniferous Huaitoutala Formation were collected from the Oulongbuluke section (Fig. 2b). The Huaitoutala Formation mainly consists of biolithite limestone and marlstone intercalated with sandstone and shale. Fossils identified in this formation include anthozoa (*Yuanophy-llum knasuense Yü*, *Lithostrotion irrgulare Phillips*, *Neoclisiophyllum*, *Cravenia*, *Rylstonia*) and Brachiopoda (*Kansuella aff.kansuensis Chao*, *Gigantoproductus geniculatus*, *Echinoconchella elegans*, *Fluctuaria undata*), indicative of Early Carboniferous time (Wang, 1987; Qinghai Bureau of Geology and Mineral Resources, 1991; Chen et al., 2003). In addition, the Keluke Formation consists of biolithite limestone intercalated with quartzose sandstone. Fossils identified in the Keluke Formation include fusulinida (*Pseudostaffella* sp., *Eoparafusulina* sp.), brachiopoda (*Christites gobicus Chao*, *Echinoconchus aff.punctatus*, *Alexenia* sp.) and anthozoa (*Cystophora hunboldta*, *Caninia* sp.), indicative of Late Carboniferous time (He et al., 1987; Qinghai Bureau of Geology and Mineral Resources, 1991; Wang and Yu, 1995). The Huaitoutala Formation overlies the Chengqianggou Formation and is unconformably overlain by the Keluke Formation. The Keluke Formation is overlain by the Late Carboniferous Zhabusagaxiu Formation.

In total, we sampled 11 Early Carboniferous sites (106 samples) and 9 Late Carboniferous sites (74 samples) at the Shihuigou section (37.4 °N, 96.1 °E), and 9 Early Carboniferous sites (83 samples) at the Oulongbuluke section (37.2 °N, 96.7 °E) (Figs. 2, 3, Table 1). Sampling was mainly conducted on limestone. In general, 10 samples were taken at each site, using a gasoline-powered drill, and were oriented using a magnetic compass.

3. Laboratory techniques

In the laboratory, the samples were cut into 2.2-cm-long cylinders for subsequent paleomagnetic analysis. All samples underwent stepwise thermal demagnetization up to 580 °C, performed with an ASC TD-48 thermal demagnetizer with an internal residual field of < 10 nT. Demagnetization temperature intervals were generally large (40–60 °C) in the low temperature part, and smaller (20–30 °C) at higher temperatures. Remanent magnetizations were measured using a 2G-755R cryogenic magnetometer. In order to identify the magnetic minerals, stepwise thermal demagnetization of a three-component isothermal remanent magnetization (IRM) were measured using a JR-6 spinner magnetometer. All measurements were carried out in a shielded room with residual fields of < 300 nT at the Key Laboratory of Paleomagnetism and Tectonic Reconstruction of the Ministry of Land and Resources, CAGS, in Beijing. Magnetization directions were determined by principal component analysis (Kirschvink, 1980). The site-mean of the paleomagnetic directions was calculated using Fisher statistics (Fisher, 1953). Paleomagnetic data were analyzed using the computer program packages developed by Enkin (1990) and Cogné (2003).

4. Paleomagnetic results

Thermal demagnetization of a three-component isothermal remanent magnetization (IRM) (Lowrie, 1990) was conducted on representative samples of the Huaitoutala Formation in the Shihuigou and Oulongbuluke sections. Fields of 1.2 T, 0.4 T and 0.12 T were used to characterize the hard, medium and soft components, respectively. The results indicate that the hard components (0.4–1.2 T) are unblocked at about 680 °C (Fig. 4a–b). Thermal demagnetization of the soft (< 0.12 T) and medium (0.12–0.4 T) components indicates an