PS Control of Stratigraphic Sequence on Karst Reservoirs: A Case Study on the Ordovician Carbonate Reservoirs in the North Tarim Basin, China*

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Abstract

Paleokarstification is one of the key elements in the formation of the Ordovician carbonate reservoirs in the north uplift of Tarim Basin. Based on the regional stratigraphic correlation and comprehensive studies on cores, thin sections, FMI and testing, the significant control of stratigraphic sequence on paleokarst has been uncovered and demonstrated as follows: (1) The primary deposition controlled by stratigraphic sequence laid the material foundation of the karst reservoirs. Organic reefs and biodetritus beaches constituted the primary deposits under the background of a low sea level and high-energy environment, in which case the primary pores provided relatively large porosity and good lateral connectivity, contributing to the shaping of the pore-cavity reservoirs and fracture-cavity reservoirs in the karst stages. (2) The sequence evolution enhanced the development of faults and fracture density which played an essential role in the fluids flow and the dissolution of the rocks during the late diagenesis stages. The conversion from an extension environment to compression environment in the Middle Ordovician led to the difference in the rocks that the Lower-Middle Ordovician carbonate rocks were relatively pure, whereas the Upper Ordovician carbonate rocks were high in mud. These two types of strata were quite different in lithology and mechanical properties, and the Lower-Middle Ordovician was more inclined to form large-scale faults and fractures under the double effects of tectonic uplifts and strike-slip motion. These development areas of fractures and faults provided good conditions for the formation of large-scale fracture-cavity aggregations. (3) The sequence boundaries formed directional zones for fluids movement, which was favorable for the fluids migration and the formation of large karst caves. The fluids movement followed a certain regularity and can be summarized as two types: the descending type and the ascending type. For the descending type, the atmospheric water either transformed the exposed surface and the near-surface strata of the carbonate paleo-uplift into karst landform or continued to migrate along the beds laterally or along the faults downward vertically. For the ascending type, the buried fluids that included organic acid, acidic gas or volcanic hydrothermal solution, ascended from the deep through the faults, unconformity surfaces or the passages in beds, reconstructing the pores and caverns that had already existed before.

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INTRODUCTION

Paleokarstification is one of the key elements in the formation of the Ordovician carbonate reservoirs in the Tabei uplift of Tarim Basin *(Figure 1)*. The sequence stratigraphy and the associated tectonic activities influenced the original sedimentation and the fracture systems, which provided material basis and percolation passages for the later karstification. The sequence stratigraphy also affected the horizontal and vertical karst distribution by controlling the unconformities and the varied paleo-water tables.

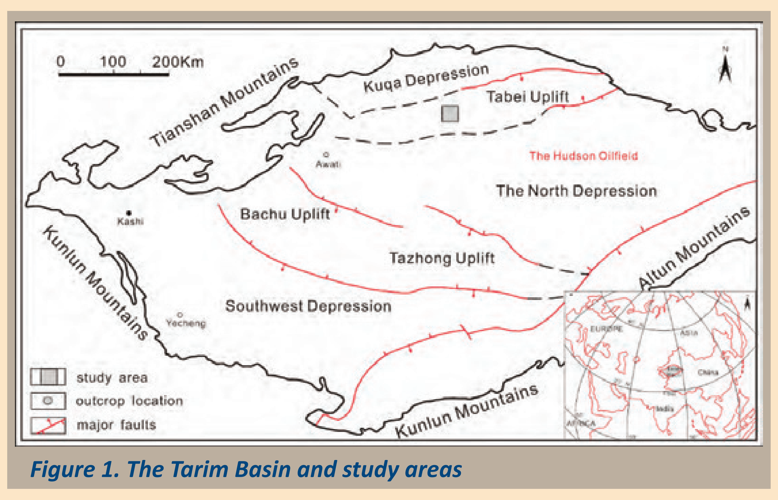

Figure 1. The Tarim Basin and study areas

METHODS

Seismic interpretation, regional stratigraphic correlation, core observation, thin sections study and well logging interpretation were conducted and combined in order to figure out the relationship between sequence and karstification.

SEQUENCE STRATIGRAPHY

2nd-order sequences

The sequence in Halahatang area can be divided into two 2nd-order sequences, both lacking the LST. The surface between these two 2nd-order sequences is a tectonic turnaround surface from extensional basin to compressional basin.

The lower sequence was cratonic carbonate platform sedimentation including Penglaiba (O_1p), Yingshan ($O_{1-2}y$) and Yijianfang (O_2y) formations. It was an asymmetrical cycle with the rising cycle dominating. The upper sequence transformed to a compressional basin margin sedimentation. It was also a asymmetrical cycle but with the descending cycle dominating *(Figure 3, Figure 5)*.

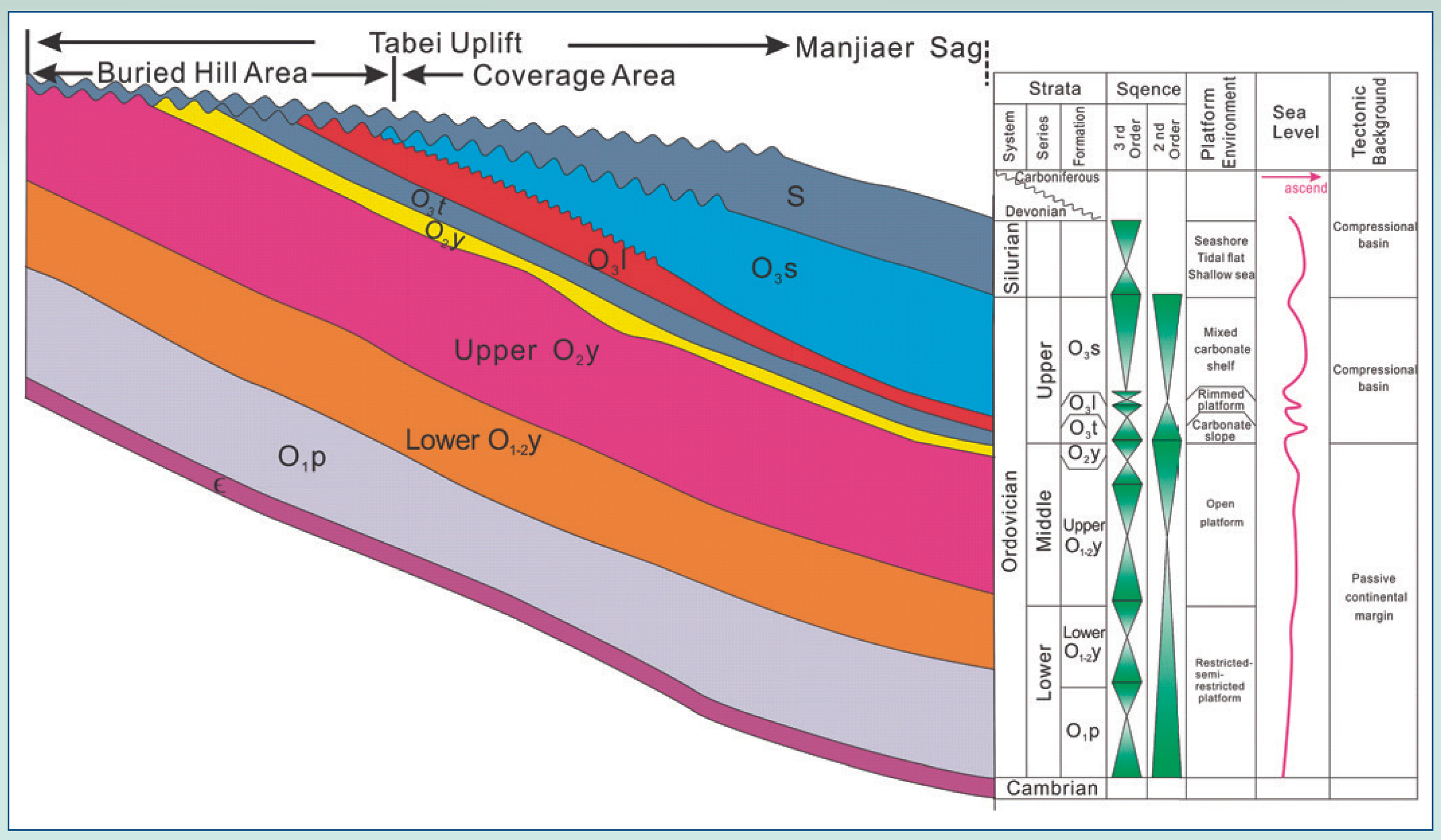

Figure 3. The sequences in the Halahatang area

GEOLOGICAL SETTINGS

Halahatang Oilfield is situated on the Tabei uplift of Tarim Basin with the Ordovician karsted carbonate rocks as its main reservoirs. It is able to be subdivided into two major areas horizontally: the buried hill area and coverage area *(Figure 3)*. The main oil producing layers are centered on Yingshan and Yijiangfang formations. The carbonate rocks experienced multi-period tectonic activities and karstification, resulting in extremely complicated landform, reservoir space and high heterogeneity *(Figure 2, Figure 4)*.

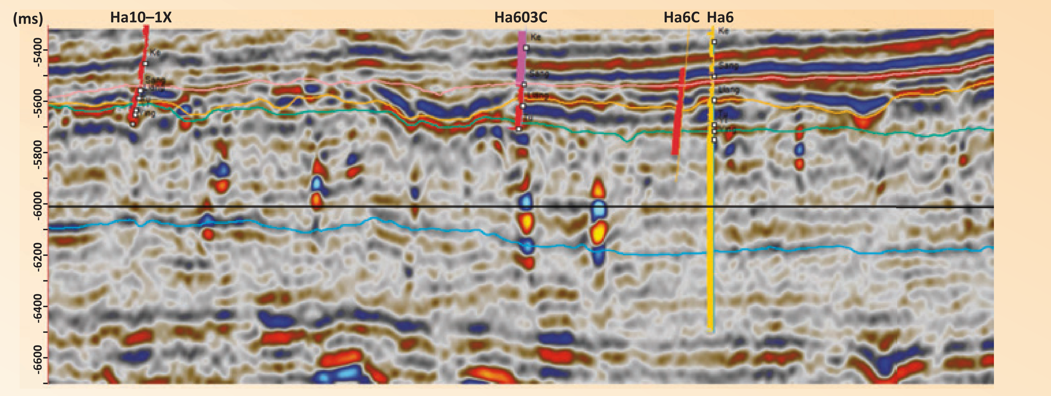

Figure 2. Effective reservoirs act as vertical strong-amplitude "beads" on seismic profile

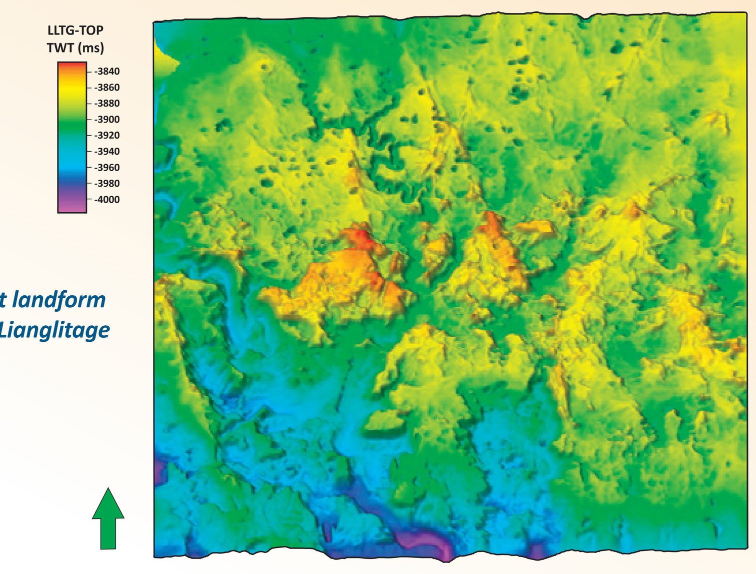

Figure 4. Karst landform on the top of Lianglitage Formation

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SEQUENCE STRATIGRAPHY

3rd-order sequences

The lower 2nd-order sequence with a over 1000m depth, is composed of three 3rd-order sequences. The first two 3rd-order sequences constitute the TST of the 2nd-order sequence, and the third 3rd order sequences forms the HST of the 2nd-order sequence. Penglaiba (O_1p) and the lower Yingshan ($O_{1-2}y$) formations constitute one 3rd-order sequence. The lithology is mainly dolostone in the Penglaiba (O_1p) formation and limestone in the lower Yingshan ($O_{1-2}y$) formation. The percentage of dolomite decreases upward. The upper Yingshan ($O_{1-2}y$) formation and Yijiangfang (O_2y) make up two 3rd order sequences separately. There is some dolomite distributed in the upper Yingshan formation, however in the Yijianfang formation, little dolomite exists.

The upper 2nd-order sequence is composed of three 3rd-order sequences as well. The Tumuxiuke (O_3t) and the Lianglitage (O_3l) formations are two separate 3rd-order sequences, which constitute the HST of the upper 2nd-order sequence. The Sangtamu (O_3s) formation, the third 3rd-order sequence, makes up the HST of the upper 2nd-order sequence. Because of the transition of the basin attribute from extensional to compressional, the lithology is higher in clast compared with that in the lower 2nd-order sequence.

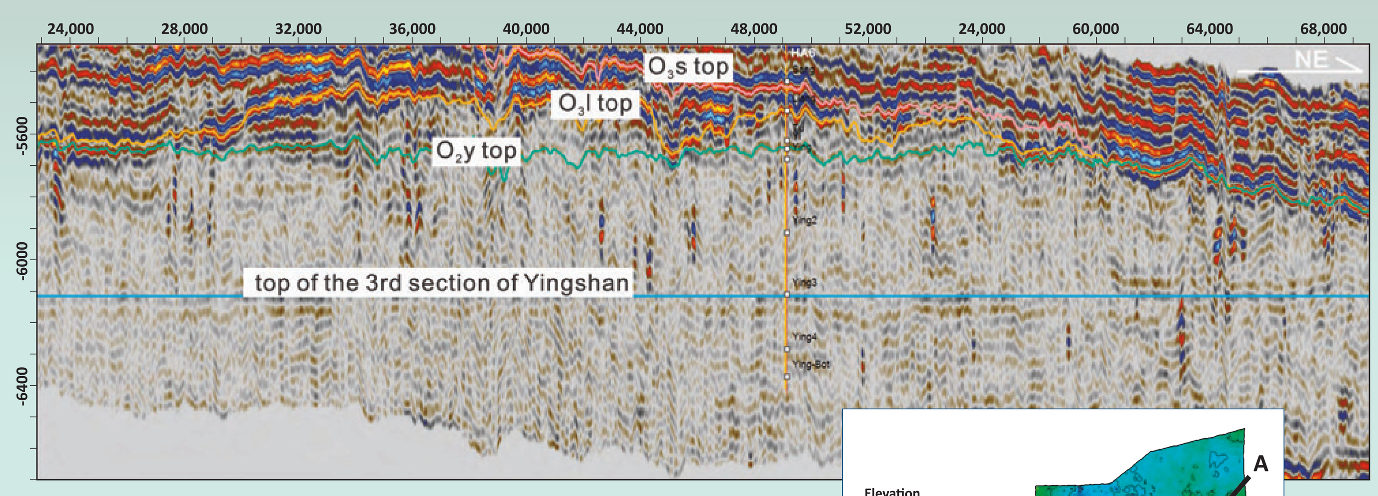
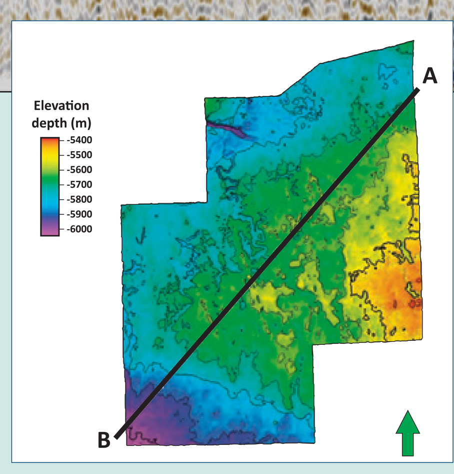


Figure 5. High-frequency profile of the seismic volume flattened at the top of the 3rd section of Yingshan Formation



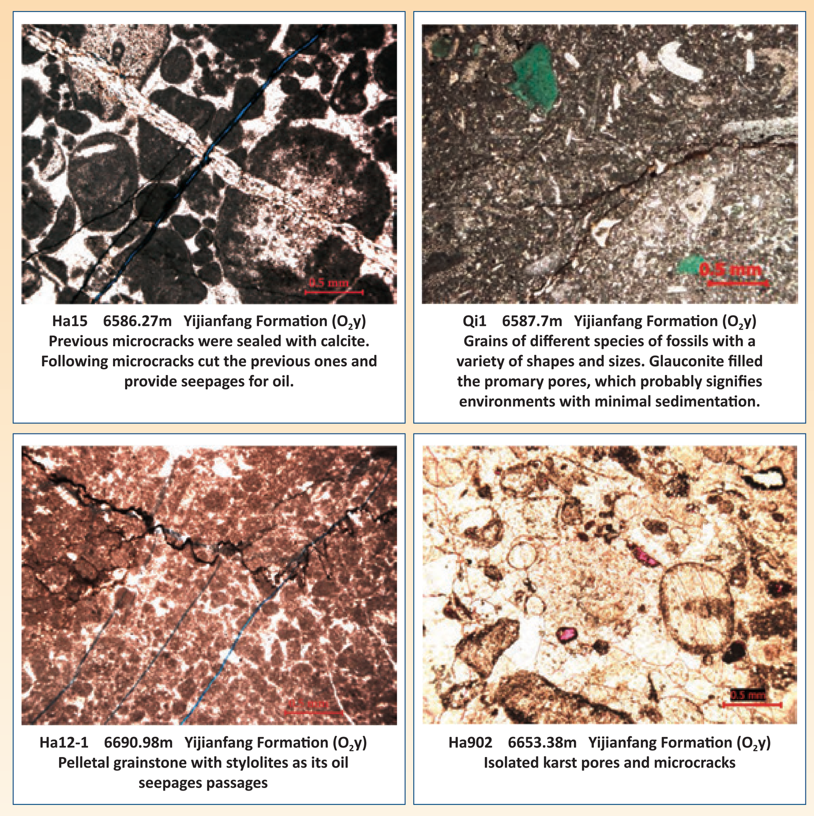
CONTROL ON KARSTIFICATION

The significant control of stratigraphic sequence on paleokarst has been uncovered and demonstrated as follows:

1. The primary deposition controlled by stratigraphic sequence laid the material foundation of the karst reservoirs.

Effective reservoirs are mainly found in the Yingshan formation and the Yijiangfang formation. The Yingshan formation and the Yijianfang formation were all sedimented in the open platform environment. The Yingshan formation was mainly Intraplatform shoal and Intraplatform depression sedimentation and the Yijiangfang formation was mainly Intraplatform shoal and patch reefs *(Figure 6, Figure 7)*.

Organic reefs and biodetritus beaches constituted the primary deposits under the background of a low sea level and high-energy environment, in which case the primary pores provided a relatively large porosity and a good lateral connectivity, contributing to the shaping of the pore-cavity reservoirs and fracture-cavity reservoirs in the karst stages.



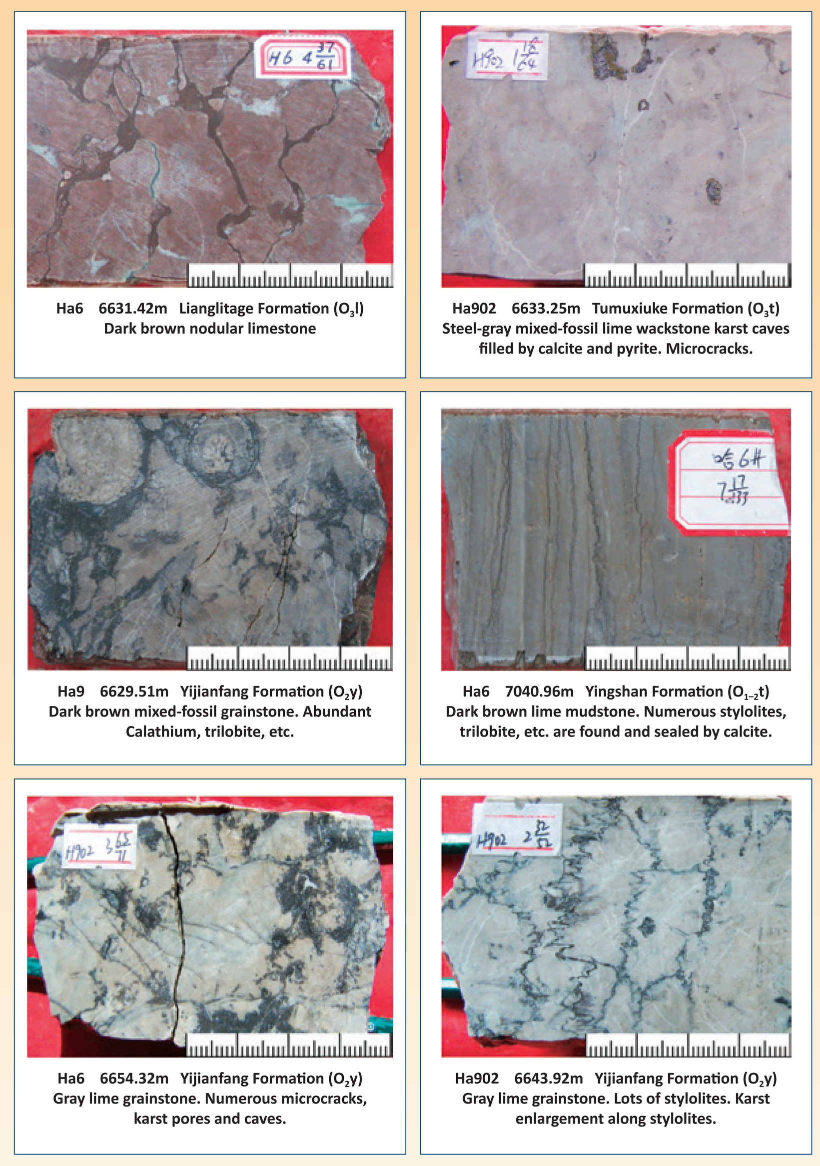
Ha15 6586.27m Yijianfang Formation (O_2y)
Previous microcracks were sealed with calcite. Following microcracks cut the previous ones and provide seepages for oil.

Qi1 6587.7m Yijianfang Formation (O_2y)
Grains of different species of fossils with a variety of shapes and sizes. Glauconite filled the promary pores, which probably signifies environments with minimal sedimentation.

Ha12-1 6690.98m Yijianfang Formation (O_2y)
Pelletal grainstone with stylolites as its oil seepages passages

Ha902 6653.38m Yijianfang Formation (O_2y)
Isolated karst pores and microcracks

Figure 6. Typical thin sections of Ordovician carbonate rocks in Halahatang area



Ha6 6631.42m Lianglitage Formation (O_3l)
Dark brown nodular limestone

Ha902 6633.25m Tumuxiuke Formation (O_3t)
Steel-gray mixed-fossil lime wackstone karst caves filled by calcite and pyrite. Microcracks.

Ha9 6629.51m Yijianfang Formation (O_2y)
Dark brown mixed-fossil grainstone. Abundant Calathium, trilobite, etc.

Ha6 7040.96m Yingshan Formation ($O_{1-2}t$)
Dark brown lime mudstone. Numerous stylolites, trilobite, etc. are found and sealed by calcite.

Ha6 6654.32m Yijianfang Formation (O_2y)
Gray lime grainstone. Numerous microcracks, karst pores and caves.

Ha902 6643.92m Yijianfang Formation (O_2y)
Gray lime grainstone. Lots of stylolites. Karst enlargement along stylolites.

Figure 7. Typical cores of Ordovician carbonate rocks in Halahatang area

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2. The sequence evolution enhanced the development of faults and fracture density which played an essential role in the fluids flow and the dissolution of the rocks during the late diagenesis stages.

The conversion from extension environment to compression environment in the Middle Ordovician led to the difference in the rocks that the Lower-Middle Ordovician carbonate rocks were relatively pure, whereas the Upper Ordovician carbonate rocks were high in mud. These two types of strata were quite different in lithology and mechanical properties and the Lower-Middle Ordovician was more inclined to form large-scale faults and fractures under the double effects of tectonic uplifts and strike-slip motion *(Figure 7, Figure 8)*. These development areas of fractures and faults provided good conditions for the formation of large-scale fracture-cavity aggregations.

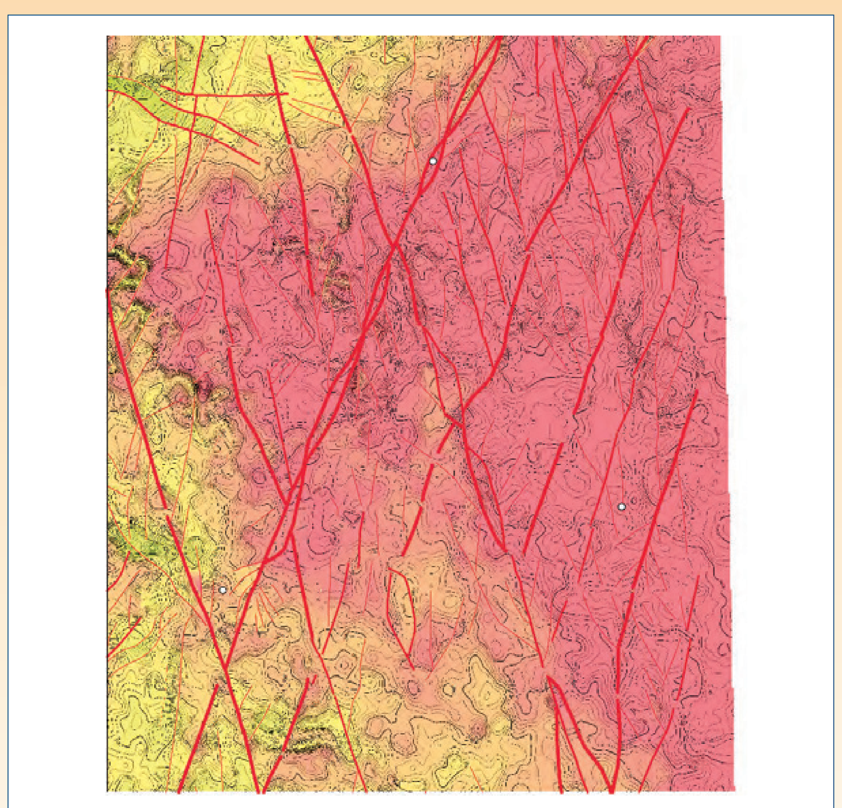
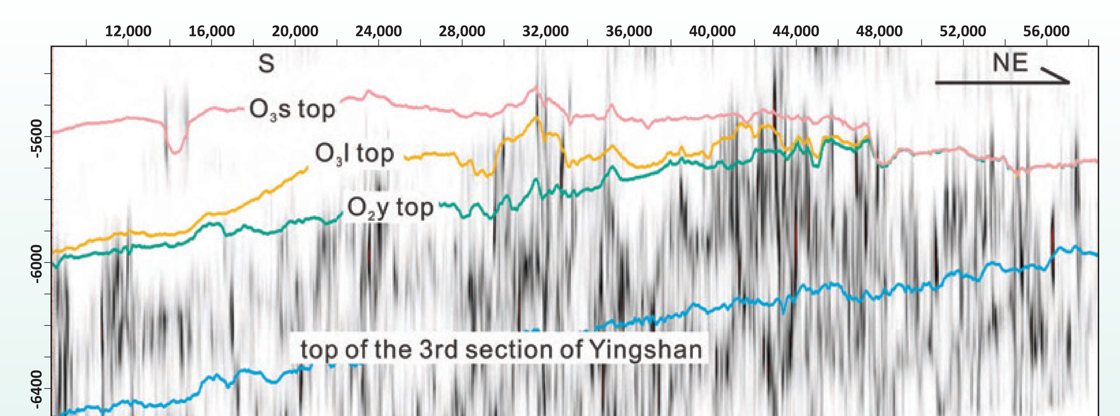


Figure 8. Planar distribution of the strike-slip faults in Halahatang area



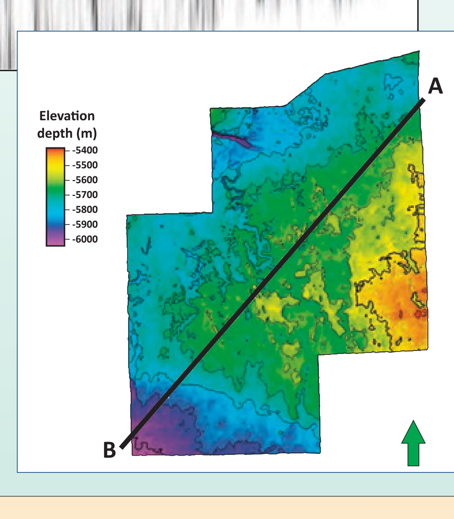


Figure 9. Coherence profile of the Halahatang area (NE–SW)

Note that the vertical faults are mainly found in Yijiangfang Formation and Yingshan Formation

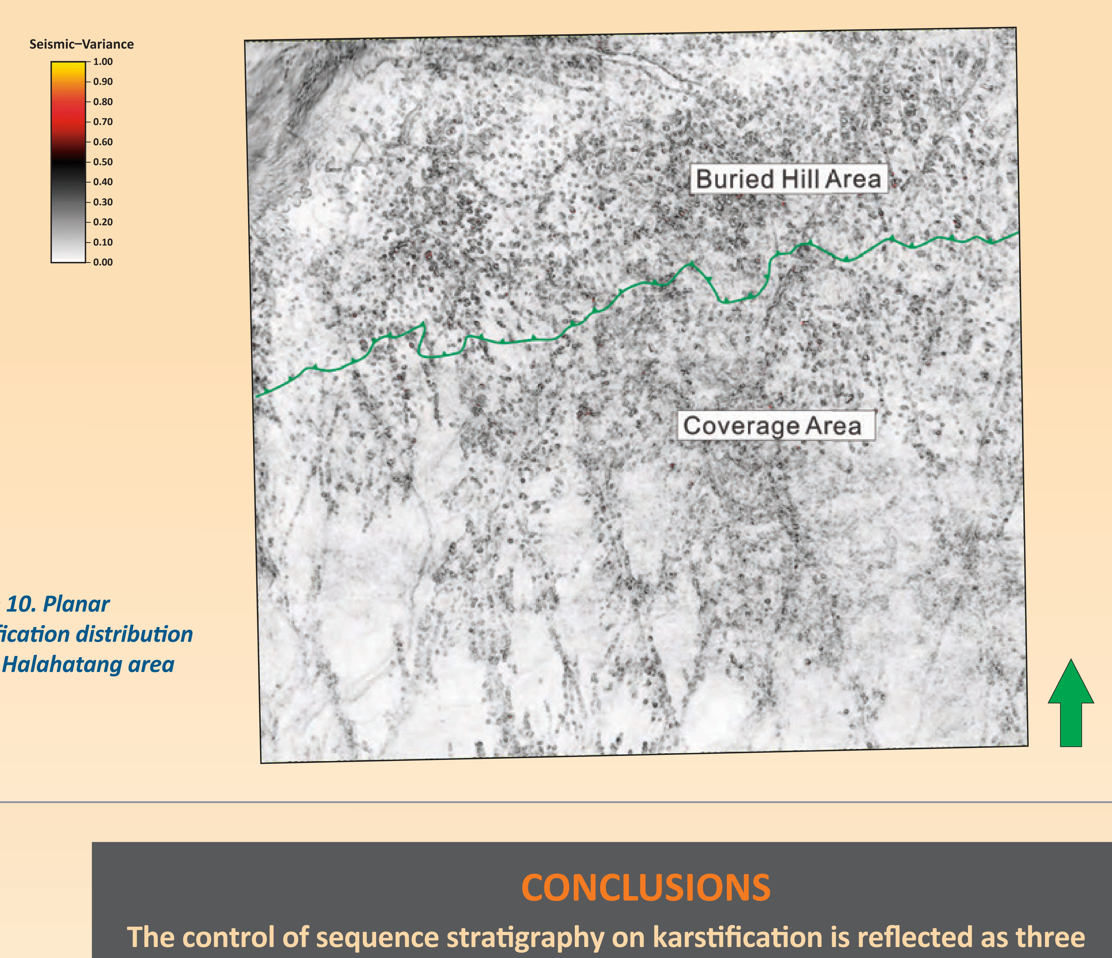


Figure 10. Planar karstification distribution of the Halahatang area

3. The sequence controlled the spatial distribution of the karstification.

Vertically, the karstification mainly exists closely beneath the unconformities, especially for the karstification beneath the unconformity at the top of the Yijianfang Formation (Figure 9). The effective reservoirs universally appear within the range of 150m under the unconformities. This phenomenon resulted from the varied paleo-water tables formed under the unconformities during the karst periods. Horizontally, the density of reservoirs becomes larger and larger towards the buried hill area because the buried hill area was overprinted by several unconformities and experienced several periods of karstification. The karst areas towards the paleo-ocean developed less karstification due to less exposure time (Figure 10).

CONCLUSIONS

The control of sequence stratigraphy on karstification is reflected as three aspects:

1. Primary deposition controlled by stratigraphic sequence laid the material foundation of the karst reservoirs.
2. The sequence evolution enhanced the development of faults and fracture density which played an essential role in the fluids flow and the dissolution of the rocks during the late diagenesis stages.
3. The sequence controlled the spatial ditribution ofthe karstifiation.