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Advances in Fan Deltaic Sedimentology

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Abstract: - The advances about sedimentological study of fan deltas were reviewed based upon a great database of numerous research literatures at home and abroad, including 1)definition, classification and terminology; 2)lithofacies and sedimentary sequences characteristics; 3)depositional models and 4)research methodology. It is suggested that classifications for fan deltas should be more practical in their applications, the hydraulic and geomorphic parameters from modern delta front, and the most important rock characters from the ancient stratigraphic records should all be considered. The hydrodynamic principle should be involved in interpretation of the lithofacies of fan deltas. More studies are needed to analyze the controlling effects of tectonic movement, climatic vibration, sea/lake level changes and depositional autocyclic processes on the formation of fan dealtaic depositional sequences. Fan delta models type may increase with time and newmethods such as flume experiment, computerized forward modeling and geostatistic stochastic simulation may be used more frequently infan delta sedimentological research in the future.

Keywords: *fan delta; sedimentary model; classification; lithofacies; sedimentary sequence*

I. INTRODUCTION

Since put forward the concept of fan deltaic sedimentology in 1965, Academic and industry to give a wide range of fan delta depositional system note. Fan delta research objects formed from yuan archean to modern time; Study contents include classification and fan delta sedimentary pattern of fan delta Sediment characteristics, the formation process and formation mechanism of the system description and interpretation, Fan delta and the function of the structure relationship, fan and delta source rocks properties, types and evolution of fan delta surface river delta front region of the hydrodynamic and sediment and the fan delta sedimentary bodies geometry the control function of form, rock fabric fan delta river basin of a few any shape, size, depth of water and water physical and chemical properties of sedimentary system the influence of the distribution, etc; Research methods by the vertical section, vertical sequence sedimentary simulation analysis to structural elements analysis, cistern, meter computer simulation and random simulation method, etc.; The geochemical research of development dating techniques, ground penetrating radar (GPR), lateral sonar, seismic and well logging technology, the integrated application of remote sensing remote sensing technology. Involved in the fan delta includes various types such as Marine and terrestrial facies, fan delta sedimentary dynamic process including rivers, sliding sliding, wind, glaciers, volcanoes, earthquakes, tidal waves, biological and other sedimentary agent.

Chinese scholars study of fan delta began in the 1980 s. Literature [1] to study the ancient eastern China fan delta deposits, literature [2] to study the modern luanhe river alluvial fan delta system and literature [3] and [4] of biyang sag basin and south duct fan delta and related reservoir of liaohe basin were studied. After entering the 1990s, successively in songliao, victory, sichuan, jidong, dagang oilfields, tarim, the south China sea basin or discovered and studied a lot of fan delta reservoirs and fan delta deposits. Sag in recent years, xinjiang oilfield in ring found a series of coarse grain associated with fan delta glutenite reservoirs, opened the oil and gas exploration in junggar basin is a new field. A comprehensive understanding of research progress of fan delta sediments, the correct understanding of fan delta glutenite sedimentary system has reference significance.

II. THE CLASSIFICATION OF THE DELTA AND FAN DELTA

Fan delta is water into the stability of alluvial fan, fan delta type is closely related to the type of alluvial fan, but for a long time the classification of the fan delta is not classified according to the type of alluvial fan, but according to the classification of the delta method.

2.1 delta classification problems

In 450 BC, the navigator and the mouth of the Nile alluvial plains historian Herodotus "delta" form geomorphic unit known as the delta. With the deepening of the research, found that many delta does not show "delta" form, and put forward the fan-delta, braided river delta, slope apron delta and delta lobes terminology. Because of various terms defining fuzzy, identify standard is not clear, the results tend to generate controversy.

For the classification of the delta must first clear "fan", "braided plain", or "braided river" and so on the exact definition, how to distinguish between the sedimentary system in the stratigraphic record. The literature [5] think classification terms should reflect the characteristics of the delta of terrigenous supply system as much as possible. On a steep rock shore, terrigenous system is given priority to with rock fall collapse, a cone-shaped or relatively broad petticoat, can use "debris cone delta" or "cuttings skirt delta terms such as" characterization. For the "braided delta", should be abandoned, and using "braided stream delta" and "bending branch delta" relatively appropriate. In addition, people always used to revolve around the supply of fan delta system to discuss the classification of fan delta, but on the basis of rock record divided into fan delta is very difficult.

2.2 the alluvial deltas

Holmes argues that delta is not formed by rivers or alluvial system, the existence of fluvial delta, delta, such as volcanic clastic rock and lava, lobes of Hawaii's shores and Iceland in the body has a lot of overflow of molten rock into the bottom of the sea. Some delta may is "hybrid" model, including volcanic sedimentary and other possible from alluvial formation. Continental volcanic eruption of material into product produce deposited lava flows to the sea and breccia, and Gilbert delta, also can form "progradation" layer. Pyroclastic delta is a volcanic detritus fan, steep cone body or a broad petticoat body of advancing into the oceans and lakes. Far land sedimentary bodies sometimes associated with the progradation of aeolian sand dune system, for example the Sahara region of Chad wu niang plug lille (Ounianga Serir) salt lake in the huge tongue shape "aeolian delta".

2.3 the classification of the fan delta

Literature [6] think，mechanism of "delta" not only depends on the interaction of river runoff and sediment load, and depends on the mechanism of basin, including basin shape, size, depth and kinetic characteristics of basin. The mechanism of controlling the supply of the delta system, formation thickness distribution, tectonic geomorphic background, delta front and sediment particle size, current reference more fan delta classification scheme, basic all follow this principle.

Literature [7] in delta front of sediment grain size and fan delta foreslope slope difference index are classified, in outcrop, according to the "giant foreset cross-bedding," large "delta" type cross-bedding and collapse sliding, etc., to identify the above two indicators. Literature [8] according to the characteristics of delta plain distributary channel depth of the surface at the bottom of the slope and the delta, delta the three indexes to establish delta classification system. According to the characteristics of delta plain distributary channel to identify four kinds of delta supply system, the corresponding slope is very steep, braided river alluvial fan alluvial system system, stable and river mouth bar supply system, and high constructive digitate supply system. According to the water depth of delta front, and then divided into two major categories, shallow and deep water to shallow water delta according to the slope is divided into slope slower Hjulstrom and gradient larger Gilbert 2 subgenera, thus divided into 12 kinds of "prototype" delta. The delta based, covers a wide range of landscape classification means that each prototype delta represents almost an infinite number of similar delta, the delta basin and different gravity evolution degree of transform.

III. FAN DELTA SEDIMENTATION MODEL

In the 1970 s, the literature [9] to study the modern Copper river fan delta sediments and stratigraphic framework, as a fan delta mode was widely quoted. For decades, sedimentary scientists put forward a lot of fan delta depositional model, and with the accumulation of research, in the fan delta depositional model is growing. But all patterns from the phenomenon that the special investigation, no model is completely conforms to now the research object, to know more about the sedimentary patterns help understanding of the research object, and judgment.

3.1 the subaqueous fan delta sedimentation model

Literature [10] through the arctic modern delta and Spain some ancient delta sedimentary research established a subaqueous fan delta mode, this mode shows some of the sliding surface, delta front development form some trough, the sediment by gravity down a slope handling. From the sliding surface to the front trough, the structure of the sediment from massive gradually into layered structure, sediment from slump deposits of debris flow head constantly by grain flow and turbidity current deposits cambium-like structure. On the east coast of South Korea, Japan many deep Marine fan delta belongs to this kind of mode.

3.2 Gilbert type fan delta sedimentation model

Italian Crati basin pliocene - holocene Gilbert type fan delta illustrates the structure of sedimentary sequence features of control function. Under the background of the expansion of the basin, Gilbert model with the characteristic of the single fan fan delta, under the background of strike-slip, Gilbert fan-delta sequence is

superposition type formation of complex foreset, represents the fracture of large events and provenance of rising and basin subsidence for many times, many times is considered to be representative of the classic fan delta.

3.3 near the volcano fan delta depositional model affected by the glacier

Southern Alaska Wrangll White River ice outcrop, recorded the sedimentary near volcanoes, fan delta sedimentary characteristics affected by the glacier. Literature [11] through the two respectively 1, 200 m and 200 m thick profile measurement, found that the formation of glacial deposits and volcanic debris in each layer. Baihe sedimentary sequence is composed of slope and fan delta sedimentary filling valleys complex, there is no place glacial deposits, glacier just provides a coarse clastic sediments. Such a pattern rarely appreciated.

3.4 estuary dam type fan delta sedimentation model

Literature [12] think, early pleistocene basin valdano debouch bar type fan delta development in shallow water lake basin, the coarse grain fluvial-dominated delta system at the top of the characteristics of geomorphology and sedimentology of alluvial fan is similar to the damp climate. Very thick, no fabric or depositing sediment during flood in one body in braided river. To the bottom of the fan, braided river channel evolution of stable straight river, formed the conglomeratic sandstone and sandstone body. Under water, straight distributary channel incised in lacustrine facies mudstone; At the far end, channel coarsening upward thickening of sandstone lens, buried ancient river during low water level by density flow erosion. Very shallow lakes, small, low-power is suitable for the formation of mouth bar type fan delta.

3.5 development terrace and fan delta depositional model of precipice

In the gulf of California to 2 fan delta of geomorphology and sedimentology study [13], reveals the synsedimentary fan delta sedimentary body surface topography changes below. Due to the tectonic setting and Marine erosion, formed in the fan delta plain terraces, alluvial fan on the surface of the slope is 3.1 ° and 3.8 °, the length of the two fan were 2.0 km and 5.5 km, the edge of the basin tectonic subsidence rate is 0.1 ~ 0.3 cm/a, the Agua Caliente fan delta form 3 m high terrace, on the edge of the alluvial fan formed 8 ~ 10 m fault scarp. The model for understanding the internal structure of heterogeneity of the fan delta sedimentary system provides a new train of thought.

3.6 mega delta - underwater fan complex depositional model

Literature [14] believe that modern Indus Indus river delta sedimentary formation marginal zones of the Indian Ocean - underwater fan complex system, this system covers the area of the 2.05×10^4 km ^{2}, is a broad sector. The Indus river cutting along the piedmont south of the Himalayas flow, sediment in India land west of the unloading of the Indus river delta formation, axial formation of underwater delta fan in India. India underwater fan 1 500 km long, 960 km wide, occupies an area of 125×10^4 km in the Indian Ocean (2) the Ganges and Brahmaputra river also have similar features, the two rivers together form the Bengal fan. China in the middle and lower reaches of the Yellow River has the similar characteristics, huge fan system and there is big difference between the traditional fan delta, offers a large and super large delta, subaqueous fan sedimentary model of another.

3.7 related to biological and carbonate fan delta sedimentation model

Literature [15] southeast Spain ebro basin is studied in the fan delta system and plane of action and gravel in the cause of the boring; Literature [16] to study the st Lawrence mountain in northeast Spain a fan delta lobe of carbonate sedimentation and its response to sea-level fluctuation; Literature [17] studied Spanish Cantabri - an extended to the carboniferous fan delta carbonate shelf on stratigraphy and tectonic action, summarizes the sedimentary pattern of the area. But the lacustrine carbonate rocks and biological building development widely in continental lake basin, the contact of fan delta system research.

3.8 river fan delta sedimentation model

Literature [18] to identify the two rivers in eastern ebro basin fan: Cardona - Suria fan and Solsona - Sanauja fan, the radius of 40 km respectively and 35 km, the area is 800 km and 600 km respectively.. On the outcrop identified 14 types of rock facies and 7 kinds of combined, on behalf of the river fan, channelized endings lobe, the channelized endings lobe, mudflat, delta, evaporation dry salt lake and rich carbonate shallow lake environment. Horizontal contrast detection two rivers, the lakes transformation style, terminal lobe in lakes during the low water level development, formed during the period of high water river delta and distributary bay. River fan as a large fan delta system, is more and more attention in recent years.

3.9 the evolution of the peripheral fan pattern

Literature [19] the Permian in southeast Utah outraged endings fan system the space-time evolution of Rock group, the fan is also called "peripheral" or "distributary channel fan". Measured stratigraphic section of article 84, described the 5 km of outcrop, identify the 17 kinds of rocks and sedimentary filling, unrestricted river, river eolian dunes sedimentary, aeolian sand and wind into five kinds of structure elements such as deposit, and between sand dunes detailed stratigraphic framework was established. Using the high resolution stratigraphic structure diagrams, describe a single river system of sedimentary facies and geometry, to elucidate the space-time evolution characteristics of sedimentary system, provides the reference for the study of shallow water lake basin fan delta.

IV. FAN DELTA OF RESEARCH METHODS

Fan delta method with sedimentology study progress and development, in the study of modern sedimentary, side scan sonar has already been used in the bottom of the sea and lake topographic survey, remote sensing remote sensing technology in early topography measurement plays an important role, is still an important means of modern sedimentary research at present. In recent years, ground penetrating radar (GPR) to study the shallow sedimentary system play an important role, Mosaic technology, laser scanning technology to replace the camera provides effective means for fine descriptions of outcrop. Especially with modern computer technology and the development of modern analytical techniques, sedimentary simulation test, the ancient environment and quantitative chronology analysis, computer simulation, sedimentology study methods such as random modeling combined with seismic logging technology, promotes the research of fan delta constantly updated.

4.1 fan delta sedimentary flume experiment

Fan delta sedimentary simulation experiments at home and abroad have been seriously, flume experiment for fan delta sedimentary mechanism provides an intuitive quantitative way. But so far, the water tank is mainly used to simulate sediment transport mechanism, the formation of sedimentary sequence and sedimentary facies belt distribution of macroscopic, also can't quantitative reconstruction of fan delta sedimentary sequence. Literature [20] through the indoor flume experiment, studies the type Gilbert delta foreset spin sediment separation effect in the back. Experiment with deep sink 7 m long, 0.38 m, width 0.158 m and 0.075 m. The results show that the gravel dam on either side of the head of the migration of the channel, will not be evenly to lateral gravel, and form the granularity of rhythm, the export is narrow, foreset rules, presents the thinner upward tendency; The export is wide, foreset show the upward change coarse and fine cyclicity. Foreset structure of orderly change can be explained from the cycle of the supply system of the width of the response, delta estuary if is very narrow, uniform sediment supply, easy to form a sequence of thinner upward; If delta channelized severe, bar, is on the edge of the basin sediments in lateral instability uneven distribution, do not have a unified form lateral horizon and foreset. Literature [21] since the cycle characteristics of fan delta, is studied in the experiment were conducted three times back, each time flow back, other parameters constant, the experimental results through camera system records, then computer system processing, forming a series graphic images, in order to study the evolution of the delta.

4.2 in the fan delta sediments composition analysis

Fan delta sediments from the near provenance, rainwater catchments basin is small, high deposition rate, composition of rocks is closely related to the structure characteristics of the source area of the earth, sediment provenance parent rock composition contains rich information. Research of fan delta sediments, for analysis of parent rock properties, stratigraphic correlation of fan delta depositional system plays an important role. Will fan delta sediments of petrological and geochemical analysis, the combination of quantitative research can fan delta sedimentary system parent rock area tectonic background, analyze the process of accumulation of fan delta sedimentary bodies, restore the fan delta sedimentary characteristics of geomorphology, this kind of research is more and more attention. Literature [22] to study the Eocene in southern Spanish pyrenees - 2 in the same period of Miocene alluvial fan system, think climate and the structure of the alluvial fan sedimentary process play an important role in control, but alluvial fan bedrock lithology of drainage basin is an important index for control of alluvial fan. Ebro basin in Eocene - Miocene two adjacent alluvial fan, a predominantly mudslides, another is given priority to with water. Nueno fan is nearly at the matrix support of conglomerate, 80% are gravel of gypsum, its matrix is sandy gypsum, the basin area of the fan is yanchang formation of gypsum, marl and microcrystalline limestone; San Julian fan body by the upper Paleozoic and Triassic - cretaceous limestone gravel composition, fan body of clastic support multiple ingredients conglomerate. These two fan sediments interfingering, composition differences between fan is caused by the river bedrock lithology is different. By plaster and plaster group for the bedrock of basin to provide a large number of fine grained

sediment formation of debris flow, terrain is flat; Made of limestone region are mainly composed of dilution water, steep terrain.

4.3 fan delta sedimentary sequence of stochastic modeling

Reservoir rock physics characteristics of sedimentary facies is the most main control factors of sedimentary facies modeling is the key of reservoir modeling. Thinking [23] based on the outcrop modeling can provide a more concrete building structure, geometry and connectivity information. Under the condition of geological conditions is very good, rely on outcrop data modeling can be system comparison of different modeling strategies. The author using the st. Lawrence mountain fan-delta outcrop data test different modeling strategies, for example by changing conditions well density, formation of layered, modeling algorithm and a variety of trends. Of modeling result with deterministic modeling method is adopted to establish the model is the basis of the comparison. Think in different modeling scheme, conditions well density play an important role for reconstruction of stratigraphic structure, the method of using trends to predict building structure is suitable for the example of well data is less.

V. DEVELOPMENT TRENDS

According to the present situation of the fan delta sediments research progress at home and abroad, the future study of fan delta sedimentary, at least in the following four aspects will be further developed.

1) Fluid mechanics, hydraulics and sediment movement mechanics theory and method will bring new vitality fan delta sedimentary study. The application of these theories, is not only beneficial to the classification of fan delta, fan delta deposit and make the interpretation of the transportation and deposition mechanism of more accurate, promote sedimentary fabric of fan delta sediments, facies belt distribution, quantitative sequence structure research.
2) Fan delta sedimentary study will pay more attention to and paleoenvironment and paleoclimate and tectonic background research, explore the various controlling factors in fan delta sedimentary evolution, more effectively explain fan delta deposits, the forming process of sedimentary facies, sedimentary sequence, and predict the distribution of the sedimentary system.
3) Fan delta sedimentary pattern will emerge in endlessly, but related to foreland depression basin of large fan delta system will be more and more attention. The system distribution at the edge of a large lake basin water flow in fan is relatively stable, large catchment basin basin area, the sediment carried large volume, is helpful for forming large reservoirs and reservoirs group.
4) The new method, new method will promote progress in the research of fan delta. Including the flume experiment, forward modeling and stochastic modeling, geophysical inversion, such as comparative sedimentology method, as well as remote sensing remote sensing, ground penetrating radar (GPR), underwater sonar, clastic dating, geochemical analytical techniques, such as in the fan delta sedimentary study gets more and more applications

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