# The Sequence Stratigraphy of Mixed Carbonate-Siliciclastic Depositional Systems in the Northern South China Sea*

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## Abstract

The mixed carbonate-siliciclastic deposition is very popular in Neogene in the northern South China Sea (SCS). The paleo-Zhujiang delta facies is the main petroleum reservoir of the Zhujiangkou Basin. The other reservoir is a carbonate reef.

The paleo-topography, sedimentation and strata superposition styles in the mixed carbonate-siliciclastic deposition in marine shelf of the northern SCS show the following characteristics:

- The paleo-topography gradients of the sequence boundaries such as SB18, SB17.5, SB17 and SB16.5 are 4.7, 0.38, 0.17 and 0.13 degrees, respectively;
- The siliciclastic sediments within the sequences such as NSQ2 (21 to 18 Ma), NSQ3 (18 to 17.5 Ma), NSQ4 (17.5 to 17.1 Ma) and NSQ5 (17.1 to 16.5 Ma) were deposited in a relatively paleo-topographically low area; in contrast, the carbonate deposition occurred in high paleo-topographic areas;
- In four sequences of NSQ2 (21 to 18Ma), NSQ3 (18 to 17.5Ma), NSQ4 (17.5 to 17.1 Ma) and NSQ5 (17.1 to 16.5 Ma), the carbonate sediments are overlain by the siliciclastic sediments in paleo-topographically lower area, while the carbonate is overlain by the sequence boundaries in the paleo-topographically higher area of the Dongsha uplifted area.

The relative sea-level change, sediment supply and paleogeography may have been the main controlling factors of the level 3 sequence based on the following analysis of the sequence characteristics. In the northern shelf of SCS, the siliciclastic sediments were deposited during the period when relative sea level fell rapidly and rose slowly. In contrast, the carbonate sedimentation, such as

biogenic reefs, occurred during the rapid rise in relative sea level and early highstand system tract. Because of the pulsation of sediment supply of the paleo-Zhujiang River, the distribution patterns of deposits vary in different stratigraphic sequences. Siliciclastic sediments were deposited from abundant terrigenous siliciclastic sediment supply systems. In contrast, the carbonate deposits occurred from “clean water” conditions. The original paleo-geomorphology also exerted a significant influence on the styles of stratigraphic sequences. For example, during HST of NSQ2, the wide shelf area of Huizhou was paleo-topographically flat and thus not a significant supply of siliciclastic sediments, consequently, the limestone reefs and beaches developed. The carbonate deposition resulted in the sediment shelf-break in the wide shelf area of Huizhou and the unconformity contact between sequences.

## Introduction

The mixed carbonate-siliciclastic depositional systems occurring on the Dongsha and Shenhu uplifted area in the northern South China Sea continental shelf consist of terrigenous clastic deposits from the paleo-Zhujiang delta/onshore and carbonate platform or reef (bioherm) in Neogene, from which oil and gas are mainly being produced in the Zhujiangkou Basin. The reservoirs are platform reefs and beach facies carbonate rock, and delta front distributary channel and the mouth bar facies sandy conglomerate rock. It is reported that the mixed carbonate-siliciclastic deposition in the eastern Borneo, the southern South China Sea is composed of the Neogene delta with its front patch reefs (Wilson, 2005), which can be compared with the deposition in the northern South China Sea in the development times and eco-environmental characteristics.

The carbonate rocks are limestones, micrites and grainstones. The limestone mainly consists of coralline algae, red algae and coral reef, while the particles of the grainstone consist of insect fragments, algal fragments of various reef-building organisms, such as bryozoans, echinoderms, sponges, gastropods, brachiopods and foraminifera and other biological fragment (Feng and Hong, et al., 1996; Soreghan, 1997; Yan and Ying-min, 2001; Bingquan Lv et al, 2002). The siliciclastic rocks are sandy conglomerate rocks from delta front distributary channel and mouth bar. Due to the cyclical change of sea level, as well as the paleo-Zhujiang intermittent supply, terrigenous clastic sediments came from delta front distributary channels and mouth bars when depositional supply was adequate, and instead of it, mixed carbonate from coral and algae reefs/bioherms and siliciclastic deposits from delta develop when the terrigenous material supply was inadequate resulting from distributary channel and mouth bar abandonment. Sequences of mixed carbonate-siliciclastic depositional systems will be divided by analyzing stratigraphic architecture, stacking patterns and influence factors of the mixed carbonate-siliciclastic deposition, which plays an important role in determining characteristics of sequence and discussing sedimentary evolution of the basin and the distribution of oil and gas reservoirs.

## Stratigraphical Architectures and Stack Patterns

The depositional mechanism of carbonate and siliciclastic deposits is different (Sarg, 1988, Zhongxian, 1997). Siliciclastic rocks usually prograde toward the basin (Van Wagoner, 1990; Barnaby and Ward, 2007) while depositional processes of carbonate platforms and reef/bioherms show accretion and sometimes progradation (Read, 1985; Goldhammer, 1993; Khetani and Read, 2002; Laurin and Uličn;ý, 2004; Burgess, 2006; Phelps and Kerans, 2007; Nalin, 2009). Therefore, depositional characters should be considered when analysis of mixed carbonate-siliciclastic deposition. The sequence is divided and correlated according to architectural characteristics, stacking patterns and influence factors, which help establish modes of sequence stratigraphy.

## Progradation of Siliciclastic Sediments

Data from well logging and drilling and seismic data of the mixed carbonate-siliciclastic deposition indicates that the two lithologies show significant differences in features in a single well and seismic profiles. The thickness of the delta or shore sandstone and mudstone, the grain sizes of sediments and sedimentary structures on the single well section show rhythmic changes from bottom to top, i.e., alternating change from box-, bell- to funnel-shaped well logs, and basinward stepping of clastic sediments on seismic section (Figure 1).

## Accretion of Carbonate Sediments

The carbonate rocks are composed of reef limestone such as coral, algae and foraminifera, micritic limestone on the well log. The limestones show small changes in thickness, and upward accretion character on the seismic profile (Figure 2).

## Framework and Model of Sequence Stratigraphy

By means of analysis of the sequence interface, the architecture and stacking pattern, we identified four third-order sequences such as NSQ2 (21 to 18 Ma), NSQ3 (18 to 17.5 Ma), NSQ4 (17.5 to 17.1 Ma) and NSQ5 (17.1 to 16.5 Ma), establishing framework sequence stratigraphy of mixed carbonate-siliciclastic deposition in Neogene of the Zhujiangkou Basin in the South China Sea (Figure 3).

The depositional style and stacking pattern of mixed carbonate-siliciclastic deposition show that NSQ2 and NSQ3 represent type 1 progradational sequence in four mixed sedimentary sequences, highstand systems tracts. Clastic rocks continued stepping basinward, and finally covered the proximal shelf carbonate of transgressive and early highstand system tracts; while NSQ4 and NSQ5 sequences are type 2 aggradational sequences (Figure 3). In these two sequence, the sandstone and mudstone of the transgressive and highstand systems tracts are accreted, and thus the clastic and carbonate rocks show “keep-up” and “catch-up” characteristics of aggradation.

## Influence Factors of Sequence Development

The main influential factors of the sequence development of the mixed carbonate-siliciclastic deposition in the Neogene in the northern South China Sea include the relative sea level change, sediment supply and paleogeography. In the northern shelf of South China Sea, especially in the paleo-topographically higher area of the Dongsha uplifted area, the reef-beach facies carbonates continually superimpose on even higher areas of the paleo-geomorphology with a rise in the relative sea level.

The relative sea-level changes have an effect on the depositional mode of carbonate depositional processes of mixed depositional sequences (Wright and Hine, 2005; García-García and Soria, et al., 2009; Nalin, 2009). In early stages of sea level rise, carbonates showed “keep-up” growth, and continued aggradation onto topographic elevation. In late transgressive system tracts or early highstand system tracts, sea level is expected to rise rapidly and reach a relatively high position. Under this condition, carbonates have growth rates lower than that of the rise in sea level, thus no carbonate growth occurred and showed a drowning deposit hiatus (Schlager, 1981, 1989). During late highstand system tracts, terrigenous clastic sediments were fully supplied and deposited under a delta environment and covered the carbonate rock. Subsequently, as the relative sea level fell rapidly, siliciclastic rocks and carbonate rocks were exposed and eroded.

The depositional supply was an important influence on sedimentary processes and types of siliciclastic deposits, and relationship of carbonate and siliciclastic deposition (Cunningham and Locker, et al., 2003). The evidence of pulsatory sediment supply of paleo-Zhujiang River was clear in the Neogene in the continental shelf of northern South China Sea. Especially during rapid relative sea level rise and/or early highstand system tracts, due to the lack of terrigenous sediments supply, the carbonate reef/beach facies developed extensively and rapidly at the higher area of the Dongsha uplifted area, which was far away from the provenance. However, in lowstand, early transgression or late highstand, where sediment was fully supplied, siliciclastic rocks developed and might cover the prior reef /beach facies carbonate.

Paleogeography mainly influenced the discharge rate of terrigenous detrital material and distribution of sediment during sequence developing, and thus influenced the stacked relationship of siliciclastic rock and carbonate rock in the sequence. Existence of the local higher area of the Dongsha uplifted area slowed down the flow rate of paleo-Zhujiang River at the distal end, and resulted in quick unloading and deposition of terrigenous clastic material. So depositional topography gradients increased significantly to form sediment shelf-break in the wide shelf area, and finally formed unique type 1 mixed depositional sequences in the shelf area of the northern South China Sea (Figure 4).

## Conclusions

The sequence stratigraphy of mixed carbonate-siliciclastic depositional systems in the northern SCS were controlled and influenced by factors such as the relative sea level change, sediment supply and paleogeography. The relative sea-level change mainly influence carbonate productivity and growth patterns, keep-up carbonate platforms and reefs were formed during the stage of slow rise in the relative sea level, catch-up and drowned carbonate platforms and reefs were formed during the stage of quick rise in relative sea level and higher sea level. The sea level change also influenced the relationships of carbonate and siliciclastic deposits. Obviously, sediments were pulsatively supplied from the paleo-Zhujiang River in the northern shelf of SCS. On one hand, terrigenous sediment supply controlled depositional patterns of terrigenous siliciclastic deposits; on the other hand, the large amount of terrigenous clastic sediments inhibited carbonate deposition, which resulted in the formation of carbonate platforms and reefs on higher site during constant rising of sea level. Paleogeography such as flatness and landform gradient controlled unloading of terrigenous clastic sediments from the paleo-Zhujiang River and resulted in depositional break in the northern shelf of SCS, and thus a “type 1”sequence of mixed carbonate-siliciclastic depositional system occurred.

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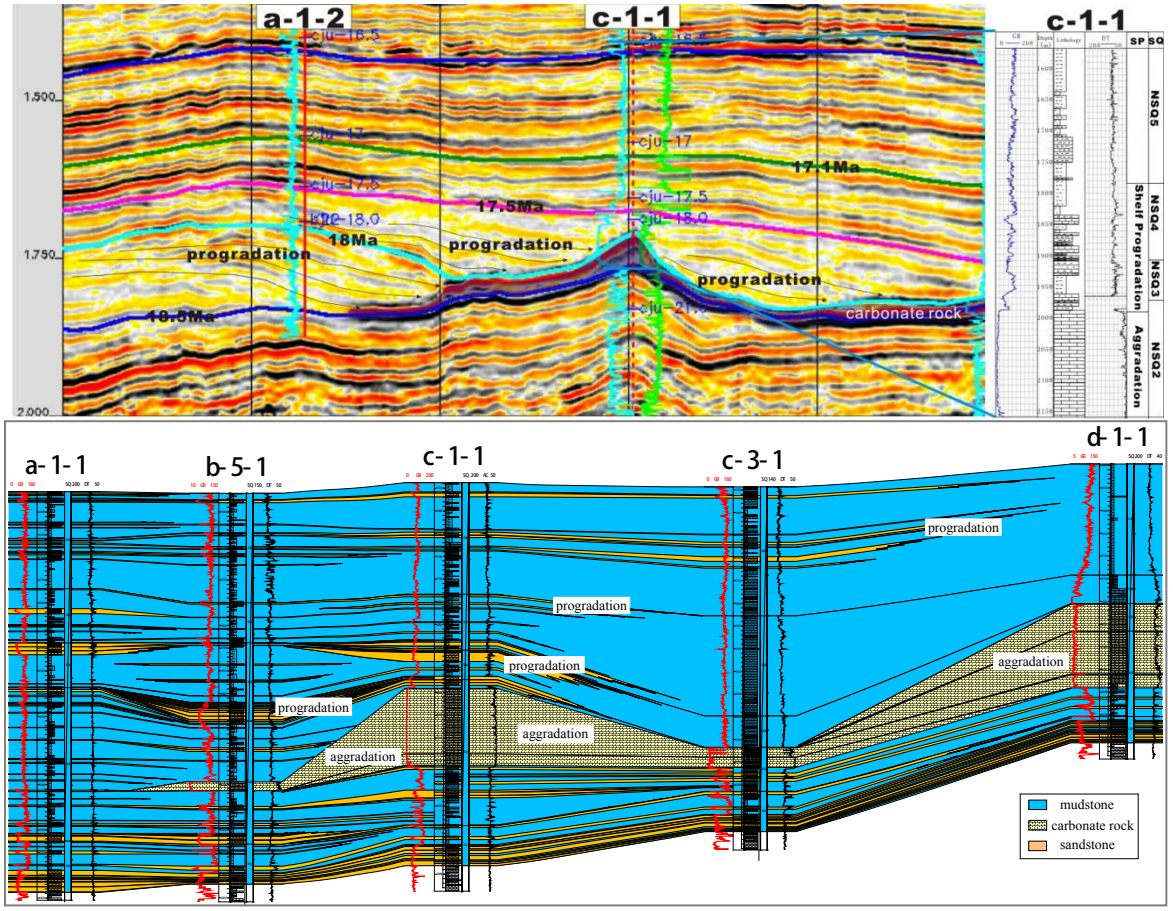


Figure 1. Progradation of the delta and onshore sand-mud rock.

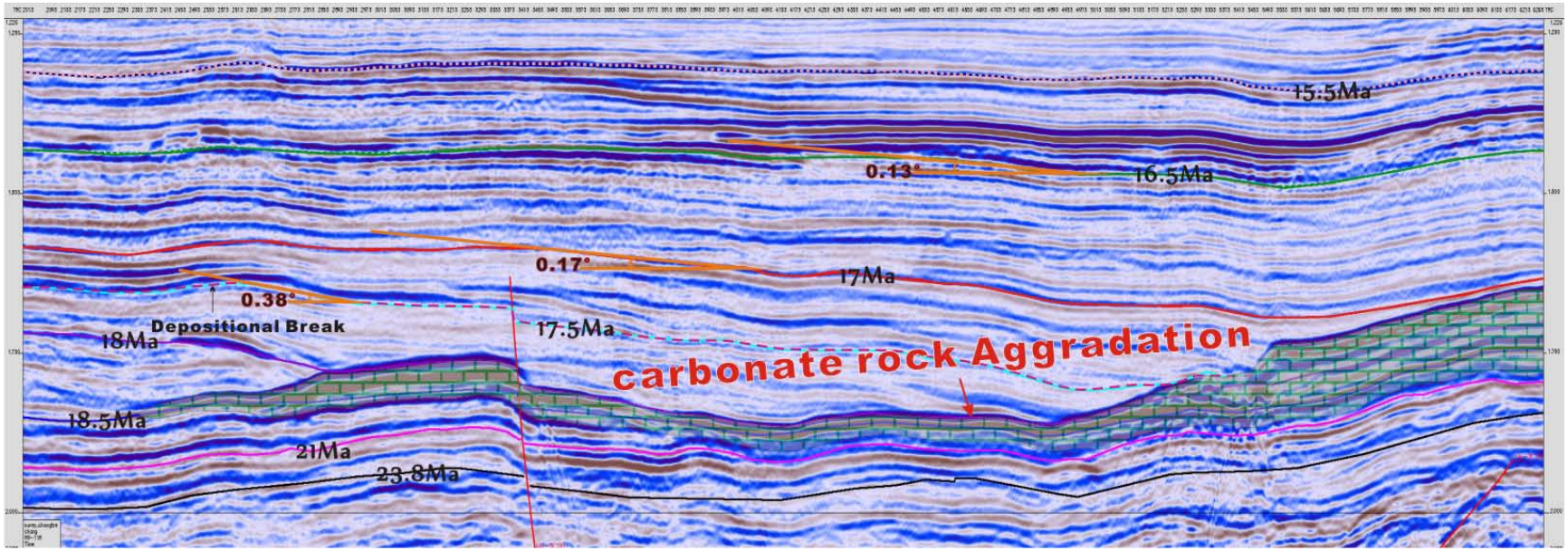


Figure 2. Seismic responses of the accretion of carbonate rocks.

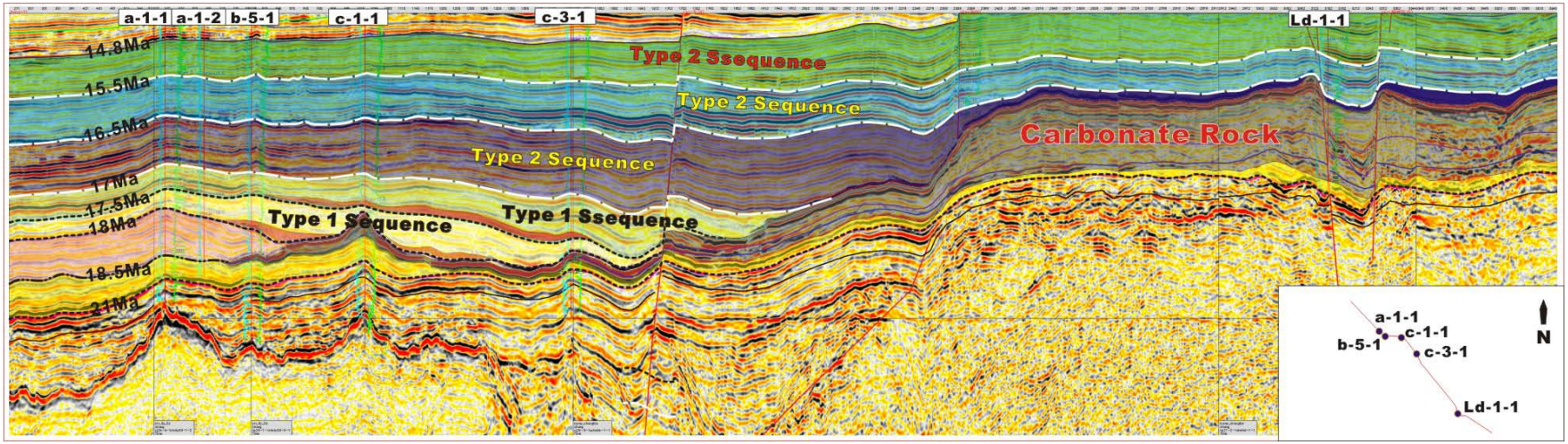


Figure 3. Stratigraphic sequence framework of the mixed carbonate-siliciclastic deposition in Neogene, the Zhujiangkou Basin.

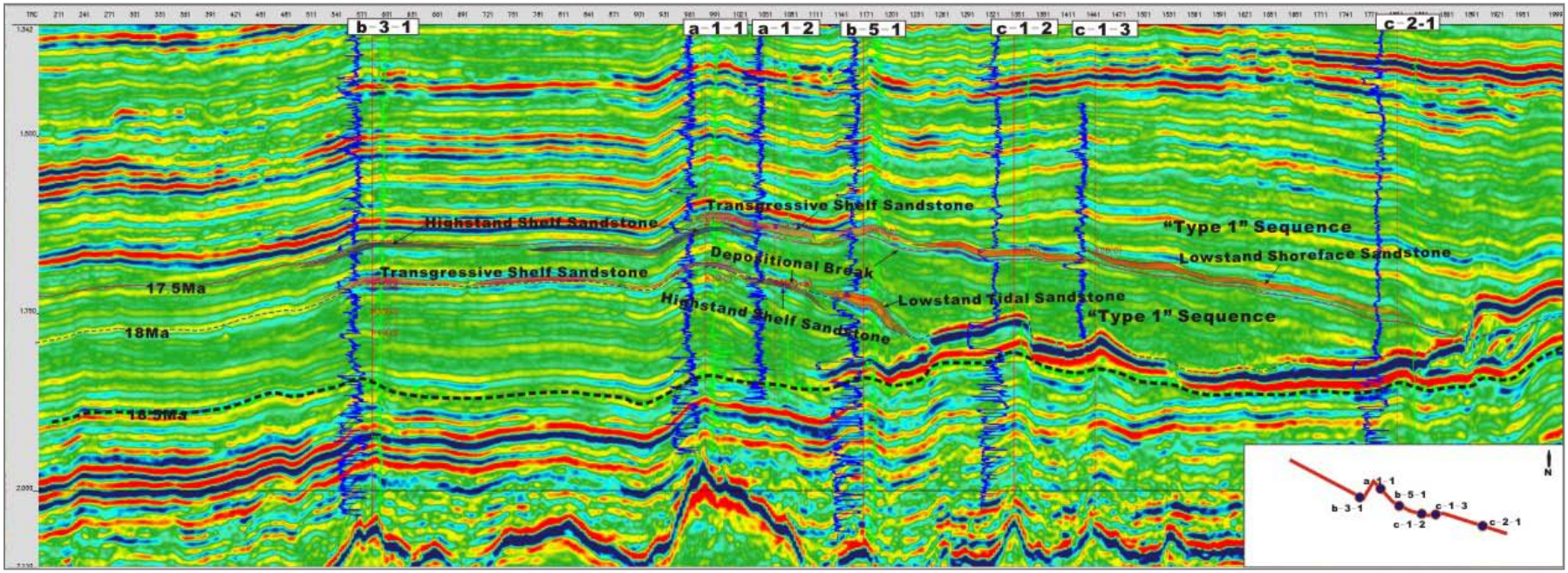


Figure 4. The shelf area of the northern South China Sea and type 1 mixed sequence