Microfacies and platform characteristic of the Ordovician in the northwestern Tarim Basin, NW China

Xiaolan Hu¹, Bo Li¹, Xiaozhi Chen², Keyan Hong¹, Shenglin Jiang¹, Liangliang Zhu¹ and Di Wang¹

¹China Huadian Green Energy Corporation, Beijing 100160, China
²CNOOC Research Institute, Beijing 100027, China

The corresponding author: Xiaolan Hu; e-mail: huxl@cg.com.cn; telephone: +86 10 135-8189-8840

Abstract. The Ordovician deposition is characterized by a thick carbonate in the Tarim Basin. In northwestern section of the basin, rocks are chiefly deposited in a carbonate ramp. Twelve microfacies have been distinguished on the basis of their depositional textures and petrographic analysis. Four depositional belts such as tidal flat, lagoon, shoal and open marine can be identified.

1. Introduction
The Tarim basin was in a carbonate platform environment in the Ordovician, with more than one thousand meters carbonate deposited. Many oil reservoirs have been discovered in the Tarim basin. Previous studies shows the palaeogeographic of the Tarim basin; shallow platform and various banks deposited in the western area of the basin; the slopes and ramps developed in the east and south part types of the reservoirs: dolomite reservoir, grainy banks reservoir and reef-bank complexes reservoir as a result of environmental change. This paper is to present the different microfacies; to interpret the depositional environment of the Ordovician based on field and petrographic observation, which are beneficial for further exploration of the carbonate bank reservoirs.

2. Geological setting and method
The Tarim basin, NW China has undergone several phases of structural deformation and formed the major structural elements (Figure 1a)[3]. Nearly the entire Paleozoic section in the Tarim basin is comprised of marine strata and the Ordovician consists of Penglaiba, Yingshan, Yijianfang, Tumuxiuke, Lianglitage and Sangtamu Formations upwards. The carbonate platform sediments started with massive dolomite and banded dolomitic limestone at the upper Penglaiba Formation, then followed by dolomitic limestone of the Yingshan Formation, lastly grainy limestone of the Yijianfang Formation and the Lianglitage Formation(Figure 1b)[2]. Two sections, section A located at Keping area and section B located at the northwest Bachu area. Our results are concluded from the field sections and approximately 200 thin sections sourced from section A and section B. The carbonate classification and microfacies analysis follow the scheme of Dunham[4] and Flügel[5]. The petrographic observations lead to the definition of depositional microfacies, which can be attributed to depositional characteristics and development conditions.

3. Sedimentary analysis
Petrographic analysis led to the recognition of thirteen microfacies of the Ordovician in the Tarim basin, which can be attributed to four facies belts. These microfacies are described from shallow to deep environment.

### 3.1. Tidal flat

Three microfacies are associated with tidal flat and mainly composed of fine crystalline dolomite and algal peloids.

#### 3.1.1. MF1, dolomite mudstones

This microfacies consists mainly of dense, tightly packed, light to grey, very fine to fine crystalline dolomite (Figure 2a and 2b). The deposits of this microfacies are devoid of macrofossils. Bioclasts in thin sections are very rare. The intraclasts and scattered detrital quartz grains, laminas and fenestral fabrics can be observed. Interpretation: The features of the thin sections are small crystal size, fabric, scattered detrital silt-size quartz, preserved original depositional textures and absence of fossils. All of the above suggest these dolomite mudstones are formed under near surface, low-energy conditions. It is probably in a tidal flat setting.

#### 3.1.2. MF2, fenestral algal bindstones

This microfacies consists of fine grained fenestral algal bindstones\(^5\) with fine plannar, formed by alternation of dark micritic laminae and spritic laminae (Figure 2c and 2d). Bioclasts are absent, fenestrate structures are well developed. Sparry cement (blocky or granular) is the most frequent pore-filling material. Interpretation: Birdseye or fenestral structures are typical products of shrinkage and expansion, gas bubble formation, and air escape during flooding, or may even result from burrowing activity of worms or insects. Fenestral bindstones of algae and the vuggy structures are typical in a tidal flat zone\(^6\). The intraformational breccia is interpreted as a reworked deposit originated in an intertidal-shallow subtidal environment, probably by desiccation, fracturing and erosion of semilitihfied carbonate mud from the underlying substrate or from horizons that underwent subaerial exposure.

#### 3.1.3. MF3, aggregate grain grainstones

This microfacies consists of peloids, subangular intraclasts, aggregate lumps, calcareous green algae. Bioclast-bearing peloidal mudstones and aggregate grainstones are poorly represented (Figure 2e and 2f). A few scattered small-sized intraclasts and bioclasts occur as well. Contacts between a grainstone with moderately sorted, with fine to medium size intraclasts and a fine-grained aggregate grains and amalgated peloids are clearly developed. Interpretation: The depositional environment of this microfacies can be interpreted as restricted shallow subtidal environment. The sub-angular to round grains and well-lighted conditions are deduced from common burrowing and abundance of algae. Aggregate grains are ascribed to a shallow...
subtidal environment with restricted circulation. The restricted circulation condition is indicated by low-diversity biota dominated by a few taxa adapted to salinity fluctuations. Micrite laminae point to microbial binding of the sediment.

3.2. Lagoon

Two microfacies are associated with each other in this environment. Both are composed mainly of peloid, green algae and benthic foraminifera.

3.2.1. MF4, mudstones. This microfacies consists of intensely bioturbated calcimudstones, shells and intraclasts. The lime mud generally comprises from 90-100 percent of this rock. Bioclasts such as fragments of green algae, benthic foraminifera, echinoids are very rare, and very few bivalves scattered (Figure 3a and 3b). Interpretation: This microfacies is considered to be deposited in a lagoon environment. Evidence for this interpretation includes the paucity of fauna both in diversity and abundance, and lack of subaerial exposure feature.

3.2.2. MF5, bioclast wackestones. Echinoid debris (40%) is the most abundant components in this microfacies. Most of the echinoid debris is polymodal in size, ranging from 0.2mm to 0.6mm, with an average size of 0.3mm. Other components are dasyclads, peloids and benthic foraminifera (Figure 3c and 3d). Interpretation: This microfacies should be situated in the margin of a lagoon. The light condition and well sorted bioclasts indicate that a moderate to high energy environment is influenced by tidal currents near shoal.

3.3. Shoal

Six microfacies are associated with shoal depositional belt, and they are composed mainly of peloids, intraclasts, oolites, green algae, echinoid and benthic foraminifera. Reefs developed in the Yijianfang Formation of the middle Ordovician and the skeleton and bioclasts are the main components of the reefs (Figure 4a and 4b).

3.3.1. MF6, dolomite-intraclast grainstones. The dolomite grains and intraclasts are the main components of this microfacies, up to approximately 95%. The dolomites show euhedral and two metasomatisms, which indicate that the dolomites come from intraclasts. Intraclasts are polymodal in size, ranging from 3mm to 1.2cm, with an average size of 0.8cm. Most of the intraclasts are well rounded. Others display internal compositions such as the bioclasts and re-working oolites, the native shapes can be observed by microscope (Figure 5a). Interpretation: The features of this microfacies indicate a moderate energy shallow-water condition with significant movement and reworking of intraclasts. This microfacies is interpreted as shoal environment effected by tidal current.

Figure 2. Microfacies (tidal flat). (a) Dolomite mudstones with laminae; (b) Dolomite mudstones, (c) Fenestral algal bindstones with birdseye structure; (d) Fenestral algal bindstones; (e) Aggregated-grain grainstones; (f) Aggregated-grain grainstones with some quartz and weathering features.
3.3.2. MF7, Intraclast grainstones. The major components of this microfacies are intraclasts. The intraclasts are well sorted and rounded, taking up a volume of 90%. The grains sizes are from 0.6cm to 1.6cm, with an average of 1.2cm. Bioclasts and re-working oolites are rarely observed (Figure 5b). All of the grains are cemented by sparry calcite. Interpretation: grainstone texture and cement indicate the microfacies is deposited in high-energy area, which is considered as a shoal facies.

3.3.3. MF8, oolite grainstones. This microfacies consists of a large amount of micritic envelopes, coated grains and oolites. Thin sections contain 85% of oolites which are well sorted, showing thinly laminated fine-radial cortices and bioclasts, peloids, and quartz grains in the cores (Figure 5c). Bioclasts and other composition are very rare. All the grains are cemented in sparry calcite. Interpretation: the dominant grainstone texture, scarce bioturbation and no micritic matrix indicate active shoals are developed in open-marine high-energy areas, located above or around the fair-weather wave base and the central part of a shoal.

3.3.4 MF9, bioclast-intraclast grainstone. Intraclasts are the main components of this microfacies, up to approximately 85%. Intraclasts are polymodal in size, ranging from 1mm to 3mm, with an average size of 2mm. The intraclasts are well rounded. Others compositions such as the bioclasts and oolites, the native shapes can be observed by microscope (Figure 5d). All the grains are cemented by sparry calcite. Interpretation: the features of this microfacies show a moderate energy shallow-water condition with significant movement and reworking of bioclasts. This microfacies is interpreted as a leeward shoal environment, because of abundant typical lagoon skeletal fauna including benthic foraminifera with imperforate walls, gastropods, green algae, and intraclasts and oolites in sparry calcite cement.

3.3.5 MF10, bioclast grainstones. This microfacies is characterized by abundant Girvanella coral colonies and echinoid debris that are mostly in growth position. Some corals are coated by coralline algae, the coralline algae are important as both sediment and framework-building organisms in this microfacies. The bioclasts are almost 90% and cemented by sparry calcite (Figure 5e and 5f).
Interpretation: this microfacies is considered to be formed by in situ organisms as an organic reef in margin of the platform and located above the fair-weather base.

3.3.6 MF11, bioclast packstones. The main characteristics of this microfacies are rudists, Girvanella coral fragments, echinoids, crinoid debris, peloids and undifferentiated small benthic foraminifera. Minor particles include sponge spicules, gastropod debris, green algae, and large benthic foraminifera. Relatively high degrees of fragmentation exist in the large benthic foraminifera. The grains are almost 75% and subangular cemented by sparry calcite (Figure 5g and 5h). Interpretation: the depositional environment is regarded as high-energy and is located at the seaward in a shoal of the platform. This interpretation is supported by the faunal comments, grainstone texture, the size, high degree of fragmentation of bioclasts and the sparry cement.

3.4. Open marine

The open marine environment is mainly in Tumuxiuke Formation in Bachu area and it developed about 20m shale and it is a type of black shale in Shaergan Formation of Keping area (Figure 6a and 6b). One microfacies is identified in this environment and composed mainly of sponge spicules and micrite.

3.4.1. MF12, bioclast mudstone/marls. This microfacies is dominated by sponge spicules and radiolarias. Peloids are scarce in this microfacies (Figure 6c and 6d). Interpretation: the occurrence of radiolarian indicates that this microfacies belongs to the deepest part of the open marine environment[5]. Abundant radiolarian indicates deep, cold water environment.

Figure 5. Microfacies (shoal). (a) Dolomite Intraclast grainstone, leeward shoal; (b) Intraclast grainstone with sparry calcite cement; (c) Oolite grainstones, well sorted; (d) Bioclast – intraclast grainstone: with echinoids and crinoids fragments; (e) Bioclast grainstones, fragments of forams, coralline algae and crinoids, echinoids; (f) Bioclast grainstones with the reef skeletons and the echinoids debris; (f) Bioclast packstones with Girvanella coral fragments; (h) Bioclast packstones, echinoids, crinoid debris, peloids and undifferentiated small benthic foraminifera scattered.

Figure 6. Field view and petrography characteristics of the open marine. (a) Field view of the Tumuxiuke Fm. of the Bachu section; (b) The local feature of the mudstone in the open marine of the Keping section, black shale and limestone interlayers; (c) Mudstones/marls, radiolarian sponge spicules wackestone representing deep open marine; (d) Mudstones, fine crystal calcite.
3.5. Conceptual model
Based on the detailed microfacies analysis, a conceptual 3D depositional model is shown in Figure 7, integrating the regional knowledge of facies distribution of the Ordovician. The tidal-flat belt is moderate-high energy depositional environment. The subtidal subfacies form the tidal-dominated shoal in the open shelf and contain intraclasts and aggregated grains. The intertidal-supratidal includes the reworking of partly lithified microbial laminites and finely grained, burrowed dolomudstone formed in a low energy environment; the lagoon is low energy depositional environment, fauna are rare and the fine to very fine pack-mudstone indicate quite sheltered conditions; the shoal deposits include intraclasts, oolites and the coral and reef fragments which are formed sediment reworking by storms in the seaward direction and by the tides in the leeward direction; the open marine mainly include the fine sedimentary deposit in the low energy environment.

![Figure 7. Depositional conceptual model of Ordovician in the northwestern area](image)

4. Conclusions
Ordovician sediments deposited on a carbonate ramp in the northwestern Tarim Basin. Thirteen microfacies are identified and are grouped into four depositional belts: tidal flat, lagoon, shoal and open marine. The dolomite mudstones (MF1), fenestral algal bindstones (MF2), aggregate grain grainstones (MF3) belong to the tidal flat facies; the mudstones (MF4) and bioclast wackestone (MF5) are classified in the lagoon depositional belt; the dolomite - intraclast grainstones (MF6) and intraclast grainstones (MF7), oolite grainstones (MF8), bioclast - intraclast grainstones (MF9), bioclast grainstones (MF10) and bioclast packstones (MF11) are classified into the shoal facies; the mudstones/marls (MF12) are categorized into the open marine.

Acknowledgments
This research was financially supported by the Key Project of the National Science & Technology grant (2016ZX05034004-004).

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