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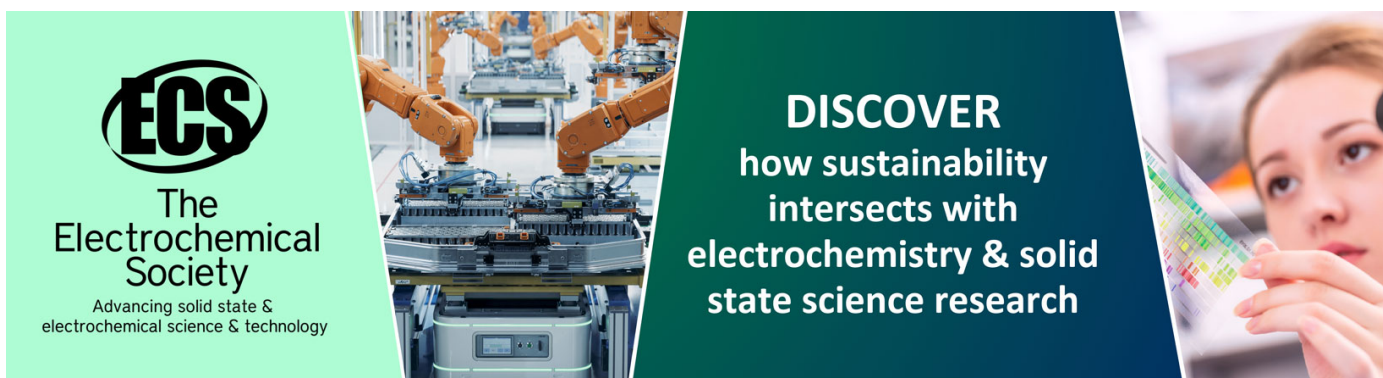
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Characteristics and Geological Significance of Strike-slip Faults

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Abstract. Strike-slip faults are nearly vertical sections and their two plates move relatively horizontally along strike. The existence of strike-slip faults makes the basin's structural styles diverse, forming abundant fault structural assemblages and structural style types. These abundant structural assemblages and styles may become favorable places for hydrocarbon accumulation. Distribution of hydrocarbon-rich sags is often controlled by faults, such as source rocks in the main period of Lishu fault depression near Sangshutai fault and Xiaokuan fault. Strike-slip faults control the sedimentary system and its evolution of oil-bearing basins and the distribution of secondary structural belts in basins, thus controlling the oil-gas system of basins. The exploration value and prospecting area of a petroliferous basin are determined in a large direction. The effect of Altun fault on Qaidam basin and Tanlu fault on Bohai Bay basin belongs to this category.

1. Introduction

Traditional structural geology divides faults into normal faults, reverse faults and translation faults. Others, combined with bedding faults, fall into four categories. In fact, bedding faults should be a special form of thrust faults or an early stage of development, and it is not very meaningful to list them separately[1,2]. Translational faults are generally defined as horizontal or horizontal relative displacement of rock blocks on both sides of the fault surface, and a special "translational fault system" developed on the seabed, which does not change along the strike displacement range, but "abruptly stops" and transits to compression or extension types with different orientations and properties. Structure. This type of fault causes the affected surface area of the crust to increase (mid-ocean ridge expansion) or decrease (ocean margin reduction). G.T. Wnson suggests that such faults, located between passive crust blocks, be referred to as "transition faults"[3]. Conversion faults can be divided into boundary transition faults and Hailing transition faults [4]. Because they are not the focus of this paper, they will not be described in detail.



In the early 1970s, Harding proposed the concept of "Flower Structure" to describe typical structural deformation related to strike-slip faults [5], and to analyze the seismic response and interpretation methods of such structures [6]. This has greatly increased the attention of prospectors to strike-slip faults. As a result, a large number of flower-like structures have been proposed in the process of seismic interpretation. Due to the misreading and abuse of strike-slip faults, Harding later published a supplementary article detailing the possible traps in the interpretation of flower-like structures [7]. With the deepening understanding of strike-slip faults, it has been found that strike-slip faults are a common phenomenon and have important geological significance in oil and gas exploration.

2. Definition and classification of strike-slip faults

2.1. Definition

The basic meaning of strike-slip faults is that they are near vertical sections and their two plates move relatively horizontally along strike. Its basic characteristics are straight fault line, steep cross section and narrow fault zone, which can be divided into left and right lines. Including the main conversion faults in the ocean area and the translation faults in the continental area [8].

The relative displacement vectors of strike-slip faults are usually oblique. When the displacement vectors of strike-slip faults have large component of inclined displacement, they can be called "normal strike-slip faults" (the component of inclined displacement is normal fault) or "reverse strike-slip faults" (the component of inclined displacement is reverse fault). In this sense, there are almost no "pure" strike-slip faults with no strike-slip component in nature, just as there are almost no "pure" strike-slip faults with no strike-slip component at all. This also shows that strike-slip faults should be ubiquitous from one side.

2.2. Classification

There are many methods to classify strike-slip faults, which can be divided into left-lateral strike-slip faults and right-lateral strike-slip faults according to the relative movement direction of the two sides of the fault; normal strike-slip faults and negative strike-slip faults can be classified according to the characteristics of dip stress components; and transformation faults can be classified according to the relationship between deformation of other strata in the same stress field. According to the scale of faults, strike-slip faults can be divided into five categories: plate-level strike-slip faults, basin-level strike-slip faults, zone-level strike-slip faults, trap-level strike-slip faults and micro-level strike-slip faults. From the perspective of oil and gas exploration, the last classification method is more favorable for exploration and development.

3. Mechanical mechanism of strike-slip fault action

3.1. Pure shear mechanism

Pure shear mechanism (Fig. 1-A) can explain the orientation problem of faults related to triaxial stress field in homogeneous media [9]. It indicates that a set of conjugate, left-lateral and right-lateral complementary strike-slip faults can be formed along the direction of the shortening direction at the angle of ϕ angle (where ϕ is internal friction angle). Tensional faults or normal faults are at right angles to the extension axis. The folds and thrust faults are perpendicular to the shortening axis. Most pure shear does not rotate and has orthogonal symmetry (oblique symmetry) type [8]. Because of the spatial problems caused by the convergence of large crustal blocks, no large-scale horizontal faults will occur in strike-slip faults in pure shear domain [9].

3.2. Simple shear mechanism

The study shows that large strike-slip faults are located in the simple shear domain, and their geodynamic background is the relative horizontal movement between lithospheric plates and their oblique convergence or dispersion. Simple shear is a kind of rotational strain, which belongs to

monoclinic symmetry. Riedel model is widely accepted and applied as a simple clipping model, and its content is constantly enriched and developed [10-15]. Five groups of faults can be formed in the single shear mechanism (Fig. 1-B): 1. R shear (Riddell shear), or isotropic or pinnate strike-slip faults; 2. R'shear (conjugate Riddell shear), or reverse strike-slip faults; 3. P shear, secondary syn-strike-slip faults, with an angle of $-\phi/2$ with the actual shear direction; 4. T fault, with the main displacement. Tensile faults or normal faults with an angle of 45 degrees; Y shear faults with parallel principal displacement zones. Simple shear deformation has similar shape on different scales. The whole deformation domain is composed of secondary deformation zones experiencing simple shear in many special cases. Its structural combination has systematic self-similarity.

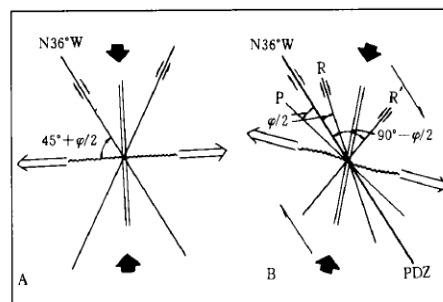


Figure 1. Plane pattern of pure shear mechanism and single shear mechanism of strike-slip fault action.

A. Coulomb-Anderson pure shear mode; B. Riedel single shear mode: short black arrow for compression axis; blank arrow for tension axis; parallel double lines for tension direction; wave line for fold axis direction; P for P shear; R for coaxial shear; R' for reverse shear; PDZ for main slip zone; and ϕ for internal friction angle.

3.3. Pressure-shear and tension-shear mechanisms

Compression-shear means that the initial stress state has both simple shear and compressive stress, and the initial stress state of tension-shear has tension stress besides simple shear. Zhong Jiayong used photoelastic experiments to reveal the different stress distributions between compression shear and tension shear and simple shear. Sanderson [16] gave the development characteristics of the related structures in three mechanisms (Fig. 2). Among them, α^{-1} is the vertical elongation of the deformation zone and $\alpha^{-1} - 1$ is the horizontal and transverse shortening of the vertical deformation zone, i.e. the ratio of the initial width after deformation to the initial width of deformation. Compression shear includes pure shear (shear strain $\gamma = 0$) and single shear ($\gamma = 1$).

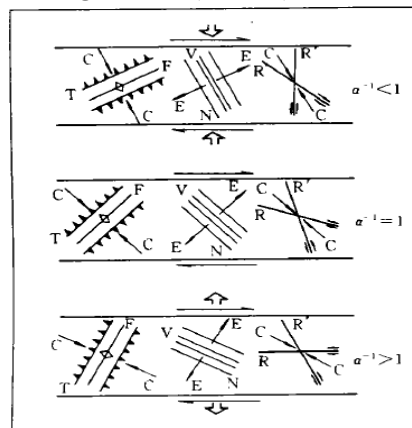


Figure 2. Comparisons of Pressure-shear, Tension-shear and Simple-shear modes.

4. Controlling factors of strike-slip faults

4.1. Stress

The nature of stress determines the formation mechanism of faults, and the distribution of stress controls the type and distribution of deformation of faults. When the stress is large, the fault size and displacement increase correspondingly, and the related structures are easy to reach a certain scale and their properties are affected by strike-slip displacement. The change of stress direction will produce oblique motion component, even reverse movement of whole fault [17]. Stress action time affects rock deformation behavior, and restricts the size of strike-slip faults, deformation strength and the development of related structures.

4.2. Strain

The physical properties of deformed media, especially rock strength, determine the degree of strain development. If the strength of rock or strata is low, plastic deformation will easily occur and plastic structure will be formed. Conversely, brittle structures are easy to form [18]. Strain rate is a function of actual deformation rate, medium strength, temperature and pressure. Low strain rate and long acting time are beneficial to the formation of plastic structures.

4.3. Preexisting structure

As a structural type, pre-existing structure is actually one of the physical characteristics of deformed media. Preexisting structures restrict the formation and development of later structures, such as strain decomposition when tectonic stress obliquely acts on the weak surface of early structures. Therefore, in the study of strike-slip faults, it is necessary to match their related structures by stages and to use tectonic chronology to determine their tectonic deformation facies and sequence [19].

5. Identification of Strike-slip Faults

5.1. The fault section is steep and straight into the basement

The occurrence of dipping faults is basically Plough, and the general trend of relatively complex slope-flat faults is the same. On the contrary, strike-slip faults are mostly characterized by gentle upward and steep downward faults, which are nearly upright in depth and deeply embedded in sedimentary basement. This is one of the most typical characteristics of strike-slip faults on the section. Seeing such section characteristics, we can basically identify them as strike-slip faults (Figure 3).

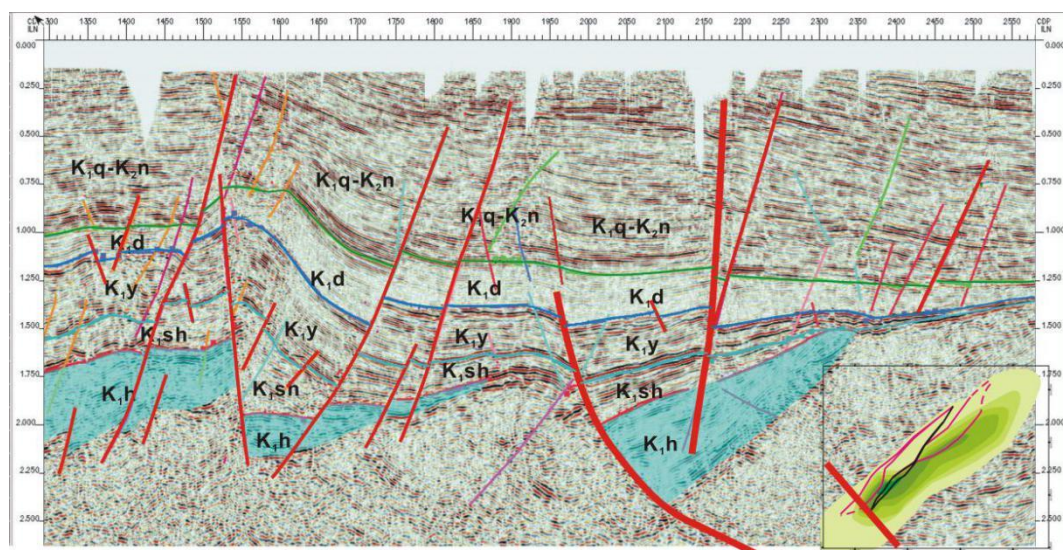


Figure 3. Qindong Strike-slip Faults.

But not all strike-slip faults have this characteristic. Two known special cases are accommodation faults and inheritance strike-slip faults. The spade-shaped section of regulating faults is usually simple and vertical, but regulating faults are the "by-products" of the main tectonic deformation. The cutting depth of regulating faults is controlled by the depth of the main slip surface of the main deformation and will not penetrate into the sedimentary basement. Another case is that strike-slip occurs on the basis of early dip faults, which inherit the fault sections of dip faults. Therefore, most of the faults are distributed, and their profile characteristics are very similar to those of dip faults. Of course, it will produce some structural phenomena related to strike-slip in other aspects.

5.2. Flower structures may be developed on the section

Flower structure is the most typical deformational structural style produced by strike-slip faults. On the cross section of strike-slip zone, a main fault (strike-slip fault) and several derived faults together form a structure similar to "flower". The main faults generally dip steeply and are nearly vertical in depth and inclined upward to a certain extent. Derivative faults converge from shallow to deep and intersect the main faults separately. Each derived fault is a "petal" (Fig. 4).

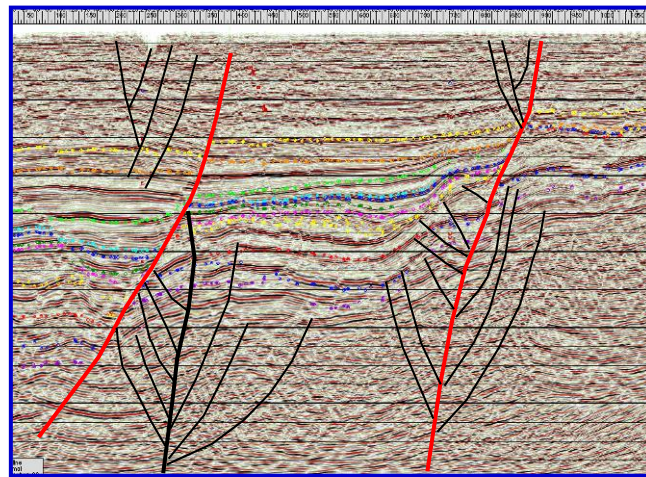


Figure 4. Flower structures in strike-slip faults in Qikou Depression.

5.3. "Dolphin effect" or "ribbon effect" can be seen in space

The nature of a fault with the same dip is consistent transversely. That is to say, if a normal fault is cross-sectioned at any point in its entire extension, it will show as a normal fault; the situation of a reverse fault is similar. But strike-slip faults are different. The track of strike-slip faults with a certain scale is usually not a smooth straight line, but curved. As mentioned earlier, sometimes trajectory shapes are complex. In this way, the angle between fault plane and strike-slip direction is different at different locations of the curved fault trajectory, and the properties of the component of inclined stress at different bending positions are also different. Some parts are extruded, called Restraining Bend; others are stretched and become Releasing Bend. Strike-slip faults are characterized by reverse faults at tightening bends and normal faults at loosening bends. That is to say, the same fault is not only normal fault but also reverse fault from the section, sometimes positive and reverse. The two walls of a fault can not be clearly divided into ascending and descending plates as the dipping faults do, but rise and fall one after another, like dolphins playing on the sea, so they are called "Dolphin Effect" [20-22].

The cross-section occurrence (tendency) of a fault with the same dip is consistent horizontally, and the dip angle will be different, but the dip will not reverse, either eastward or westward. Strike-slip faults have no such rule. Strike-slip faults generally occur steeply, reaching a near-upright degree to the deep, and the upper part will have a certain dip, but the tendency is not fixed. Sometimes the phenomenon of tilting eastward and westward may occur, just like a soft ribbon, so it is called "Ribbon Effect".

5.4. Layer thickness, sedimentary facies and occurrence on both sides of fault are inconsistent

Except for some cases (e.g. synsedimentary faults), the thickness and deposits on both sides of the faults are basically the same. However, when strike-slip faults cut continental strata with rapidly changing sedimentary thickness and environment, the movement of the two plates is dominated by strike-slip, which will result in thickness mismatch and abrupt change of sedimentary facies in the same set of strata on both sides of the fault (Fig. 5).

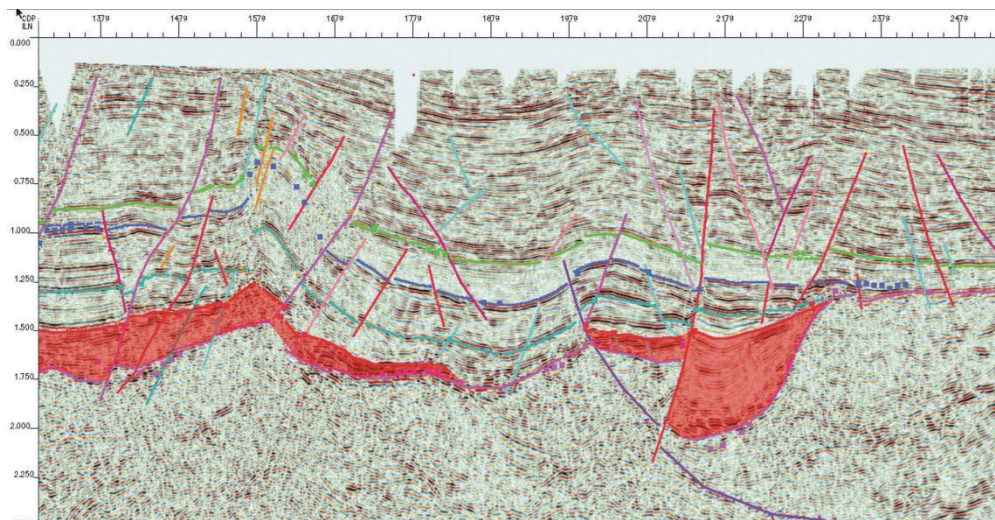


Figure 5. The thickness of strata on both sides of strike-slip faults in Qindong fault is inconsistent.

6. Conclusion

Strike-slip faults widely exist in nature and have unique geometric shape and structural deformation characteristics. Developed in special structural positions, vertical structural strike, steep cross-section, straight basement, flower-shaped structure, cutting and dislocation of other faults, various plane combinations, and abrupt changes in two strata are all identification marks.

Strike-slip faults are closely related to oil and gas accumulation. Especially, they can effectively improve the pore and permeability conditions of reservoirs, reduce the threshold of oil and gas entering reservoirs, and make traps that could not be formed by matrix pore become effective traps.

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