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PALAEOWORLD online submission:
http://ees.elsevier.com/palwot/

PALAEOWORLD full-text (Volume 15 – ) available at:
http://www.sciencedirect.com/science/journal/1871174X
LATE DEVONIAN TO EARLY CARBONIFEROUS SEQUENCE STRATIGRAPHY OF THE TARIM BASIN, XINJIANG, NW CHINA

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Nanjing Institute of Geology and Palaeontology, Academia Sinica, Nanjing 210008

Abstract: In order to improve the basin analysis and petroleum exploration of the Tarim Basin, this paper concentrates on the Late Devonian to Early Carboniferous sequence stratigraphy of the Tarim Basin. The studied material of this paper was collected from 2 outcrop sections at Damusi and Xiao’aizi respectively, and 14 well logs from the Manxi, Hetianhe, Tazhong and Tabei areas of the Tarim Basin. The sliding window spectral analysis of Gamma ray logs with the spectrum/cyclicity band and sequences is applied to the analysis of logs under the deserts. Herein, four major sequences corresponding to the 3rd- order cycles are identified from the Late Devonian and Early Carboniferous outcrops and logs in the Tarim Basin. Among them, Sequences I and II form Supersquence I; Sequences III and IV consist of Supersquence II. In addition, sequences are divided internally into parasequence sets and Punctuated Aggradational Cycles (PACs) probably corresponding to the 4th-, 5th- or 6th- order cycles. Seventy-one Punctuated Aggradational Cycles (PACs) within Supersquence II are also recognised from the Damusi section by analysing microfacies and palaeoecology. The smaller scale units commonly display an upward shallowing motif, at least 4 orders of cycles are preserved in the record of sediments. Sequences and depositional system tracts are correlative basinwide and synchronous within the resolution of bio- and event- stratigraphy. Several major drops in relative sea level are represented by sequence boundaries. The "Donghe Sandstones", the famous oil beds, can compare directly to the shallow grey quartz sandstones at the bottom of the Donghetang Formation in the Bachu area and the purple quartz sandstones at the upper portion of the Qizilafu Formation in the SW Tarim Basin, and they were likely deposited during the latest Famennian Stage (Late Devonian).

Keywords: Sequence stratigraphy, punctuated aggradational cycles, "Donghe Sandstones", Late Devonian to Early Carboniferous, Tarim Basin

INTRODUCTION

The Tarim Basin occupies a diamond-shaped area of 572,700 sq. km. and is the largest inland sedimentary basin in China (Fig.1). It is located between latitudes 36°-42° N and longitudes 75°-93° E, with elevations ranging between 800m and 1600m. Situated on the hinterland side of the Tibetan Plateau, the basin is enclosed by the Tianshan Mountains to the north, the Kunlun Mountains to the SW. and the Aerjin Mountains to the SE (Fig.1). Crustal thicknesses in the region vary from a maximum of more than 60 kms below the Kunlun Mountains to about 50 kms below the Tianshan Mountains and a minimum of 41 kms below areas to the NE (Wang, Q.M., et al., 1992).

The results of petroleum exploration in the Tarim Basin since 1977 have been encouraging. So far, five groups of source rocks with a combined thickness of over 4.5 kms have been identified in more than 170 wells. With the petroleum exploration spreading over the entire basin, more and more oil-gas pools have been found under deserts. Most of them are related to Upper Devonian to Lower Carboniferous.

On the basis of the systemic studies of seismic stratigraphy of the entire basin, 7 structures were divided by Tong, X.G. (1992) into: (1) Kuqa depression; (2) Tabei uplift; (3) Manxi depression; (4) Tazhong uplift; (5) South-western depression; (6) Tanan uplift and (7) Tanan depression (Fig. 1).
Fig. 1 Sketch map showing the researched areas and seismic structures of the Tarim Basin. (adapted from Tong, X.Q., et al., 1992)
1. city or county 2. location of section 3. fault 4. well location 5. boundary of structure

This paper summarizes the characters of sea-level changes of the Tarim Basin from Late Devonian to Early Carboniferous through a study of sequence stratigraphy. The studied material in this paper was collected from two outcrop sections and 14 well logs distributed in the Tabei uplift, Manxi depression, Tazhong uplift and SW Tarim depression.

**BIOSTRATIGRAPHY OF THE UPPER DEVONIAN AND LOWER CARBONIFEROUS FROM THE TARIM BASIN**

Although the Carboniferous biostratigraphic framework of some areas of the Tarim Basin has been classified by several previous authors (Urstrisky, 1960; Zhao, Z.X., et al., 1984; Xiang, J.F., 1990; Jiao, C.Z., et al., 1992), the systemic palaeontological zone successions aren't established up to now. The assemblage zones referred in this paper are summarized from this study and the previously published biostratigraphic records, as shown in Tab. 1; the assemblage zones of fusulinids, corals and conodonts from the SW Tarim are quoted from Zhao, Z.X., et al. (1984); the conodont zones from the Bachu area are quoted from Xiang, J.F. (1990); and the brachiopod assemblage zones are provided by the present research.
Table 1 The Late Devonian to Early Carboniferous biozones from the Tarim Basin

<table>
<thead>
<tr>
<th>Fm./Mem.</th>
<th>Brachiopoda</th>
<th>Rugosa</th>
<th>Foraminifera</th>
<th>Fusulinid</th>
<th>Conodont</th>
<th>Fm./Mem.</th>
<th>Brachiopoda</th>
<th>Conodont</th>
<th>W.E.</th>
</tr>
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<tbody>
<tr>
<td>Heshilafu Fm.</td>
<td>Gigantoprocessus -Kansuessa</td>
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<tr>
<td>3rd</td>
<td>Dibunophyllum</td>
<td>Archaeodina -Pitiogyra</td>
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<td>2nd</td>
<td>-Pugilis</td>
<td>Janischenkina</td>
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<tr>
<td>1st</td>
<td>Rugosochonetes -Marginatus</td>
<td>Eostaffella</td>
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<tr>
<td>Kellitang Fm.</td>
<td>Martinella chengliensis</td>
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<tr>
<td>upper</td>
<td>Spathognathodus stabilitoides</td>
<td>Schuchertella</td>
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<tr>
<td>lower</td>
<td>Pseudopolygnathus premus</td>
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<tr>
<td>Qizilafu Fm.</td>
<td>Cystospirifer - Tenticospirifer</td>
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<tr>
<td>Donghetang Fm.</td>
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<tr>
<td>Lopingian Fm.</td>
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</table>

As shown in Table 1, the upper portion of the Qizilafu Formation, the Donghetang Formation, the Ganmulig Formation and the basal Bachu Formation are assigned to Late Famennian (Late Devonian) in age, the upper parts of the Kellitang Formation and the upper portion of the Bachu Formation are dated as Tournaisian (Early Carboniferous), and the Heshilafu Formation is referred to Viséan (Early Carboniferous) in age.

THE OUTCROP SEQUENCE STRATIGRAPHIC FRAMEWORK OF THE SW TARIM AREA

The Upper Devonian to Lower Carboniferous, deposited in the south-western area of the Tarim Basin, is composed dominantly of two supersequences: Supercsequence I comprises the upper portion of the Qizilafu Formation and the Kellitang Formation, and is divided into Sequence I and Sequence II (reflecting the 3rd order sequence by Vail, et al., 1977); Supercsequence II is constituted by the Heshilafu Formation including Sequence III and Sequence IV, as described below:

Sequence I

Sequence I comprises the upper part of the Qizilafu Formation to the lower part of the Kellitang Formation, it is bounded at its base by a minor scouring surface and is overlain by a widely spread minor erosion surface forming the lower boundary of Sequence II (Fig.2). The brachiopod assemblage Cystospirifer - Tenticospirifer, assigned to the latest Famennian (Late Devonian) in age, is found in this sequence. The purple quartz sandstones of the upper member of the Qizilafu Formation constitute the Lowstand System Tracts (LST) of Sequence I, and the greenish quartz sandstones above containing brachiopod fossils reveal the first marine flooding of this sequence. The upper
portion of the upper member of the Qizilafu Formation is composed of the rhythmic unites of mottle sandstone and mudstone. The bimodal cross-beddings and large diagonal beddings are well developed in the quartz sandstones, and the lithologic grains become finer, and the sand/mud ratio becomes smaller upward in the rhythmic unites. These unites form the Transgression System Tracts (TST) of Sequence I and indicate the depositional features of retrogradational stacking pattern of sandstones and shales.

Fig. 2 Composite section showing the Famennian-Tournaisian lithostratigraphy, palaeontology, sequence stratigraphy and sea-level changes in the SW Tarim area.

The upper portion of the rhythmic unites is composed of less than 10 m thick black shales and thin-bedded dolomitic limestones. Sedimentary structures such as: hardgrounds, worm trails and shell lamellae are conspicuous in the less than 10 m thick strata, they indicate a large scale marine flooding event and comprise the Condensed Sections (CS) of Sequence I.

Dolomitic limestones of the intertidal flat facies in the basal Kelitag Formation constitute the Highstand System Tracts (HST) of Sequence I. Some sedimentary structures (e.g. birdeyes and algae lamella) revealing upward shallowing are recorded perfectly in these unites.
Sequence II

Sequence II is consisted of the middle to upper portions of the Kelitag Formation, and is considered as Tournaisian (Early Carboniferous) in age on the basis of brachiopod assemblage *Martiniella chinglungensis* Chu. The basal surface of Sequence II is marked by a minor exposure surface, and is overlain by the quartz pebble conglomerates of the Heshilafu Formation (Sequence III) (Fig. 2).

During the sedimentation of Sequence II, the shales and black mudlimestones in the middle portion of the Kelitag Formation consist of TST of Sequence II, and the oolitic limestones in the top portion of the Kelitag Formation constitute HST of this Sequence. These strata packages are composed of grey, block and thick bedded, packstones and grey, thin bedded, marlites. The marlites are deposited dominantly at the early stage of HST of Sequence II, the extensive early submarine cement marls and algal laminaset are obvious in the rocks under microscope. They indicate a relative slow rate accumulation of sediments. The packstones are settled at the last stage of HST, consisting of carbonate platform facies intrabiopelmicrites, intrasparites and block oolitic-limestones, relative small amount of the early submarine cement under microscope, displaying a relative rapid rate accumulation of sediment.

Shallowing upward parasequences, consisting of the lower and upper unites, are easy to be identified in the top portion of the HST by the analysis of microfacies. (Fig. 3). The lower unites are composed of the lower shore microfacies, thin bedded, organic rich marlites, and indicate the quiet and deeper water environment; The upper unites are consisted of the oolitic limestones or interbiosparites. The oolites comprise mutul-oölites with radial cores, and indicate the subtidal to intertidal micro-environment. They display the characters of shallowing upward from lower unite to upper unite.

Sequence III

Sequence III corresponds to the first and second member of the Heshilafu Formation assigned to the Early Visean (Early Carboniferous) in age (Fig.4). The basinward correlation of this sequence is on the basis of some Palaeontological zones including brachiopod assemblage zones: (1). *Marginatia-Rugosoconetes*, (2). *Pugilis-Vitiliprocessus*; conodont zone: *Gnathodus bilineatus - G. homopunctatus*; fusulinid zone: *Eostaffella mosquensis*. Sequence III is bounded at its base by a shallowing abrupt surface and its top by a minor erosion surface.

The first member of the Heshilafu Formation comprises about 70 m thick purple red quartz conglomerates and sandstones, displaying the features of the incised valley filled (ivf) systems with anti-graded texture at its lower portion and upright graded texture at its upper portion. (Fig. 5). The incised valley filled system is bounded at its base by the lower boundary of Sequence III, and is overlain by the purple marlites indicating the first marine flooding event. The sedimentary rocks have good sorting and high maturity under microscope, and also develop well large cross beddings reflecting the features of stream channel deposits. In addition, the bimodal cross-beddings are well developed in the incised valley filled systems, these sedimentary features suggest that the incised valley filled systems belong to the sediments of the embayment facies influenced by the lowstand sea water. They comprise the LST of Sequence III.

Fig.3 Showing the framework of parasequence in the Sequence II from the Damushi of the SW. Tarim Basin
The second member of the Heshilafu Formation consist of quartz sandstones with the interbeds of thin bedded marlites rhythmic units. Thirty-six Punctuated Aggradation Cycles (PACs) of Goodwin and Anderson (1985) can be identified by analysing microfacies and Paleooecology from this unit (Fig. 6). Herein, the retrogradational upward stacking from cycle (1) to cycle (32) indicates the typical accumulation characteristics of TST; The CS of the Sequence III is located at the bottom of cycle (33) and formed by the black shales with horizontal lamination sets, abundant worm traces and fossils. The diversities of brachiopods show the biggest value is scattered near the CS of the Sequence III (Fig. 4).
Fig. 6  Sequences III and its component PACs of the Heshilaifu Formation from the SW. Tarim Basin

Comparing with TST, the HST of Sequence III isn't well developed, and is composed dominantly of shales with numerous bands of thin bedded marlites, it ranges from cycle (34) to cycle (36)(Figs. 4, 6).

**Sequence IV**

Sequence IV ranges the third member of the Heshilaifu Formation, which is assigned to the Late Visean (Early Carboniferous) in age. The correlation of Sequence IV is on the basis of some

Fig. 7  Sequence IV and its component PACs of the Heshilaifu Formation from the Damushi section in the SW. Tarim Basin
assemblage zones containing brachiopod: *Gigantoproductus-Kansuella*, coral: *Dibunophyllum clisiophyllum*, conodont: *Gnathodus bilineatus-G. homopunctatus*, fusulinid: *Eostaffella mosquensis* etc.. Sequence IV is bounded at its base by a minor erosion surface, and over lain by the widespread quartz sandstones to pebble conglomerates referred to the Upper Carboniferous Karawuyi Formation.

Thirty-five PACs can be also identified from those units by the same method (Fig.7). Among them, thirty-one cycles are stacked retrogradely from cycle (1) to cycle (31), and consist of TST, and the rest four cycles are accumulated progradedly from cycle (32) to cycle (35), and composed of HST. The CS of the Sequence IV isn't clear in the records of strata.

**THE OUTCROP SEQUENCE STRATIGRAPHIC FRAMEWORK OF THE BACHU AREA**

The marine Upper Devonian and Lower Carboniferous is distributed extensively in the Bachu area too. The perfect succession is exposed in Xiaohaizi section, located to east of Xiaohaizi reservoir in the Bachu County (Fig.1). They are divided into the Donghetang Formation, the Ganmulig Formation, the Bachu Formation, the Karasay Formation and the Xiaohaizi Formation from lower to upper and consist dominantly of four sequences reflecting the 3rd order cycle (Fig.8).

![Stratigraphic Diagram](image)

Fig. 8 The Late Devonian to Early Carboniferous sequence stratigraphic framework from the Xiaohaizi section in the Bachu area

<table>
<thead>
<tr>
<th>Strata Units</th>
<th>Beta</th>
<th>Lithofacies</th>
<th>ST.</th>
<th>Palaeontology</th>
<th>Seal level changes</th>
<th>sequence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Xiaohaizi Fm.</td>
<td></td>
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<tr>
<td></td>
<td>20</td>
<td>parasequences</td>
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<tr>
<td>Lower Carboniferous</td>
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<tr>
<td>Karasay Fm.</td>
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<td>17</td>
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<td>Bachu Fm.</td>
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<td>9</td>
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<td></td>
</tr>
<tr>
<td>Upper Devonian</td>
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<tr>
<td>Donghetang Fm.</td>
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<td></td>
<td>4</td>
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<tr>
<td>Keziertag Fm.</td>
<td>1</td>
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</tbody>
</table>

[source: Xiang J P. 1991]
Sequence I

Sequence I corresponds to the sediments of the Donghetang Formation, the Ganmulig Formation and the basal Bachu Formation, and it is referred to time ranges from the latest Famennian (Late Devonian) to the earliest Tournaisian (Early Carboniferous), containing brachiopod assemblage zone: *Trifidorostellum-Ptychomaletoechia*, and conodonts: *Bispathoda aculeatus aculeatus* Bramsum and Mehl, *B. cf. spira*, etc. The Donghetang Formation consists of 90m thick shallow grey quartz sandstones with cross beddings, and forms the LST of the Sequence I. Overlying the Donghetang Formation, the calcareous nodule beds or calcareous conglomerates represent the first marine flooding event, the Ganmulig Formation interbeds of quartz sandstones and slitic mudstones overlying the calcareous nodule beds constitute the TST of the Sequence I. (Fig.8).

The CS of Sequence I is composed of about 2m thick marlites with rich fossils (e.g. brachiopods, bivalves, conodonts, cephalapods). The upper portion of the lower member of the Bachu Formation, the interbeds of quartz sandstones and slitic mudstones, forms the HST of Sequence I.

Sequence II

Sequence II is constituted by the upper member of the Bachu Formation, a 182m thick, thin bedded limestone and biocalcarenite, and assigned to the latest Tournaisian (Early Carboniferous) in age, including brachiopods assemblage zone: *Eocoristites neiplayaensts* Chu, conodonts: *Polygnathus inornatus*, *Spathograthodus stabilis*, *Bispathoda aculeatus*, *Siphonodella cf. suctata* etc. (Fig.8). The HST of Sequence II is well developed and consisted of carbonate platform margin facies biocalcarenites. Many shallowing upward parasequences are also identified from this unit. Generally, they include A, B type parasequences. (Fig. 9).

![Fig. 9 Two types of parasequences of the Sequence II from the Bachu area](image)

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>thin bedded mudlimestones</td>
<td>thin bedded limestones</td>
</tr>
<tr>
<td>2</td>
<td>calcarenites and dolomites</td>
<td>biocalcarenites</td>
</tr>
</tbody>
</table>

A: unite 1: mudstones, unite 2: fine sandstones glib biocalcarenites; B: unite 1: black thin bedded marlites, unite 2: shallow grey thick biocalcarenites.

Their common features are coarsening upward. Those parasequences are stacked progradedly or aggradedly, and form the HST of Sequence II.

Sequences III and IV

Sequences III and IV comprise the Karasay Formation, a 247.8 m thick rhythmic unite consisting of psugum mudstones and quartz sandstones. The boundary between Sequence III and Sequence IV is difficult to be distinguished out from outcrops, whereas the basal boundary of Sequence III and the top boundary of Sequence IV are marked by the extensive regressive surface and erosion surface, separating the Karasay Formation from the quartz sandstones of the Xiaohaizi Formation above and the carbonates of the Bachu Formation below. The shallowing upward PACs, consisted of quartz
sandstones and gysum mudstones, are conspicuous in Sequences III and IV. Seventy-five PACs are identified from the Karasay Formation (Fig. 8).

SEQUENCE STRATIGRAPHY OF WELL LOGS, CORES FROM SUBGROUND

Seismic features

The Upper Devonian to Lower Carboniferous strata contain T3g reflect wave groups in the seismic section. The upper wave zones display the characteristics of weak reflect waves with middle - thin bedded, middle - low frequency successive; The middle wave zones display 3 to 4 seismic facies, middle - low frequency successive, strong reflect waves; The lower wave zones indicate the middle to high frequency successive, strong reflect waves, this wave groups indicate obviously the features of onlap and down on traction in the Tabei area and Tazhong area of Tarim Basin under deserts, and contact with lower wave groups by unconformity (Zhou Lu et al., 1992)

The features of well logs and cores

For a detailed cyclicity analysis of the third order sequence, Gamma ray logs of the Upper Devonian to Lower Carboniferous were selected from 3 of 15 wells. The cyclic patterns of the Gamma ray logs are analysed with the process designed by interGeos. B.V., which uses spectral analysis to detect and quantify cyclic patterns in serial data such as wire line log data.

In order to detect high-order cyclicities, a sliding window spectral analysis is applied to the gamma ray logs of the Upper Devonian to Lower Carboniferous in selected wells (see Fig. 10), a window of fixed size (i.e. 256 equally spaced data points in most cases) is moved down the wire line data. In each step a power spectrum is calculated for the window. The left-hand side of the spectrogram is positioned at the middle depth point of the window. Only peaks with their amplitudes above a certain threshold are shown. Spectrograms of successive windows may partly overlap. This way of presentation are pronounced and a blank pattern in intervals where cyclicities are missing or blurred when the window includes a discontinuity, the
pattern is interrupted for some length. Fig.10 show the results of sliding window spectral analysis of the gamma ray logs in well TZ5. Fig. 10 also indicate that the boundaries of the third order sequences are usually characterised by apparent breaks in cyclicity patterns. Those features can be used to draw and check sequences boundaries.

THE HIGH RESOLUTION CORRELATION OF SEQUENCES FROM THE OUTCROPS AND WELL LOGS OF THE TARIM BASIN

The correlation of Sequence I

Sequence I is developed extensively in the Late Devonian to Early Carboniferous in the Tarim sea. In spite of the basal boundary of Sequence I being not distinguished at outcrops, it is conspicuous seismic unconformity in the seismic section, displaying the feature of onlap and down traction. For this reason, the basal boundary of the Sequence I is referred to I type sequence boundary in this paper.

The LST of the Sequence I, consisting of the pure quartz sandstones, is well developed in the SW Tarim, Bachu area and Tabei area of the Tarim Basin, pinching out in the Tazhong area and Manxi area of the Tarim Basin. They are composed respectively of the upper portion of the Qizilafu Formation from the SW Tarim and the Donghetang Formation from the Bachu area, and the "Donghe Sandstones" from the Tabei area of the Tarim Basin. (Fig.11).

The correlation of the CS of the Sequence I from outcrops also bases on brachiopod assemblages: the Cyrtospirifer-Tenticospirifer from the SW Tarim and the Trifidostellum-Ptychionaletochia from Bachu area, the main elements of the above brachiopod assemblages usually appear on the same horizon in south China, they are assigned to the latest Devonian in age.

Sequence interpretation

Sequence I contacts with the underlying strata by a unconformity corresponding to a long time break of deposition before transgression. Before the eustasy sea level rose, some lowstand sandbodies mentioned above had settled in the shallow water pools or shore zones, and formed many excellent reservoirs of oil-gas. When sea-level began to rise, the first marine flooding event effected many areas of the Tarim Basin from the SW Tarim to the interior of basin, and closed the deposition of LST of Sequence I. This time, the greenish quartz sandstones with brachiopod fossils were stacked in the SW Tarim; the mottle mudstones with calcareous nodule beds and unstable lag deposits of pebbles were deposited in the Bachu area, and the mudstones with calcareniteous or the breccia overlying the "Donghe Sandstones" were accumulated in the Tabei area of the Tarim Basin. In addition, The Manxi area and Tazhong area were also flooded by this transgression, and the clasticstones with bands of limestones and breccia were respectively deposited in the above areas. Since the first marine flooding, the sea-level rose rapidly, the TST consisting of littoral sandstones and mudstones was accumulated over the researched areas. With the rising rate of the sea level increasing, the accommodation became larger than before. This time, some sand banks deposited before were flooded competitively by sea-water, the black shales with the mixed beds of the thin limestones or marlites were deposited in the researched areas, and formed the CS containing the maximum flooding surfaces (mfs) of Sequence I. The thin marlites and shales from the SW Tarim, the marlites from the Bachu area, the calcareous shales underlying below "bi-peak limestones" from logs under deserts of the Tabei area, and the shales with bands of biocalcarenites from the Tazhong area of the Tarim Basin were settled at this stage.
After sea-level had risen rapidly for a long time, the rising rate of the sea level reduced slowly, on the other hand, the supplies of sediments were increasing, the accommodation (Jervey, 1988) became smaller than before, the inter-tidal flat facies dolomitic limestones or littoral facies sandstones and shales indicating regression were deposited in the ancient Tarim sea. At last, the deposition of Sequence I was over because of the sea level dropping.

The correlation of Sequence II

The correlation of Sequence II from outcrops bases on the brachiopod assemblages, the Martiniella chintungensis Chu from the SW Tarim and the Eochoristites neipantaensis Chu from the Bachu area (Fig. 11). The elements of the above brachiopod assemblage zones are usually found in the same horizon from south China, and are referred to the Late Tournaisian (Early Carboniferous) in age, (Chu, S., 1933; Tan, Z.X., 1987). Besides, the abundant sporo-pollen fossils are also found in the shales between the "bi-peak limestones" from some well logs (i.e. TZ1, MX1, DH1) (Jia, C.C., et al., 1992). They include Auroraspora macta, Rugospora sp., Grunosisporites sp., Hymenspora sp., etc., accepted as the typical elements of Tournaisian (Lower Carboniferous). The rich conodonts (i.e. Spathgnathodus stabilis, Polygnathus inornatus, etc.) are also found in the upper portion of the Bachu Formation comprising the HST of the Sequence II from the Bachu area and the bimodal limestones from the Tabei area. In brief, Sequence II from the above mentioned areas is coincide and assigned as Tournaisian (Early Carboniferous) in age.

Sequence interpretation

This sequence represents a new transgression, and consists dominantly of the deposits of the HST. Its basal boundary isn't easy to be identified because of the smaller hating of the sea level falling. During the sea-level rising, the sea-level rose so rapidly that the supplies of sediments couldn't catch up with it, and the early HST, so called catch-up carbonate systems (Sarg, 1988), was accumulated in the SW Tarim. Owing to the increasing accommodation and short supplies of source sediments, the marl in marine had enough time to be accumulated slowly and formed extensive early submarine cementation, the condition of water usually was oxygen-poor and high salinity. The deposits of the EHST are dominated by the mud-rich parasequences indicating the weak hydrodynamics.

With rising rate of relative sea-level reducing, the accommodation became smaller, the catch-up carbonates systems displayed the characteristics of the keep-up carbonates systems (Sarg, 1988), and the sediments were also settled rapidly. The late HST, consisting of carbonate platform margin facies shallow grey oolitic limestones, intrabiopelmicrite, bioclasticrites, was deposited extensively in the ancient Tarim sea. The deposits of the LHST are usually dominated by the grain-rich and mud-poor sparites cementation parasequences shallowing upward. Those parasequences, stacked by the progradation or aggradation, comprise the LHST of the Sequence II. Especially, the sea-level fell rapidly at the LHST stage so that some dry crack structures were recorded at the top of the Kelitag Formation, indicating carbonates platform exposing above the sea-level, and Sequence II died out by I type unconformity causing eustasy sea-level fall fast (see next).

The correlation of Sequences III and IV

Owing to Sequences III and IV comprising obviously of a transgressive Supersequence reflecting the 2nd cycle, they aren't easy to distinguished in some areas. Sequences III and IV are consisted of many PACs from not only outcrops but also well logs: 71 PACs dominated by the black mudstones or silt sandstones are identified from the SW Tarim, and 75 PACs composed of the quartz sandstones,
Fig. 11 The composite Late Devonian to Early Carboniferous sequence stratigraphic correlation of the Tarim Basin
gym mudstones and dolomitic limestones are detected from the Bachu area, 70 high frequency cycles are recognised by gamma ray of well logs (i.e. TZ₁, TZ₅, MX₁). (Fig.11)

The basal boundary of Sequence III and the top boundary of Sequence IV are conspicuous in the researched areas. Those boundaries display the characters of the depositional facies shifting basinward belonging to I type sequence boundary. The lowstand incised valley filled and lowstand margin wedges are well developed in the outcrop sections.

The correlation of Sequences III and IV is also depended on the same assemblage zones, referred to Visean (Early Carboniferous) in age, Those assemblage zones include brachiopods: Marginatia-Rugosoconetes, Pugilis - Vitiliproductus, Gigantoproductus - Kansuella; rugosa corals: Dibunophyllum, Clisiophyllum, Zaphrentoides; fusulinid: Eostaffella mosquensis; foraminifera: Archaeodiscus-Plectogyra-Janischewskina; conodonts: Gnathodus bilineatus-G. homopunctatus. On the other hand, rich pteridophyly ploen-spore assemblages are found in Sequences III and IV from well logs (i.e. TZ₁, NN₁₆, etc.), including: Lycospora nensis, L. motuina, L. retundat, Auroraspora sp., Granulatissporites pallidus, etc. assigned to Visean in age (Jiao, C.Z., et al., 1992). In a word, Sequences III and IV from both well logs and outcrop sections are coincide in age. The strata consisting of the Sequences III and IV include the Heshilafu Formation from the SW Tarim, the Karasay Formation from the Bachu area, the upper mudstones member and upper sandstones/mudstones member from the Tabei area and the Tazhong area (Fig.12) and the 6th lithologic members of the Manxi area, and those lithic units can be compared directly each other.

**Sequence interpretation**

After a large scale falling of sea-level, a long term eustasy sea-level containing of many orders high frequency sea-level rise and fall rose fast. The high frequency sea-level change superimposed on the long terms eustasy so that the high frequency sea-level rising was conspicuous, and the PACs dominated by black mudstones were deposited in the most areas of the Tarim Basin (Fig.12). Those PACs were stacked by the retorgradation of deposits and formed Sequence III. The CS of Sequence III resulted from the maximum flooding appeared clearly in the SW Tarim, and were characterised by the abundant fossils and worm traces. (Fig.4).

Since the long periods eustasy sea-level rose slowly or stagnated, the high frequency sea-level changes superimposed on the long terms eustasy, the high frequency sea-level falling was prominent, and the PACs dominated by quartz sandstones were deposited, they formed Sequence IV from the SW Tarim. (Fig.12). Meanwhile, the high frequency sea-level changes also effected the shallow

![Fig.12 The stacking pattern of multicycles, sequences and PACs of the Supersequence II from the Tarim Basin](image-url)
water pool of the Bachu area. While every high frequency sea-level rose, the limited shallow water basin was flooded by fresh sea water, and the thin quartz sandstones were deposited in the most areas of the Tarim Basin. Oppositely, every high frequency sea-level fell, the gyumudstones and dolomitic limestones were deposited in the shallow water basin under the hot and dry climate. At last, Sequence IV was over because of the scale sea-level falling.

THE CORRELATION OF "DONGHE SANDSTONES"

The "Donghe sandstones" distributed extensively under the deserts are considered as the important oil bearing beds in the Tarim Basin. They are consisted of the pure quartz sandstones with depositional structures (e.g. parallel beddings, bimodal cross-beddings, low angle diagonal beddings etc.). The blank space and uncontinued, weak amplitude reflection waves are displayed on the seismic section, Gamma ray is lower and flat. According to the Donghe sandstones exposed above sea-level three times (Gu, J.Y., et al., 1993), it suggests that they are retrograded and aggradated by shallowing upward parasequences (Fig.13).

On the basis of the correlation of Sequence I, the deposits forming the LST of the Sequence I include the "Donghe sandstones" of the Tabei area, the block quartz sandstones of the Donghetang Formation of the Bachu area, and the purple quartz sandstones at the upper portion of the Qizilaafu Formation from the SW Tarim. Those strata packages can be directly correlated to each other.

Further, the brachiopod Cyrtospirifer fauna, accepted extensively as the latest Famennian (Late Devonian) in age are found in the CS of the Sequence I from the Damusi section of the SW Tarim. The CS containing a maximum flooding surface is considered as the ideal isochronous surface (Van Wagoner, et al.,1988,1990). For this reason, the "Donghe sandstones" and its equivalent under deserts can correlate to the above mentioned deposits consisting of the LST of the Sequence I from the researched areas, and they are likely deposited in the latest Famennian (Late Devonian) or earlier stage.

![Fig.13 The parasequence framework of the Donghe sandstones](image)

CYCLES WITHIN CYCLES AND SEA LEVEL CHANGES FROM THE TARIM BASIN

Cycles within cycles (Miall, R.A., 1987) are mirrored extensively in the records of strata from the researched areas. Herein, Sequences I and II (reflecting the 3rd order cycles) are controlled respectively by a long term eustasy sea-level rise rapidly and rise slowly or stagnation, and form Supersequence I (reflecting the 2nd order cycle). The sea-level underwent two 3rd order rising and falling cycles corresponding to Sequences I and II within a 2nd order cycles reflecting Supersequence I (Fig.2).
Similarly, Sequences III and IV form an other Supersequence reflecting the 2nd cycles. The second long term eustasy also contains multiple order cycles (Figs. 6, 7). Fig.12 show at least four orders cycles responded by the record of strata. Herein, the PACs are the basic cycles, and consisting of high order cycles. In brief, at the latest Devonian to Early Carboniferous, the Tarim sea underwent four 3rd order sea-level rising and falling cycles controlled by two 2nd order eustasy. In addition, The high frequency sea-level changes were frequent within the last 2nd order eustasy.

CONCLUSION

(1). Four 3rd-order sequences are recognised from the Late Devonian and Early Carboniferous strata of the Tarim Basin. Among them, the Sequences I and II consist of Supersequence I, and the Sequences III and IV form Supersequence II.

(2). The first long terms transgression reflecting to Supersequence I submerged extensively the pre-Devonian exposure areas in the entire Tarim basin, and the regional unconformity as the basal boundary of the Sequence I appeared in the most areas of the Tarim Basin, it was benefit to the forming of the oil-gas pools. This long terms eustasy sea-level rise also flooded the entire Basin, and the carbonate platform facies or platform margin facies biocalcareites and sparites consisting of the HST of the Sequence II were well developed in most areas of the Tarim Basin. The second long terms teustasy sea-level rise reflecting the Supersequence II was relative small scale so that the extensive areas except the SW Tarim became evaporate shallow water basin.

(3). Seventy-one PACs are identified from the Supersequence II of the Damusi section in the SW Tarim, and 75 PACs are recognised from the Supersequence II of the Xiaohaizai section in the Bachu area. They indicate that the high-frequency sea-level changes have been active in the ancient Tarim sea in Visean.

(4). Cycles within cycles are preserved well in the Visean strata. They are divided into the 2nd-, 3rd-, 4th-, 5th- order cycles corresponding to supersequence, sequence, parasequence set and PACs.

(5). According to the correlation of the Late Devonian to Early Carboniferous sequence stratigraphy and biostratigraphy from the Tarim Basin, the "Donghe Sandstones", famous oil beds under the wells, can be compare directly to the grey quartz sandstones of the Donghetang Formation and the purple quartz sandstones at the upper portion of the Qizilafu Formation, and they may be deposited at the latest Famennian Stage (Late Devonian).

ACKNOWLEDGEMENTS

This study was done under the supervision of Prof. Liao Zhuoting (Nanjing Inst. Geol. Palaeont.). I thank Prof. Zhou Zhi-yi, Gen Liang-yu (Nanjing Inst. Geol. Palaeont.) and Senior Engineer Zhao Zhi-xin (Tarim Petroleum Exploration Company) for their providing me some important data. I thank Prof. Liao Wei-hua, Yuan Yi-ping, Yang Wang-rong, Wu Xiu-yun, Xia Feng-sheng and Dr. Yu Zhi-yan, Luo Hui, Zhu Hui-cheng, Zhu Zi-li (Nanjing Inst. Geol. Palaeont.) for their generous help in the course of field research. I also thank Prof. Sun Wei-guo (Nanjing Inst. Geol. Palaeont.) for his revising the manuscript of this paper.

Special thanks are due to Senior Engineer Li Pei-lian (Shanghai Bureau of Marine Geological Survey) and R.C.L. Wilson (Earth science dept. of Open Univ. U.K.) for their guidance in dealing well logs by computer and analysis of sequence stratigraphy.
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EXPLANATION OF PLATE

Plate 1

1. × 5, biocalcareines, the 2nd member of the Heshilafu Formation, forming the upper unite of PACs, TST of Sequence III.

2. × 8, biocalcareines, the 3rd member of the Heshilafu Formation, forming the lower unites of PACs, TST of Sequence IV.

3. 5. × 8, oolitic limestones. upper portion of the Kelitag Formation, composing of the LHST of Sequence II.

4. 8. quartz sandstones, the 2nd member of the Heshilafu Formation, and composing of the upper unites of PACs, TST of Sequence III.
6. × 10. the microstructure of brachiopods from biocalcarenites, upper portion of the Kelitag Formation, and consisting of the L1HST of Sequence II.

7. × 8. dolomitic mudlimestones. lower unites of the Kelitag Formation, and consisting of the HST of Sequence I.