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RESEARCH PAPER

Analogue modeling of through-going process and development pattern of strike-slip fault zone

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Abstract: Nine sets of sand-box experiments were designed according to actual geologic data to investigate the evolution pattern and development mechanism of simple shear strike-slip fault zone using the fault CT scanning technique. The experimental results show that R (Riedel) shears were developed early and more in number, and one set of these faults intersected with the principal displacement zone (PDZ) at relatively lower angle; the P shears (being in symmetrical distribution with the R shears) and Y shears (subparallel to PDZ) were developed later than the R shears, and the fault zone was through-going only after the formation of Y shears. The through-going process of strike-slip fault zone can be divided into four stages: embryonic stage, R (Riedel) shears development stage, P shears and Y shears development stage, and through-going stage of fault zone. In the process, the faults developed progressively from the basement to the top cover, the faults spread upward in the profile at embryonic stage, and then converged toward the PDZ on the plane at R shears development stage. The modeling supports that the en echelon structure developed in "helicoidally drag" pattern, however, the length of the en echelon fault grew linearly doubling the growth rate of its depth, and the fault intersection angle with the PDZ decreased in quadratic function with the increase of its depth. The analysis reveals that cover thickness and the maximum principal stress direction are the main factors causing the difference in "helicoidally drag" structure. The modeling provides guidance for the strike-slip fault interpretation and evolution study, and layering and segmenting faults in the marine carbonates of the Tarim Basin.

Key words: strike-slip fault zone; analogue modeling; structural evolution; en echelon structure; "helicoidally drag" pattern; Tarim Basin

Introduction

Strike-slip faults are a class of complicated geological structures widely developed on the earth[1–3], with various geometric patterns on the plane and vertical profiles and complex evolution processes[1–4]. Physical modeling is one of the key methods and tools to study the formation and evolution of complicated fault zones. Many physical modeling experiments with different materials have been performed to reveal the relationship between geological factors and fault processes[4,5]. Among these experiments, R (Riedel) shear modeling is an important target in strike-slip fault development study, in which the evolution process of strike-slip faults was investigated by modeling with different materials under different stress states[5–6], the spiral pattern and formation mechanisms of echelon structure were explored, and some actual geologic phenomena of different sizes were explained. But as many parameters could affect the physical modeling, and some factors causing faulting are hard to model, the physical modeling needs to be improved in experimental material, model design and visualization etc.[5–12]. Moreover, though there were many modeling researches on extensional structure and thrust structure, there were not consistent understandings on the structural evolution and stage division of strike-slip fault zone from echelon structure to through-going fault zone.

Although rare in most intracratonic basins[1–5, 13], a series of strike-slip faults have been identified recently in Tarim Basin[14–16] where thrust faults take the majority[13]. The strike-slip faults have not only played a constructive role in the development of the Ordovician carbonate reservoir, but also had strong impacts on the accumulation and distribution of oil and gas in the Tarim Basin[14–17]. In recent years, the study on strike-slip fault geometry in the Tarim Basin has made great progress[14–18]. Due to the limited data available, however, the interpretation of the strike-slip faulting patterns is still widely controversial[14–18], and there is not yet an experiment performed to study the evolution and formation mechanism of the strike-slip faults in the Tarim Basin.

In this study, according to the geological setting of the strike-slip faults in the Tarim Basin, physical modeling ex-

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periments were set up to find out the formation and evolution process and development mechanism of strike-slip faults, and to provide implications for the interpretation of faults and oil exploration and development in the Ordovician marine carbonates.

1. Method and design of structure physical modeling

1.1. Geological background

Tarim Basin is a large multicycle superimposed craton basin in China with complete Phanerozoic strata[13]. With the improvement of seismic data quality, multiple strike-slip fault zones have been identified from north slope in the Central uplift to south slope in the Northern uplift of Tarim Basin[14–16]. The study on these complex strike-slip faults shows that multiple kinds and stages of strike-slip faults widely occurred in the Central uplift, Northern uplift, Southeastern depression and Bachu uplift of the Tarim Basin, which could be controlled by multi-period and various direction oblique compression[13–16].

On the seismic profile of Northern-Central Tarim area, large-scale strike-slip fault zones with steep main fault plane cut down through the Cambrian to the basement, forming flower structures, en echelon structures, pull-apart grabens, and braided structures and so on[14–15]. There are mainly two sets of NE-trending and the NW-trending faults, with a length of up to 50–80 km[14–16]. The space between the subparallel fault zones is 10–30 km in general. The faults have horizontal displacements of several kilometers, vertical fault throw of hundreds of meters, and big lateral variations.

Developed mainly in late Caledonian-early Hercynian period, the strike-slip faults in the Central uplift mostly terminate in the Silurian-Devonian system, with a few extends upward to the Permian system[14–15,18]. Whereas, most of the strike-slip faults in the southern slope of Northern uplift may not only developed in the Lower Paleozoic, but also grow up to the Permian and Mesozoic with a few reactivations, indicating there were multi-period fault activities in late Caledonian stage, late Hercynian and Yanshan periods[16–17]. The strike-slip faults in the central uplift may be related to the structural convergence in the southern margin of the plate in late Caledonian-early Hercynian[14], and the strike-slip faults in the Northern uplift are related to the oblique-convergence of southern Tianshan paleo-ocean, but the initial formation mechanism of these faults is still ambiguous.

Studies and production data show the oil and gas are richer in strike-slip fault zones of Cambrian-Ordovician marine carbonate in the Central-North uplift of the Tarim Basin[14–18]. Most high production wells are located in the fault zone, and the wells differ widely in production, showing close relationship with the fault zone. Thus, the study on strike-slip faults is of great significance for the study on carbonate reservoirs, and oil and gas accumulation, and efficient exploration and development of oil and gas in the Tarim Basin.

1.2. Experiment design

According to the basic principle of similarity, physical modeling reproduces the geological process under laboratory conditions by using appropriate machinery and materials and scaling up or down the original model[5, 9–10, 19–20]. The experiments in this study were carried out in PetroChina Research Institute of Petroleum Exploration and Development. The platform for physical modeling consists of three parts: controlling station, sand-box experimental platform and CT (Computed Tomography) working area. Based on research results on the strike-slip fault patterns in the Central and Northern uplift in recent years[13–18], aiming at the evolution from small-scale isolated echelon structures to a large scale through-going fault zone, a series of simple-shear models were designed in this study (Fig. 1 and Table 1).

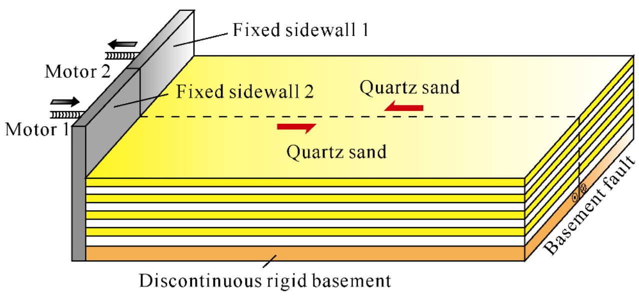

Fig. 1. Sandbox used for strike-slip fault modeling.

Table 1. Parameters of some experiments in this study

Experiment No.	Size of model (cm×cm)	Basement property	Cover material	Cover thickness/ mm	Basement displacement/mm	Slicing
1-1	60×20	Rigid	Dry quartz sand	6	62.62	CT
1-2	60×20	Rigid	Dry quartz sand	12	27.00	CT
1-3	60×20	Rigid	Dry quartz sand	16	66.00	CT
1-4	60×20	Rigid	Dry quartz sand	27	60.00	CT
1-5	60×20	Rigid	Dry quartz sand	46	60.00	CT
1-6	80×30	Rigid	Wet quartz sand	50	33.00	By hand
1-7	90×80	Rigid	Dry quartz sand	40	200.00	By hand
1-8	80×30	Rigid	Dry quartz sand	20	50.00	By hand
1-9	80×30	Rigid	Dry quartz sand	90	100.00	By hand