Stratigraphic Trap Identification Based on Restoration of Paleogeophology and Further Division of System Tract: A Case Study in Qingshui Subsag*

Cao Laisheng[1], Yu Lin[1], Liu Jianlun[1], Xiang Sheng[1], Chen Hong[1], Meng Yang[1], Liu Hua[1], Du Yinjie[1], and He Yan[1]

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[1]BGP, CNPC, Zhuozhou Hebei, China (46957467@qq.com)

Abstract

As structural exploration in East China basins has entered into the mature stage and the production becomes slow, a new exploration method is needed and the lithological exploration turns out an inevitable trend. Western sag of the Liaohe depression is one of the typical petroleum-rich sags, and the 2nd member of Shahejie Formation in Oligocene (E_3^{s2}), as one of major exploitation intervals in the sag, has more potential for petroleum exploration. This paper has developed the framework of fine system track for E_3^{s2} and studied depositional environment for each system tract in Qinshui and Hainan sub sags, both of which have less exploration level. Because of different depositional properties of source areas at the east and west part of China, a corresponding study has been carried out on the stratigraphic trap identification, and this study has utilized two techniques: sedimentary micro-facies analysis based on joint logging and seismic data, and paleotopography restoration. In addition, the application of this new method has promoted stratigraphic trap exploration in the Liaohe depression.

Introduction

After more than half a century of exploration in the eastern China continental basin, most structural traps have been identified and drilled. With less opportunity, however, the lithologic trap exploration is a very different story. The stratigraphic exploration techniques under 3rd order sequence framework cannot meet the requirement of fine exploration.

Western sag of the Liaohe depression is characteristic of multiple oil-bearing zones and large oil distribution areas are the main oil production and reserves in the field (Figure 1), and is a typical oil-rich depression in the Bohai-bay basin. Qinshui and Hainan sub-sags are two hydrocarbon generation subsags with the highest hydrocarbon abundance in the Liaohe field. The production and reserve of E_3^{s2} plays the important role in the whole western sag within the proven reserve in the slope and structural peak areas. The sag and the surrounding lower areas are less explored and the structure within them is less developed, so they are potential areas for stratigraphic reservoir exploration. Based on large-scale 3D seismic data, system tract identification has been carried out in E_3^{s2}, and then the study of depositional characteristics of each system tract, and finally stratigraphic trap identification aimed at the source area differences of the east and west.

System Tract Identification and Source Areas Determination

System tract identification

Establish sequence stratigraphic framework is the foundation for depositional body identification and lithological reservoirs prediction. The researchers in the field have carried out sequence stratigraphy studies for western sag, and achieved many results in term of 2nd and 3rd order sequences. Considering the major target zones, paper is focused on the systematical study to system tracts in E_3^{s2} in the area.

E_3^{s2} in Qinshui and Hainan subsags is a complete 3rd order sequence, and the lowstand system tract (LST), transgressive system tract (TST), and highstand system tract (HST) are established based on the identifications of unconformable surface (SB), first flooding surface (ffs), maximum flooding surface (mfs) in single wells and correlated wells through tied seismic sections.

The LST of E_3^{s2} with characteristic of discontinuous weak reflection pattern fills in the center of Qinshui and Hainan sub sags, overlaps toward the west slope belt. In addition, drilling data illustrate that they are thick sandy gravel with serrated-box shaped log configuration. TST and HST with variable thickness are widely distributed in this area, and they are sandstone inter-bedding with mudstone. The sandstone in each system tract has various variation in lateral on wells-tied inversion sections (Figure 2), favorable for stratigraphic trap development.

Source areas determination based on paleotopography restoration

The results of paleo-topography restoration of each system in Qinshui subsag shows that Shuangtaizhi structural belt dominated the sedimentation of each system tract in E_3^{s2}. Using 3D visualization to view the paleotopography properties of each system tract in different stages, it shows that the Shuangtaizhi location was shifted in the different times, and the location dominated the distributions of sediments from the source areas at west and east respectively (Figure 3).

Based on the system tract division, comprehensive analysis of single well facies, connected-well facies, seismic facies, and waveform clustering and attributes were performed to each system tract, and their results illustrate that the depositional bodies in system tracts are sediments deposited in delta fan and lacustrine environment.

The primary stratigraphic thickness of each system tract, which results from sedimentary restoration, illustrates that depositional center of each system tract is generally in the area surrounding Qinshui–Hainan subsags. Integrating the primary stratigraphic thickness with the analysis result of net to gross ratio and seismic facies to the related system tracts respectively, it shows that the sediments in system tracts come mainly from the slope in west and central high in east. The distribution pattern of each system tract shows that the deposition is without obvious inheritance but shifting in different times. LST is filling-in type of deposition dominated by Shuangtaizhi paleo-high; west source area dominated the depositional process in Hainan subsag; east source area dominated the depositional process in Qinshui sub sag (Figure 4).

Stratigraphic Traps Identification

Stratigraphic elements can be identified and delineated through system identification and fine interpretation. Based on the deposition features of various system tracts, the type and the setting of depositional bodies can be predicted which is helpful to guide the body identifying. Based on the available well data, the identification of Stratigraphic trap has been carried out to HST of E_3^{s2} in Hainan subsag and all system tracts of E_3^{s2} in the southern Qinshui subsag sourced by west and east source areas respectively.

The main source area of system tracts of E_3^{s2} in the north of Qinshui sag is Xingma structural belt and central high, and Shuangtaizhi structural belt trending NE-SW is a long-strip shaped inherited paleo-high. The paleo-topography dominated the sedimentation, especial to LST, the delivering direction of debris and the deposition location of fan body.

The results of paleo-topography restoration for each system tract in E_3^{s2} during their deposition show that LST onlap onto the east side of Shuangtaizhi structural belt. 3D visualization has been applied to model paleo-topography feature for each system tract during their deposition, and the result reveals that the location of overlapping pinch-out belt in one system tract is different from that in the other, so all onlapping sandstones in different system tracts formed at the east fringe of Shuangtaizhi structural belt would have the same possibility to form lithological trap belt (Figure 5).

Well w111 has been planned and drilled according to results of fine research, resulting in commercial production in several sets of sandstone at HST of E_3^{s2}. The estimated reserves are about $9*10^6$t. In order to increase oil reserves, integrate deploy of exploration activity on the east fringe of Shuangtaizhi structural belt has been completed, and the successive two exploration wells will add more than 100 km^2 total area of lithological traps in system tracts, and additional $3*10^7$t geological reserves.

Conclusion

The oil fields in the eastern china have entered into mature exploration stage with most structures identified and drilled, and prospecting stratigraphic traps has turned into a general trend in the hydrocarbon exploration. Sub-dividing sequence elements and system tract is the foundation to fine exploration; paleotopography restoration is the key to determine various debris sources. Joint interpretation of well and seismic data, sedimentary micro-facies analysis, and reservoir prediction are effective tools for stratigraphic-lithological trap exploration in the depression. After applying above techniques to system tracts, many stratigraphic-lithological traps have been identified, and these new discoveries increase commercial production from reservoirs sourced by east and west respectively.

Acknowledgements

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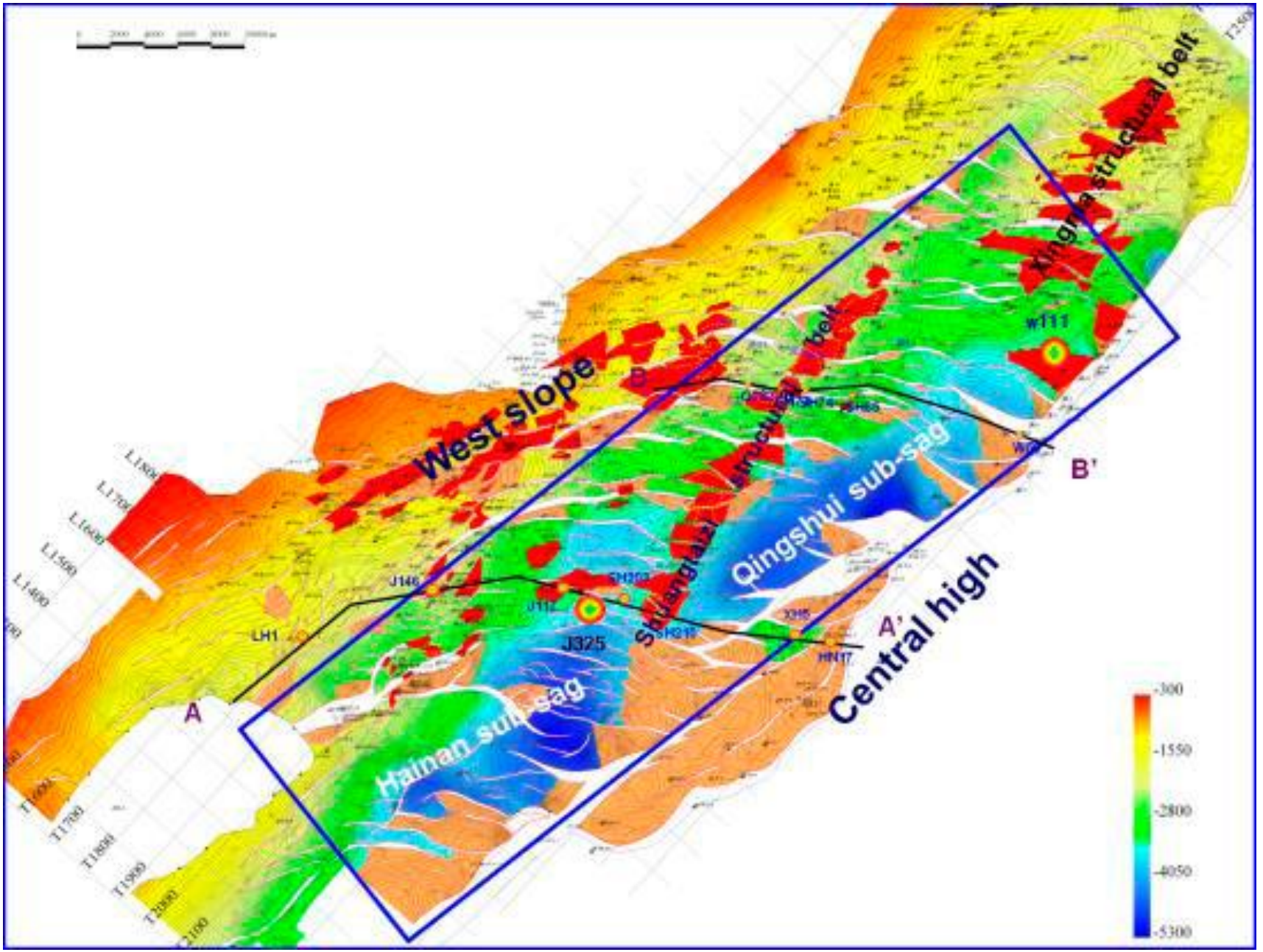

Figure 1. Location map of the study area.

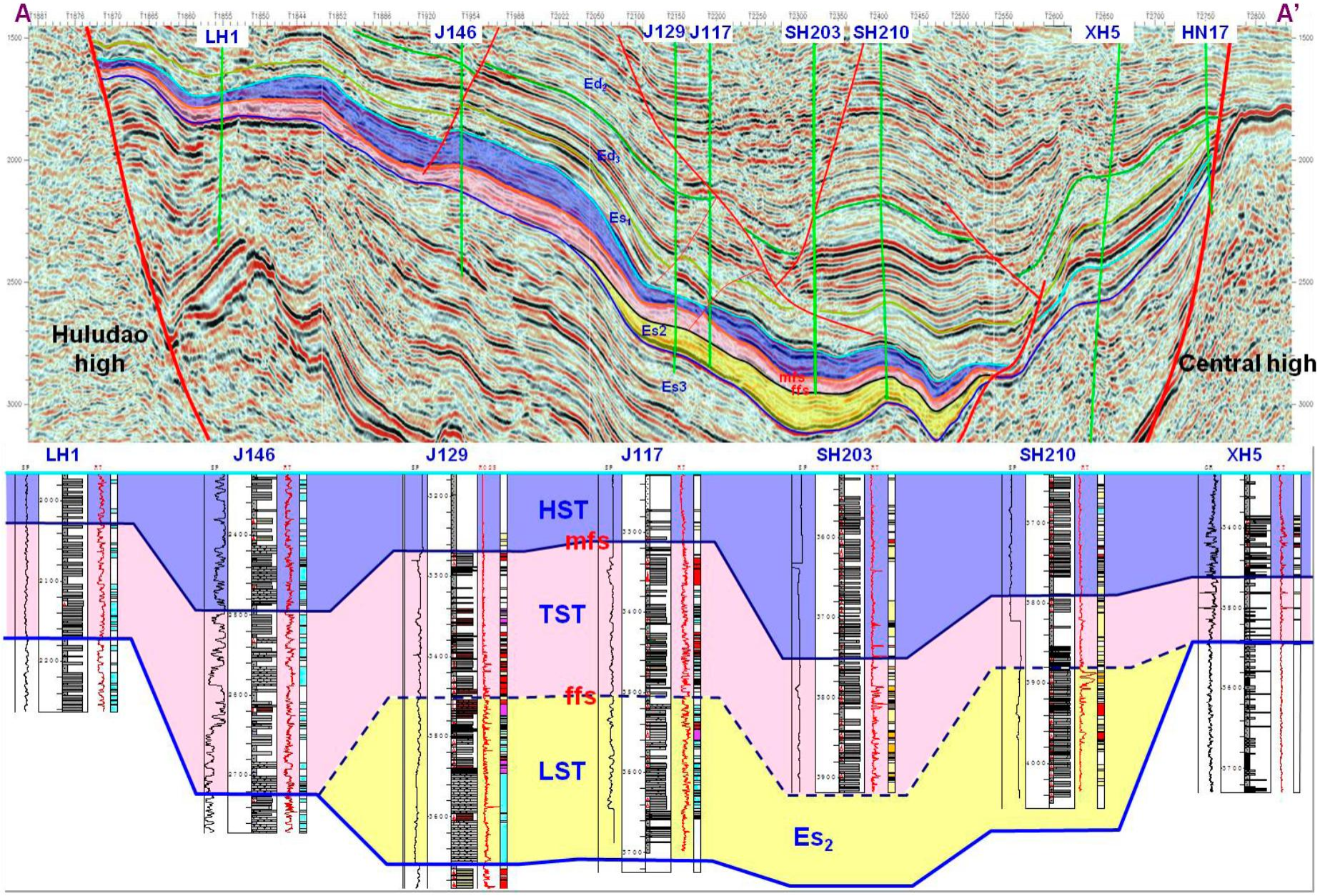

Figure 2. System tract division of E3^{s2}.

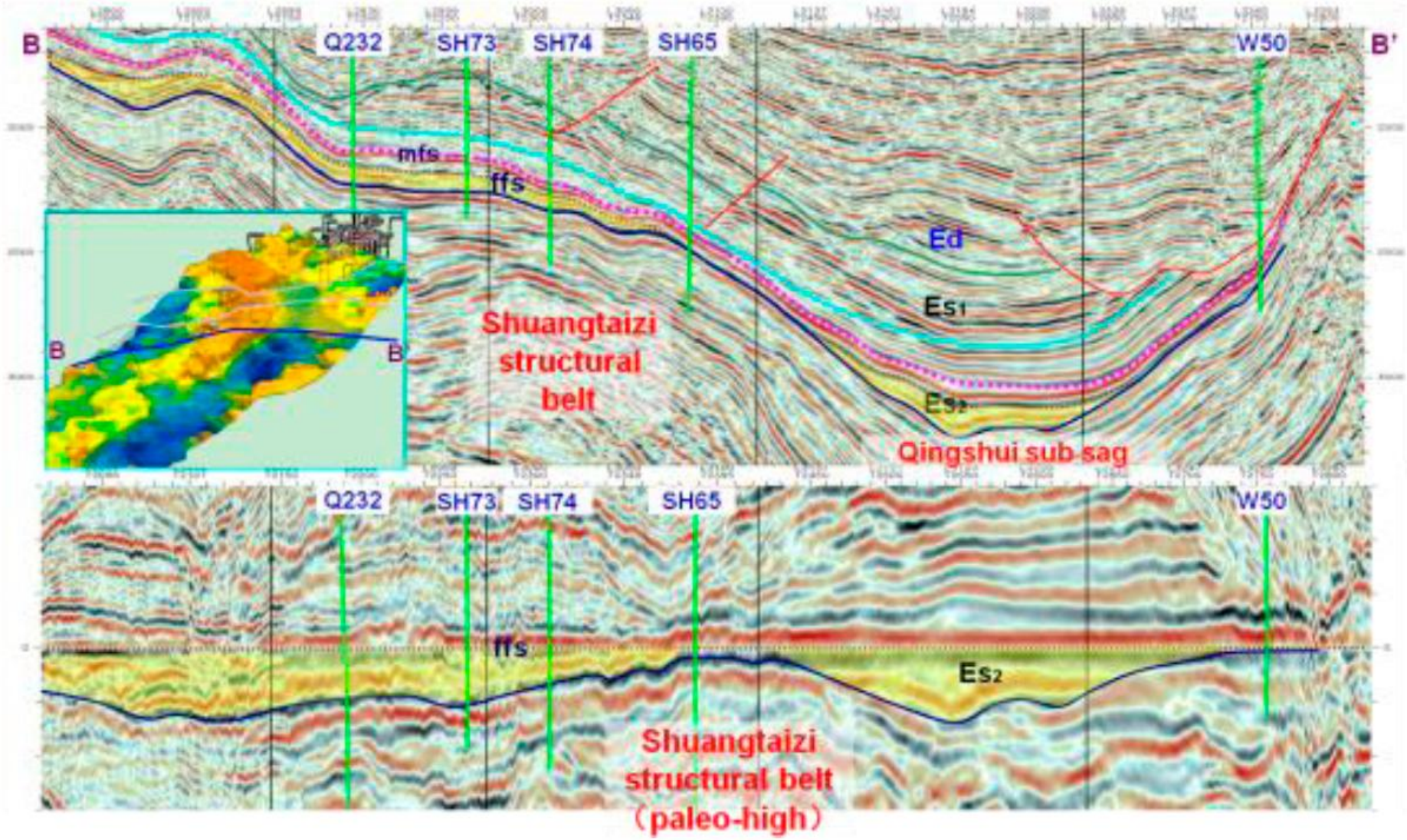

Figure 3. Paleo-topography restoration of LST in $E3^{s2}$

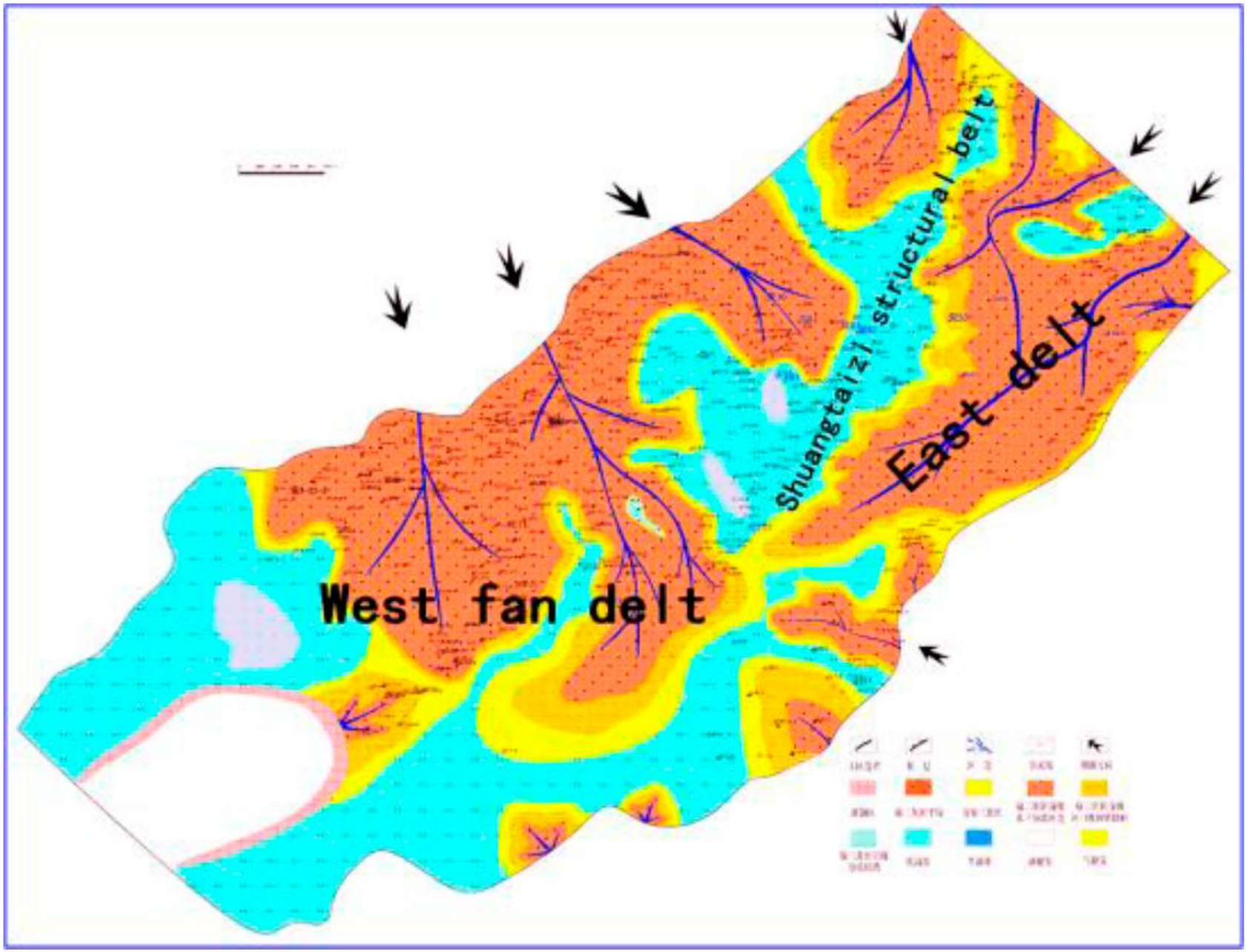

Figure 4. Sedimentary facies map of TST in $E3^{s2}$

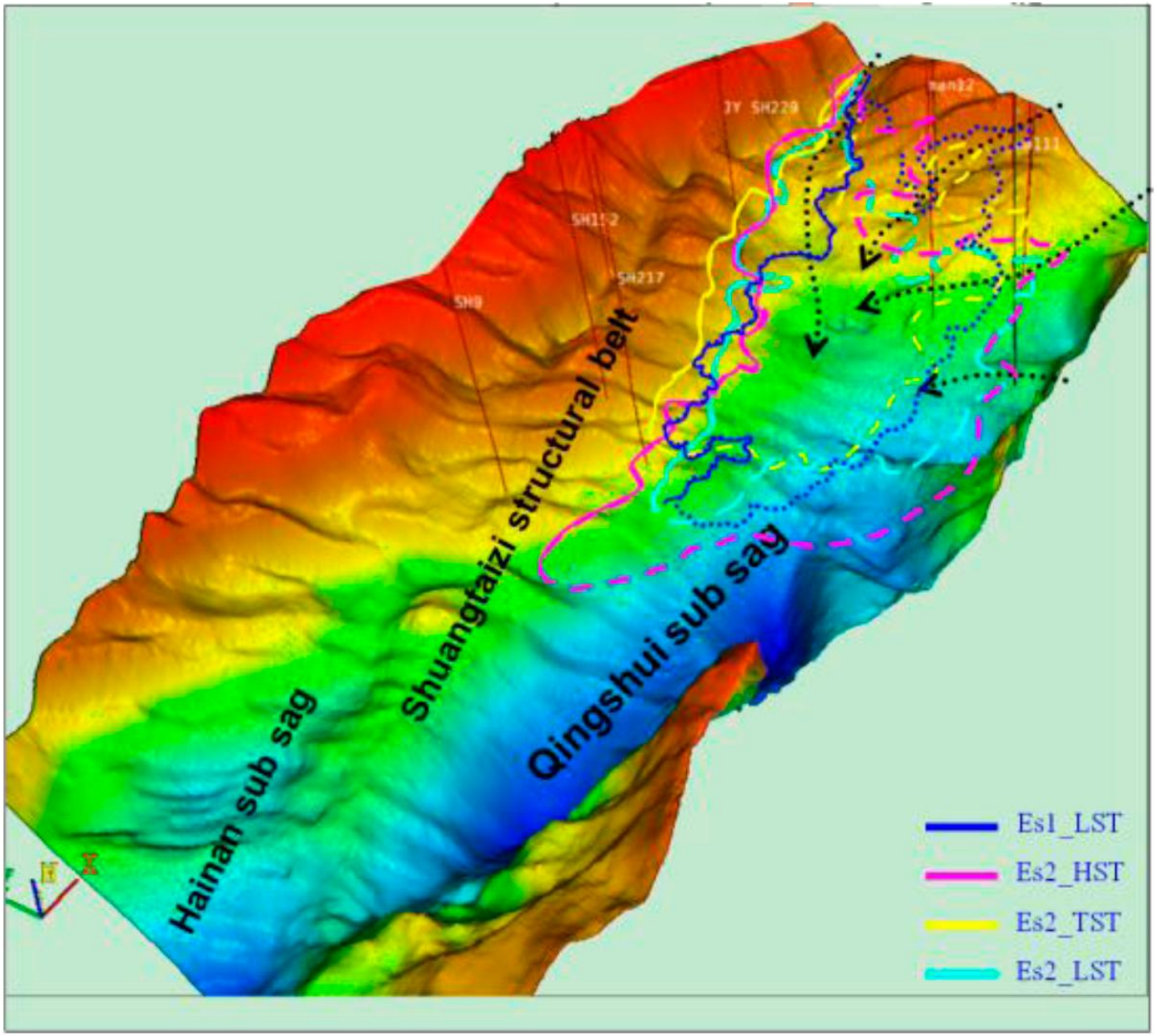

Figure 5. Superimposed map showing distribution of lithological bodies in different system tracts sourced by east source area