Sequence Architecture, Heterogeneities and Seismic Expressions of a Vaca Muerta Outcrop Analog – Implications for Unconventional Exploration

Zeller, M.[1], Reid, S.B.[1], Eberli, G.P.[1], Massaferro, J.L.[2]

[1] CSL – Center for Carbonate Research, University of Miami, Miami, USA - current Statoil ASA, Carbonate Research, Bergen, Norway - mzell@statoil.com
[2] YPF, Buenos Aires, Argentina

The Upper Jurassic to Lower Cretaceous Quintuco – Vaca Muerta System in the Neuquén Basin (Argentina) recently received much attention due to its potential as a major unconventional play. However, sedimentological studies of the Vaca Muerta Formation are generally restricted to 1D reference sections and are not covering the lateral architecture and heterogeneities within the depositional system. Combining field work, satellite imagery interpretation and seismic modeling closes this gap and helps establish rules for predicting facies and heterogeneities from subsurface data sets.

The field site, the Sierra de la Vaca Muerta, offers spectacular insights into the prograding system along a 10km long and 1km thick cross section. A novel approach of combining field geology with satellite imagery interpretation documents the sequence architecture of this prograding mixed carbonate-siliciclastic system and allows the allocation of bed scale heterogeneities within the sequence stratigraphic framework. Based on the facies distribution, the studied interval can be subdivided into 8 depositional sequences, representing a very similar scale as the 7 sequences documented in the global sea level chart in the study interval and points therefore at an eustatic control on the system.

Within this stratigraphic framework, heterogeneities occur in both temporal and lateral scales. While carbonate-rich portions are characterized by abrupt lateral facies transitions and breaks within their steep depositional profile, siliciclastic-rich parts show gently inclined profiles with no breaks and more gradual facies changes.
In the temporal scale, heterogeneities occur both as cycles and events. Meter scale alternations of pure shale with calcareous shale are the typical cyclic expressions, which occur down-slope of carbonate-dominated systems. Mixed turbidites commonly follow just after carbonate sequences, triggered by the steeper depositional gradients. This distribution indicates that carbonate-rich intervals would offer both more brittle volumes for fracturing (calcareous shales) and at the same time potential relative permeable streaks (turbidites) within the tight shale surrounding.

In order to compare this architecture with subsurface seismic, synthetic seismograms are constructed from the observed facies distribution and petrophysical properties. In the synthetic seismic models the carbonate cycles prove to be easy to detect due to their strong acoustic impedance and geometrical expressions. These findings could offer a way to identify sweet spots for unconventional exploration, since they are laterally related to carbonate sequence tops, which have a clear seismic signature.

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Sedimentology of the Upper Triassic flysch Langjiexue Group in Shannan region, southern Tibet

Zhang, C.[1], Li, X.[1]

[1] School of Earth Sciences and Engineering, Nanjing University, 210093-Nanjing, China – zck198810@126.com

The Upper Triassic flysch Langjiexue Group largely outcrops south to the river Yarlung Zangbo and east to Bailang county in southern Tibet, China, which consists of lightly-metamorphosed sandstone and slate. This deep sea flysch has been tectonically classified as a part of either the northern Tethys Himalayas or mélange (an accretionary prism) within the Yarlung Zangbo suture since it was nominated. Recent local paleocurrent and detrital zircon U-Pb isotope evidences suggested it has a different source, but few from supports of sedimentological materials. In this work, sedimentological methods, including lithological dispersal, heavy mineral assemblage, paleocurrent flowing, lithofacies, and clastic composition, were adopted to study the Langjiexue Group on a much more large scale.

Firstly, isolines of sandstone (+siltstone) vs. slate ratios display that ratios decrease from north to south in majority, indicating a total tendency of finer and finer grain southward. Secondly, the ZTR index of heavy mineral ranges from 40 to 95 and totally increases southward, implying a southward transportation of clastic grains. Thirdly, paleocurrent flowing directions predominantly vary between 100° to 260°, directly pointing to south (mean vector 200°). Fourthly, according to field observations of over two dozens of cross-section, microfacies were recognized as six associations: 1) mid-fan channels-interchannel, 2) overbank/levee, 3) crevasse-splays, 4) outer-fan-lobes, 5) fan-fringe, and 6) basin-plain, comprising southwest mid-fan and outer-fan in composite submarine fan systems. At last, it is quite clear from Dickinson triplots that sandstones are plotted within the collisional orogen and have the recycled orogen provenance.

From the results above, it is demonstrated that the Upper Triassic flysch Langjiexue Group has been derived from north, strongly supporting a viewpoint that it was not belonged to either a part of the Tethys Himalayas or of the Yarlung Zangbo suture. By combination of lithofacies analysis and clastic composition of sandstone as well as depositional time (Late Triassic), the flysch sediment could be chiefly derived from a collisional orogen, implying it was formed in a remnant sea/ocean basin between two continents, where may be a suture position during the Paleo-Tethys closure. However, it remains unknown if it was derived from the Lhasa terrane!

Syndepositional faults and its control on sequences and depositional systems of the Lower Cretaceous Gouling Member in Liudong and Yaxi Areas, Qingxi Sag, Jiuquan Basin, NW China

Zhang, C.[1], Liao, Y.[1], Xu, W.[1], Tang, J.[1]

[1] Key Laboratory of Tectonics and Petroleum Resources, Ministry of Education, Faculty of Earth Resources, China University of Geosciences, 430074-Wuhan, China - zhangcc3614@gmail.com

In the continental rift basins whose tectonics were extraordinarily active, syndepositional faults play a significant role in controlling sequence architecture and depositional filling of the basin. Based on typical three-dimensional seismic interpretation and analysis on fault activities of Qingxi Sag, this paper highlights that syndepositional faults in Gouling member in Liudong Area had different assemblage patterns and activity characteristics from that in Yaxi Area. Combining with well logs, drilling cores and other data, this paper further illustrates the differential control of syndepositional faults on sequence patterns and depositional systems. The result shows that Liudong Area was subject to the control of the western section of 527 Fault, which had a high dip angle and strong activity, while Yaxi Area was subject to the joint control of the eastern section of 527 Fault and 543 Fault, which both had relatively low dip angle and weak activity. According to the assemblage patterns of these faults, two types of fault slope-break belts were identified in the studied area: Liudong steep slope fault belt and Yaxi fault terrace belt, and each type of fault slope break belt formed its own characteristic sequence infill type. Because of the difference in activity characteristics of the syndepositional faults, the depositional systems in Liudong Area and Yaxi Area obviously differed in development position, strike, distribution scale and physical property. Analyses and discussions on the different distribution and physical property of depositional systems in different sequence patterns contribute to predicting the favorable reservoirs and traps in the studied area.

The paleosalinity analysis on Upper Permian Linxi Formation in Zhalute area, inner Mongolia, China

Zhang, J.[1]

[1] Shenyang Institute of Geology and Mineral Resources, China - 48487885@qq.com

Late Permian linxi group in north-east china, wide distribution, large thickness, dark mudstones development, it is the most favorable shale gas exploration formations of late Paleozoic in this area.Through the determination of trace elements, major elements and clay minerals of the mudstones taking from the Taohaiyingzi Section and well Lu D2 in Zhalute area, depending on the Adams's and Couch's paleosalinity formulas, the decision methods of"equivalent boron" proposed by Walker , Sr-Ba ratio method, B-Ga ratio method and biomarkers analysis, the water salinity characteristics corresponding to the sedimentary period of Linxi Formation in Zhalute area were synthetically analysed. The results showed that Linxi Formation of well LuD2 formed in the brackish-water environment, while Linxi Formation of the Taohaiyingzi Section formed in the freshwater environment. Furthermore, the water salinity appeared the decreasing trend in the sedimentary period of Linxi Formation in Zhalute area. To be specific, the lower part strata corresponded to the brackish-water lake environment, while the upper part strata corresponded to the freshwater lake environment. Above all, the brackish-water lake environment could provide the favorable condition for developing thick source rock.

Keywords: paleosalinity ; trace elements ; quantitative reconstruction ; Linxi Formation ; Zhalute area

Controls of the Base-level Change on the Submarine Fan Architecture in X Oilfield, Offshore Western Africa

Zhang, J.[1], Wu, S.[1], Li, J.[1]

[1] State Key Laboratory of Petroleum Resource and Prospecting, China University of Petroleum, Beijing, China - zhangjiajia0103@gmail.com

Although extensive studies on the controlling factors of the submarine fan deposition have been carried out so far, most of them focus on the deposition process of gravity flows controlled by the base-level change, and how the base-level change controls the more refined submarine fan architecture has not been understood explicitly. This paper, taking an oilfield in offshore Western Africa as an example, deeply studies the controlling mechanism of the base-level change on the submarine fan architecture, which has significant meaning in understanding the spatial and temporal evolution of submarine fan architecture.

The study area has 51 wells altogether, with minimum well space being 200m and systematic coring 600m approximately. And the main frequency of 3D seismic data is 65HZ, covering an area of roughly 1500 km^2. Based on the base-level change curve and integrated features of well and seismic data, six 3^{rd}-order sequences are divided in the target interval. Using methods such as core observation and description, multiple well correlation and seismic strata slicing, various types of architecture elements are identified, and the temporal and spatial evolution model of the submarine channels and lobes are established under the control of the base-level change. Following are the main conclusions.

The base-level change significantly controls the types of submarine channels. (1)A complete channel system deposits cut-and-fill debris flow channels (Type IV), erosional sandy channels (Type III), aggradational hybrid channels (Type II) and aggradational muddy channels (Type I) successively from bottom up, with composite styles displaying a trend as “disordered style→lateral amalgamated style→en-echelon style→solitary style” and the bend curvature of channel belts increasing upwards. (2)Research shows that Type IV are formed during the early forced regression (EFR), signifying the incipience of a new channel system. Type III are formed by high density turbidity during the late forced regression (LFR). And Type II and Type I are formed by low density turbidity during the lowstand tract (LST) and the early transgression (ETST) respectively. Especially, Type II can extend far enough into the basin floor from continental slope. (3) Owing to the variance in the confinement degree of canyon down the continental slope, channel systems evolve from canyon-confined to semi-confined and then to unconfined types, each bearing different combinations of Type IV ~Type I.

The base-level change plays a crucial role in the distribution and evolution of submarine lobes. (1)During the EFR, debris flow lobes (Lobe IV) deposit at the foot of continental slope. And during the LFR, sandy lobes, formed by high density flow, deposit both at slope (Lobe III^1) and basin floor (LobeIII^2), existing in the form of composite lobes. Relative to LobeIII^1, LobeIII^2 show the larger plane area and thinner sand bodies, and prograde farthest into the basin floor. From the LST to ETST, fed by low density flow channels, hybrid lobes retrograde gradually from basin floor (Lobe II) to continental slope (Lobe I), existing in the form of elementary lobes. (2)Evidence shows that the channels and lobes occur alternatively from upper slope down to the basin floor, with the combination of channels and lobes showing a trend as “Type IV /lobe I→Type II /Lobe III^1→Lobe I/Type II→Type II /Lobe III^2（up/down）”.

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Sedimentary characteristics, distribution and organic matter of lacustrine turbiditic mudstone, Jiyang Depression, Bohai Bay Basin, China

Zhang, J.[1], Jiang, Z.[1], Liang, C.[1], Wu, J.[1]

[1] College of Energy, China University of Geosciences, 29 Xueyuan Road, Haidian District, Beijing 100083, China - jianguozhangenergy@163.com

The research on turbiditic mudstones has lasted for over half a century. The recognition criteria, rhythmic alternation patterns between turbiditic mudstone and non-turbiditic mudstone, and depositional processes were all discussed based on core description in the marine realm. However, the sedimentary characteristics and types of the lacustrine turbiditic mudstone remain unclear. In the previous studies, the distribution pattern and the volumetric importance of the turbiditic mudstones in the continual strata have not been studied limited by the well core length. Organic matter in turbiditic mudstone is the key to measure its hydrocarbon potential, but it is seldom reported.

In this study, we choose five continual sections from deep-lake mudstone/marlstone cores in east China, and the total core length reaches up to 1293m.We distinguish 3 types of turbiditic mudstones, which are blue-grey massive turbiditic mudstone, dark-color massive turbiditic mudstone, and laminated turbiditic mudstone.

Blue-grey massive turbiditic mudstone is always accompanied by distal turbiditic sandstone. It is rich in terrigenous debris, and its carbonate content is very low. In a sequence, it is turbiditic sand layer, blue-grey massive mudstone, and dark-color laminated marlstone/mudstone from bottom to top. The blue-grey massive mudstone indicates short transport, weak suspension and mineral mixing.

Dark-color massive turbiditic mudstone emerges in thick continual mudstone/marlstone successionwhich can be hundreds of meters. It is rich in both terrigenous debris and carbonate minerals. There is always a great deal of severely fragmented *Osracoda*. Enriched *Gastropoda* fossils and coal debris are also common in the cross section.There is only a very thin silt layer or not at the bottom interface. Dark-color massive mudstone indicates distant transport, strong suspension and mineral mixing.

Laminated turbiditic mudstone only accounts for a small percentageof turbiditic mudstone, and is irregularly distributed. It ranges from hundreds of micrometers to several millimeters. The lamina is fining upward, and gradually changes from silt lags at the bottom to clay at the top. It represents the smallest scale turbiditic mudstone.

The average volumetric ratio of turbiditic mudstone is 8.32% of all the cores. Turbiditic mudstone is an important type but not the main type of lacustrine marlstone/mudstone succession in Jiyang Depression. Its spatial distribution within different strata and wells is heterogeneous. Most of the turbiditic mudstone develops in environment with intensive structural activity and humid & hot climate, and they are thick and continually stacked.

Organic matters in turbiditic mudstone are disorganized and chaotic, but it can clump into floccules. The average TOC content can be as low as 0.34% in blue-grey massive turbiditic mudstone or reach up to 3.08% in dark-color massive turbiditic mudstone.Its organic matters are mainly composed of planktonic organisms, and the organic matter content is closely related to that of their adjacent non-turbiditic mudstone.

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The discussion about the interpretation of sedimentary gravity flow lithofacies

Zhang, J.[1, 2], Li, C.[2], Chen, P.[2], Xie, J.[2]

[1] College of Resources Science and Technology, Beijing Normal University, Beijing, China, 100875 – jinliang@bnu.edu.cn
[2] College of Geological Science and Engineering, Shandong University of Science and Technology, Qingdao, China, 266590

Our study suggests the key reason of the confusion about the classification of gravity flow and the explanation of the origin of gravity flow sediment is that we haven't fundamentally distinguished the difference between gravity flow migration mechanism and sedimentary mechanism. On account of a single type of gravity flow will change its fluid properties as mixing with water in the process of moving, and different fluid properties have different sedimentary mechanism, thus form the combination of multiple types of petrology facies during the depositional process. This article take Lowe's high density turbidity current and Shanmugam's sandy debris flow as examples to show the importance of fluid property transformation to origins of petrology facies interpretations.

Lowe (1982) clearly pointed out that the turbidity current is a kind of sediment flows which supported by turbulence, and according to the particle size, it can be divided into low density turbidity current and high density turbidity current. Based on the description of sediment, Lowe proposes 4 kinds of deposition mechanism: (1) traction current sediment; (2) suspended sediment; (3) friction frozen sediment and (4) viscous frozen sediment, and organizes the sedimentary stage of the high density turbidites into 3 stage: (1) traction sedimentation stage; (2) traction carpet stage and (3) suspended sediment stage. In the strictly sense, the first two stages don't exist in turbidite current sedimentary process, thus Lowe's opinion on the division of the high density sedimentary stage arouses a lot of opposition sound. This paper concludes that as mixed with water the supporting mechanism of the high density turbidities will change in the process of migration of high density turbidities, which leads to different sedimentary phases. So the Lowe's high density turbidity current treads the different flow types originating from fluid property transformation as the parts of turbidity current, this obviously amplifies the implication of turbidity current.

A feature of Shanmugam's sandy debris flow experiment is the emergence of turbulent cloud on the top in the process of its motion, which forms positive rhythm bedding after deposit. Shanmugam thinks these turbulent cloud and positive rhythm bedding is a part of the sandy debris flow and sediment, but this point is wrong, and the main evidence include: (1) the sandy debris flow is a kind of plastic flow on the rheology theory, but the turbulent cloud in the experiment is obviously liquid fluid, (2) sediments support mechanisms of sandy debris flow are cohesive strength, frictional strength, hindered settling and buoyancy, but the sediments support mechanism of the top turbulent cloud is turbulence support. Only from the above two points can we conclude that the top turbulent cloud already does not belong to the category of sandy debris flow.

The gravity flow will vary in fluid type from the beginning of the movement to the end of the formation of sediment. If we ignore the transformation of fluid property in the process of gravity flow movement and deposition, it is extremely unfavorable for the classification and sedimentary system analysis of gravity flow. In this paper, we propose that it is important to focus on the change of fluid properties in the movement and sedimentary process of gravity flow when interpreting the origin of the lithofacies, under this circumstance can we solve the problem that certain types of lithofacies (or lithofacies units) are formed by single fluid type or various fluid types during the fluid properties transformation.

Origin of the Botryoidal Dolostone of Sinian Dengying Formation in Sichuan Basin

Zhang, J.[1, 2], Jones, B.[3], Shen, A.[1, 2], Pan, L.[1, 2], Zhou, J.[1], Hao, Y.[1], Wu, M.[4], Qin, Y.[1, 2]

[1] PetroChina Hangzhou Research Institute of Geology, Hangzhou, China - zhangj_hz@petrochina.com.cn
[2] Key Laboratory of Carbonate Reservoir, CNPC, Hangzhou, China
[3] Department of Earth and Atmospheric Sciences, University of Alberta, Edmonton, Alberta, Canada T6G 2E3
[4] Qinghai Exploration Bureau of Environment Geology, Xining, 810007

The Dengying Formation (Sinian) is a thick succession (up to 1000m) formed largely of finely crystalline dolostones. In some parts of the formation (mainly in Member 2 and 4) there are large, hard, variably shaped botyroidal masses of dolomite, up to 75cm long, that are either parallel to bedding or cut across bedding. Cross-sections reveal isopachous bands of various type of dolomite that developed as cements. Irregular-shaped cavities are still present in the central parts of some of the larger bodies. Although previously referred to as grapestone or prehnite, the botryoidal dolostone developed as various types of cements progressively filled cavities that formed as a result of subterranean dissolution that was associated with karst development. After the surrounding micritic dolostone originally deposited from seawater, the fact that each phase of cement is crystallographically and geochemically distinct indicates that each fabric probably formed at different times under different conditions: (1) the dolomitized automicrite in some samples was the 1st stage cement, which formed within the cavities due to various physiochemical and possible biological influences; (2) the 2nd stage fibrous dolomite had absolute ordering crystal structure and near-ideal crystal cell parameter, which may have originated from marine waters and adjusted to be ordered during the later diagenesis; (3) the 3rd stage fine-to medium crystal dolomite including traces of fibrous crystals formed near-surface meteoric environment after tectonic uplift; (4) the 4th stage medium-coarse crystal dolomite primarily precipitated under the burial environment and filled the central parts of the cavities. Irrespective of the details, it is apparent that the Dengying Formation was subject to multiple phases of diagenesis that included karst development, precipitation of various cements, and multiple episodes of dolomitization. Except the paleokarstification, all of the other processes critically reduced the porosity of the petroleum reservoir that developed in the Dengying Formation. The paleokarstification which related to botryoidal dolostone has crucial importance to the Dengying Formation reservoir. The study of botryoidal dolostone in Sinian Dengying Formation conduces to understand the reservoir origin and evolvement, the origin of Dengying Formation dolostone, and the Pre-Cambrian petroleum development of Sichuan Basin.

Key Words: Origin of Botryoidal Dolostone, Dengying Formation, 4 Stages of Dolomite Cements, Ordering Degree, Crystal Cell Parameter

Paleocene Sequence Stratigraphy and Depositional Systems in the Lishui Sag, East China Sea Shelf Basin

Zhang, M.[1], Zhang, J.L.[1], Xu, F.[2], Li, J.Z.[1], Liu, J.S.[2], Hou, G.W.[2], Zhang, P.H.[1]

[1] College of Resources Science and Technology, Beijing Normal University, No.19 Xinjiekouwai Street, Haidian District, Beijing 100875, PR China - zhangming66260@mail.bnu.edu.cn
[2] Fa Xu~Shanghai Branch of CNOOC Ltd, No. 583 Lingling Street, Xuhui District, Shanghai 200030, PR China

The East China Sea Shelf Basin (ECSSB) is located on the continental shelf and is a typical back-arc rift basin, which is divided further by a series of sag and basement ridges. The Lishui Sag lay along the southwest margin of the ECSSB and is underlain by a productive, gas-prone, marine Paleocene section. In combination with tectono-stratigraphic analysis, sequence stratigraphy and seismic geomorphology, an integrated approach was performed to map high-frequency sequence and systems tracts by using well and three-dimensional seismic data.

Fault growth index was calculated to analyze differential activity on major faults. The growth faults with high indices have resulted in the formation of various types of transfer zones and structural slope-break zones, both of which played significant roles in the formation and distribution of sequence types and depositional systems. A relative sea level curve was reconstructed by employing accurate measurements of a series of sedimentary indicators that were obtained from seismic facies analysis, which reflect a combination of eustatic and tectonic forces. Different sequence stratigraphic models including depositional sequences I (containing lowstand, transgressive and highstand systems tract), depositional sequences IV (containing falling stage, lowstand, transgressive and highstand systems tract) and a transgressive–regressive sequence (containing transgressive and regressive systems tract) were used to fit the field observations from a particular tectonic setting since the tectonic setting and eustatic level changed in different sequences. Five third-order sequences and thirteen system tracts were recognized in the Paleocene.

The depositional facies in the lower E1m Formation and upper E1l Formation have been imaged on a series of strata slices. Five types of depositional systems were recognized based on the vertical change in lithology expressed in the core and log and the geometry change expressed on strata slices. These include 1. incised valley fills and aggradational fluvial deposits, 2. subaqueous fans on the middle shelf, 3. prograding shelf edge delta systems deposited in wave-dominated and tidal-dominated environments, 4. turbidity flows distributed on the continental shelf and 5. shoreface barrier bar and sand ridges that are parallel to the shoreline. This integrated analysis provides us with an opportunity to evaluate the exploration significance of these rocks in a stratigraphic framework and improve the accuracy of petroleum plays prediction.

Original types, sedimentation mechanism and distribution of favorable tight oil reservoirs--a case from the lacustrine tempestites and gravity flow deposits, Middle-Lower Jurassic in Central Sichuan Basin, China

Zhang, T.S.[1], Shou, J.F.[1], Wu, Y.Y.[1], Tao, S.Z.[1], Pang, Z.L.[1], Feng, R.C.[1]

[1] Research Institute of Petroleum Exploration & Development, CNPC, 100083-Beijing – China – zhangtianshu@petrochina.com.cn

Middle-Lower Jurassic in Central Sichuan Basin is one of the targets of tight oil exploration in China.The purpose of this study was to reveal the favorable facies and their distribution,and thus to predict the "sweet spots"of tight oil reservoirs. Detailed information has been acquired through analyses of sesmic profiles,cores,outcrops,well logs,thin sections of rocks,geochemical data,and paleontological,geomorphological data.The observation of outcrops and cores shows in Daanzhai Member, there are three types of tempestites,which are proximal,distal and transitional.Furthermore,the distribution of the tempestites is controlled by base-level changes and palaeogeomorphology.While in Lianggaoshan Formation,four types of gravity flows have been identified,which are debris flow,hyperconcentrated density flow,concentrated density flow, and turbidity current.These gravity flow deposits form two depositional models of slump-induced terbidite fan and flood-induced terbidite fan.It is indicated that palaeogeomorphology and provenance control the distribution of slump-induced terbidite fan.However, flood-induced terbidite fan is triggered by base-level changes and seasonal provenance.Based on the characteristics analyses microscopically, and the physical properties analyses of tempestites and gravity flow deposits,it is concluded that the transitional type of tempestites and flood-induced terbidite fan sands,which overlap and cover a huge area of gentle slopes, due to the base-level changes, are the "sweet spots"of tight oil reservoirs.

Keywords: Jurassic in Sichuan Basin, tight oil reservoir, tempestites, gravity flows

Elemental compositions and zircon U-Pb age patterns of Qiantang River incised valley fill: Implications for sediment provenance and coupling relationship with the Changjiang River incised valley

Zhang, X.[1], Lin, C.-H.[1], Wang, S.J.[1]

[1] School of Earth Sciences and Engineering, Nanjing University, 210046, Nanjing, Jiangsu, China – zhangxiananjing@163.com

The significant late Quaternary shallow-biogenic gas accumulation (<100 m) is found in the Qiantang River (QR) incised valley region, Zhejiang Province, with the tidal channel sand bodies of paleo-estuary facies serving as the main gas reservoirs. Thus there is a close relationship between the reservoir distribution and sedimentary facies, which in turn is controlled by the combination of tectonic, sea-level and sediment supply. Previous studies on the QR incised valley were mainly focused on the sedimentary facies and evolution, sequence stratigraphy, and characteristics of the shallow biogenic gas reservoirs, details on the provenance and its temporal and spatial evolution, however, remain unknown. This paper aims to identify the provenances and discuss the coupling relationship with the Changjiang River incised valley by using a combined zircon U-Pb ages and geochemical analyses of the QR incised valley fill based on the newly-drilled SE2 core sediments.

Geochemical proxies including fractionation parameters of rare earth elements and elemental ratios Cr/Th, Nb/Co and Th/Co, as well as zircon U-Pb age patterns suggest that fluvial and paleo-estuarine sediments have remarkably different provenances from the offshore shallow marine and present-day estuarine sediments in the QR incised valley. The data imply that the former was mainly derived from the QR drainage basin with more silicic sources and the zircon U-Pb age patterns characterized by four main peaks (99-251 Ma, 350-450 Ma, 600-1000 Ma, 1600-2100 Ma), whereas the latter was sourced from the Qiantang and Changjiang River drainage basins with more basic provenances including the Emeishan basalt province in the upper Changjiang valley and zircon U-Pb ages of six peak ages (< 25 Ma, 50-200 Ma, 200-400 Ma, 400-550 Ma, 800-1000 Ma, and 1800-2000 Ma).

We propose that the Changjiang River sediments began to significantly influence the QR incised valley fill during the offshore shallow marine period in the SE2 core area. In this period, the water overflowed and connected the Changjiang and QR incised valleys with sea level rise; the alongshore currents enhanced the exchange between the Qiantang and Changjiang River sediments. In addition, sediment supply and tidal current intensity are also of importance. During the paleo-estuary period, sediments on the continental shelf of the East China Sea were mainly composed of fine sand derived from the paleo-Changjiang River and paleo-QR, which were not easier to be transported to the landward part of the paleo-estuary. While, in the present-day estuary period, the surficial shelf deposits consist predominantly of fine-grained sediment (silt, clayey silt, and clay) supplied by the Changjiang River by means of an alongshore current, which along with the Changjiang River delta sediments deposited in the QR incised valley area were transported to the landward part of the modern estuary area by the tidal bore current resulted in the formation of huge silt bar.

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A method of particle size analysis of lacustrine siltstone and it's application identifying tempestites and beach-bars

Zhang, Y.[1], Wang, M.[2]

[1] 100083, No.29, Xuanyuan Road, Haidian District, Beijing, China - zyf@cugb.edu.cn
[2] 100083, No.20, Xuanyuan Road, Haidian District, Beijing, China.

Particle size analysis is a common method in sedimentology. For consolidated sedimentary rocks, traditional methods include thin-section observation and image analysis. In recent years, laser particle size analyzer has been widely used in particle size analysis of sedimentary rocks. Unlike the pretreatment of loose samples, consolidated rock samples must be crushed, added acid to wipe out cement, and washed. The washing step often results in a lost of the finest components (<63um). In consequence, the grain size results of siltstones containing particles of less than 63um are incorrect. This paper presents a siltstone sample pretreatment method which contains a step of washing with acid and centrifugation. Compared with traditional decantation methods, these results show that the median particle size reduced 33.2μm on average. Compared with precipitation methods which are commonly used for handling loose samples, the change of solid-liquid separation time is reduced from 12 hours to 10 minutes, while the average reduction of median particle size is about 15μm. The grain size value corresponded to the cumulative volume of 10%/90% reduced 2.5μm/20.3μm on average. The percentage of the clay component less than 2μm increased 2.88% on average. The fine particle (2-4μm) and silt component (4-63μm) increased 1.71% and 5.56% on average. We analyzed two similar lacustrine siltstones using this method corresponding to a tempestite and a beach bar which are difficult to identify in the Lijin sub-depression, Dongying depression, in the Shengli oilfield, China. The final grain-size probability plot of tempestite is the type of "one jump component and three suspension components". The content of suspension components can reach 80% to 90%. The beach bar is the type of "one jump component and two suspension components". The content of suspension components can reach 40% to 45%. They both have the characteristics of high slope meaning well sorted. But we can distinguish them based on the suspension sedimentary characteristics which were well preserved using the described sample pretreatment methodology.

Sedimentary facies analysis based on cluster of seismic attributes by fuzzy C-means algorithm

Zhang, Y.[1], Qiu, L.W.[1], Yan W.Y.[1]

[1] School of geosciences, China University of Petroleum, 266580-Qingdao, China - regogo@sina.com

With a long period of development, the research of sedimentary facies is being perfected day by day. The geological thought based on sedimentary system will provide us with correct ways to predict reservoirs. When it comes to the exploration of deep stratas and new areas, the accuracy of sedimentary facies analysis will be affected by the lack of efficient core, logging and drilling data. The seismic data, which is one of the most important basic data in the field of petroleum geology, contains abundant geological information. The seismic attribute technology can extract useful information hidden in the seismic data, so it is helpful to improve the accuracy of sedimentary facies recognition.

Based on the understanding above, this article comes up with a sedimentary analysis method based on cluster of seismic attributes by fuzzy C-means algorithm. By making full use of seismic data, this method can obtain seismic facies after seismic attributes extraction, attributes optimization and cluster of seismic attributes by fuzzy C-means algorithm, then the sedimentary types can be figured out by the analysis of other data, giving the seismic facies accurate sedimentary meaning, with which to analyze the distribution regularities of the sedimentary systems. There are two key points in the process of analyzing sedimentary facies by using the cluster of seismic attributes by fuzzy C-means algorithm. The first one is the optimization of seismic attributes. The correct selection of seismic attributes combination used in clustering determines the accuracy of sedimentary facies analysis directly. As a result, it is essential to consider fully of the sensitivity between seismic attributes and sand body, the correlation between seismic attributes and their clustering results. The second one is how to give accurate sedimentary meanings to different seismic facies clustered. By making full use of the cores, logging and seismic data, the types of sedimentary facies should be recognized firstly, then combined with other factors which control the sedimentation, the distribution of sedimentary facies can be analyzed by putting the single well sedimentary facies onto the clustered seismic attributes plan. This method also has certain deficiencies, the accuracy of the sedimentary facies recognized by seismic facies still needs to be improved. Usually, it can recognize the sub facies precisely, but it's relatively weak in microfacies recognition and fine sand body depiction. Now, this deficiency can be made up by other data and subjective analysis.

Following the thought of cluster of attributes controlling the plane, cores and logging data controlling the points, this method provides reliable basis for the sedimentary analysis in the deep stratas and new exploratory areas, and it is an objective and accurate new method.

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Groundwater as a graver: an insight of its effect on sediment transport and landscape evolution

Zhang, Y.[1], Slingerland, R.[1], Duffy, C.[1]

[1] Department of Civil and Environmental Engineering, Penn State University, University Park, PA 16802 – yzz130@psu.edu

Investigating the impacts of properties, distribution and evolution of regolith on river channel, fluid pathways, flow rate and sediment transport is essential to resource management and restoration efforts. Under relatively constant forcing, current landscape evolution models predict landscapes with specific concave-convex slopes, spatially variable regolith thicknesses, drainage densities and relief. But these models do not include realistic groundwater and overland flows, bedrock weathering, and channel-hillslope interactions. This study fully couples the hydrologic processes in the Penn State Integrated Hydrologic Model (PIHM) with hillslope and channel sediment transport processes to form a 3D hydrologic-morphodynamic model (LE-PIHM) for regolith formation and landscape evolution.

LE-PIHM computes the feedbacks among infiltration, recharge, groundwater and surface water runoff, creation of regolith and its erosion by streams, and downslope movement by tree-throw by using the semi-discrete finite volume strategy. Two scenarios are presented here to demonstrate the importance of this coupling: 1) a simulation of landscape evolution without groundwater flow, and 2) a simulation of landscape evolution fully coupled with groundwater flow. The comparison of the landforms at steady state indicates that the hill slope is steeper in the simulation with groundwater flow than the simulation without groundwater flow. In the simulation with groundwater, a stair pattern of the channel profile appears from the channel head to channel mouth compared with a much smoother channel profile in no groundwater case.

The Geochemical Characteristics of Saturated Hydrocarbons of Recent Sediment in Bohai Bay, China

Zhao, H.[1, 2], Zhang, M.[1, 2], Wu, X.[1]

[1] School of Earth Environment and Water Resources, Yangtze University, 430100, China - zhaodiana@qq.com
[2] The Key Laboratory of Exploration Technologies for Oil and Gas Resources, Ministry of Education, Yangtze University, 430100, China

More than 100 sediment samples collected from 2 areas in Bohai Bay, China. HGS samples were collected from costal shallow sea floor, while BC samples were collected from sea floor near open sea. In general, the bitumen content in BC samples is smaller than that in HGS samples. Bitumen in all BC samples is less than 200 μg/g sediment with most as 10 ~ 50μg/g sediment, while bitumen in all HGS samples is greater than 10μg/g sediment, with most as 50 ~ 100μg/g sediment. Moreover, there are 3 samples with bitumen more than 500μg/g sediment, indicating possible anthropogenic pollution.

Although the main component of saturated hydrocarbons is normal alkanes for all samples, there is obvious difference of their geochemical characteristics between HGS and BC samples. First of all, there is more UCM in the TIC of BC samples than HGS samples, indicating more complex origin and secondary alteration. For the concentration of individual normal alkanes in sea floor sediment, it is similar as smaller than 0.30311μg/g sediment for HGS samples and smaller than 0.69181 μg/g sediment for BC samples. For most samples, there are more normal alkanes in BC samples than in HGS samples. However, the distribution of normal alkanes is different for HGS samples and BC samples. There are strong odd-even predominance for HGS samples but little for BC samples, with OEP as 2.34 to 11.99 for HGS samples and as 0.49 to 5.17 for BC samples. Moreover, HGS is more abundant in long - chain n - alkanes ($>C_{25}$) and its TAR ratio is higher, indicating more land plant input. However, the range of Pr/Ph ratios of BC samples is more wider than HGS samples, indicating possible contamination.

Both of the abundance of biomarkers in recent sediment from HGS area and BC area is similar to each other and lower than n-alkanes, such as concentration of total hopanes lower than 0.16 μg/g sediment and total steranes lower than 0.07 μg/g sediment. However, The *m*/*z* 191 and *m*/*z* 127 mass chromatograms of HGS and BC samples are dramatic different. For most BC samples, pregnane is dominant in *m*/*z* 127 mass chromatograms and tricyclic terpanes is dominant in m/z 191 mass chromatograms, while norhopane, hopane, homohopanes, and regular steranes are dominant for HGS samples, indicating difference of biomarker origin. Moreover, BC samples is obviously richer in C_{27}ααα*R* sterane than HGS samples, suggesting there is more aquatic organic matter input in open sea sediment. Similar abundance of gammacerane of BC and HGS samples indicates similar salinity of marine environment. The biomarker maturity ratios, such as C_{29}ββ/(αα+ββ), C29S/(S+R), C32 S/(S+R), and Ts/Tm of BC samples are higher than what of HGS samples, indicating possible contribution of exogenous organic matter.

Based on the bitumen content, geochemical characteristics of n-alkanes and biomarkers, HGS and BC samples have different organic matter input and exogenous organic matter input. HGS samples, collected from coastal sea floor, is rich in bitumen and long chain n-alkanes with odd even predominance, with land plant as main organic matter input. BC samples, collected from sea floor near open sea, rich in pregnane and tricyclic Terpanes, C_{27}ααα*R* sterane, with aquatic organism as main input. Moreover, some HGS samples may have anthropogenic pollution and BC samples have exogenous organic matter, such as hydrocarbon seeps.

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Depositional Response to Lithospheric Thinning in Baiyun Sag, Northern South China Sea

Zhao, Y.[1], Ren, J.[1, 2], Yang, L.[1]

[1] China University of Geosiences, Wuhan, 430074, China – yhzhao1003@gmail.com
[2] Key Laboratory of Tectonics and Petroleum Resources of Ministry of Education, China University of Geosciences, Wuhan, 430074, China

The Baiyun sag, located at the transition from weakly thinned continental crust (~20 km) to hyper-extended crust (<5 km), is a typical basin in necking zone of the Northern South China Sea (NSCS). Due to the poor seismic data in the past, stratigraphic framework construction and related deep structure analysis are far from complete. This study identified two regional seismic-stratigraphic unconformities in rifting stage and subdivided the rifting strata into two stratigraphic units to highlight the process of the lithospheric thinning. In contrast to previous works on the marginal basins in NSCS, the end of the rifting stage in Baiyun sag can not be marked by the T70, known as "breakup unconformity" covering the whole distal domain; and this unconformity interface also does not comprise a complete seismic and stratigraphic expression of lithospheric thinning in SCS.

Researches in deep-offshore region of West Iberia and Newfoundland proposed a term of "Breakup Sequences" to clarify the depositional changes during the lithospheric thinning until its breakup. Nevertheless, the lithosphere in Baiyun sag had been extremely stretched; before the mantle exhumed, the stretching stopped and moved to south. In this paper, based on an integrated study on drill data and high quality three-dimension seismic data, four tectono-stratigraphic units (unit A, B, C and D) together with seven sequence boundaries have been recognized. Our work proposes that unit B represents the period of the lithospheric thinning in the second rifting stage, floored by the syn-detachment unconformity (SDU) and topped by the post-detachment unconformity (PDU). By naming the SDU and PDU, we emphasize that the deep-seated low angle faults with heaves on the order of 20-30 km exerted a strong influence on this well-defined stratigraphic sequence. Under the condition, the main characteristic of unit B is the wedge-shaped geometry of the reflections; the asymmetric half graben infilling is a south-ward thickening to the main detachment faults. Besides, unit A, controlled by high-angle normal faults in the first rifting stage, was strongly rotated while the detachment faulting. Unit C deposited in the transitional stage between the cessation of the deep faults activity and the opening of the SCS. And thermal subsidence mainly led to unit D formed during the post-rifting stage. Hence, combining with other boundaries identified in the basin filling and subsidence analysis, the Cenozoic tectonic evolution of the Baiyun sag could be divided into four stages: rifting stage including stretching(unit A), thinning(unit B), and rift-drift transition(unit C), fault-sag stage which corresponded to ridge jump, post-rifted thermal subsidence stage and post-rifted accelerating subsidence stage.

The result suggests the end of the rifting stage in Baiyun sag predates T70 (32Ma), the beginning of sea-floor spreading. It supports the theory of an ocean-ward migration of tectonic activity during the continental breakup and formation of rifted margins and provides an analogue for studying other basins with similar tectono-stratigraphic events.

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Seismic stratigraphic framework and architecture of the submarine canyon-fan system in deep-water Arakan area, the Bengal Fan

Zhao, Y.[1, 2], Wang, Y.[1, 2], Xu, S.[1, 2], Zhuo, H.[1, 2], Diao, W.[1, 2]

[1] State Key Laboratory of Petroleum Resources and Prospecting (China University of Petroleum, Beijing), Beijing, People's Republic of China - yanan_zhao@hotmail.com
[2] College of Geosciences, China University of Petroleum (Beijing), Beijing, People's Republic of China

Integrated 2D/3D seismic data were used to investigate the stratigraphic framework and seismic geomorphology of the shelf-edge and deep-water deposits in northeastern part of the Bengal Fan, the largest submarine fan in the world.

Based on seismic stratigraphy and facies, the canyon is characterized by important basal erosional surfaces (2nd-order sequence boundaries). Four 3rd-order sequences, including SQ1, SQ2, SQ3, and SQ4, can be recognized in the canyon fill. Each of these is bounded by regionally erosive surfaces (3rd-order sequence boundaries) and the internal architectures are characterized by the chaotic high amplitude reflections which are interpreted as basal lag sand covered by low-amplitude to transparent reflections which are interpreted as shale drape complexes. Thus, each 3rd-order sequence consists of a fining-upward succession.

The submarine fan is interpreted to exhibit vertical depositional cyclicity of distributary channel-lobe complexes (DCLCs), shale drape complexes (DCs), channel-levee complexes (CLCs) and mass transport complexes (MTCs) when the supply of sediment is adequate. DCLCs, characterized by erosive basal surface and moderate to high amplitude reflections, are sand-rich depositional units in the late forced regression to lowstand normal regression and the internal stacking patterns are controlled by high-frequency sea-level changes and autocyclicity. DCs are thin highly continuous seismic units and present the condensed-section deposits during periods of sediment starvation. CLCs, characterized by low-amplitude moderate continuous reflection and "gull-wing" cross-sectional profile, are mud-rich depositional units in the highstand systems tract. MTCs located in the flank of the "wing" of the leveed-channel are chaotic seismic facies because of the instability caused by the rapid deposition of CLCs. When the sediment supply is poor, the vertical depositional cyclicity changes to channel-lobe complexes (DCLCs) and shale drape complexes (DCs). These units represent an integral part of the sediment cyclicity.

In the early period of forced regression, sediments bypassed by gravity flows through the canyon as same as the erosive channels in the upper to middle fan, then consequently deposit in the lower fan. Correspondently, the identified stratigraphic surfaces from shelf-edge to deep-water contain the basal surface of forced regression (BSFR), regressive surface of canyon erosion regressive surface of channel erosion and the correlative conformity (CC*). Late forced regression and the transgression are major period for the deposition of the basin fan and canyon, respectively. Characterized by high amplitude and continuous seismic reflection, the identified maximum flooding surface (MFS) covered the whole depositional area. Subsequently, in highstand normal regression, the canyon fill was covered by the shelf-edge delta with convex-up shoreline trajectory. Meanwhile, the deep water would be dominated by muddy suspended sediments when the sediment supply is adequate. If on the contrary, only little sediments could be delivered to the deep-water.

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Sedimentary characteristics and origin of Lower Permian carbonate mud-mounds from Inner Mongolia

Zhen, Y.[1], Jianbo, L.[2]

[1] School of Earth and Space Sciences, Peking University, 100871-Beijing, China – yanzhen20071239@126.com
[2] School of Earth and Space Sciences, Peking University, 100871-Beijing, China

Carbonate mud mounds develop widely in the Paleozoic, reaching developmental summit during Carboniferous-Early Permian. Waulsortian-type mud-mounds were well-develop in Tournaisian and Viséan, whereas, biodetrital-microbial mud-mounds and algal mounds are the major types in Mississippian and Moscovian to Asselian respectively. Rare biodetrital-microbial or biodetrital mud-mounds have been reported from the Upper Carboniferous-Lower Permian around world. In addition, rare mud-mounds develop in middle latitude region during this period. This study is to describe sedimentary characteristics of Lower Permian biodetrital-microbial and biodetrital mud-mounds, located in Hinggan-Mongol Sea Trough, from Alxa Left Banner and Sonid Right Banner, Inner Mongolia, China, to shed highlight on the origin of mud, formation mechanism of mud-mounds, and controlling factors.

The mud-mounds in Inner Mongolia are commonly massive- to thick-bedded with syn-sedimentary relief, distinct from thin- to medium-bedded limestone of intermounds. Two types of mud-mounds are distinguished based on the scale and lithofacies. Type Ⅰ is 1-8 m in thickness and tens of meters in lateral extending, and composed of mudstone and skeletal wackestone with 15%-25% skeletal fragments. This type mud-mounds are commonly isolate or superposed vertically. Type Ⅱ is larger, 25 m in the maximum thickness and over 100 m in the maximum lateral extending, are composed mainly of skeletal wackestone (15%-30% foraminifer, echinoderm, and other skeletal fragments) and microbialite. This type mud-mounds are commonly superposed each other vertically. The intermounds sediments are characterized by skeletal wackestone and mudstone with rare sandstone and rudstone.

The mud-mounds in Inner Mongolia were deposited in a low-energy, deep-subtidal setting on a ramp or slope. Regional tectonic subsidence and sea-level change produced enough accommodation for the deposition of the mud-mounds. Allochthonous mud is dominant sediment for type Ⅰ and type Ⅱ mud-mounds, whereas, there is autochthonous mud from disintergration of phylliod algae in type Ⅰ mud-mounds and from cyanobacterial metabolism, lithification, and degradation in type Ⅱ mud-mounds. Besides physical processes dominating the formation of type Ⅰ mud-mounds, microbial activities played a marked role in forming, binding, and solidifying allochthonous mud in type Ⅱ mud-mounds.

The first report on the Lower Permian mud-mounds from Inner Mongolia enlarged the spectrum of mud-mounds in North China, even in the world. Comparing with contemporary algal mounds distributed mainly in low-latitude region, the mud-mounds in this study were controlled by paleoclimatic and tectonic conditions of the Hinggan-Mongol Sea Trough.

Seismic Facies and Depositional Evolution of the Late Miocene to Quaternary Submarine Canyon and Fan Systems on the Northern Continental Slope, South China Sea

Zhong, G.[1], Wang, L.[2], He, Y.[1], Kuang, Z.[2], Guo, Y.[2]

[1] State Key Laboratory of Marine Geology, Tongji University, 200092-Shanghai, China - gfz@tongji.edu.cn
[2] Guangzhou Marine Geological Survey, 510760-Guangzhou, China

High-resolution 2-D multichannel seismic data, combined with high-precision multibeam bathymetric map, were utilized to investigate the characteristics, distribution and evolution of submarine canyon and fan systems between the Dongsha Islands to the east and the Yitongansha shoal to the west on the northern continental slope, South China Sea. The seismic data consist of a 1 by 4 km grid with dominant frequencies between 40 and 50 Hz in the upper Miocene to Quaternary section, providing a maximum vertical resolution of *ca* 9-11 m. The multibeam bathymetric map reveals that a set of 19 downslope-extending submarine canyons are developed in the region. The canyons are kilometers apart, and separated by inter-canyon sedimentary ridges. Water depth ranges from 300 to 1600 m. Regional slope is 1.62° on average.

Ten types of seismic facies were recognized, which are discontinuous high-amplitude fill, onlapping fill, prograded fill, wavy onlapping fill, mounded divergent, sigmoid to oblique progradational, migrating wave, flat mounded or lenticular, parallel to subparallel, and chaotic facies, respectively. From seismic facies analysis, five depositional elements constituting the canyon-fan systems were identified, which are canyon fills, levees, lateral aggradation bodies, submarine landslides, and slope fans, respectively. The canyon fills are characterized by the discontinuous high-amplitude fill or onlapping fill facies, and laterally transition into or are downlapped by lateral aggradation bodies on canyon margins. Lying in the inter-canyon regions, the levee deposits are featured by mounded, triangular or irregular divergent facies with strata thinning away from the canyon fills. Submarine landslides, including sediment-wave-like creeps and slumps, are distributed around the canyon fills and on the levees or inter-canyon ridges. Downstream of the canyon mouths, slope fans have been constructed, which are characterized by flat mounded or lenticular seismic facies. Updip of the canyon-fan systems, prograding wedges featured by typical sigmoid to oblique progradational configuration are developed, which are interpreted as lowstand shelf-margin to upper slope deltaic deposits. Integrated analysis suggests that the canyon-fan systems were initiated from the late Miocene, and have experienced three major evolution stages, which are the late Miocene, Pliocene and Quaternary, respectively. Triggered by submarine landslides, the canyon-fan systems are presumed to be sculpted predominately by turbidity currents.

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Non-contemporary, normal Seawater for the formation of crystalline dolomite in the Lower Triassic Feixianguan Fm Reservoirs, NE Sichuan Basin, China

Zhong, Y.J.[1, 2], Huang, S.J.[1, 2], Huang, K.K.[1, 2], Feng, M.S.[1, 2]

[1] State Key Laboratory of Oil and Gas Reservoir Geology and Exploitation, Chengdu University of Technology, Sichuan, Chengdu 610059, China - 403034521@qq.com
[2] Institute of Sedimentary Geology, Chengdu University of Technology, Sichuan

In the past decade, a series of giant or large-scale gas fields have been discovered in the Lower Triassic Feixianguan Fm carbonate reservoirs in the northeastern Sichuan Basin. Most of them occur in the dolomite and the distribution of dolomite was concentrated in a semi-isolated carbonate platform which was separated to the east from a large, shallow, carbonate platform by the Kaijiang-Liangping sea trough. Relative to the dolomitized intervals, undolomitized equivalents in the fields to the west of the trough are commonly associated with a greatly decrease in reservoir productivity.

The Feixianguan Fm contain three textures of dolomite: 1)dolomitized mudstone and wackestone that consist of pervasive matrix-replacive, micritic dolomite replacing the lime, 2)very finely crystalline, grain-dominated dolomite with good fabric preservation, and 3)finely crystalline dolomite that partially to completely obliterated precursor limestone textures. These three dolomite types form the top, middle-upper part, and lower part of a shallowing-upwards carbonate cycle, respectively. Good reservoir units are mainly contained in the type 3 dolomite which has abundant intercrystalline porosity or/and some preserved primary intergranular porosity. In this study, 376 core samples from 8 wells have been investigated by thin-section petrography, cathodoluminescence, geochemistry to characterize the origin of the crystalline dolomites of Feixianguan Fm which exhibiting good reservoir quality.

Petrographically, this dolomite composed of small-sized crystals ranging from 0.1-0.3mm. At the scale of an individual crystal, they have only planar crystal boundaries and no measurable gaseous-liquid fluid inclusions can be found in them, indicating low temperature of dolomitization. The dolomite is characterized by very low Mn(14 to 30ppm) and Fe concentration (56 to 455ppm), and relatively high Sr contents (90 to 270 ppm), indicating the sea water or marine-derived fluid responsible for the formation of dolomites. The dolomite yielded $\delta^{18}O$ values ranging from -6.38‰ to -4.19‰ PDB. Assuming the temperature of 40-60℃, the $\delta^{18}O$ values of dolomitization fluid overlaps with Early Triassic sea-water values. T`he carbon isotope compositions of crystalline dolostones are consistent with the equivalent of contemporary sea water, indicating that diagenetic fluids were buffered by precursor carbonate rocks. 70% of crystalline dolostones have the $^{87}Sr/^{86}Sr$ ratios that range from 0.70745 to 0.70785, which is slightly enriched compared to strontium-isotope composition of seawater of Feixianguan time, but correspond to those of Jialingjiang time, another time of late Induan younger than Feixianguan one.

These data may suggest that the crystalline dolomites precipitated from normal marine waters percolating through the platform-margin at shallow-burial depths. Comparing the fields to the west of Kaijiang-Liangping sea trough, the carbonate platform to the east had steeper margin, and oolitic rock developed much earlier (1st to 2nd Member of Feixianguan Fm), so there is more enough time for dolomitizing before the decline and extinction of the platform. And the thick evaporite succession of 4th Member of Feixianguan Fm, which occurred only in the platform to the east of Kaijiang-Liangping sea trough may enhance the thermal convection of internal fluids in platform interior. All these factors made the region to the east of Kaijiang-Liangping Trough having significantly more potential of dolomitization.

Saddle dolomite cement in Upper Paleozoic clastic reservoir rocks from Ordos Basin and the effect on reservoir properties

Zhong, Y.J.[1, 2], Huang, S.J.[1, 2], Huang, K.K.[1, 2], Feng, M.S.[1, 2]

[1] State Key Laboratory of Oil and Gas Reservoir Geology and Exploitation, Chengdu University of Technology, Sichuan, Chengdu 610059, China - 403034521@qq.com
[2] Institute of Sedimentary Geology, Chengdu University of Technology, Sichuan, Chengdu 610059, China

Dolomite cements within the sandstones of the Upper Paleozoic in the Ordos Basin displays common saddle morphology features including wavy extinction. Those saddle dolomite cements are abundant in Benxi formation of Carboniferous, Taiyuan formation and the lower part of Shanxi Formation of Permian, which represent a marine environment. The study of the mineralogy, petrology and geochemical characteristics of these dolomites may be helpful to identify the origins of the saddle dolomite, as well as the relationship between saddle dolomite and reservoir quality. Petrographic, chemical composition, stable (O,C) and radiogenic (Sr) isotope, cathodoluminescence image and XRD data suggest that: 1)The high Fe content (13 to 23 mol% $FeCO_3$) suggest these dolomites can be defined as ankerites. 2) quartz overgrowths in the sandstones followed by saddle dolomite precipitation and the temperature of formation of saddle dolomite ranges from 80 to 120℃.3) the $\delta^{18}O$ composition of the precipitating fluid would have varied between -6 and +3‰ SMOW, which indicates that the fluids responsible for precipitating of the saddle dolomite were slightly more saline than the value of Permian seawater. 4) The carbon isotopic analyses of these dolomites revealed that the inorganic carbon in seawater is the dominant source in the formation of saddle dolomites 5). The radiogenic $^{87}Sr/^{86}Sr$ ratios for saddle dolomite（0.707116-0.725223）suggests the participation of some radiogenic Sr, which derived from fluids that had interacted with the clastic rock of the Upper Paleozoic itself. 6) If the saddle dolomite is not the abundant diagenetic constituent (about <5 bulk vol.%), it may have contributed to preservation of porosity and the formation of saddle dolomites is a retention process. Otherwise, the process of saddle dolomite development is a destructive process, thus its effect on reservoir quality may be negative.

Sequence stratigraphy and reservoir characteristics of a Cenozoic submarine fan from the Dongfang area of Yinggehai Basin, South China

Zhong, Z.[1], Wang, Z.[1], Liu, J.[1], He, X.[1], Liu, X.[1], Ren, J.[2]

[1] Zhanjiang Branch of CNOOC Ltd., Zhanjiang 524057, China - zhongzhh@cnooc.com.cn
[2] Institute of Resources, China University of Geosciences, Wuhan 430074, China

Since 2010, a large-scale submarine fan has been confirmed in an upper Miocene formation (T30-T31 sequence from 5.7 Ma to 6.98 Ma) in the Dongfang area in the center of Yinggehai Basin, South China, and it has been found to contain natural gas of 100 billion m^3 in reserves in the fan since then. This paper discusses sequence stratigraphy and reservoir characteristics of the fan, and inquires into its controlling factors of tectonic activity.
The research methods include 3-D seismic analysis, core description and imaging logging of several typical cases and laboratory analysis and testing of the samples from tens of wells around the Dongfang area, and basin structure analysis.
There is an obvious erosion surface above T31 boundary and the submarine fan is distributed over it. 6 fourth-order sequences were divided in T30-T31 sequence, among them the submarine fan developed in 1~ 3 sequences (LST). There are accordingly 6 cycles of change in planktonic foraminifera curve in high-precision in this sequence. The fan consists of lobes formed multi-times, and which summarize to simple fan lobes and complex ones, most of them in concave-downward channel types in seismic profile. The whole fan is about 1400 m^2 in measure of areal extent.
The sedimentary facies marker of the gravity flow has been found. Bouma units AB, BCE or AE are seen. Irregular mud gravels, mudstone fragments and cross-bedding are found in channel sandstones, with mud gravels of mixed sizes in alignment, and with charcoal and scour surfaces seen locally. C-M diagrams are of graded suspension characteristics. The components of the fan are mainly channel sandstones, natural levee and interchannel deposits.
The submarine fan is divided as Dongfang 13-1 zone in northeast and Dongfang 13-2 zone in southwest. Particles of Dongfang 13-1 zone are very fine sandstones, part silt, and those of Dongfang 13-2 zone are very fine sandstones and fine sandstones. The terrigenous component is mainly single crystal quartz. The clasts are mainly subangular to subrounded, medium to good sorting. The fan is about 16- 120 m thick in fine- very fine sandstones by wells statistics.
Particles are point or line contacted, as moderate to slight strong compaction. Primary intergranular pores are of 70% in relative content in Dongfang 13-2 zone, and those of 50% in Dongfang 13-1 zone. The cement in Dongfang 13-2 zone is mainly of carbonate which is only of 1.3% to 3.0%. It is middle cemented in Dongfang 13-1 zone, of 5.3% to 8.2% in cement content. The provenance of the fan is fairly good.
The reservoir in Dongfang 13-1 zone is mainly of mid porosity and low permeability. And it is mid porosity and mid permeability in Dongfang 13-2 zone. The buried depth of the sandstones is about 2628- 3352m, the physical properties of the reservoir have been protected by overpressure of pressure coefficient from 1.74 to 2.10.
To contrast the heavy mineral combination of Red River in the north and Changhua River in the northeast of the submarine fan, it is inferred that the Lam River west of the Dongfang area is the main provenance of the fan.
The Dongfang submarine fan is isolated on the view of macroscopic and marine mudstones are all around it. Some tectonic events induced jointly sediment distribution of Dongfang area at that time and promoted the forming of the Dongfang submarine fan. That is, the Red River Fault is transformed from left-lateral slip to right-lateral slip and the Khorat Uplift has been rotated clockwise up to 15^0 relative to the South China Sea at about 7 Ma.
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Fluvial processes and facies sequences in the shallow water GanJiang Delta, China

Zhou, C.M.[1, 2], Gao, Z.Y.[1, 2], Feng, J.R.[1, 2], Cui, J.G.[1, 2], Zhang, Y.Y.[2], Dong, W.T.[2], Zhou, H.Y.[2]

[1] State Key Laboratory of Enhanced Oil Recovery, Beijing 100083, China - zhouchuanmin@petrochina.com.cn
[2] Research Institute of Petroleum Exploration and Development, PetroChina, Beijing 100083, China

The GanJiang River has a long term average discharge of 275 m^3/sec, with flood peaks in the range of 3086 to 6000 m^3/sec. GanJiang Delta is located in the southwest of the Poyang Lake where Ganjiang inflows. This paper focuses on the deposition of the Ganjiang River Delta by using remote sensing, ground-penetrating radar survey, trenching and borehole drilling. The result shows that the delta plain is mainly characterized by channels, slip face bounded bars, vegetated sand flats, vegetated islands and floodplains. The bedforms are dominated by ripples formed at the channel margin and interdistributary bays. The delta comprises an extensive floodplain with several trunk channels and multiple distributary channels because of the very gentle basement slope which is less than 0.0002(0.2m/km). Channels are 0.5-8 m deep, up to 2000 m wide and vegetated islands are up to 10 km long. Long straight-crested cross-channel bars form at the areas of flow expansion. During the falling stage, a small part of the crest of the cross-channel bar may be emergent, and acts as a nucleus for downstream, upstream, and laterally growth of a new vegetated sand flat. Cross-channel bars develop large sets of planar tabular cross beddings. Sand flats that grow from nucleuses on cross-channel bars are mostly composed of smaller planar tabular sets, with some parallel lamination and ripple cross-lamination. Almost all sand flats have been vegetated both subaerial and subaqueous areas. Coarse and medium sand are rare in channel axis because sediments with mean grain size of 6~7Φ are too fine to deposit with an average flow velocity about 0.5m/sec. Shell-bearing find grain sand could only deposit around the channel bars or the channel margin. A typical facies sequence of vegetated sand flats would start with elder consolidated lacustrine mud underlying, continue with a large planar tabular set (cross-channel bar), be overlain by a complex association which is characteristics with small planar tabular cross-beds, ripple cross-lamination, and shell interbeds, and then pass upwards into entirely bioturbated silty and muddy vegetated soil. During the abandoned channel filling, ripple cross-lamination and thin clay layers may develop. Faces sequence of the vegetated islands and the floodplains are similar with the vegetated sand flats. The differences between them are the thicknesses of the overlain silty and muddy vegetated soil. In the delta plains, the thickness of these sequences varies from meters to centimeters from upstream to downstream.

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Lithofacies paleogeographic evolution of the Middle-Upper Yangtze region in Llandoverian time and its restriction on sedimentology of source-reservoir-cap rocks

Zhou, K.[1], Wei, L.[1], Mou, C.[1], Ge, X.[1]

[1] Key Laboratory for Sedimentary Basin and Oil and Gas Resources, MLR, 610082 - Chengdu, China – zhouken_53@126.com

Through reconstruction of lithofacies paleogeography at corresponding scales, the comprehensive analysis for tectono-sedimentary evolution and sedimentology of source-reservoir-cap rocks of a basin or a key area is one of the most important preliminary works for oil-gas exploration. Based on governing factors such as local tectonic movements, global sea-level change and inherited basin structures, the study on lithofacies paleogeography in the Middle-Upper Yangtze region of South China in Llandoverian time (the Early Silurian) was carried out. In the latest stratigraphic subdivision, the lithofacies paleogeography for three successive stages (Rhuddanian, Aeronian and Telychian) is reconstructed. Then on this basis, the time-space distribution and sedimentology of source-reservoir-cap rocks are summarized. The results indicated that the early Rhuddanian inherited and developed the layout of semi-confinement stagnant basin resulting from tectonic compression started in the Late Ordovician. Then widely-covered organic-rich muddy shales occured in a global-scale transgression after the Hirnantian glaciation and subsequent relatively slow regression. Moreover, the sagged areas, which formed by inherited structures, tectonic tilting and the plugging effect of a rigid continental nucleus, act as sedimentary centers of organic-rich muddy shale. At the stage of intermittent tectonic compression during the Aeronian, a mix-sedimented “carbonate ramp”, which is different from “rimmed carbonate platform”, formed in the promotion of such factors as global sea-level drop and warm-humid climate. The reef-bank type carbonate reservoir rocks occur in high-energy subtidal environments within inner ramp. In the subsequent Telychian stage, intensified tectonic compression terminated the carbonate environments and resulted in regression and overall uplifting of the basin. The eastern region is dominated by shoreface and tide-dominated delta where sand barrier type reservoir rocks occurred. The widespread muddy sediments in the late Telychian could be cap rocks for underlying potential oil-bearing layers.

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Typhoon sedimentary records in a coastal lagoon in southeastern Hainan Island, southern China

Zhou, L.[1], Gao, S.[1], Jia, P.H.[1], Yin, Y.[1], Ge, C.D.[1], Wang, D.D.[1], Zhao, Y.Y.[1]

[1] Ministry of Education Key Laboratory for Coast and Island Development, Nanjing University, 210023, Nanjing, Jiangsu, China - geozhouliang@126.com

Hainan Island is frequently hit by tropical storms in the western Pacific Ocean. The most destructive typhoon that directly striking the Hainan Island since 1949 was Marge in September 1973, with a wind speed of up to 80 m/s. The typhoon events would influence the sedimentary environment, coastal morphology, ecosystems and coastal engineering. A thorough understanding of how the frequency and intensity of past tropical cyclones changes is essential for predicting future changes and making appropriate management decisions. One of the approaches to the reconstruction of typhoon history is to analyze the geological record. During a typhoon event, the normal lagoon sequences may be disturbed by enhanced typhoon-generated waves and storm surges. The sedimentary layers representing such disturbances can be used to reconstruct the typhoon-induced storm events. With rare tsunami events and numerous coastal lagoons, Hainan Island in southern China is a suitable area to study sedimentation during typhoon events.

In this study, sediment cores were taken from the Xincun and Li'an Lagoons located in southeastern Hainan Island. A set of storm-induced deposits were identified on the basis of detailed core descriptions, loss-on-ignition (LOI) and grain size analysis. These cores show several sand layers with anomalous grain size variations. These layers are characterized by shell fragments, low organic content and relative light colors grading from greyish white to greyish. All sand layers in XC-06 and LA-02 contain dominated high peaks in their coarser grain part of grain-size distribution that was very different from their surface samples. These sand layers were formed under the condition of high-velocity flow during a high energy event.

The shell fragment layers, mixed with coral blocks and gravel/sand, were identified in the cores. Coral blocks (mainly broken debris of *Acropora sp.*) have a high roundness value with some small angular or sub-angular clasts. They have a sharp upper boundary with overlying sediments consisting of well-sorted sand, absence of organic material. LOI analysis shows a rapid decrease in organic matter content across this contact. The content of coarse particles (i.e., grain size$>$ 125 μm) of the shell fragment layers show grain size peaks in the sediment column. As such, the shell-rich layers were deposited in response to high-velocity flow, in the form of washover sediment, in a high-energy environment.

Furthermore, these cores were dated by the methods of ^{210}Pb and AMS^{14}C. The dating results suggest that sediment accumulation in the lagoon was continuous over the last 350 years, with deposition rates varying from 4.95 to 12.6 mm/yr. We demonstrate here that distinct records of major typhoon events during the past 350 years can be obtained from coastal lagoon strata.

Keywords: Paleo-storms; typhoon-induced deposits; coastal lagoon; Hainan Island (southern China)

Salt-marsh deposition rate mapping based on morphological proxy and expansion process of *Spartina alterniflora* plants: A case study from Jiangsu coast, eastern China

Zhu, D.[1], Gao, S.[1]

[1] Key Laboratory of Ministry of Education for Coast and Island Development, Nanjing University, 210023, Nanjing, Jiangsu, China - zhudonglw@126.com

Based on field investigations on the Jiangsu coast, eastern China, a proxy derived from the morphology of *Spartina alterniflora* plants can be used to estimate deposition rates of salt-marshes associated with a tidal flat environment. This method is based on the assumptions that the root and stem system of the plant, below the bed surface, is quite stable for living plants, and that buried, old plants can be found in the strata. For such an analysis, the colonization time of *S. alterniflora* must be known; if the timing for any site within the salt-marsh can be determined, then it is feasible to apply this technique to mapping the deposition rate over a large area. In the present study, the position of the *S. alterniflora* front for different years was detected using remote sensing imageries, then the time series of *S. alterniflora* covered areas was obtained. Thus, the age of the old plants in the sediment layers was determined and the deposition rate was estimated. Based on fifteen phases of satellite imageries from 2000 to 2014 and field observation data, the salt-marshes on the central Jiangsu coast are characterized by a deposition rate of 1-5 cm/yr. Where short sediment cores were available, ^{210}Pb measurements were carried out to obtain independent estimates. The results from the two methods were generally consistent. This preliminary study shows that the methodology proposed has a potential for deposition rate mapping over a large area.

Key words: *Spartina alterniflora*; root-stem morphology; remote sensing; expansion process ; salt-marsh sedimentation; eastern China coast

Paleoclimate Characteristics and its control on sediments in the Late Triassic Xujiahe Formation, Sichuan Basin

Zhu, R.[1], Bai, B.[1], Li, T.[1], Luo, Z.[1], Su, L.[1]

[1] State Key Laboratory of Enhanced Oil Recovery (Research Institute of Petroleum Exploration & Development), Beijing 100083, China - zrk@petrochina.com.cn

Sichuan basin is one of the compressional petroleum basins located in central-western China, hosting a great number of hydrocarbon fields, among which the late Triassic Xujiahe formation possesses 3.5 Tcf. The Xujiahe formation contains black shales, mudstone, carbonaceous mudstone with some coal beds and marine to non-marine transitional light gray thick to massive feldspar-quartz-sandstone interbedded with siltstones. In an ascending order, the Xujiahe formation is divided into six lithologic members from Xu1 to Xu6. The three members including Xu1, Xu3 and Xu5 consist mainly of mudstone, while the other members consist of sandstones. Based on the analysis of samples in six outcrop profiles and the application of multiple methods such as sporopollen, clay minerals composition and major-minor elements, the late Triassic climate has been reconstructed as with humid and warm, tropical to subtropical. Thus, the Xu1 member corresponds to a tropical coast climate; the Xu 2 member to a dry and mild climate; the Xu3 member turns into humid and warm palustrine environment; the climate of Xu4 member becomes dry and mild; Xu5 member appears to be the hottest and wettest tropical-subtropical climate; and mild and dry climate dominates the Xu6. The alternation of hot and cold, dry and wet climate evolution leads to a sediment distribution pattern of the Xujiahe formation of interbedded sandstone and mudstone.

1) Sporopollen fossils are mainly fern spores, with dominant Dipteridaceae (especially *Dictyophyllidites*). Meanwhile, others are also observed, such as *Cyathidites, Osmundacidites, Marattisporites, Cycadopites,* featuring *Dictyophyllidite-Concavisporites-Cycadopites* sporopollen associations. Modern plants-*Dipteris* with close relationship to *Dipteridaceae* distribute in humid-warm tropical, subtropical areas such as South China, western-southern parts of China, and Himalayas mountain areas. It indicates a warm-hot and humid climate. The Xu 2, Xu4 and Xu6 members contain gymnosperm and fern sporopollen, indicating dry and hot climate, while the Xu1, Xu3 and Xu6 members suggest relatively warm and humid climate.

2) The distribution of minor elements suggests relatively warm and humid conditions for Xu1, Xu3 and Xu5 members, and a comparatively hot and dry environment for the Xu2, Xu4 and Xu 6 members. CaO/MgO ratio and B also indicate the temperature gradually increases during the deposition of the Xu1 member reaching a maximun during the Xu5 member deposition and decreasing significantly during the Xu6 member deposition. At the final-stage of the late Triassic, the dominant climate of the region was warm and humid with strong reductive environment, with V/Ni>1. The sedimentary environment for the Xu1, Xu3 and Xu5 members is relatively warm and humid and Xu1 has the strongest reductive intensity. Xu2, Xu4 and Xu6 members all form in reductive environment. Xu1, Xu3 and Xu5 members have source-rock developing environment.

3) The type, content and association of clay minerals show the inversion of paleotemperature and paleohumidity as shown ba the ratio of kaolite to illite content in all members of the Xujiahe formation.
These results indicate that the dominant climatic conditions during the different time periods have controlled the development of the source and reservoir rocks within the Xujiahe formation.

Sedimentary characteristics and seismic geomorphologic responses of shallow-water delta of Qingshankou Formation in Qijia area, Songliao Basin, China

Zhu, X.[1], Zhao, D.[1] Zeng, H.[2], Sun, Y.[1], Zhu, S.[1]

[1] China University of Petroleum (Beijing), 102249-Beijing, China - xmzhu@cup.edu.cn
[2] Bureau of Economic Geology, Jackson School of Geosciences, The University of Texas at Austin, 78712-Texas, USA

Under the guide of modern sedimentology and seismic geomorphology, combined with the comprehensive analysis of core data from more than ten wells and geophysical data, the Qingshankou Formation is divided into 3 long-term cycles and 6 medium-term cycles in Qijia area, Songliao Basin. The 3 Long-term cycles, SQ1, SQ2 and SQ3 correspond to the members,Qing I, Qing Ⅱ and Qing Ⅲ, and the time scale of a medium-term cycle is about 0.5~1.5Ma, with thickness ranging from 45m to 116m. Shallow-water delta which consists of high-maturity fine-grained sandstone is mainly developed in Qingshankou Formation, and erosion surfaces reflecting strong flow action, parallel bedding and long-scale cross-bedding are well developed. Distributary channel sandstone is well developed in the shallow-water delta sedimentary system, with single channel thickness about several meters. The accumulative thickness of distributary channels can reach to tens of meters with a large distributing area, extending to the center of a lacustrine basin over tens of kilometers wide. The development of subaqueous distributary channel of shallow-water delta is closely related to the base level (lake level) change. In the early stage of rising semi-cycle and the late stage of falling semi-cycle, the fluviation is significant and the channel sandstone which can extend towards the center of the lacustrine basin more than 50 kilometers is well developed, with large accumulative thickness of compound sandbody (17-28m) and high sandstone to strata ratio (78%~88%). In the late stage of rising semi-cycle and the early stage of falling semi-cycle, the lake level rises and the fluviation becomes weak, resulting in the extending distance of distributary channel, less than 30 kilometers, with small accumulative thickness of compound sandbody (5-12m) and low sandstone to strata ratio (22%~45%). The delta front can be divided into an inner front and outer front. The subaqueous distributary channel in the inner front has good continuity and extends further, whereas the subaqueous distributary channel in the outer front has poor continuity and a sheet sand is well developed. Two typical sedimentary models of shallow-water delta are established in the Qijia area, Songliao Basin: delta plain well-developed in humid climate, and delta front well-developed in arid climate. Stratal slices from seismic geomorphology are applied to display the branch-like sandstone dispersal pattern of shallow-water delta and the characteristics of wide distribution. This study also points out that the delta front channel sandstone which is near to oil source and faults would be the favorable exploration targets.

Keywords: sequence framework, sedimentary characteristics, shallow delta, seismic geomorphology, Qingshankou Formation, Cretaceous, Songliao Basin, China

Sedimentary characteristics of miniature glutenite on southern steep slope zone of Biyang rift basin, East China

Zhu, Y.[1, 2, 3, 4], Qiang, K.S.[5], Li, D.H.[1, 2, 3, 4], Zhou, Z.G.[4], Chen, C.G.[1, 2, 3, 4], Yu, H.[4]

[1] Key Laboratory for Shale Gas Resource & Exploration, Ministry of Land and Resources, Chongqing Institute of Geology and Mineral Resources, 400042 Chongqing, China - fishzy68@163.com
[2] Chongqing Engineering Research Center for Shale Gas Resource & Exploration, Chongqing Institute of Geology and Mineral Resources, 400042 Chongqing, China
[3] Chongqing Shale Gas Research Center of State Key Laboratory of Petroleum Resource and Prospecting, 400042 Chongqing, China
[4] Schlumberger Zhongyu Shale Gas Technical Services (Chongqing) Co., Ltd., 400043 Chongqing, China
[5] Institute of Petroleum Exploration and Development, Henan Oilfield of Sinopec, Zhengzhou, 450016 Henan, China

The Biyang rift basin is one of Meso- Cenozoic minor faulted, hydrocarbon-rich lake basins in East China. In this paper, our studies focus on the southern steep slope zone of Biyang rift basin, and make use of seismic, logging, and core data to establish isochronous stratigraphic framework and to reconstruct medium-term cycles of rising and falling semi-cycles. The rising and falling semi-cycles are symmetric. The former controls the retrogradation of sand body, as vertical sedimentary sequence of underwater distributary channel (near source) →underwater distributary channel (far source) →mouth bar→sheet sand. The latter controls the progradation of sand body, in contrast to the sedimentary sequence of the former, and the intermediate flooding surface is thick dark mudstone.

Seismic data, stratigraphic sections and microfacies analysis indicate a sedimentary system of steep fan delta area-turbidite deposit (SDA-TD) that developed in the study area from provenance to central basin. Plain facies were developed in a narrow range, in lenticular structure and banded distribution. Front facies were developed in a wide range, with underwater distributary channel, mouth bar and sheet sand in layered structure and planar distribution. Slump turbidite fan was developed in a limited range, only distributed in the periphery of the larger fan delta front, in layered structure and lobal distribution. The activities of boundary faults and structures were the most important factor controlling the formation and distribution of fan body, and the activity intensity determined the size of fan body. The position of adjustment transformation zone controlled the channel of supply from provenance to fan body, thus further affecting the ancient landscape features and forming a "ditch and fan" sedimentary pattern.

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The sedimentary evolution characteristics of continental shelf facies black shale of Lower Cambrian Shuijingtuo Formation in northeast of Chongqing, SW China

Zhu, Y.[1, 2, 3, 4], Qiang, K.[5], Li, D.[1, 2, 3, 4], Zhou, Z.[4], Chen, C.[1, 2, 3, 4], Yu, H.[4]

[1] Key Laboratory for Shale Gas Resource & Exploration, Ministry of Land and Resources, Chongqing Institute of Geology and Mineral Resources, 400042 Chongqing, China - fishzy68@163.com
[2] Chongqing Engineering Research Center for Shale Gas Resource & Exploration, Chongqing Institute of Geology and Mineral Resources, 400042 Chongqing, China
[3] Chongqing Shale Gas Research Center of State Key Laboratory of Petroleum Resource and Prospecting, 400042 Chongqing, China
[4] Schlumberger Zhongyu Shale Gas Technical Services (Chongqing) Co., Ltd., 400043 Chongqing, China
[5] Institute of Petroleum Exploration and Development, Henan Oilfield of Sinopec, Zhengzhou, 450016 Henan, China

The northeast area of Chongqing is located in the joint part of Sichuan Mesozoic foreland basin and thrust-fold belt at the southern edge of Yangtze landmass, structurally forming E-W-trending dense, roughly parallel and asymmetric anticline and syncline. Lower Cambrian Shuijingtuo Formation is a good hydrocarbon source rock deposited in a stagnant marine basin setting which formed at the edge of continent, intercratonic depression and foreland flexure. Because of deep buried depth, varying lithofacies associations and lack of seismic and drilling data, we can't get deeper understanding about the sedimentary evolution characteristics and it may affect the next exploration of shale gas.

In this paper, strata combination, lithology, fossil, marker bed, formation thickness and geochemical indexes are used to divide Shuijingtuo shale into two third-order sequences (SQ1 and SQ2), and each sequence is further divided into two system tracts, TST and HST. Combining well tie profiles, black shale distribution and geochemical elements to analyzing sedimentary facies and the distribution, Lower Cambrian Shuijingtuo Formation are identified: neritic deep shelf deposit, shallow shelf deposit and arenaceous shelf deposit.

The deep continental shelf setting is a hydrostatic strong reducing environment and favorable for preservation of organic matter. Mainly developed in middle – early Shuijingtuo, the area had experienced a large-scale transgression since Sinian Period, sea level rising. Experiencing deposition, burial metamorphism, compaction and diagenesis, the suspended sediment developed a set of black organic-rich shale, mainly including black carbonaceous shale and calcareous shale with a high organic content. Rock composition are mainly composed of quartz and clay minerals, pyrite is the most common, mainly developing massive bedding and horizontal bedding. In late Shuijingtuo, Shallow shelf deposit and arenaceous shelf deposit are both in weak redox environment, usually forming gray-light grey silty shale and siliceous shale. Therefore, Lower Cambrian Shuijingtuo shale is controlled by shelf deposit system, forming in continental shelf setting where deposition rate is fast, geological condition is blocked and organic matter is prolific.

After the comprehensive research and analysis, the following conclusion are made: north and east are two black shale depocenters with EN-WS, stable and continuous distribution. The thickness is between 500m and 700m, mainly above 600m. Continental shelf facies black shale of Lower Cambrian Shuijingtuo Formation is good for shale gas development and has the characteristics of high TOC, fine grain, deep colour, pure lithology and large thickness. Therefore, there is a wide prospect for shale gas exploration in this area.

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A new tool for studying annually laminated sediments – the online Varve Image Library

Zolitschka, B.[1], Francus, P.[2, 3], Ojala, A.[4], Schimmelmann, A.[5], Telepski, C.[6]

[1] Univ. of Bremen, Germany - zoli@uni-bremen.de
[2] Institut National de la Recherche Scientifique, Québec, Canada
[3] GEOTOP-UQAM-McGill, Montréal, Québec, Canada
[4] Geological Survey of Finland, Espoo, Finland
[5] Indiana University, Bloomington, Indiana, U.S.A.
[6] PAGES, Berne, Switzerland

Annually laminated (i.e. varved) sediment sequences are important natural archives of paleoenvironmental conditions that offer accurate "internal" age spacing in calendar years, exceptional high (up to seasonal) temporal resolution and the possibility to calculate sedimentation flux rates. The new website displays images of various types of varves and sedimentary components based on contributions from the "varve community". It exemplifies the compositional and structural diversity of varved sedimentary sequences and summarizes the existing knowledge about varves with images.

Although the scientific community has come to appreciate the paleoenvironmental value provided by annually laminated sediments, both marine and lacustrine, there remains a widespread lack of awareness about the need to carefully document and prove the truly varved character of laminated sediments before exploiting lamina counts for geochronological purposes and paleoenvironmental interpretations through time. A misconception between varved versus finely laminated sediments might partially originate from the history of the expression "varve", a term that was introduced by the Swedish geologist De Geer (1912) to describe annually laminated and minerogenic proglacial lake sediments of Sweden. Later on, the term "varve" was extended to other lacustrine as well as marine sediment types with preserved annual successions and seasonal sub-laminae. The large diversity of sediments featuring a "varved" character sometimes led to the misconception that most, if not all finely laminated sediments must be varved, which is of course not always the case. It is the specific aim of this Varve Image Library to provide exemplary visual information about annually laminated sediments to assist, train and guide researchers in the critical judgement of the relative timing of (sub)laminae and constraining the geochronological potential of newly recovered laminated sedimentary sequences. The Varve Image Library also intends to disseminate existing image information about varves and to facilitate efforts of students and scientists to get acquainted with the challenging topic of finely laminated sedimentary structures. Additionally, examples of tree rings are documented, as this entirely biological natural archive is comparable with the structure of annual sedimentary laminae. Each image of this data base is accompanied by metadata which include information about the study site, the image itself and references with DOI links of the publications reporting the varved record.

Hydrological variations and Southern Hemispheric Westerlies (SHW) in Argentina – the record of the ICDP project PASADO

Zolitschka, B.[1], Gebhardt, C.[2], Gogorza, C.S.G.[3], Hahn, A.[1], Hoelzl, S.[4, 5], Irurzun, M.A.[3], Kliem, P.[1], Mayr, C.[5, 6], Oehlerich, M.[5], Ohlendorf, C.[1]

[1] University of Bremen, Germany - zoli@uni-bremen.de
[2] Alfred Wegener Institute for Polar and Marine Research, Bremerhaven, Germany
[3] Centro de Investigaciones en Física e Ingeniería del Centro de la Provincia de Buenos Aires (CIFICEN-CONICET), Tandil, Argentina
[4] Rieskrater-Museum, Nördlingen, Germany
[5] University of Munich, Germany
[6] University of Erlangen-Nuremberg, Germany

Semiarid conditions are prevailing at the site of Laguna Potrok Aike (52°S, 70°W; 116 m asl; diameter: 3.5 km, water-depth: 100 m), a currently terminal maar lake in the extra-Andean steppe of Patagonia. Depositional processes of various autochthonous sedimentary compounds are controlled by the evaporation/precipitation ratio (E/P), which is a direct function of climate. E/P is governed by precipitation-controlled runoff as well as by temperature- and wind-controlled evaporation. Stratigraphic and chronological correlation of the 106 m composite profile from the central deep basin with sediment cores from littoral zones and outcrops in the catchment area allows to reconstruct hydrological fluctuations during the last 51 ka providing evidence for lake-level variations in the range of >50 m.

During the Late Pleistocene, sediment deposition was influenced by comparatively high inflow and little evaporation with a responding high lake level. During deglaciation and in particular during the Late Glacial (ca. 17-12 kcal BP) a lake-level lowering (higher E/P) indicates warming and/or migration of the SHW to more southern latitudes, whereas in the early Holocene a higher lake level re-established. Since 9.3 kcal BP intense carbonate precipitation together with salinity-indicating diatoms document that subsaline lacustrine conditions prevailed until today with one interruption during the neoglacial “Little Ice Age” (LIA).

For long-term hydrological variability several factors are important: 1) changes in runoff due to permafrost sealing of the ground during the last Glacial period, 2) variations in precipitation and wind-induced evaporation linked to changes in intensity and position of the SHW and 3) the temperature increase from the Glacial to the Holocene. Based on multiproxy evidence a lake-level record for the last 51 ka was reconstructed and interpreted as the result of the SHW being in a more northerly position during the Glacial period followed by a southward movement. At 9.3 kcal BP the SHW intensified in the study area and caused a pronounced negative water balance with a lake-level lowering of more than 50 m compared to glacial conditions. Two millennia later either SHW intensity or its position changed and the lake level started to rise in a step-like manner to its Holocene maximum during the LIA. Since the 20th century strengthening of SHW increased the evaporative stress resulting again in a more negative water balance.

Comparison of our data with other Patagonian records indicates that the core of the SHW shifted southward and established at 52°S around 9.3 kcal BP. As the late Holocene lake-level high-stand during the LIA is documented from various sites in Patagonia, it appears to have occurred synchronously over a large latitudinal range and thus seems to be related to a SHW weakening instead of a latitudinal shift of the SHW belt. To improve our understanding of past hydrological variability, new isotopic ($^{87}Sr/^{86}Sr$) and rock-magnetic data (ARM/SIRM ratio) will be presented and compared to geochemical and paleobiological evidences. Both parameters are not related to changes in sediment accumulation rates and thus provide an independent and continuous record of eolian dust and runoff conditions.

Feeder pipes – Expression of the uppermost plumbing system in Oligocene methane-seep deposits, Washington State, USA

Zwicker, J.[1], Smrzka, D.[1], Gier, S.[1], Goedert, J.L.[2], Peckmann, J.[1]

[1] Department of Geodynamics and Sedimentology, Center for Earth Sciences, University of Vienna, 1090 Vienna, Austria – jennifer.zwicker@univie.ac.at
[2] Burke Museum of Natural History and Culture, University of Washington, Seattle, Washington 98195, USA

Plumbing systems of methane seeps are complex pathways along which hydrocarbon-rich fluids migrate upward through the marine sedimentary column. Seeps commonly maintain fluid flow over long periods of time, providing a steady supply of methane to shallow sediments and the water column. At greater sediment depths, fluid transport is facilitated by faults and conduits, which enable migration of fluids sourced from deep hydrocarbon reservoirs. In the shallow subsurface, plumbing systems may become successively filled by authigenic carbonates, whose precipitation is partly triggered by sulfate-dependent anaerobic oxidation of methane (AOM).

To expand our knowledge of the uppermost plumbing network of ancient seeps, this work investigates fluid conduits that were mineralized by a distinct succession of authigenic mineral phases. These mineralized conduits, which occur below an Oligocene seep deposit in the Lincoln Creek Formation in Washington State, are here referred to as feeder pipes. The concentrically-zoned feeder pipes are 2 to 3 cm in diameter. The mineral phase that formed first is matrix micrite, making up the outer part of pipes. Toward the center, pipes are filled by clear, banded and botryoidal aragonite cement, which is intercalated with yellow aragonite cement. The innermost portions of the pipes are filled by either pipe-filling micrite, microspar, or brownish calcite. The observed paragenetic sequences archive successions of various biogeochemical processes. Clear and yellow aragonite cements are distinctly depleted in ^{13}C, revealing that their formation was favored by AOM. In contrast, later phases including brownish calcite and microspar are enriched in ^{13}C, pointing to precipitation from fluids affected by methanogenesis. Their size and morphology indicate that the pipes were initially produced by seep-dwelling, burrowing organisms. The burrows subsequently acted as preferred fluid pathways. Possible producers of the burrows include various bivalves and callianassid decapods. Based on petrography and stable isotopes patterns, we conclude that the pipes facilitated seepage of methane-rich fluids to the sediment-water interface.