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Guiding and method for division of petroleum exploration play in superimposed reformation basin

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Abstract: Reasonable play division played an important role in the evaluation for the exploration and deployment in petroliferous basins. However, there were few studies on the play division in superimposed reformation basins of central and western part of China with multi-cycle evolution and complex accumulation process, and there was no relatively unified scheme. Based on the concept and extension of the play, it was proposed in this paper for the idea, method and process of division with the main line of "prototype-controlled sources and superposition-controlled accumulation" with the view of the characteristics of superimposed reformation basins with multiple sets of combinations, multi-phase reforms, and multiple types of petroleum systems. Play division needs to be started from the overall study of the basin, analysis for the distribution of original reservoir-forming geological elements and the subsequent generation, migration and accumulation of hydrocarbon in the process of basin construction and reformation, clarify the types and distribution of petroleum systems of different plays in the basin during the process of superposition and reformation, reveal the main controlling factors of hydrocarbon accumulation in each type of petroleum systems, and determine the types and boundaries of the plays. According to the type of petroleum system, the play name adopted the combination of "(paleo) and modern tectonic unit + strata or combination + main controlling factors of reservoir". The play division scheme plays a guiding role in deepening the understanding of the regularity of hydrocarbon enrichment in the basin and guiding exploration practice. **DOI:** 10.11781/sysydz2021061078-en

Keywords: prototype-controlled sources; superposition-controlled accumulation; play division; superimposed reformation basin

A petroleum exploration play is a kind of oil and gas geological unit. The division and evolution of oil and gas units reflect the researchers' understanding on the law of hydrocarbon accumulation and distribution in the basin. Throughout decades of research history of oil and gas basins, many scholars at home and abroad have proposed concepts similar to oil and gas geological units, such as oil and gas accumulation zone [1], petroleum system [2-3], compound oil and gas accumulation zone [4], and accumulation assembly/play [5-7], etc. Compared with the other two, the petroleum system and the accumulation assembly/play emphasize more on the filling system that reflects oil and gas generation and migration. The introduction and evolution of the concept reflect the change in people's understanding on objective things, and each change in turns promotes the further development of oil and gas exploration to some extent. The evolution process of the concept of oil and gas geological unit is manifested in the evolution from early static analogy description to the dynamic genetic analogy research, which supports the change of academic thought from "source control theory" to "dynamic hydrocarbon accumulation".

Most of the existing method for divisions of geological units in petroleum basin is based on the Mesozoic and Cenozoic graben basins with relatively simple structures and cycles in eastern China [8-9], and the division of petroleum exploration plays is further developed therefrom, and which is relatively mature. However, with the shift of the focus of oil and gas exploration to reformation basins in central and western China, the previously established unit division method according to the basins in eastern China with relatively simple structure evolution and hydrocarbon accumulation factors cannot fully meet the technical requirements of exploration and evaluation of reformation basins with multi-cycle evolution, multi-set accumulation play, multi-type structure and multi-stage accumulation. The author found from the published literature that there is still no unanimous

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agreement on the nomenclature rule for division of petroleum exploration plays of large superimposed reformation basin in central and western China, and studies at this are also less. The division and nomenclature of existing exploration plays in superimposed basin are highly arbitrary, and most of them are divided by a mixture of modern structure unit, strata and exploration zone, such as karst-fissure-cave in Mao-3 member at the edge of Luzhou paleo-uplift, Cambrian pre-salt zone in north Tarim Bain, etc; or use the structure deformation zone instead of exploration play, such as the fault-fold zone in piedmont of Nanjiang Mountain; some are even directly divided and named by geographic name, structure zone or reservoir facies type, such as Fuling Jurassic channel sand, Shunbei No.5 fault zone, Paleozoic strata in southern Hubei, Hangjinqi, Daniudi, etc. Obviously, the existing division method or play nomenclature applicable to the Mesozoic and Cenozoic basins in eastern China cannot clearly reflect the hydrocarbon accumulation characteristics and exploration-deployment direction in central and western China, which directly hinders the oil and gas resource evaluation, exploration and deployment in superimposed reformation basins in the region.

Reasonable division of petroleum plays exerts an important role in exploration, evaluation and deployment in petroleum basins. At present, the study on division of petroleum plays in superimposed reformation basin is inadequate. Based on the concept and extrapolation of petroleum play, and in view of the characteristics of superimposed reformation basin with multi-set assembly, multi-stage modification, and multi-type petroleum system, the author attempts to establish a new idea and method of division of petroleum plays that can not only reflect the characteristics of hydrocarbon accumulation in the basin, but also guide the exploration and deployment, so as to provide a theoretical and technical support for exploration, evaluation and deployment of the petroleum basin.

1 Concept and extrapolation of petroleum exploration play

The study of petroleum exploration plays has undergone multi-stage development. In the 1930s, the concept of hydrocarbon accumulation zone was put forward for the first time [1]. The underlying connotation is that the hydrocarbon accumulation is controlled by structure zone, which emphasizes the division principle of being consistent with structural level, and divides the traps into 5 categories according to its type, i.e., structure, reef, lithology, stratum and composite lithology and stratum type [10-12]. This classification focuses on the static description of stratigraphic and structural trap style, which is applicable to macro analysis in the early stage of exploration, but it has little significance in guiding the exploration of oil and gas in deep reservoirs.

In 1972, DOW first put forward the concept of oil system. After more than 20 years of continuous study [2-3, 13-15], MAGOON and DOW defined the petroleum system in 1994 as a natural hydrocarbon fluid system in a sedimentary basin, which contains matured source rocks, existing oil and gas reservoirs and all essential and interrelated geological factors and their interactions during hydrocarbon accumulation. Its scope refers to the critical moment when the source rock enters the peak period of hydrocarbon generation and expulsion, and discharges from the hydrocarbon generation window to areas where the adjacent traps form reservoirs. Obviously, the petroleum system is the petroleum unit between the basin and the petroleum accumulation plays. A petroleum system can contain several petroleum accumulation plays. This division method is based on its origin in combination with static and dynamic factors and applicable to the overall basin anatomy and resource evaluation.

In the 1980s, Chinese scholars put forward the concept of complex petroleum accumulation zone [4,16] according to the characteristics of multiple grabens, multiple fault blocks, multiple petroleum plays and multiple reservoir types in Bohai Bay Basin, appearing as the superposition in time and compound in space of different structural layers, multiple petroleum plays and multiple reservoir types. It is a special manifestation of petroleum accumulation play in graben basin, and its formation is mainly controlled by the secondary structure zone, with anticlines, fault block structure traps and stratigraphic-lithologic composite traps developed. This theory attaches great importance to the trap assemblies, focuses on static comprehensive description, and is suitable for the genetic types of secondary structure zones. Whereas it does not truly reflect the genesis and the main controlling factors of different oil and gas reservoirs, and is applicable to analogy prediction in the early and middle stages of exploration.

In 1972, the Geological Survey of Canada (GSC) proposed the concept of exploration play/accumulation play for the first time. In 1984, American petroleum geologists represented by BAKER defined the exploration play as a trap group of similar geological geneses [5], highlighting the economic value of exploration and development evaluation by oil and gas companies. ALLEN [6] defined it as a group of undrilled prospective traps and discovered oil and gas reservoirs, sharing a common reservoir, regional caprock and oil and gas filling system in a specific strata section, i.e., an unconfirmed accumulation play. The key factors of accumulation play include reservoir, regional caprock, oil and gas filling system, trap, and the effective configuration relationship of such four factors. This definition emphasizes the dynamic genetic process of oil and gas. There can be different trap types in the same play, but it must be a reservoir-caprock combination in the same oil and gas filling system. In terms of classification, it is a secondary classification under the petroleum system, which is applicable to analysis of the areas with medium and low exploration degree, but does not reflect the main controlling factors for oil and gas accumulation and

enrichment, and is not suitable for guiding exploration deployment. Chinese scholars study the definition of exploration play mostly from the perspective of geological genesis, the connotation they relied upon is more consistent with that of scholars in other countries, and similar expressions, such as "gas accumulation play/zone" [17-18], "oil and gas play" [7,19-20], and "oil and gas bearing zone" [21-22], etc are put forward accordingly.

The "play" proposed by scholars in other countries actually is a set of unconfirmed accumulation plays, and there may exist similar original accumulation geological conditions in them. If the later modification of the basin is considered, the hydrocarbon accumulation process and its main controlling factors of the same accumulation play will be different. However, the definition of both petroleum system and play does not fully consider the role of later basin modification, which is obviously not fully applicable to the superimposed reformation basin with complex accumulation process after multi-stage modification. Based on the purpose of study and division, the petroleum exploration play is an exploration target group with the same sedimentary system (or sedimentary facies) and similar accumulation conditions in the same structure unit of the basin. The target group in the same exploration play should be a unified integrity in space and have similar geological conditions for accumulation, but the types of targets (traps) may be different.

Studies of division of exploration play in China also undergo the process from static description to dynamic genetic accumulation, and the classification of play is mostly divided by geological factors, petroleum basin types and exploration degree [19,22]. Other countries pay more attentions to the evaluation of exploration value of the play, and mostly divide the play into the conceptual play and the established play according to oil and gas bearing probability of the play, so as to facilitate oil companies to make decision on exploration, development and deployment in areas with low level of exploration.

2 Particularity of accumulation conditions in superimposed reformation basin

The multi-cycle tectonic evolution in Central and Western China made the basins develop on or at the edge of small craton to generally have the characteristics of long evolution time, strong cyclicity, multiple movement periods and complex and diverse modifications [23-24]. The characteristics of development and evolution of these basins determine the particularity and complexity of their hydrocarbon accumulation conditions and processes [25], including large space-time span of formation of the source-reservoir assembly, multiple assembly types, complex modifications and oil and gas response processes, and multiple accumulation types.

2.1 The basin is characterized by multi-stage superimposed development and modifications

The long-term activity and complexity of China's tectonic evolution determine the particularity of formation and evolution of the superimposed reformation basins in central and western China [26]. China's Mainland has undergone multiple stages of splits and assembly since the Proterozoic era. It is a composite continent [24,26-27] consisted of such small cratons as Tarim, North China and Yangtze as the core and assembled more than 20 such mini geologic bodies as Qiangtang, Junggar, and Qaidam. In recent years, a large number of regional deep seismic reflection, seismic prospecting and drilling activities have gradually revealed the geological structure, genesis and evolution in major basins.

Superimposed reformation basins in central and western China are mainly developed on or at the edge of small cratons. The split and assembly of paleo-plates and the growth and extinction of paleo-oceanic crust determine the formation and evolution of marine basins in China. Through comparative studies on the development and evolution of China's marine basins since the Proterozoic, the author believes that the evolution of China's marine basins has generally experienced four geological history stages, showing the characteristics of multi-stage superimposed development and modification (Fig. 1).

During the middle Proterozoic to early Qingbaikou period, corresponding to the formation stage of "China's paleo-continent" from the split of Columbia supercontinent to the formation of Rodina supercontinent[26], basins at this stage were mainly developed at the edge of three landmasses, and characterized by continental margin rift, discrete continental margin depression and back-arc extensional basin developed in extensional environment. At this stage, basins were only developed in North China Craton, with basin sequence transformed from rift to depression [28], and this is the only area where Mesoproterozoic source rocks are developed inside the craton among those three landmasses.

During late Qingbaikou to Silurian period, corresponding to the formation stage of "China's paleo-continent" from the splitting of Rodina supercontinent to the converging of Gondwana continent [26]. It appeared as the splitting, expansion and subduction of "China's paleo-ocean". During this process, the continental collision or accretionary orogeny controls the formation and evolution of small marine cratonic basins such as Yangtze, North China and Tarim, forming the evolution sequences of rift-discrete continental margin depression and intra-platform depression back-arc spreading and foreland basins. The special properties of small cratons and the interactions between them cause strong structural differentiation in marine basins, resulting in sedimentary differentiation and differences in the distribution of basic hydrocarbon geological conditions in different structure units [29].

During Devonian period to early Mesozoic era, corresponding to the stage from the formation of Pangaea supercontinent to the formation of "Asian paleo-continent" splitting [26], it mainly appeared as the long-distance convergence between accretionary continents, convergence in

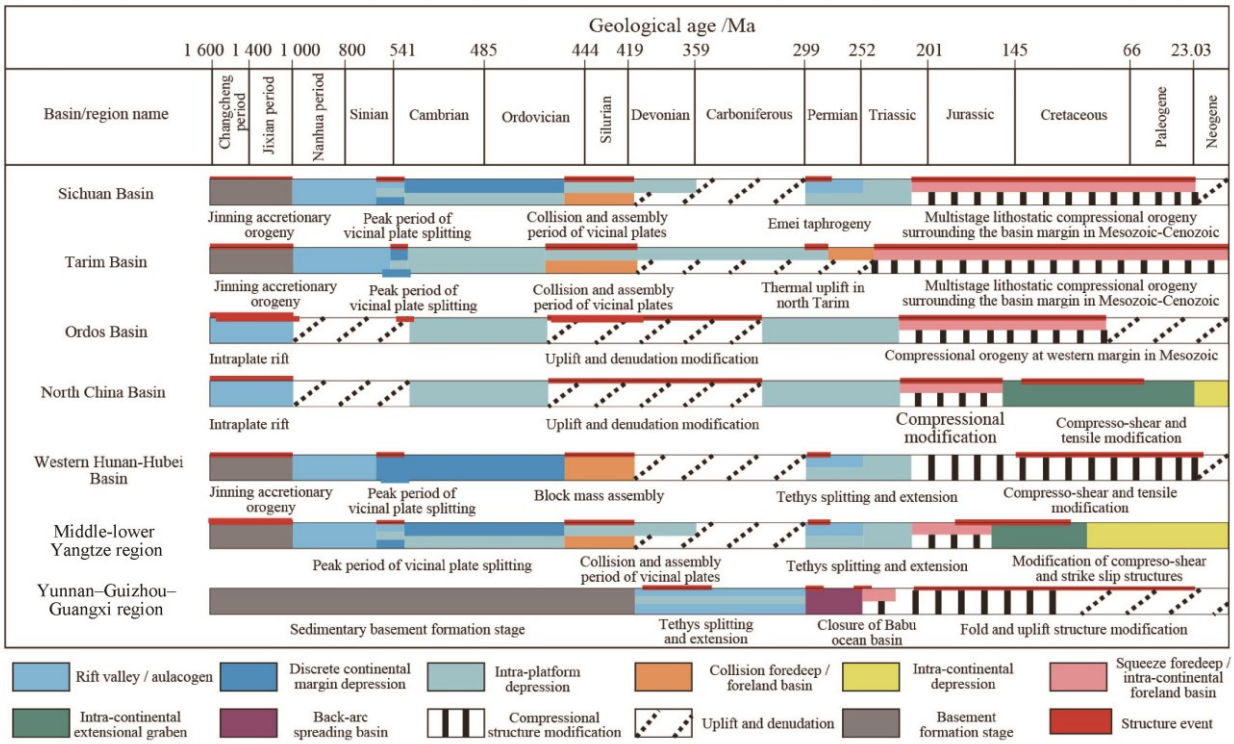

Fig. 1 Comparison of prototype evolution sequences of main marine basins or regions in China

the north and divergence in the south, and emergence of continental cycles and intra-continental basin sequence. The plate movement pattern of north convergence and south divergence and the interaction mode between landmasses jointly control the multiple distribution forms of tectonic stress in landmasses, resulting in the convergence of continental margin trench-arc-basin system of Tianshan-Xingmeng structure zone during late Devonian to early Carboniferous and the subsequent superimposed rift adjustment system, as well as the parallel of discrete continental margin depression and rift in the southern Tethys tectonic domain. At this time, the sedimentary filling of the basin transformed from marine facies sediments to marine continental transitional facies clastic rocks.

During Mesozoic to Cenozoic, corresponding to the formation of "new Asian continent", it appeared as the convergence and accretion of continental margins and the squeeze-repulsion deformation of intra-continents [26], the change of structure pattern of marine basin and superimposed intra-continental basin sequence.

2.2 Accumulation geological factors and their combinations controlled by structure sedimentary differentiation

Since such cratons or landmasses as Tarim, Yangtze, North China and Junggar are small in scale, poor in structure stability and strong in structural-sedimentary differentiation [25,29], the marine basins have undergone tectonic differentiation activities such as tensional rifting, uplift and denudation and basement fault activation, resulting in the juxtaposition of a variety of prototype subsidence structural units, and forming structural-sedimentary units with obvious filling structure differences. This primitive structure sedimentary pattern controls the development of source rocks and the type and distribution of reservoirs and source-reservoir assemblies [25]. For example, the "Deyang-Anyue rift" in Sinian-Cambrian Central Sichuan Basin and the "Kaijiang-Liangping rift" in northeast Sichuan Basin are all developed with high-quality source rocks in rift zone, and high-energy reef beach reservoirs on both sides of the rift zone, forming a superior source-reservoir configuration, and a number of large and medium-sized gas fields have been found accordingly [25,29,30-31].

Nowadays, the boundaries and structures of the basin are often very different from those of prototype basin in the geological history stage. The prediction of hydrocarbon accumulation factors and their assemblies in the marginal area of the basin must be carried out on the basis of restoring the original structure-subsidence pattern. The sizes of such superimposed reformation basins in geological history as Tarim, Sichuan and Ordos in central and western China are much larger than those of present basins. Exploration practices in the piedmont area around the basin also confirm that there may exist new type of hydrocarbon accumulation assemblies under the "old mountain". For example, the full set of upper Palaeozoic sequence is still developed under the Haitangpu-Xiangshui-Xiaoba thrust fault in the middle and north section of Longmen Mountain piedmont area. The

Permian deep lacustrine hydrocarbon source rock layers are still developed under the nappe of Zaire mountain in the northwestern of Junggar Basin.

2.3 Structuremodification and formation and preservation of composite petroleum system

Since Mesozoic, the cratonic marine basins have generally undergone multi-stage structure modification, and the superposition of multi-stage and multi-type tectonic activities has occurred at the margin and inside of the basin. Accompanied by the oil and gas response to diversified internal structures, changing hydrocarbon accumulation factors, and dynamic accumulation and dispersion inside the basin, multiple hydrocarbon accumulation types have been formed after accumulation, destruction, adjustment and re-accumulation [32-33].

In the past, when discussing the effectiveness of "petroleum system" in a basin with single cycle characteristic, the hydrocarbon generation and expulsion of source rocks were often emphasized. However, for multi-cycle superimposed reformation basins, more attentions are paid to whether the source rocks used to be effective are still effective or whether there are active "hydrocarbon source kitchens". Therefore, the superposition of basin prototypes and their composite mode after modification have a decisive impact on the formation and preservation of petroleum system, while the style of petroleum system determines the scale, type, combination mode and distribution law of oil and gas reservoirs. In a superimposed reformed basin, the effective preservation of petroleum system is controlled by multiple factors, such as deep buried thermal evolution of source rocks, uplift and denudation of caprock, communication and destruction of fault fluid migration system, etc.[34]. The types and distribution of residual basins at present control the preservation of petroleum systems and determine the way in which oil and gas reservoirs are preserved and destroyed. Primary preservation, primary residue, primary destruction and later reconstruction are the four possible basic types of reservoirs [35], and their oil and gas resource potential, oil and gas reservoir types and oil and gas distribution patterns are quite different.

3 Idea, method and process for division of petroleum play

3.1 Division idea of "prototype-controlled sources and superposition-controlled accumulation"

As mentioned above, the division of petroleum exploration plays must reflect the characteristics of superimposed reformation basin evolution and dynamic hydrocarbon accumulation, while the idea of "prototype-controlled sources and superposition-controlled accumulation" provides a method to study the basin from overall to local and from evolution of original hydrocarbon accumulation factors to systematic integration. It emphasizes the study of basin from a holistic approach, analyzes the distribution of original accumulation geological factors and the subsequent hydrocarbon generation, migration and accumulation in the process of basin formation and modification, clarifies the types and distribution of petroleum systems in the process of superposition and modification of different accumulation assemblies, and reveals the main controlling factors for hydrocarbon accumulation in each type of petroleum system, thus identifying the type and boundary of the play accordingly (Fig. 2)

The idea of "prototype-controlled sources and superposition-controlled accumulation" is drawn from numerous exploration practices and analyses, and is based on the "Theory Conception of Active Tectonic History" by ZHU Xia and his TSM basin analysis model ("3T (environment) – 4S (action) – 4M (response)") [36-37]. Basin prototype is a unified subsidence structure entity consisted of a certain rock strata,

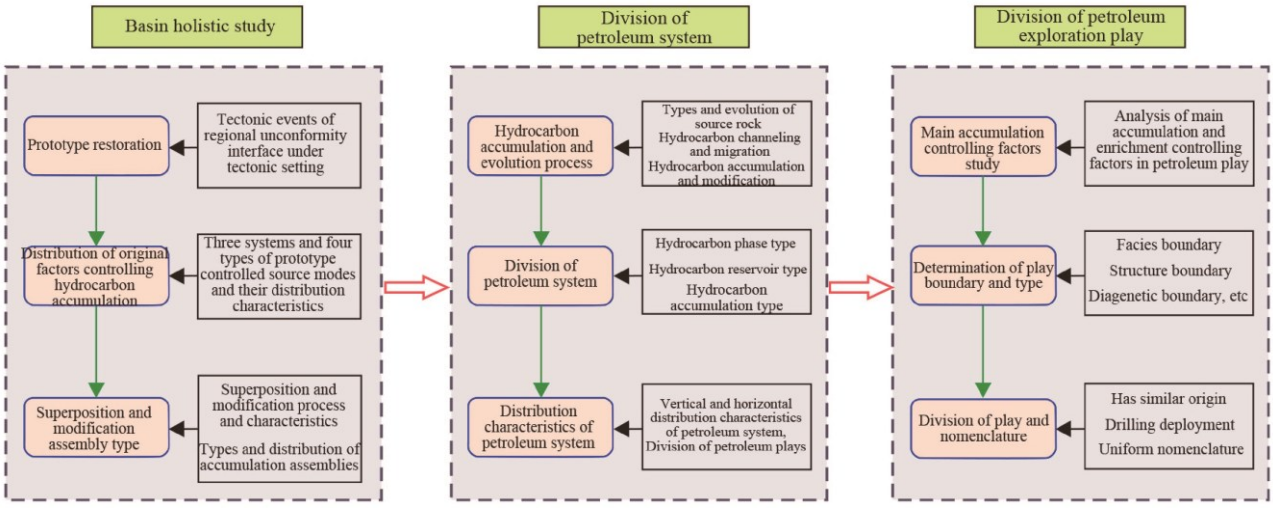

Fig. 2 Guiding and method for the division of petroleum exploration play in superimposed reformation basin

formed and developed under a certain tectonic-thermal system in a certain stage of geological development history. It is not only a structure form, but also a sedimentary entity with its own style [38]. The prototype structure entities of same era and epoch can be juxtaposed horizontally, each with its own corresponding tectonic-thermal system, and the prototype structure entities of different era and epoch are often superimposed each other vertically through prototype sequence. The basin today as a whole actually is a juxtaposed and superimposed combination of prototype sequences of different era and epoch. Taking the three factors as the classification end members, i.e., the tectonic environment formed in the cycle stage of plate movement, the composition of rock layer where the prototype subsidence is located, and the tectonic-thermal system when the prototype was formed. ZHANG Yuchang divided the petroleum basins in China into 4 sequences of discrete continental margin, discrete intra-continent, convergent intra-continental and convergent continental margin, which are further classified into 13 prototypes [39-40] (Fig.3).

"Prototype-controlled source" refers to the control mode of the basin's prototype subsidence structures of different generations and the sedimentary filling characteristics under their constraints to the formation and distribution of hydrocarbon geological factors, which summarizes the mutual control and subordinate relationship among "basin-forming system-basin prototype-sedimentary system-sedimentary factors" in petroleum basins. Different structure systems and different types of prototypes have unique laws on the formation and development of source rocks, reservoir rocks and their assemblies. "Superposition-controlled accumulation" refers to the dynamic analysis of the oil and gas response relationship among geological factors under such geological processes as subsidence, sedimentation and tectonic movement through the restoration of basin evolution process, and the study of the process of hydrocarbon generation, migration and accumulation under prototype constraint mechanism by systematic-holistic method, so as to attain the purpose of predicting the type and distribution of oil and gas reservoirs. Under the guidance of the idea of "prototype-controlled sources and superposition-controlled accumulation", the "description of hydrocarbon accumulation factors – depiction of dynamic process-prediction of oil and gas reservoirs" is cooperated with the characteristics of superimposed reformation basin, and the division of petroleum exploration play under complex structure is settled according to the principle of gradual division from the whole to parts, i.e., from basin to petroleum system to play, so as to better serve the oil and gas evaluation, exploration and deployment.

3.2 Process and method of division of plays

Following the idea of "prototype-controlled sources and superposition-controlled accumulation", division of petroleum exploration play of superimposed reformation basin can be made step by step by "basin–petroleum system–play".

3.2.1 Holistic study of basin

The main task of holistic study of the basin is to clarify the type characteristics of assemblies of "basin prototype-controlled sources and superposition- modification assembly", establish and summarize the mutual control and subordinate relationship among factors of "basin-forming system-basin prototype-sedimentary system – accumulation" in petroleum basins, and clarify the types and distribution of hydrocarbon accumulation assembly. The content of study is mainly to rebuild the evolutionary sequence of prototype superposition and modification through restoration of the prototype basin in key periods of geological history, analyze

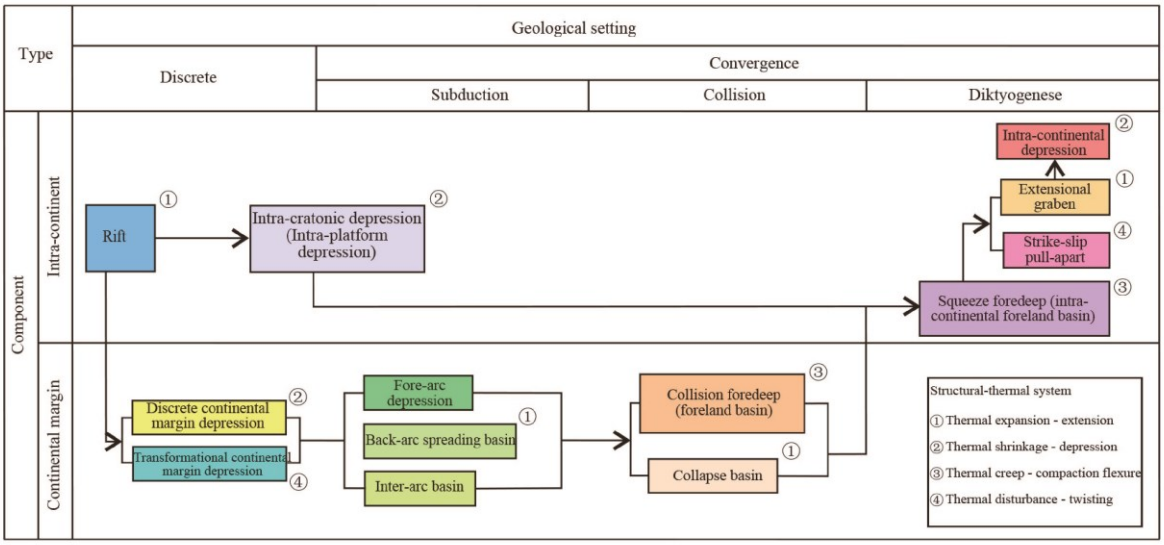

Fig. 3 Basin prototype classification

Revised according to information in References [39-40], with a few changes.

the prototype-controlled sources and their assemblies of 4 prototypes such as rift, depression, foredeep and graben under 2 systems of continental margin and intra-continent [41], speculate the distribution of original hydrocarbon accumulation factors under prototype control, and divide the superposition and modification assemblies. Through holistic study of the basin, the hydrocarbon accumulation assemblies of different types and their distribution in both vertical and horizontal directions in the basin shall be clarified.

3.2.2 Division of petroleum system

The main task of petroleum system division is to analyze the evolution of hydrocarbon accumulation factors and the response relationship between hydrocarbon accumulation and adjustment under different superposition and modification assemblies, and to clarify the types of petroleum system and the space distribution in vertical and horizontal directions. Based on the holistic study of geology of the basin and the understanding therewith, taking the hydrocarbon accumulation assembly as a unit, the dynamic hydrocarbon accumulation process is analyzed under different superposition and modification assemblies in the same hydrocarbon accumulation assembly, so as to clarify the evolution process of hydrocarbon accumulation factors under different superposition and modification assemblies. Through analysis of dynamic hydrocarbon accumulation process in hydrocarbon accumulation assemblies, the types of petroleum system and their plane distribution are divided, and 4 possible hydrocarbon accumulation types such as primary preservation, primary residue, secondary adjustment and remote enrichment are confirmed (Table 1).

Table 1 Basin-system-play gradual research and division naming method

Basin	Petroleum system		Type of exploration play	Boundary	Nomenclature	Example
		Type	Hydrocarbon accumulation play			
xx basin	Gas, Oil, Oil & Gas	Primary preservation type	Facies controlled platform margin, Facies controlled intra-platform, Facies controlled volcanic rock	Facies zone	Paleo-structure unit + strata + main controlling factors	① Sinian platform margin zone east of Mianyang-Changning rift; ②Cambrian marginal shoal zone west of East Sichuan depression; ③Cambrian platform margin zone in Manjiaer depression
		Secondary adjustment type	Transition zone I Transition zone II Thick zone	Structure	Present structure unit + strata + main controlling factors	①In-situ structure zone of at the downthrown side of middle and north section of Longmen Mountain transition zone II ②Fault-fold zone in the piedmont of Micang Mountain transition zone II
		Primary residual type	Structure + facies controlled type	Structure Facies zone	Paleo-tectonic unit + strata + main controlling factors	①Cambrian post-salt fault-fold zone west of East Sichuan depression; ②Platform margin fault-fold zone of Dengying formation southeast of Yangtze continental margin depression
		Remote enrichment type	Structure type Fracture type Stratum type	Structure Physical properties Fluid potential	Modern structure unit + strata + main controlling factors	①Cambrian tidal facies gentle slope zone in Katake uplift; ②Jurassic channel in West Sichuan depression; ③Neogene ultra-denudation zone northwest of Junggar Basin

3.2.3 Division of petroleum exploration plays

The key task of exploration play division is to analyze the key factors for hydrocarbon accumulation and enrichment in terms of different hydrocarbon accumulation types, determine the play boundary types and confirm the space distribution characteristics of petroleum exploration plays.

By analyzing and evaluating the main controlling factors of hydrocarbon accumulation and enrichment in different petroleum systems or accumulation plays, the type and boundary of the play are determined (Table 1). In the well preserved primary petroleum system or accumulation play, the main controlling factor affecting hydrocarbon accumulation and enrichment is the original sedimentary facies zone, in which there may exist platform margin type, intra-platform type, or volcanic rock type petroleum plays, while the facies boundary can be used as the division boundary of the play. The secondary adjustment type petroleum system is mostly located in the piedmont zone of the basin. The hydrocarbon accumulation in the piedmont zone has the characteristics of multi-stage accumulation, mainly in the late stage. The structure type reservoir is the main type of oil and gas reservoirs. The deformation structure zone bounded by large fault often controls the hydrocarbon accumulation and enrichment. Therefore, the structure boundary generally constitutes the play boundary of the secondary adjustment type petroleum system, while the thick zone, transition I and II zones are the main play types [42]. The primary residual type petroleum system is mostly distributed in the structure reformation zone with multi-layer detachment deformation, such as East Sichuan structure zone. The hydrocarbon accumulation in this kind of petroleum play generally has the dual controlling characteristics of "facies control + structure". The structure and facies boundaries together constitute the boundary of this kind of play. The remote enrichment type petroleum system refers to the long-distance migration of oil and gas along such channeling systems as fault and unconformity and the accumulation of reservoirs behind the passage. It should be noted that the accumulation is different from the conventional accumulation assembly, which belongs to a special type of exploration play, such as Shunbei fault zone and Central Tarim oil and gas reservoir where the main controlling factors for hydrocarbon accumulation are fault zone, unconformity, and stratum, and the structure, physical properties and fluid potential constitute the boundary of the play.

3.3 Play nomenclature

The name of the play often directly reflects the characteristics of hydrocarbon accumulation and enrichment, and indicates the type of oil and gas reservoirs and exploration target. The nomenclature of the play highlights the practical and concise principle. Generally it is a composite name based on "(paleo) modern structure unit + stratastrata or assembly + main controlling factors of accumulation". The modern structure unit is named by the present name of secondary order structure of the basin. The paleo-structure unit is named by the prototype basin name that controls the formation and distribution of original hydrocarbon accumulation factors. The strata or assembly is named according to the exploration target layer or accumulation assembly; The main controlling factors of hydrocarbon accumulation that control the petroleum system or accumulation play are consisted of two factors at most.

The nomenclature of plays of primary preserved and primary residual types in petroleum system or accumulation play generally adopts the pattern of "paleo-structure unit + strata + main controlling factors of accumulation", such as the platform margin of Dengying formation west of Mianyang-Changning rift, the platform margin fault-fold zone of Dengying formation southeast of Yangtze continental margin depression, the Cambrian outer gentle slope zone in Manjiaer continental margin depression, etc. The nomenclature of plays of the secondary adjustment type and remote enrichment type petroleum system or accumulation play generally adopts the pattern of "modern structure unit + strata + main controlling factors of accumulation", and the main controlling factors may or may not decide to participate in the nomenclature, such as the Cambrian tidal facies gentle slope zone in Katake uplift, the in-situ structure zone at the downthrown side of Longmen Mountain transition zone II, etc.

4 Case study of exploration play division

4.1 Precambrian hydrocarbon accumulation assembly in Sichuan Basin

4.1.1 Analysis of dynamic hydrocarbon accumulation process and division of petroleum system

The Precambrian hydrocarbon accumulation assemblies in Sichuan Basin are of large oil and gas resource potential. Following the discovery of Anyue mega gas reservoir, they have become the key area for breakthrough in oil and gas exploration. During the Dengying period of Sinian, two discrete continental margin depressions on the eastern and northern margins of the upper Yangtze region and the Mianyang-Changning rift in the craton controlled the distribution of source rocks and reservoir facies in this area (Fig. 4). After the hydrocarbon accumulation assembly was formed, it underwent multistage unbalanced superposition and modification of Paleozoic depressions and foredeeps (Fig. 1), forming 3 modification types: western edge piedmont thrust type, abdominal superposition type and eastern multilayer detachment thrust type (Fig. 4).

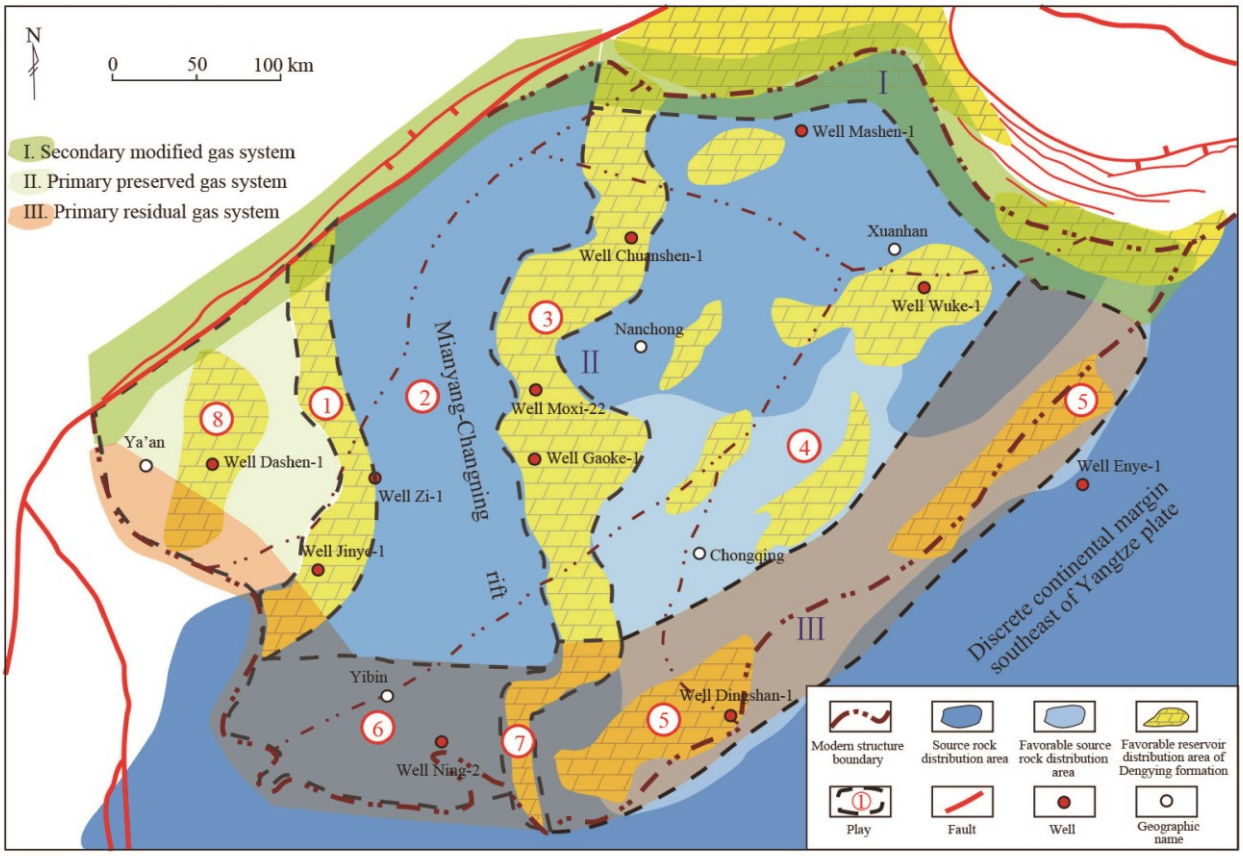

Fig. 4 Play division of Precambrian in Sichuan Basin

① Platform margin of Dengying formation west of Mianyang-Changning rift; ② Continental shelf of Dengying formation in Mianyang-Changning rift; ③ Platform margin of Dengying formation east of Mianyang-Changning rift; ④ Intra-platform shoal of Dengying formation east of Mianyang-Changning rift; ⑤ Fault-fold zone at platform margin of Dengying formation southeast of Yangtze continental margin depression; ⑥ Fault-fold zone at continental shelf of Dengying formation in Mianyang-Changning rift; ⑦ Fault-fold zone at platform margin of Dengying formation in Mianyang-Changning rift; ⑧ Intra-platform shoal of Dengying formation west of Mianyang-Changning rift.

The modification of abdominal superposition type controls the evolution of hydrocarbon accumulation factors and the response process of hydrocarbon generation, migration, accumulation and adjustment in the process of prototype superposition. During the later non-equilibrium discontinuous superposition and transformation of multi-stage depression and foredeep, the Precambrian hydrocarbon accumulation assembly experienced the facies transformation from oil reservoir to oil-gas reservoir and then to gas reservoir, and the hydrocarbon source also expanded from single source rock to multi-type composite of source rock and paleo-reservoir. The position of reservoirs is also re-adjusted and re-enriched multiple times along with the change of paleo-structure highs in the reservoir during the superposition process, and finally form a distribution pattern of primary preserved gas reservoirs accommodated for the modern structure system.

The thrust modification of piedmont was manifested differently in the thrust modification process in Mesozoic and Cenozoic. It appeared as a forward spreading thrust deformation since late Indochina period. Due to the differences in the development of main detachment layers and thrust boundary conditions in the piedmont of Longmen Mountain, it is characterized by two-section deformation in the north and south. The rears of middle and north section zone I and zone II in late Yanshan period were continuously to be thrust, while the frontier was relatively stable; the Himalayan period is characterized by strong uplift and rear nappe[43]. From Indochina to early Yanshan period, early oil and gas reservoirs were formed while thrusting. In late Yanshan-Himalayan period, the deformation evolution in different parts was differentiated. The downthrown side of Jiangyou-Zhangming fault was characterized by structure uplift and high change, and the deformation layer at the entrained transition zone II between the two faults of Jiangyou and Xiaoba faults and the continental strata was characterized by episodic thrust and uplift; while the transition zone I and thick zone west of Xiaoba fault were manifested by strong thrust deformation and uplift. The difference of late deformation results in different oil and gas responses. The strata at

the downthrown side of Jiangyou fault in the transition zone II are the primary adjustment enrichment, while the strata at the upthrown side is the secondary adjustment enrichment, and the transition zone I and thick zone are subject to destruction. Since the late Indochina period, the southern section of Longmen Mountain has experienced multi-stage thrust, which is forward spreading thrust and uplift from the rear to the frontier, the intensity of structure deformation and fault activity become weaker in turn, and gas accumulation at the transition zone I is the secondary adjustment enrichment type, while the thick zone is subject to destruction.

During the Mesozoic and Cenozoic detachment thrust modification of the eastern multi-layer detachment thrust, due to the limited separation of regional detachment layers, the oil and gas have undergone a process of interlayer adjustment and re-enrichment, some of them are subject to destruction. The present gas reservoirs are mainly the residual primary reservoirs [35].

4.1.2 Analysis of main controlling factors and division of plays

Present exploration confirms that the gas distribution of Dengying formation in Sichuan Basin is mainly controlled by dominant reservoirs, and the development of reservoirs is determined by the original carbonate sedimentary facies [25,28-31]. There are also obvious differences in reservoir development at the edges of rimmed platform and gentle slope platform controlled by prototype basin in the original sedimentary period. The oil and gas properties at the east side of platform margin of Mianyang-Changning rift are obviously better than those in the west, and few oil and gas discoveries have been made in the marginal facies of discrete epicontinental depression of the southeast margin of Yangtze plate. Therefore, the preserved primary gas system or accumulation play in the abdomen of the basin can be divided into five plays according to the structure sedimentary pattern of prototype basin. All the plays are facies controlled, and named according to the nomenclature rules (Fig. 4).

The hydrocarbon accumulation and enrichment in the primary residual gas system or accumulation play in East Sichuan are affected by the development of reservoir and also controlled by the modification of fault structure since the Mesozoic and Cenozoic. The gas accumulation and enrichment in this area are jointly controlled by original sedimentary facies and later structure modification. The play division is made according to pattern of "facies + structure", and there are three exploration plays in the division (Fig.4), which are named according to the nomenclature of combination of "paleo-structure unit + exploration horizon + facies and structure", such as the fault-fold zone at platform margin of Dengying formation southeast of Yangtze continental margin depression.

The gas accumulation and distribution in the secondary adjustment gas system or accumulation play in the piedmont of Longmen Mountain are controlled by the structure of modern deformation zone, mainly the structure petroleum play. The division of the play highlights the deformation zone, and the middle and north section of Longmen Mountain is divided into four plays (Fig. 5), while the south section is divided into two. The division of Micang-Daba Mountain secondary adjustment gas system or accumulation play is similar to that of Longmen Mountain Piedmont zone, and we will not explore it in this paper.

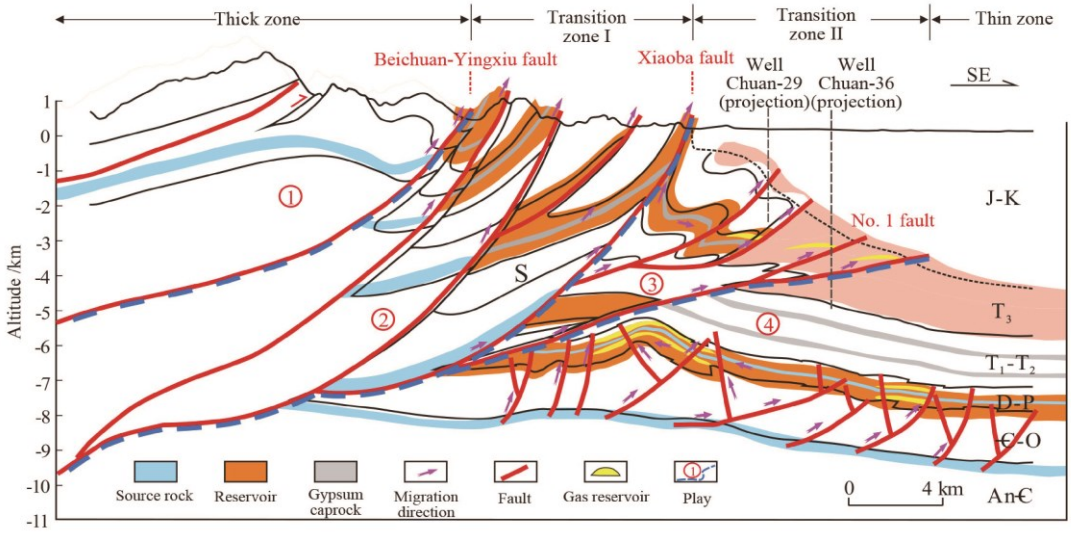

Fig. 5 Play division and naming of secondary adjustment type petroleum system in north-central section of Longmen Mountain

① Sinian thick thrust system in the north central section of Longmen Mountain ② Paleozoic thrust system of transition zone I in the middle and north section of Longmen Mountain; ③ Sinian thrust system at the upthrown side of transition zone II in the middle and north section of Longmen Mountain; ④ In-situ Paleozoic-Mesozoic structure zone at the downthrown side of transition zone II in the middle and north section of Longmen Mountain

4.2 Cambrian pre-salt assembly in platform-basin region of Tarim Basin

With the breakthrough in Well Luntan-1, the Cambrian pre-salt assembly in the platform-basin of Tarim Basin has become a hot spot for oil and gas exploration. However, due to such factors as low level of exploration, low quality of seismic data, large buried depth, and large regional differences in oil and gas geological conditions, division of exploration plays in the pre-salt zone of the whole basin is difficult, and hence study thereof is limited.

The Cambrian pre-salt zone in the platform-basin region of Tarim Basin has experienced multiple stages of south and north discrete continental margin depression ($\in_1$), intra-platform depression ($\in_2$-O_2), back-arc foreland (O_2-S), intra-platform depression (D-P_2), juxtaposition of compressing and squeezing foredeep with intra-platform depression (P_3-T), and juxtaposition of compressing and squeezing foredeep (J-Q) (Fig.1). In the early and middle Cambrian, the transformation, from two discrete continental margin depressions (north and south) to intra-platform depression, controlled the distribution of source rocks of Yuertus formation and the reservoir facies zone of Xiaoerbulake formation and their assemblies. Due to the lack of source rocks, in-situ vertical hydrocarbon accumulation assemblies were not developed in the central uplift zone of Central Tarim. The pre-salt accumulation assemblies were affected by the later prototype superposition and differential modification, and the main shapes of North and South Tarim areas were changed into superimposed transformation type, while the Central Tarim area was evolved into a fault-fold transformation type.

The analysis of structure evolution and hydrocarbon accumulation process shows that the regionally distributed Cambrian gypsum salt rocks perfectly separate the two sets of accumulation systems in the post- and pre-salts in superimposed reformation areas of North and South Tarim [44-45]. The strike slip faults developed therein has little influences, and the main body of play is the preserved primary petroleum system (Fig.6). The fault-fold type modification area of Central Tarim is located in the superposition area of multi-stage tectonic activities, faults and unconformities are well developed, and the local primitive accumulation assembly is not developed. The hydrocarbon sources are mainly subjected to a long-distance migration from the north and south sides, and the petroleum system is a remote enrichment type in Central Tarim (Fig. 6).

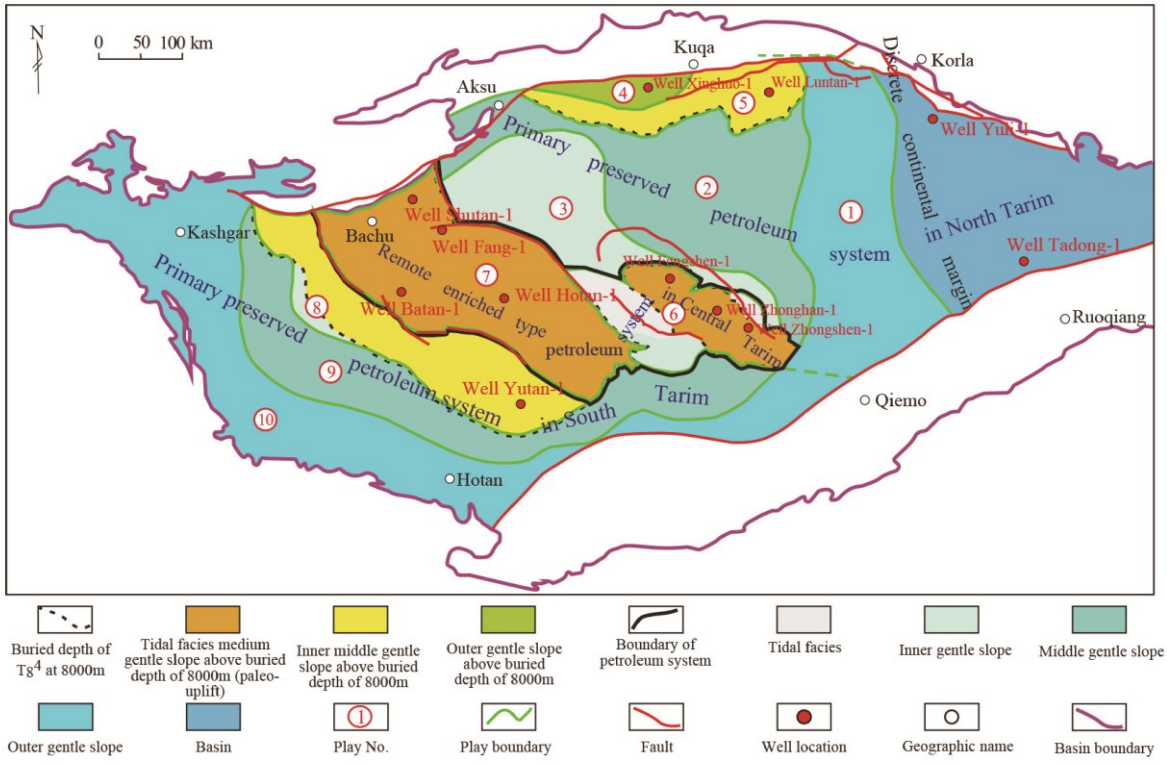

Fig. 6 Play division of the Cambrian presalt Xiaoerbulake Formation in the platform-basin area of Tarim Basin

① Cambrian outer gentle slope zone in Manjiaer continental margin depression; ② Cambrian middle gentle slope in Manjiaer continental margin depression; ③ Cambrian inner gentle slope zone in intra-platform depression of North Tarim area; ④ Cambrian outer gentle slope zone in continental margin depression of North Tarim area; ⑤ Cambrian middle gentle slope zone in continental margin depression of North Tarim area; ⑥ Cambrian tidal facies gentle slope zone in Katake uplift; ⑦ Cambrian tidal facies gentle slope zone in Bachu uplift; ⑧ Cambrian inner middle gentle slope zone of in continental margin depression of South Tarim area; ⑨ Cambrian middle gentle slope zone in continental margin depression of South Tarim area; ⑩ Cambrian outer gentle slope zone in continental margin depression of South Tarim area

The analysis of drilling result of pre-salt zone shows that the failure of all 12 wells in the Bachu uplift and the northwest edge of Tanggubasi depression is due to poor oil and gas filling, while the wells in South and North Tarim areas encountered hydrocarbon accumulation assemblies during drilling, and the reservoir properties affect the hydrocarbon enrichment. Accordingly, the two preserved primary petroleum systems in North and Sourth Tarim areas are divided into 8 exploration plays based on the sedimentary facies, the remote enrichment petroleum system in Central Tarim is divided into 2 exploration plays, and all of them are named according to the nomenclature rules (Fig.6).

5 Conclusions

(1) A petroleum exploration play refers to an exploration target group sharing the same sedimentary system (or sedimentary facies) and similar accumulation conditions in same structure unit. The target group in the same exploration play is a combined whole in space and have similar geological conditions for accumulation, but the types of targets (traps) may be different.

(2) The particularity of hydrocarbon accumulation conditions in superimposed reformation basin lies in that: the basin has undergone multi-stage superimposed development and modification, and formed multiple sets of accumulation assemblies and multiple superimposed reformation assemblies in the vertical direction; the structural-sedimentary pattern of prototype basin controls the geological factors and assembly distribution of hydrocarbon accumulation, and the structure modification in the process of prototype superposition and its composite control the formation and preservation of petroleum system.

(3) The particularity of hydrocarbon accumulation condition and process in the superimposed reformation basin determines that the division of petroleum plays must follow the active train of thought of "prototype-controlled sources and superposition-controlled accumulation", i.e., following the principle of division according to "basin-petroleum system – play" step by step: It starts from the holistic study of the basin, analyzes the distribution of original accumulation geological factors and the subsequent hydrocarbon generation, migration and accumulation in the process of basin formation and modification, clarifies the types and distribution of petroleum systems in the process of superposition and modification of different accumulation assemblies in the basin, reveals the main controlling factors for hydrocarbon accumulation in each type of petroleum system, and determines the type and boundary of the play accordingly. The nomenclature of the play is named by the combination of "(paleo) modern structure unit + strata or assembly + main controlling factors of accumulation".

(4) The method for division of petroleum exploration play based on "prototype-controlled sources and superposition-controlled accumulation" is applicable to superimposed reformation basins in central and western China. Plays divided by this method can better serve the study of hydrocarbon enrichment law in the basin and the exploration practice, thus improving the scientificity and efficiency of exploration and deployment.

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