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Full Length Article

Evolution of the Neoproterozoic rift basins and its implication for oil and gas exploration in the Tarim Basin

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ABSTRACT

According to the aeromagnetic, seismic, and geological data, the surface structure, sedimentation, and distribution characteristics as well as the deep dynamic mechanism of the north-south differentiated Neoproterozoic rift basins were well investigated to reveal the tectonic evolution and its control on the distribution of the Early Cambrian sedimentary basin and source rocks in the Tarim Basin. The rift basin in the southern Tarim was a product of superplume activities during the early breakup period of the Rodinia supercontinent. It initiated in the Early Cryogenian (about 780 Ma) and appeared as NE-direction aulacogens extending into the Tarim Basin. The rift basin in the northern Tarim was a back-arc rift basin derived from the subduction of Pan-Rodinian oceanic plate, which initiated in the Late Cryogenian (about 740 Ma) and occurred as a nearly EW-direction narrow band across the Tarim Basin. The northern Tarim back-arc rift basin had similar formation and evolution process to the Late Mesozoic-Cenozoic back-arc rift basins in East Asia, both showing an oceanward migration; however, the Tarim rift basin finally evolved from the fault-depression basins into passive continental margin. The Neoproterozoic rift basins controlled not only the distribution of source rocks in the syn-rift period but also the development of Early Cambrian sedimentary basin. Nearly EW-distributed syn-rift (Cryogenian to Ediacaran) and post-rift (Lower Cambrian Yurtusi period) source rocks were likely to develop between the present Tabei uplift and central uplift belt.

1. Introduction

The Tarim Basin is the largest hydrocarbon-bearing cratonic basin in China, and presently surrounded by arc-shaped mountains, of which the northern margin is the South Tianshan Mountains of the Paleo-Asian tectonic system, and the southern margin is the West Kunlun–Altun Mountains of the Tethys tectonic system. In the Early Neoproterozoic, collision and collage of the Central Tarim arc terrain and the North and South Tarim blocks resulted in formation of the unified basement of the Tarim Craton (Guo et al., 2005; Xu et al., 2013a, b). As a response to the Rodinia supercontinent breakup, the rifting tectonics and magmatic activities developed widely during the Cryogenian and Ediacaran, and controlled formation of the first set of sedimentary cover (Jia et al., 2004; Xu et al., 2013a, 2013b). Aeromagnetic and seismic data reveal that the Tarim Basin showed the rift pattern with a north-south differentiation during the Cryogenian and Ediacaran, which might belong to different genetic types and have different dynamic mechanisms. In particular, the latest geological evidence shows the Neoproterozoic rift in the northern Tarim Basin may form by subduction around the Rodinia supercontinent (Ge et al., 2012, 2014), which is quite different from the previous view of the mantle plume rift (Jia et al., 2004; Turner, 2010; Xu et al., 2013a, 2013b; Gao et al., 2015).

At present, there is a big dispute on distribution of the Early Cambrian sedimentary basin in the Tarim Basin, i.e., the one opinion is that the deep water basin developed in the eastern Tarim, while the carbonate platform developed in the western Tarim (Pan et al., 2015; Du and Pan, 2016), and the other opinion is that a north-south differentiation developed in the Tarim (Guan et al., 2017). In the former, the structural-sedimentary framework is basically consistent with that in the Middle Cambrian to Ordovician; while in the latter, the structural-sedimentary framework is similar to the Neoproterozoic rift with different structural-sedimentary framework in the north and south. These two distinct structural-sedimentary frameworks imply that the source rocks in the Lower Cambrian Yurtusi and Xishanbulake formations

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have quite different distribution patterns, thus leading to different exploration directions. Researches on formation and evolution dynamic mechanism of the Neoproterozoic rift basin provide the possibility to solve such a problem.

Based on aeromagnetic, seismic, geological, and geochemical results, the surface structural and sedimentary characteristics of the north-south differentiation in the Tarim Neoproterozoic rift basins were well studied; the deep dynamic mechanism of the north-south differentiation and its control on distribution of Early Cambrian sedimentary basin and source rocks were also investigated to promote deep oil and gas exploration in the Tarim Basin.

2. Characteristics of rift basins in the northern and southern Tarim Basin

In the Tarim Basin, the Neoproterozoic rifts are the important response and symbolic extensional structure to the Neoproterozoic Rodinia supercontinent breakup (Li et al., 2008, 2013; Lu et al., 2008; Xu et al., 2013a). The rifts in the Tarim Basin are characterized by a north-south differentiation, which shows obvious differences in the rift filling sequence, basin initiation time, and distribution pattern.

2.1. Rift filling sequence

The Cryogenian-Ediacaran strata in the Tarim Basin are mainly outcropped in the Kuruktag region at the northeastern margin, the Aksu region at the northwestern margin, and the Tielieketi region of West Kunlun at the southwestern margin (Fig. 1). Thickness of the outcrop strata are thousands of meters with the maximum of 6000 m at the Kuruktag; however, the Cryogenian-Ediacaran strata are less encountered or drilled in the basin interior, so the filling sequence is mainly tracked and deduced according to the marginal outcrops and the seismic data.

In the Kuruktag area, the Cryogenian-Ediacaran strata are unconformably underlain by the Tonian Pargangtag Group and granites with age of about 780 Ma (Feng et al., 1995; Huang et al., 2009; Long et al., 2011), and are characterized by multiple sets of volcanic rock interbedded with tillite (Fig. 1a). At the bottom of Cryogenian System, the Beiyixi Formation has the filling sequence of coarse to fine grain size, and the bimodal volcanic rocks develop extensively (740 Ma, Xu et al., 2009), which are products in the faulting peak period. The presence of volcanic rocks in the Beiyixi, Aletonggou, and Teruiaiken formations indicates intensive volcanism and probable development of multiphase faulting activities in the Cryogenian. In the Ediacaran, the volcanism was weak and volcanic rocks were partially found in the Zhamoketi and Shuiquan formations. On the whole, in the Kuruktag area, the fault structure mainly developed in the Cryogenian, and the depression structure developed in the Ediacaran. In addition, four glacial events (i.e., Beiyixi, Aletonggou, Teruiaiken, and Hangerqiaok) developed alternately with volcanism, and well correspond to the four global ice ages of the Neoproterozoic “snowball event” (Xu et al., 2009; He et al., 2014a), indicating that the volcanism is likely to be the main controlling factor for the development of interglacial period.

In the Aksu area, the Xifangshan Formation at the bottom of Cryogenian System is characterized by large variation of particle size and development of sedimentary rhythm, reflecting characteristics of rapid accumulation. The lithology changes to diamictite, graywacke and tillite in the Qiaoenbulak and Yourmeinak formations (Fig. 1b). However, the bottom of the Cryogenian System and its contact with the Aksu Group are not observed, while the Yourmeinak Formation is unconformably underlain by the Aksu Group, and contains the blueschist gravels of the Aksu Group. The Ediacaran System is in unconformable contact with the Cryogenian System, and unconformably underlain by the Aksu Group; it includes fluvial-lacustrine clastic rocks of the Sugetbulak Formation and marine dolomite of the Qigbulak Formation from bottom to top. Although Turner (2010) proposed that it possibly represents a new rifting event, the Ediacaran System is likely overlap sediments in the depression period due to the thin volcanic rocks, small thickness (<1000 m), and little lateral variation. Compared with the Kurutag area, the Cryogenian and Ediacaran volcanic rocks are rare in the Aksu area.

In the Tielieketi area, the Cryogenian System is unconformably underlain by the Sukuluok Group, and is characterized by rapid accumulation from coarse to fine particle size. At the bottom of the Cryogenian System, a large set of red conglomerate occurs in the Yalaguz Formation, and it changes upwards to sandstone, siltstone, and mudstone. Moreover, tillites develop in the Bolong and Yutang formations (Fig. 1c), and the Yutang tillite can correspond to that in the Teruiaiken and Yourmeinak formations (Fig. 1). The Ediacaran System is in conformable contact with the Cryogenian System, and is mainly composed of sandstone and siltstone as well as a small amount of dolomite, reflecting a depression environment with weak structural changes. No Cryogenian-Ediacaran volcanic rocks are found in this area.

In summary, the Cryogenian and Ediacaran systems in the Tarim Basin show a typical rift fault–depression filling characteristic. The faulting activity mainly occurred in the Cryogenian, while the depression mainly developed in the Ediacaran. In addition, the rift filling sequences and volcanic activities in different areas have different characteristics.

2.2. Initiation time of the rift basins

Rift magmatism and strata can be used to constrain the initiation time of the rift basin. The rift magmatism includes the large igneous provinces, basic dyke swarms and bimodal magmatic rocks in the early period of the rifting activity, of which the large igneous provinces and basic dyke swarms generally occur earlier than the initiation time of the rift basin (Bialas et al., 2010), while the bimodal magmatic rocks indicate that the rift basin has been already opened. The rift strata are dominated by the typical sedimentary sequence in the rift basin, which is also called as the rift-genesis facies with rapid change from coarse to fine particle size (Wang and Li, 2003). It represents the exact development time of the rift basin. The rift magmatism and strata data indicate that the southern and northern Tarim have different basin initiation time.

At the southwestern margin of the Tarim Basin, the basic dyke swarm and bimodal magmatic rocks have zircon ages of 802 Ma and 783 Ma, respectively (Zhang et al., 2006, 2010), indicating that the rift basin in the southern Tarim may be opened in the Early Cryogenian (about 780 Ma). This is consistent with the unconformable cover of the Cryogenian rift sequence on the basic dyke and the maximum sedimentary age of the Bolong Formation at about 750Ma (Zhang et al., 2016) (Fig. 1c). In the northern Tarim, however, the 773–759 Ma basic dyke swarm intruded the metamorphic basement and the early granites (820–780 Ma) (Zhang et al., 2009), both of which are unconformably overlain by the Cryogenian–Ediacaran System, indicating that the rift basin in the southern Tarim has not been opened before 759 Ma. Meanwhile, the Beiyixi Formation which represents the early deposition in the rift basin has a zircon age of 740 Ma for the bimodal volcanic rocks (Xu et al., 2009), and the Xifangshan Formation has the sedimentary age less than 748 Ma (He et al., 2014b). These ages suggest that the rift basin in the northern Tarim may initiate at about 740 Ma. Therefore, the rift basin in the southern Tarim was opened about 40 Ma earlier than that in the northern Tarim.