Sedimentary facies and evolution of the lower Urho Formation in the 8th area of Karamay oilfield of Xinjiang, NW China

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Cogent Geoscience (2017), 3: 1333667
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Abstract: On the basis of core descriptions, examinations of rock thin sections, and EMI logging, a fluvial-dominated fan delta depositional system consisting of the fan delta plain and front subfacies from the lower Urho Formation of the Upper Permian in the Karamay oilfield of Xinjiang, NW China, was recognized in this research. The typical characteristics of this kind of fan delta is the depositional processes that were dominated by the fluvial and tractive current structure that developed very well, while pro-fan delta and gravity deposition occurred very less. The key microfacies associations in the fan delta plain subfacies are braided channel, sheeted flow, mud flow, and sieve deposits, while the fan delta front subfacies commonly contains subaqueous channels, interdistributary channels, debris flow, grain flow, and subaqueous levee microfacies. A study of image logging, grain size, and compositions of rocks indicate that provenance directions are different from the early to the last depositional periods of the Urho Formation, i.e. it changed from the southwest initially to the northwest in the latest among the fifth period to the first period. In addition, with the corresponding provenance direction changing, the sedimentary facies also transform regularly. This paper illuminated the sedimentary facies, subfacies and microfacies and also discussed deeply the depositional

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PUBLIC INTEREST STATEMENT
When a river carrying a large amount of deposits influxes into the sea or a lake, those deposits would be unloaded and gradually develop into a fan-like alluvial plain on the mouth of the river, which is named delta. The aquatic part of a delta is the delta plain, whereas the continuous extension into the underwater is called the delta front. It is known as the prodelta, which mostly consists of muds, when the bottom of the delta reaches into the shallow lake or half deep lake area. The sedimentary area of a delta is usually a good oil and gas zone in the geological history because prodelta muds, always containing a large amount of organic matter, are good source rocks; delta plain and delta front sand bodies are favorable reservoir; oil and gas migrates upward to the inclination along the slope direction and can form good reservoirs. Therefore, the area of the delta deposited is the favorable zone for oil and gas exploration.
distribution and evolution of the lower Urho Formation. A sedimentary model of the fluvial-dominated fan delta was presented in this paper.

Subjects: Earth Sciences; Earth Systems Science; Geology - Earth Sciences; Mining, Mineral & Petroleum Engineering

Keywords: fluvial-dominated fan delta; sedimentary facies; provenance analysis; upper Permian; lower Urho Formation; Karamay oilfield, NW China

1. Introduction
The lower Urho Formation of the Upper Permian has been yielding high commercial oil and gas flow since 1960s. Sedimentary facies and its spatial distribution are the key control factors for oil and gas reservoir distribution and directly dominate the results of exploration and development. However, as a typical kind of conglomerate reservoir, the sedimentary facies research of the lower Urho Formation of the Lower Permian at the 8th zone of Karamay oilfield has a long history, but has been controversial. In the 1980s, although Larerson (1989) from SSI Petroleum Company of the United States defined the sedimentary facies of the lower Urho Formation as a wet fan deposit, a facies association from mountain alluvial fan, alluvial fan to fan delta was proposed by Xu (2001), while the Research Institute of the Petroleum Exploration and Development of CNPC (RIPED) and the Branch Company of the Xinjiang Oilfield (2004) concluded a depositional model of a braided river. In recent years, with great progress being made in the oil and gas exploration and development, sedimentary facies research of the lower Urho Formation has been highlighted. Multiple theories were presented. Most of the researchers thought that the conglomerate reservoirs are fan deltas (He, Qiu, Luo, & Wu, 2014; Pang, 2015; Yang, Wei, Abulimidi, Chen, & Bing, 2016). Pang (2015) further divided the fan delta into traction current sand-conglomerate and gravity current sand-conglomerate in the lower Urho Formation. Comparing the physical characteristics among different reservoirs, Zhang et al. (2015) found that the reservoir property of the lower Urho Formation (Pw) is the best in the Kebei area of the northwestern Junggar Basin. Wu et al. (2013) presented a sub-lacustrine fan having a Bouma sequence, and the grain size distribution revealed a typical turbidity deposit. Other researchers thought it was an alluvial fan (Hu & Gong, 2016), a composite fan (Lu, Shi, Ge, & Zhang, 2012), and a subaqueous fan (Li et al., 2015), respectively. Obviously, there are still some ambiguous views on the identification of sedimentary facies in the lower Urho Formation. It is necessary to re-research the sedimentary characteristics of the lower Urho Formation of the Lower Permian for pinpointing the direction of oil and gas exploration.

Our research, which is based on observations and descriptions of more than 1,000-m-long cores and examinations of rock thin sections from 12 wells and on the analysis of well logging of more than 800 wells and especially electrical micro-imaging (EMI) logs of 15 wells, suggests that the lower Urho Formation of the Upper Permian would be a fluvial-dominated fan delta depositional system and corresponding facies association in the 8th area of the Karamay oilfield. Two subfacies and nine microfacies were recognized further and studied in detail.

2. Geological setting
The south fault of Baijiantan is located in the central south of the Karamay–Urho fault zone, which is in the northwestern margin of Junggar Basin of Karamay oilfield. The 8th zone is located in the lower plate of the south Baijiantan fault (Figure 1). The Lower Permian, includes the Fengcheng Formation and Jiamuhe Formation, and the Upper Permian consists of the upper Urho Formation and the lower Urho Formation, which is overlain by the Mesozoic Xiazijie Formation. The Permian lower Urho Formation is overlapped layer by layer in the 8th zone of the Karamay oilfield, Junggar Basin. It suffered from intense denudation because of the late strong thrusting and uplifting (Wu et al., 2015), so that the top and bottom of the lower Urho Formation were both bounded by a regional unconformity in the 8th zone. This study focused on the sedimentary facies and provenance of the lower Urho Formation, in which a number of oil reservoirs were explored. A series of structures bearing oil and gasses in the NE–SW trend were tectonically presented (Figure 1). The lower Urho Formation of
Table 1. Classification of lithological stratigraphy and sequence stratigraphy of the lower Urho Formation

| Stratigraphy | Sequence stratigraphy |
|--------------|-----------------------|
| Triassic      |                      |
| Permian       |                       |
| Upper Permian |                       |
| Urho Formation|                      |
| Member No. 1  |                       |
| Layer         | Parasequence set      |
| 1-1           | Progradation           |
| 1-2           | Highstand system tract (HST) |
| 1-3           | Sequence II           |
| 1-4           | 6                     |
| 1-5           | 5                     |
| 1-6           | 4                     |

| Member No. 2  |                       |
| Layer         | Retraction             |
| 2-1           | Transgressive system tract (TST) |
| 2-2           | 4                     |
| 2-3           | 5                     |
| 2-4           | 2                     |
| 2-5           | 1                     |

| Member No. 3  |                       |
| Layer         | Progradation           |
| 3-1           | Highstand system tract (HST) |
| 3-2           | 4                     |
| 3-3           | 5                     |
| 3-4           | 2                     |

| Member No. 4  |                       |
| Layer         | Retraction-Aggradation |
| 4-1           | Transgressive system tract (TST) |
| 4-2           | 2                     |
| 4-3           | 1                     |

| Member No. 5  |                       |
| Layer         | Aggradation-Progradation |
| 5-1           | Lowstand system tract (LST) |
| 5-2           | 5                     |
| 5-3           | 4                     |
| 5-4           | 3                     |
| 5-5           | 2                     |

L. Per. Jiamuhe Formation
the Upper Permian is made up mainly of coarse sediments of conglomerate and subdivided into five lithological members and 22 layers on the basis of studies of spectral logging, combination logging (Li, Wang, Zhou, Tan, & Li, 2004), seismic data, depositional evolution, and sequence stratigraphy; two sequences and five system tracts or parasequences were recognized (Table 1) (Lei et al., 2005).

3. Sedimentary facies
Two subfacies and nine microfacies were recognized, respectively, in the lower Urho Formation of the Upper Permian in the 8th zone of Karamay oilfield, Junggar Basin. Four microfacies in the fan delta plain subfacies are braided channel, sheeted flow, mud flow, and sieve deposits, while the fan delta front subfacies commonly contains subaqueous channels, interdistributary channels, debris flow, grain flow, and subaqueous levee microfacies. Detailed descriptions of these microfacies are shown in the text of this paper.

3.1. Braided channel
Braided channel deposits, occupying 80% in a total thickness of the fan delta plain, is the main microfacies in the fan delta plain and consists of mainly conglomerates in various grain size (Figure 2(A)) and occasionally pebble sandstones (Li, 1997). Parallel bedding, large-scale
cross-bedding, and anti-dune cross-bedding in a fining-upward sequence and eroding surface on the bottom are common (Figure 2(B)). Generally, it appears a feature upward from light to dark in color and big to small in white points in the EMI logging and remarkable bedding or lamination and fining-upward in grain size, although cross-bedding and parallel bedding are common (Figure 2(C)). In addition, a gamma curve with great amplitude shows a teeth-like case or campaniform. Resistivity displays teeth-like campaniform or case-form (Figure 2(D)).

3.2. Sheeted flow
It is defined as finer grained sediments deposited by sheet flow or overbank flooding at the distal fan channels, which consists of reddish shale sandstone or siltstone (Figure 3(A) and (B)), and cracks are common because of the exposed environment (Figure 3(B)). Gamma curve of sheet flow deposits is always jigsaw with the number of teeth crests in small amplitude, which becomes smaller upward (Figure 2(D)). This microfacies is also identified as the dark areas in the alternation ribbon of bright and dark in the EMI image logging (Figure 3(C)).

3.3. Mud flow
Mud flow is a type of massive mixture sediments in varied grain size, i.e. clay, sand, and gravels, poorly sorted and huge floating conglomerates, rare bedding, and rich in mud (Figure 4(A)). This microfacies is generally thin in thickness and poor developed. Resistivity curve of this microfacies is jagged zigzag, the peak value is higher, and gamma curve appears jigsaw in moderate amplitude; both resistivity and gamma curves display gradual patterns on the top and bottom (Figure 4(C)), and the EMI logging represents white dotted floating images among gray mid-lower resistivity matrix (Figure 4(B)).

3.4. Sieve deposit
Sieve sediments, appearing occasionally, is mainly moderate–coarse conglomerate with well voids (Figure 4(D)).

Figure 3. Sedimentary characteristics of sheeted flow showing in thin sections, cores and well logging. (A) Middle and upper part: pink reddish mudstone, clayey sandstone with gray green siltstone ribbons, sheet flow; deposit of braided channel on the bottom, mainly micro-grained conglomerate, 2,564.67 m depth of well T85722; (B) sandstone and mudstone, mud cracks in the middle part, sheet flow deposits, 2,828.79 m depth of well 3 of Jianwu; (C) sheeted flow deposit, 2,619.55–2,620.38 m depth of well T85689.
3.5. Subaqueous distributary channel

Deposits of subaqueous distributary channels, characterized by gray, finer sandstone with well-developed cross-bedding compared with braided channels, are dominantly in the fan delta front and consist of gray-green fine or coarse micro-conglomerates with normal rhythm. Coarse gravels appear generally on the bottom of the rhythm, whereas coarse sandstones with gravels on the top occasionally erode the surface (Figure 5(A)–(E)).

Its resistivity curves are lower zigzag and moderate amplitude, and gamma curves appear zigzag, case-like, or campaniform with high amplitudes (Figure 5(G)). The EMI log of this microfacies exhibits an obvious change in lightness from light at the lower part to dark at the upper portion (i.e. from coarse to fine sediments) (Figure 5(F) and (H)).

3.6. Subaqueous levees

Subaqueous levees are characterized by the interbedded thin deposits of sandstone and mudstone with limited extensions (Figure 6(A)). The gamma curve is sharp or straight with little amplitude and dark ribbons in the images of EMI log (Figure 6(C)).

3.7. Subaqueous interdistributary channel

It refers to the gray or dark-gray sandy mudstone or sandstones interbedded with conglomerates of subaqueous channels, with horizontal or parallel bedding, cross-bedding occasionally. The gamma curve is straight, and interbedded light and dark ribbons are presented on the well logging images (Figure 6(D)).

3.8. Debris flow

Except for the gray color, this microfacies is similar with reddish mud flow microfacies in grain size, texture, and sediment compositions (Figure 6(B) and (E)).
3.9. Grain flow

Grain flow sediments are characterized by a depositional succession of coarsening-upward sequences (Li & Guo, 2000). It is composed of coarse sandstones with pebbles, fine conglomerates, and coarse conglomerates from bottom to top and rare sedimentary structures. A layer of grain flow deposition is not too thick, i.e. sand grain flow deposits are only several centimeters in thickness, although one layer of grain flow deposition mainly composed by gravels can be several centimeters to meter scale. Gamma curves of grain flow deposits present infundibuliform with serration. In the image curves, it displays color grading from dark to light from lower to upper or light points becoming bigger upward (Figure 6(F)).
4. Discussion: Sedimentary model of fluvial-dominated fan delta

Previous studies have shown that the reservoir characteristics are better than fan delta or alluvial fan, while the reservoir distribution has some fan features (Zhang et al., 2015) in the lower Urho Formation. We also found that the lower Urho Formation has a series of sedimentary characteristics of fan delta, but it has a key difference from alluvial fan and subaqueous fan, i.e. gravity flow; characterization of fan sedimentary characteristics occurred rarely in the lower Urho Formation.

Table 2 lists the similarities and differences of the main sedimentary characteristics among the common alluvial fan, fan delta, fluvial-dominated fan delta, and braided delta. Coarse-grained depositional system includes alluvial fan, fan delta, braided river delta, etc. Currently, the progress of research on alluvial fan deposition mainly includes the deepened research on the main factors controlling the development and evolution of such deposition and the application of diversified means to the establishment of its sedimentary models (Zhu et al., 2016).
The main factors controlling the development and evolution of alluvial fan mainly include piedmont tectonic activities, climate, material source, mountain pass landforms, base level lift, etc., and piedmont tectonic activities and climate are the main factors controlling the development of alluvial fan. The tectonic uplift amplitude controls the pattern and scale of the alluvial fan. Climate conditions influence the weathering extent of the mother rock and control the volume of clastic materials and hydrodynamic conditions in that drainage area, thus controlling the sedimentary characteristics of the alluvial fan. Geographic relief controls the pattern of the alluvial fan and its sedimentary characteristics; the steeper topographic slope shall render larger alluvial fan thickness, and such fan is dominated by conglomerate and sandstone; relatively gentle topographic slope shall render larger alluvial fan area, and such fan is dominated by conglomerate, sandstone, and siltstone. Base level lift influences the development pattern of the alluvial fan; base level ascending shall render thick alluvial fan deposition with a small area, whereas base level descending shall push such fan forward toward the basin, and therefore, the area of alluvial fan deposition is large.

Usually, a fan delta deposit is a kind of coarse clastic sedimentary system from the continental surface to the subaqueous formed by the alluvial fan into the lake (Galloway & Hobday, 1989; Xue & Galloway, 1991). It usually develops a series of microfacies, such as mud flow, braided channel, debris flow, subaqueous distributary channel, distributary mouth bar, etc. in the front delta; there is often some coarse-grained bore in the pre-delta mud. It is the important sedimentary characteristics for fan delta system that gravity flow deposits are dominant in it, in which the grain size is always coarse and mainly sandy conglomerates, few distributary channels distributed in the gravity flow deposits taking the form of small lenses in most cases, which is the product of the temporary channel for the fan on the flood. Sediments experienced only a little modification and a few distributary mouth bars. So this kind of fan delta resulted from a paroxysmal catastrophic incident bearing abundant material resources from a nearer area (Zhu et al., 2016).

Braided river delta is a common coarse-grained sedimentary type in continental basins. Its sedimentary models and main controlling factors are different from those of the fan delta (Xue & Galloway, 1991). Oil/gas exploration practices and scientific researches in recent years show that

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**Table 2. Comparison with sedimentary characteristics among four coarse-grained depositional systems**

| Characteristics                        | Type of channel of a river | Stability of channel       | Mechanism of transportation | Variability of flux     | Slope of landform | Sedimentary structure | Texture of sandstone | Ratio of sandstone and mudstone | Distributary mouth bar and sheet sandstone in front of the delta | The distance from resource area |
|----------------------------------------|---------------------------|----------------------------|----------------------------|------------------------|------------------|-----------------------|-----------------------|--------------------------|---------------------------------------------------------------|-----------------------------|
|                                        | Braided channel           | Without a fixed channel    | Gravity flow               | Paroxysmal            | Biggest          | Massive bedding       | Mainly disordered conglomerate | High                      | No                                                             | Nearest                     |
| Depositional model                     | Braided channel           | Extremely Unstable         | Gravity flow mainly        | Extremely largest     | Bigger           | Massive bedding and graded bedding | Mainly disordered conglomerate and sandy conglomerate | Higher                    | Extremely rare                                  | Nearer                     |
|                                        | Fan delta under arid climate conditions |                     | Tractive current mainly    | Larger                | Gentle           | Cross-bedding and fining-upward succession | Mainly disordered conglomerate and sandy conglomerate | Higher                    | Rare                                      | nearer                     |
|                                        | Delta under wet climate conditions |                     | Traction current mainly    | Large                  | Big or gentle    | Lateral accretion cross-bedding and massive bedding | Conglomeratic sandstone and sandstone with conglomerate | Highest                   | Few                                       | Near                        |
|                                        | Braided river delta       |                            |                            |                        |                  |                      |                       |                          |                                                              |                             |
Depositional systems of braided river deltas exist in Ordos, Tarim, and Bohai Bay basins in China (Dong, Yang, Chen, Wang, & Cao, 2014; Zhu, Deng, et al., 2013; Zhu, Pan, et al., 2013). In the margin of large-scale depression lake basin and faulted lake basin, the deltaic sedimentary area is closed to the source area, which is favorable for the sand/gravel-rich braided river with bedload to prograde into the Lake Basin and form a delta. Shallow-water sedimentary structures like erosion surface and large cross-bedding as well as intermittent depositional positive rhythm have been developed on such delta, the underwater distributary channels are well ramified, the sand body is thick and extends to a long distance; under the common control of tectonic activities, sedimentary source, seasonal flooding, lake level fluctuation and other factors, a coarse-grained composite sand body with the superimposition of multi-stage distributary channels is easily formed (Dong et al., 2014; Zhu, Pan, et al., 2013).

We learn that based on the number of microfacies recognized and described above, the lower Urho Formation of the Upper Permian in the 8th zone of the Karamay oilfield mainly consist of subaqueous channel, sieve and sheet flow deposits that cover a vast area, and rare mud flow deposits. A fluvial-dominated fan delta depositional system, consisting of the fan delta plain and front subfacies from the lower Urho Formation of the Upper Permian in the Karamay oilfield of Xinjiang, NW China, was recognized. The typical characteristics of this kind of fan delta are the depositional processes that were dominated by the fluvial and tractive current structure that developed very well, while pro-fan delta and gravity deposition occurred to a lesser degree. Pebble-braided rivers formed braided river plains for the fan delta plain in wet regions with perennial river (Hasiotis, Charalampakis, Stefatos, Papatheodorou, & Ferentinos, 2006; Yu, 2002) and landform with a genital slope, with much more distributary channels with a shallow cutting and fast migration (Reading, 1978); there developed dispersed parallel cross-bedding in the conglomerates bar, while it developed diversity cross-beddings in the channels’ pebbles and sandstones. The river channel extends to the subaqueous. The mud flow (and debris flow) deposits are rare due to perennial surface runoff. Because mud flow (and debris flow) deposits often developed in the drought area where there is a lack of rain, a lot of hillside wastes from weathering products accumulating will mix with the flood and then form high-density, high-viscosity flow—mud flow (or debris flow) when heavy rains come in the summer. Therefore, debris flow deposits in this area is less, and the river deposition, sieve deposition, filter flow deposits formed by low-viscosity flow distributed widely. Typical depositional succession of these deposits in the study area represents a normal fining-upward rhythm, i.e. conglomerate, sandstone, and mudstone from bottom to top. Beddings formed in high-energy regime, for example, cross-bedding of retrograde sand wave, are common. The braided channel that extended into the lake formed the subaqueous distributary channel with a variety of tractive current structures, which dominated the front delta.

Tectonic conditions and the size of the catchment basin have a strong influence on the distribution of the surface runoff, and the size of the basin area is proportional to the scope of the distribution of the fan delta (Yu, 2002). Meanwhile, around a depositional area of 40 km² of the extended lower Urho Formation, there are no sediments of predelta subfacies and rare deposits of distal front delta such as channel mouth bar and distal bar (Reading, 1978), where the front delta deposits is dominant and the distal front delta is out of the study area. All of these indicate that the depositional range of the fan delta in study area is very large. Therefore, this study suggests that the lower Urho Formation of the Upper Permian in the 8th zone of the Karamay oilfield is a depositional system of fluvial-dominated fan delta. It also suggests that the sedimentary water system is widely distributed, and terrain slope is not very big. In this context, even in drought areas, it can also develop fluvial-dominated fan delta.
The term of the fluvial-dominated fan delta here can also be defined as a wet fan delta; it differs from the dry fan delta or fan delta (Dang, Yin, & Zhao, 2004) in sediments and facies association. The former is characterized by the dominant deposits of channel microfacies, and the latter is mainly gravity flow deposits. In other words, gravity flow (including mainly mud flow in the plain delta and debris flow in the front delta) developed very well in the dry fan delta environment (Chen, Sun, & Jia, 2006; Meng et al., 2006), are rare or a very small-scale, while braided channel and subaqueous distributary channel microfacies are perfectly developed in the fluvial-dominated fan delta. Furthermore, the covering area of sediments from the fluvial-dominated fan delta may be much larger than the dry fan delta, and the cumulative thickness of sediments is also great. Thus, the fluvial-dominated fan delta is different from the common fan delta. Figure 7 is the sedimentary model of the fluvial-dominated fan delta.

5. Provenance analysis and sedimentary evolution

5.1. Provenance analysis

In this study, based on the EMI log of 15 wells, plenty of cross-bedding structures were recognized, and then the trend and dip of 443 cross-beddings and stratigraphy were measured and revised by Wulff net calibration. The total measured data from cross-bedding structures of the lower Urho Formation are listed in Table 3. The measured data number of rose maps of cross-bedding dip and average dip distribution of cross-bedding of the lower Urho Formation were worked out (Figure 8).

Figure 8(A) shows that the dips of cross-beddings from wells of T86120 and T85024 (southwest), and T85015 (south) and T85722 (southeast) present one dominant trend, while those of wells of T85006, T85072, T85713, 85607, etc. display two centralized trends, i.e. northeast and south or southeast. This fact indicates that at least two provenances exist in the periods when the lower Urho Formation was deposited.
Table 3. Statistic table of the average cross-bedding dip in the lower Urho Formation

| Well  | The 1st member | The 2nd member | The 3rd member | The 4th member | The 5th member |
|-------|----------------|----------------|----------------|----------------|----------------|
|       | Azimuth of average trend (°) | Number of cross-bedding | Azimuth of average trend (°) | Number of cross-bedding | Azimuth of average trend (°) | Number of cross-bedding | Azimuth of average trend (°) | Number of cross-bedding | Azimuth of average trend (°) | Number of cross-bedding |
| T85722 | 108.0          | 3               | 135.3          | 6              |                |                |                |                |                |                |
| T85601 | 100.3          | 3               | 68.0           | 5              | 91.8           | 4              |                |                |                |                |
| T85689 | 111.0          | 3               | 126.5          | 9              | 66.2           | 5              | 56.2           | 2              |                |                |
| T86277 | 111.4          | 7               | 126.3          | 8              | 82.0           | 9              |                |                |                |                |
| T86245 | 140.8          | 2               | 107.6          | 13             | 90.2           | 7              | 75.5           | 2              |                |                |
| T85713 | 125.6          | 20              | 92.8           | 13             | 86.5           | 11             | 48.6           | 5              | 102.5          | 3              |
| T85027 | 157.7          | 3               | 117.4          | 10             | 108.4          | 7              | 65.5           | 2              | 56.2           | 2              |
| T85006 | 184.7          | 3               | 139.9          | 16             | 134.6          | 5              | 71.8           | 5              | 56.8           | 6              |
| T85462 | 164.3          | 21              | 162.8          | 20             | 116.1          | 8              | 51.0           | 8              | 36.2           | 3              |
| T85015 | 150.9          | 7               | 165.2          | 6              | 162.0          | 1              |                |                |                |                |
| T85024 | 167.7          | 25              | 176.2          | 11             | 160.0          | 4              |                |                |                |                |
| T86120 | 200.1          | 18              | 172.7          | 15             | 169.4          | 7              |                |                |                |                |
| T86166 | 155.7          | 18              | 123.4          | 17             | 159.3          | 3              |                |                |                |                |
| Total amount | 153.3         | 131             | 130.5          | 158            | 120.3          | 96             | 71.2           | 42             | 61.6           | 16             |

Figure 8. Rose map of cross-bedding dip and the current direction of the lower Urho Formation in the study area.
For the 5th member of the lower Urho Formation, except well T85713 in which the average dip trend is east, the other four wells' average dip trend of cross-beddings is northeast, which supports a southwest provenance. The provenance of the 4th member succeeded the 5th; seven wells' average dip trend of cross-beddings is mainly northeast and a southwest provenance except for wells of T85601 and T86277's eastern average dip trend (Figure 8(B)). Although average dip trend from the 3rd member changed to southeast, some wells represent northeast average dip trend, which suggests that the southwest provenance in the depositional periods of the 5th and 4th members was replaced gradually by a northwest provenance (Figure 8(B)). As for the depositional period of the 2nd member, northeast provenance was completely replaced by a southeast one, and a poor south provenance was added (Figure 8(B)).

The above statement indicates that three changeable provenances had prevailed in the period of the late Permian. They were, respectively, located at the southwestern and northern area of wells 805, 8545, and JY5 and northwestern region around well 805 (Figure 8(C)). These three provenances have played different roles in different periods during which the lower Urho Formation was deposited.

5.2. Sedimentary evolution

Combining the stratigraphy distribution (Lei et al., 2005), sedimentary facies (Xing, Zhu, Kuang, Aa, & Liu, 2006) and palaeocurrent research, sedimentary evolution of the lower Urho Formation experienced two big cycles and formed two sequences. Members 5 to 3 comprise sequence I; members 1 and 2 constitute sequence II. Member 5 is mainly distributed in the lower part of the paleotopography, which gradually overlapped upward to the top of the monoclinic slope (Figure 9(A)). The depositional area of the 4th member was most widely distributed by fan delta front subfacies; moreover, the microfacies types were most complete than other members (Figure 9(B)). After the 3rd member deposition, the southwestern part of the study area rose up and suffered from erosion, and the local unconformity formed between member 2 and member 3. Corresponding to lake level fluctuation and changing of provenance directions, the sedimentary facies also changed. From period 5 to 4, deposited range increased gradually, and the proportion of the plain delta decreased, while the proportion of the front delta increased and reached the maximum at the end of the fourth member deposition. From period 4 to 3, the depositional range of the front delta decreased, accompanying the plain delta continuously extending from the southwestern edge to the northwestern edge. After the 3rd member deposition, which was affected by rising and suffering from erosion in the southwest of the study area, the plain deposit remained less in the southwestern edge (Figure 9).

The 1st and 2nd members remained incomplete, especially missing much more on the uppermost part. At the beginning of the 2nd member deposition, water quickly overlapped to the southwest direction, which makes the range of sedimentary records in member 2 larger than those in the period of member 3 deposition. Member 1 remained less because of late denudation. During the 2nd member deposition, the plain delta had quite a wide range, but later, the plain area decreased, and the front of the delta deposits increased with the transgression toward the southwest. With the lake level down during the 1st member deposition, the range of the front delta reduced, and the plain deposits increased. But now, member 1 maintains a narrower range due to late erosion (Figure 9(D) and (E)).
Figure 9. Sedimentary evolution of the lower Urho Formation in the 8th area of Karamay oilfield.
6. Conclusions

The lower Urho Formation of the Upper Permian is considered as sediments of a fluvial-dominated fan delta facies, which mainly consists of fan delta plain and fan delta front subfacies. This delta is controlled by river and main channel sediments and rare gravity flow deposits. Nine key microfacies of fluvial-dominated fan delta were recognized, i.e. braided channel, sheeted flow, mud flow and sieve deposits in fan delta front subfacies and subaqueous channel, inter-distributary, debris flow, grain flow, and subaqueous levee in fan delta plain subfacies. The distribution of cross-beddings dip, based on EMI log, indicates that four provenances prevailed in the period of Late Permian: southwestern, northwestern, northern and northeastern, which implies a paleo-landform with high in the west and lower in the east that had existed in the Late Permian in the northern Junggar Basin.

Funding

This research was supported by the National Natural Science Foundation of China Projects [grant numbers 41272021, 41372109]; China Geological Survey Project [grant number 12120115068901].

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Citation information

Cite this article as: Sedimentary facies and evolution of the lower Urho Formation in the 8th area of Karamay oilfield of Xinjiang, NW China, Hongwei Kuang, Guangchun Jin & Zhenzhong Gao, Cogent Geoscience (2017), 3: 1333667.

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