

PS 3D Geomorphology of Pleistocene Fluvial Systems in the Northern Shelf of the South China Sea: Implications for the Mid-Pleistocene Climate Transition*

Haiteng Zhuo¹, Yingmin Wang¹, Hesheng Shi², Min He², Weitao Chen², and Ying Wang²

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¹Ocean College, Zhejiang University, Zhoushan, Zhejiang Province, China (zhuohaiteng@hotmail.com)

²China National Offshore Oil Company Limited-Shenzhen, Guangzhou, China

Abstract

Multiple successions of buried fluvial channel systems were identified in the Quaternary section of the mid-shelf region of the northern South China Sea. Using three commercial 3D seismic surveys, accompanied by 2D lines and shallow boreholes, the sequence stratigraphy, seismic geomorphology and the stratal architecture of the fluvial channels were investigated. Based on their origin, dimensions, planform geometries and infill architectures, six classes of channel systems, from Class 1 to Class 6, were recognized within five sequences of Quaternary section (SQ1 to SQ5). Three types of fluvial systems among them are incised in their nature, including the trunk-incised valleys (Class 1), medium incised valleys (Class 2) and incised tributaries (Class 3). The other three types are unincised, which comprise the trunk channels (Class 4), lateral migrating channels (Class 5) and stable channels (Class 6). Trunk channels and valleys that contain braided channels at their base are hypothesized to be a product of deposition from the “big rivers” that have puzzled the sedimentologists for the last decade, providing evidence for the existence of such rivers in the ancient record. Absolute age dates from shallow boreholes indicate that the landscapes associated with these fluvial systems changed significantly near the completion of the mid-Pleistocene Climate Transition (MPT), which approximately corresponds to SB2 with an age of ~ 0.6 Ma BP. Below SB2, the Early Pleistocene sequence (SQ1) is dominated by a range of different types of unincised fluvial systems. Evidence of incised valleys is absent in SQ1. In contrast, extensive fluvial incision occurred in the successions above horizon SB2 (within SQ2 – SQ5). Although recent studies call for increased incision being a product of climate-controlled increase in river discharge, the down-dip location of our study area suggests that relative sea level change was the most important control of the fluvial systems. We speculate that completion of the MPT as well as the onset of 100 ky climate cycles at ~ 0.6 Ma, during which the duration of cycles and magnitude of sea level change both increased, are considered to trigger the extensive development of incised fluvial systems. The intensification of the East Asia Monsoon at 0.9 Ma and 0.6 Ma driven by the episodic uplift of the Tibetan Plateau may have also enhanced the amplitude of sea level falls and thus the fluvial incisions of the northern shelf of the South China Sea.

Multiple successions of buried fluvial channel systems were identified in the Quaternary section of the mid-shelf region of the northern South China Sea. Using three commercial 3D seismic surveys, accompanied by 2D lines and shallow boreholes, the sequence stratigraphy, seismic geomorphology and the stratal architecture of the fluvial channels were investigated. Based on their origin, dimensions, planform geometries and infill architectures, six classes of channel systems, from Class 1 to Class 6, were recognized within five sequences of Quaternary section (SQ1 to SQ5). Among them, the trunk channels and valleys are hypothesized to be a product of deposition from the “big rivers” that have puzzled the sedimentologists for the last decade.

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Research Highlights

- 3D characterization of buried fluvial systems in northern South China Sea shelf;
- Direct evidences for the presence of ancient “big rivers”;
- Influences of Mid-Pleistocene Climate Transition on fluvial styles;
- Implications for evolution of the East Asian monsoon.

Location of the Study Area

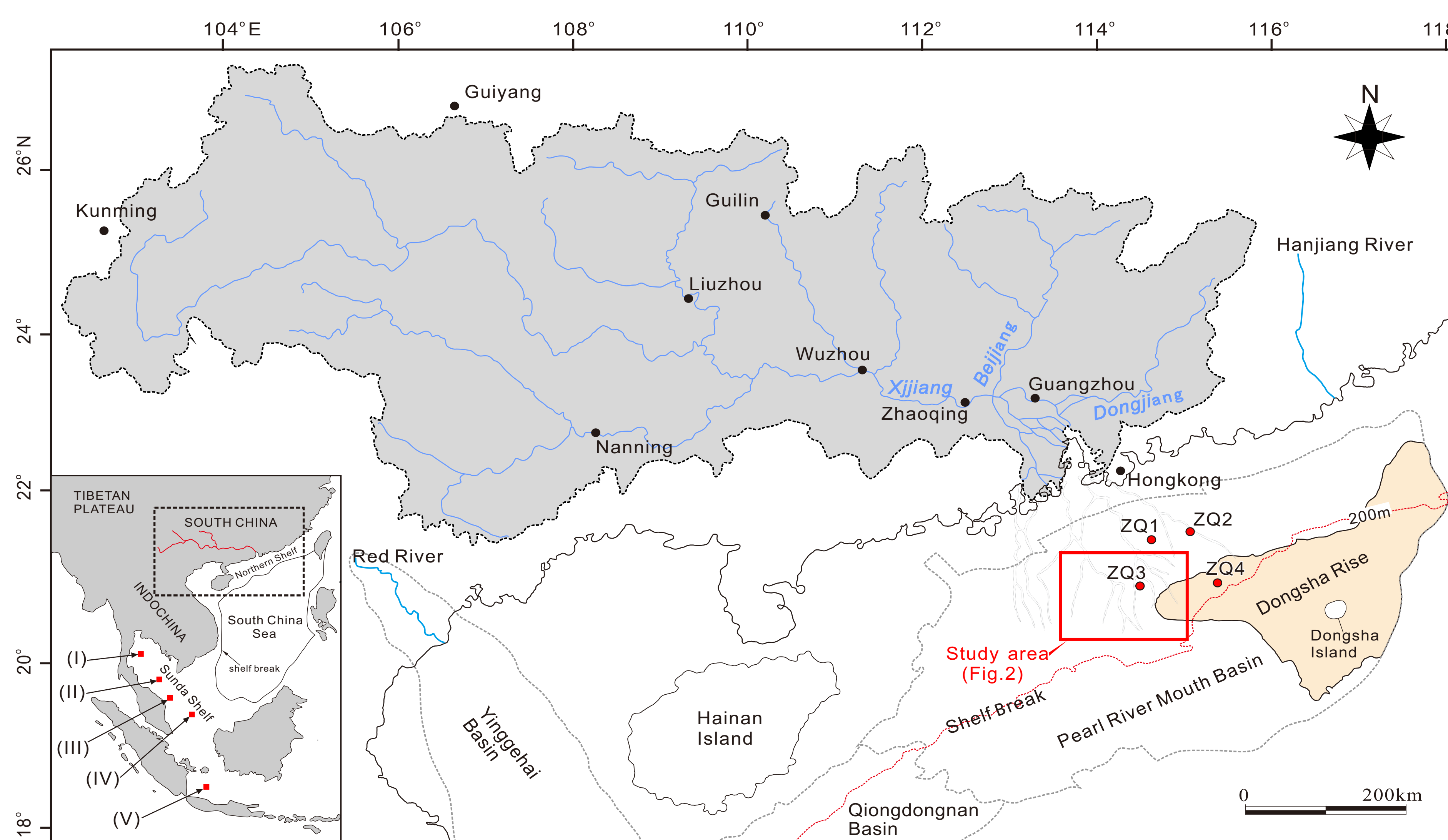


Fig. 1: Index map showing the regional context and the location of the study area. Four shallow boreholes, from ZQ1 to ZQ4, are from Feng et al. (1996) and Lüdmann et al. (2001). The inset map denotes the locations of previous studies documenting buried fluvial systems on South China Sea shelves: I – Reijenstein et al. (2011), II – Miall (2002), III – Alqahtani et al. (2015), IV – Darmadi et al. (2007) and V – Posamentier (2001). Also note the approximate extent of the Dongsha Rise which was tectonically active during Late Quaternary (Wu et al., 2014).

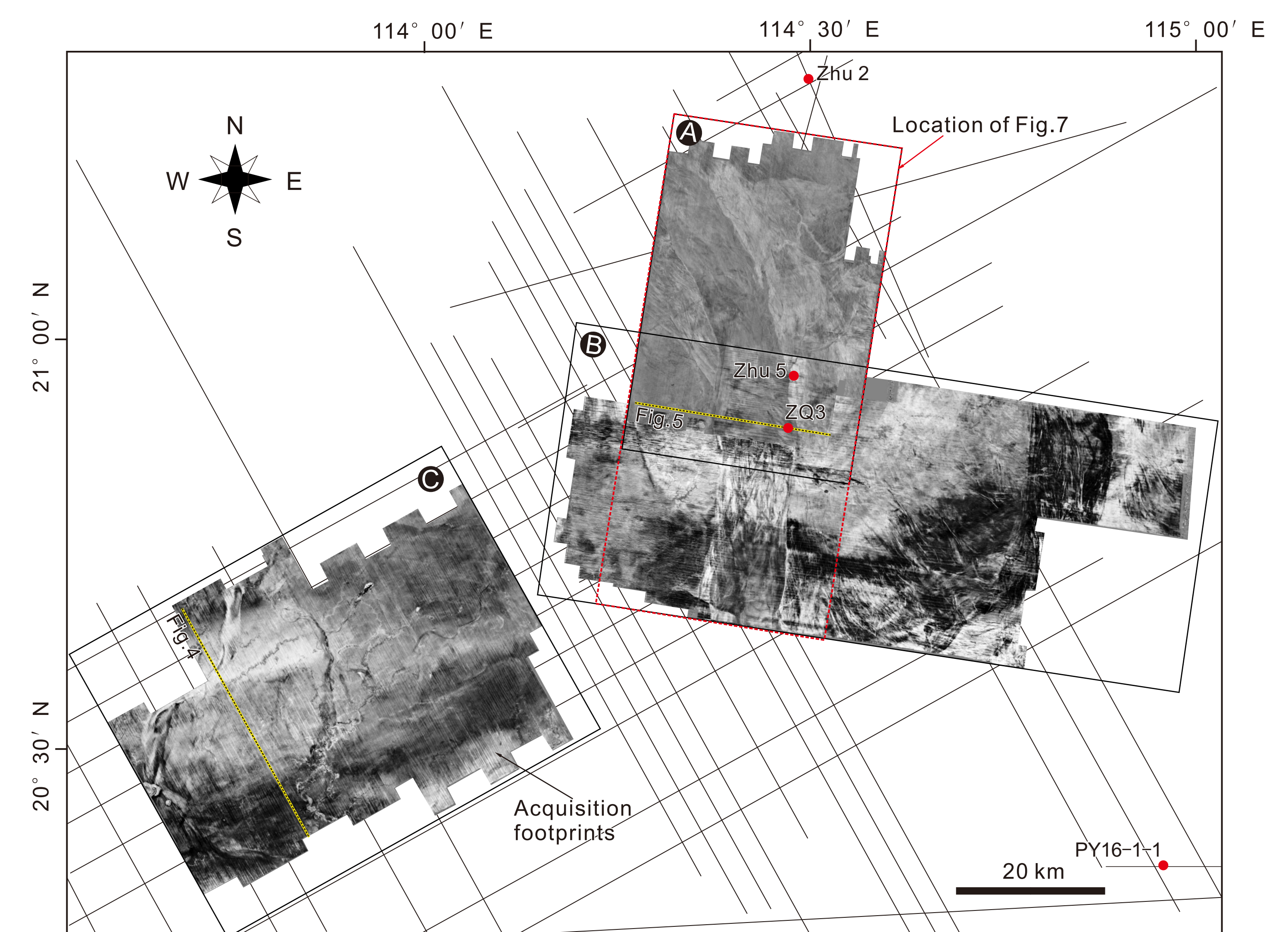


Fig. 2: Map showing the 3D seismic surveys, 2D seismic profiles and key wells utilized in this study. The total 3D seismic coverage is over 5500 km², including datasets A, B and C. Black solid lines denote the 2D seismic profiles utilized in this study. Note the acquisition footprints due to seismic processing.



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Sequence Stratigraphy

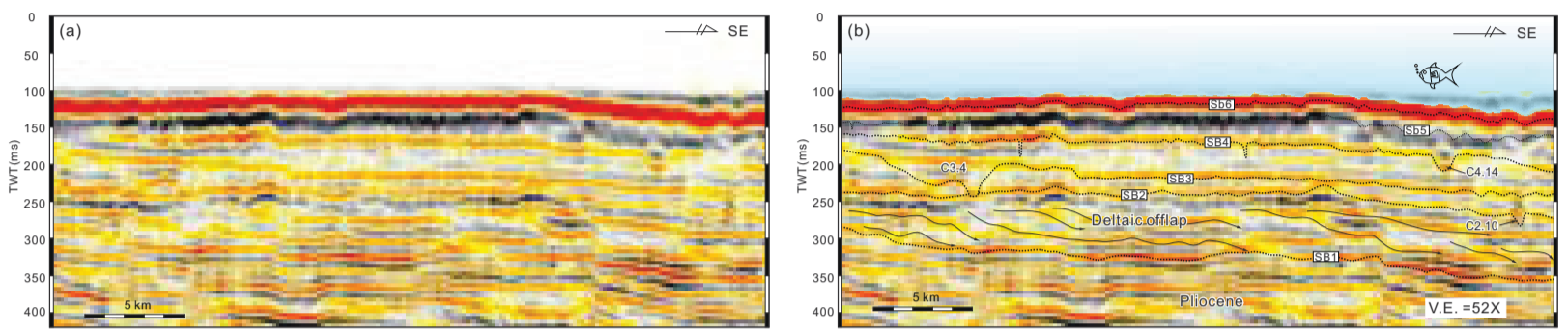


Fig.3. Seismic profile across the dataset C, showing the stratigraphic subdivision of the Quaternary section. Note the u- or v-shaped seismic response of fluvial incisions. Also note the scheme we use to label the channels. For instance, "C2.10" represents the tenth fluvial channel recognized with the sequence SQ2.

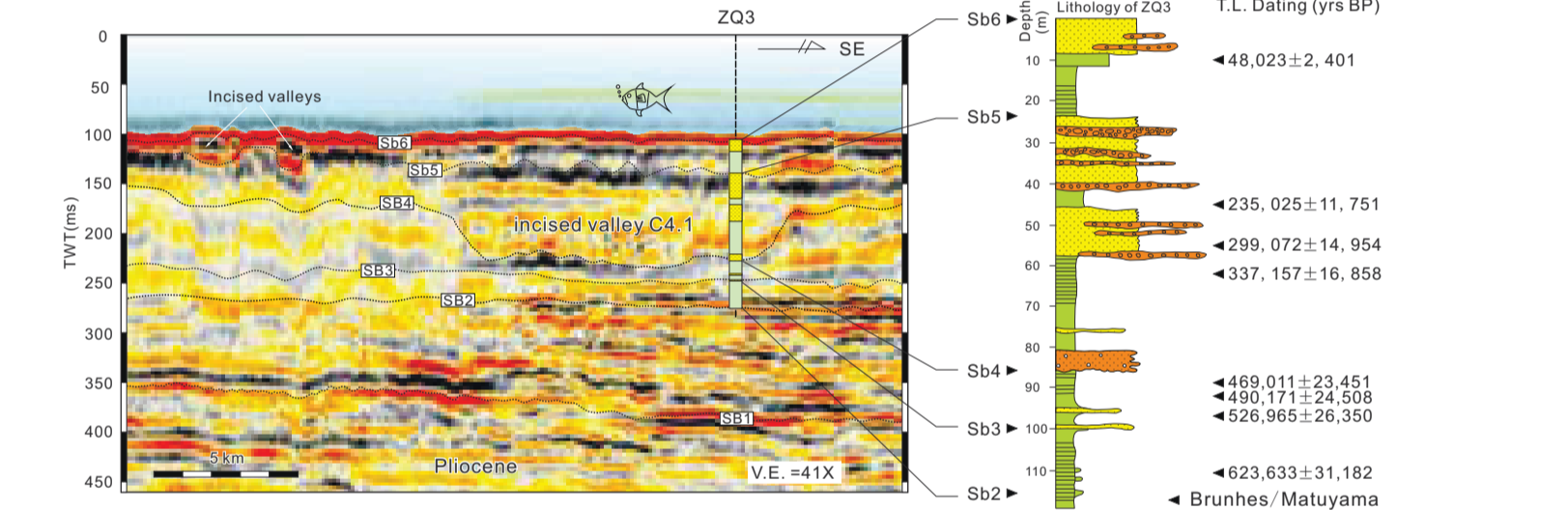


Fig.4. Calibration between major sequence boundaries and the shallow borehole ZQ3. The lithological column and thermo-luminescence dating results of ZQ3 are from Feng et al. (1996). T.L. = Thermo-luminescence.

Classification of Fluvial Systems

• Class 1 - trunk incised valleys

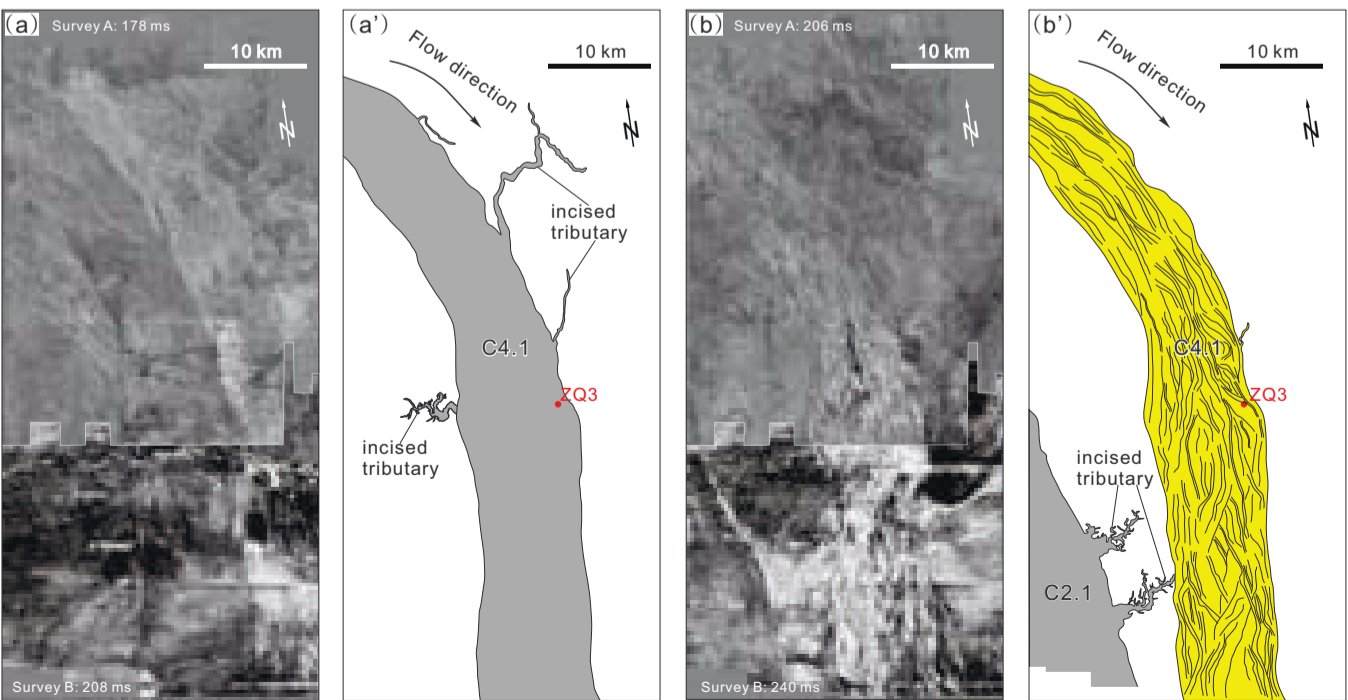


Fig.5. Seismic slices and corresponding interpretations depicting the geomorphology of trunk incised valley C4.1. Note the seismic slices were pieced up by datasets A and B.

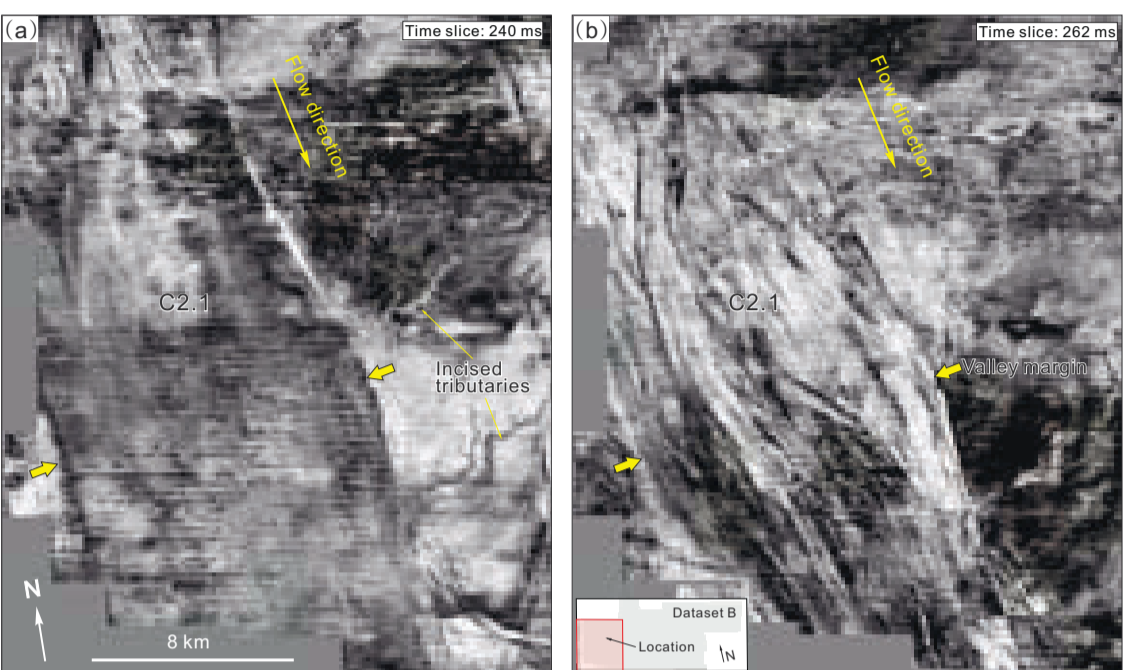


Fig.6. (a) Seismic time slice through the upper part of C2.1, showing well-developed dendritic incised tributaries on the right side of the valley; (b) seismic slice through the lower part of C2.1. Note that the valley base is occupied by numerous clustered channels cutting across each other. Also note the dimensions of the internal channels are orders of magnitude smaller than the valley.

• Class 2 - medium incised valleys / Class 3-incised tributaries

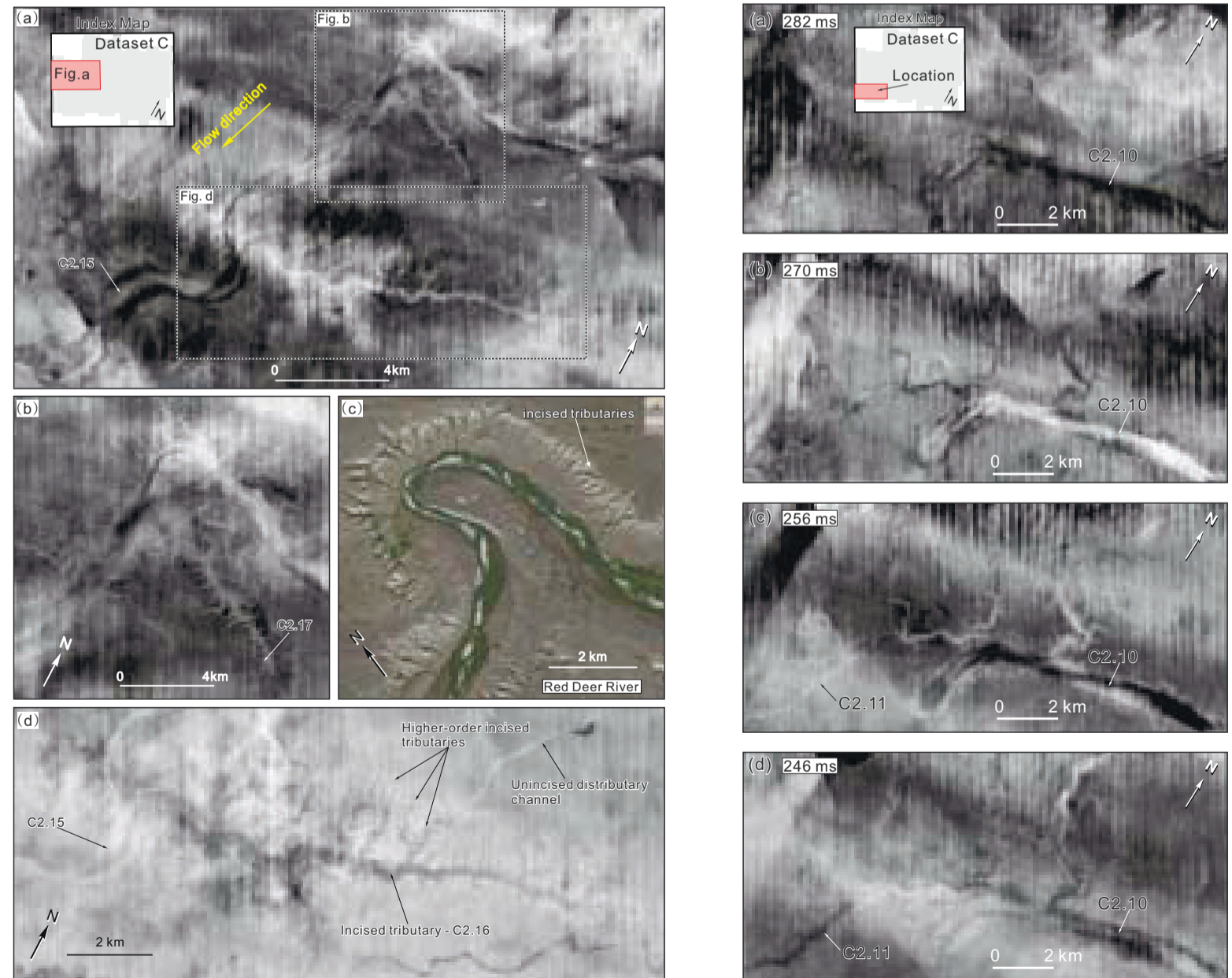


Fig.7. (a) Seismic time slice showing the geomorphology of medium incised valley C2.15 and corresponding incised tributaries. Note the comparison between C2.15 (b) and the aerial photo of a part of the Red Deer River in Canada (c) (Posamentier, 2001).

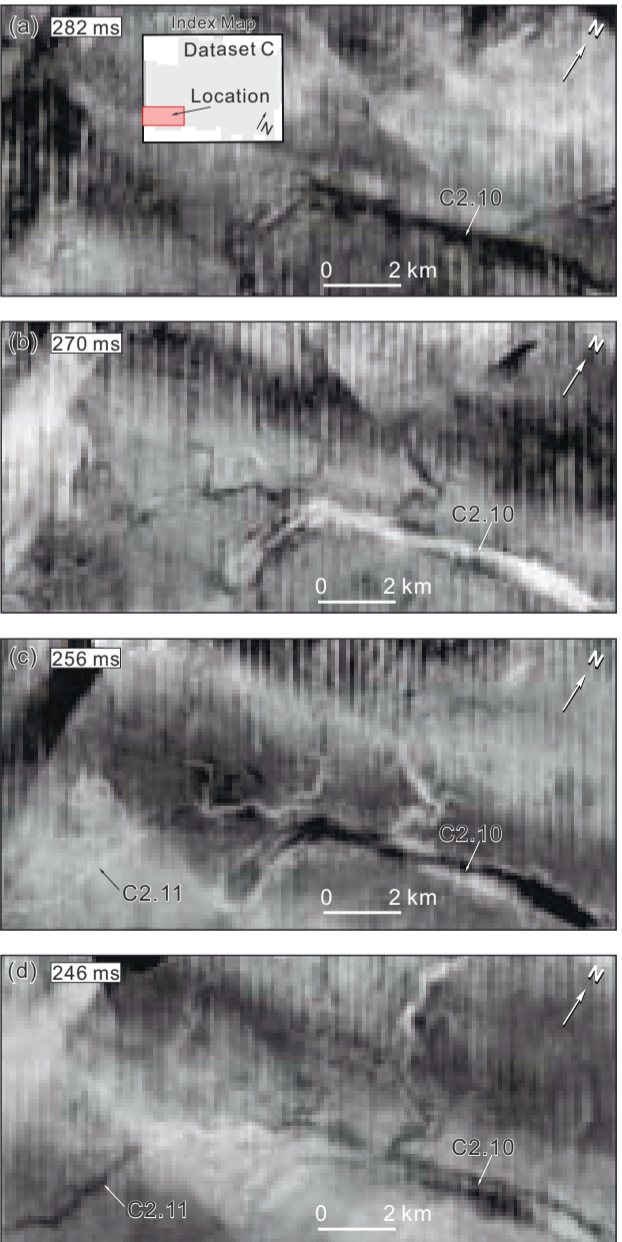


Fig.8. Four successive seismic slices indicate the variation in the geomorphology of medium incised valley C2.10 and corresponding tributaries from bottom up (a - d).

• Class 4 - trunk channels

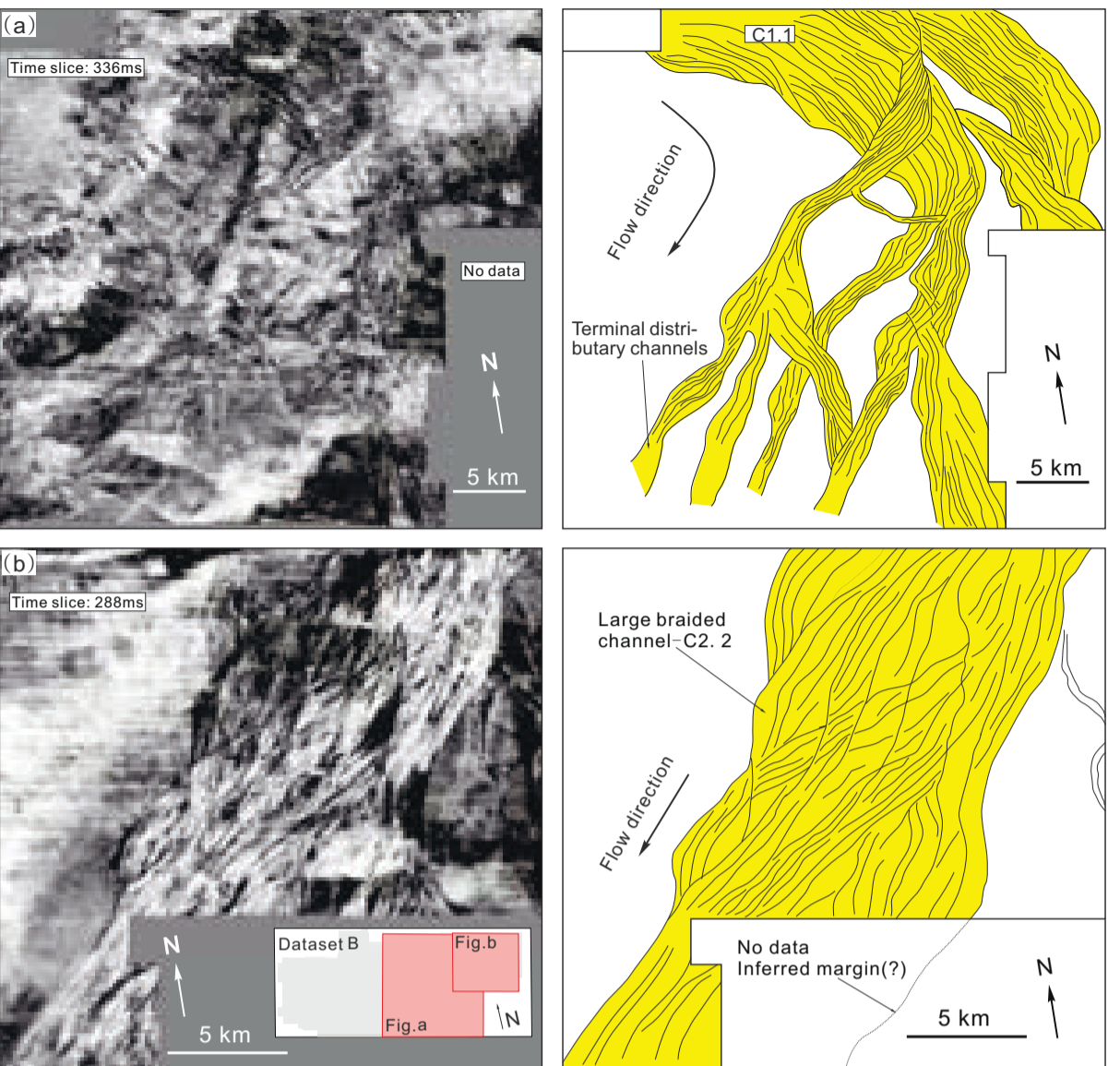


Fig.9. Representative seismic slices and interpretations of trunk channels. Note none incised tributaries are present with these channels.

• Class 5 - lateral migrating channels

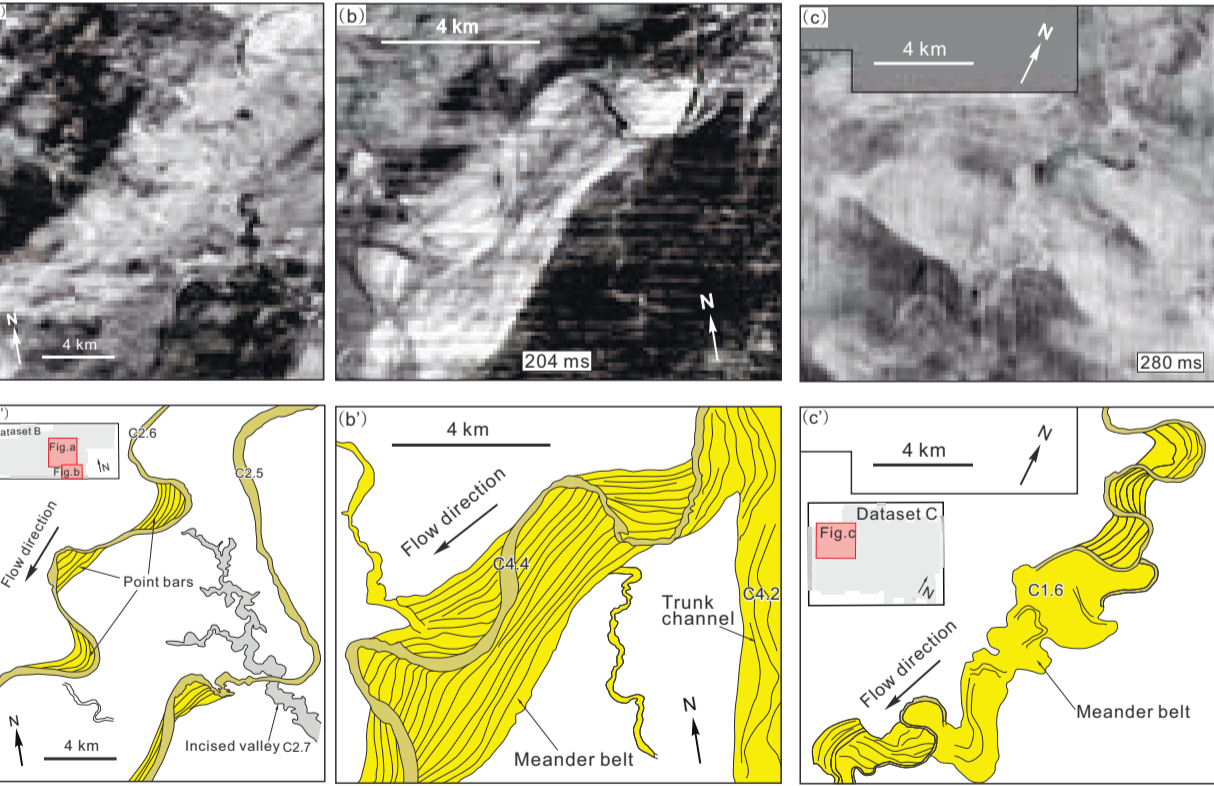


Fig.10. Representative seismic slices and interpretations of laterally migrating channels. The most striking feature of such channels is the presence of lateral accretion deposits.

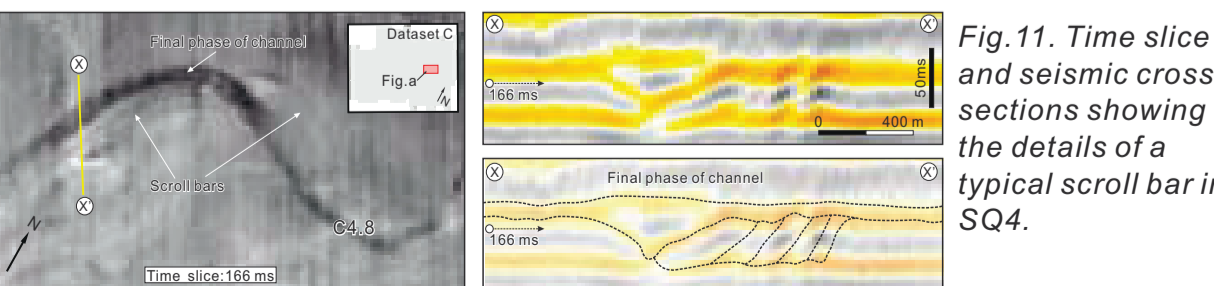


Fig.11. Time slice and seismic cross sections showing the details of a typical scroll bar in SQ4.

• Class 6 - stable channels

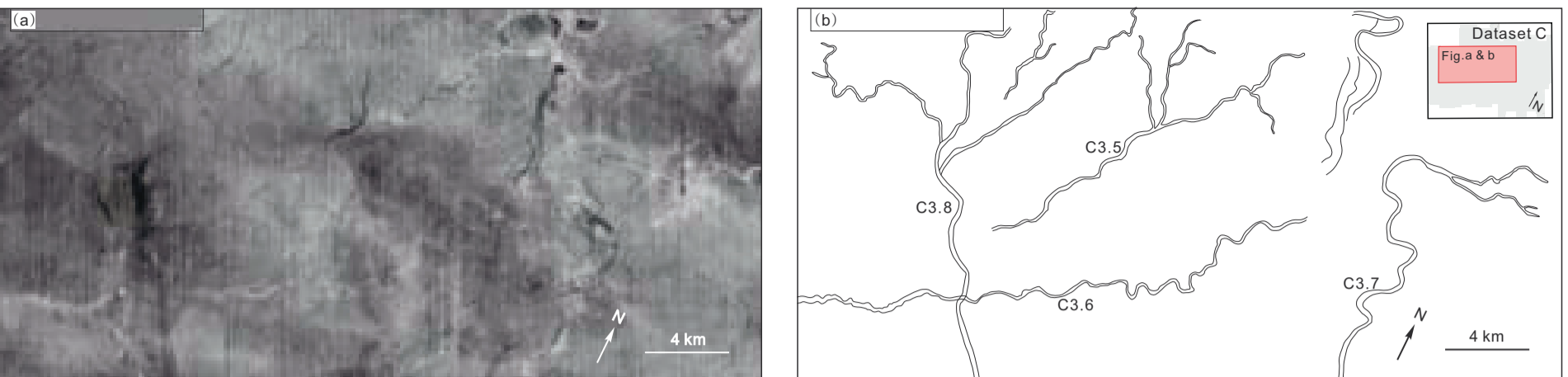


Fig.12. Representative seismic slice and interpretations showing the stable channels of SQ3. This class of channels is small in scale and have none evidence of later migration.

Summary for Seismic Geomorphology

- (1) Distinguishing incised valleys from unincised channels
 - the presence of subordinate tributary valleys draining into the trunk valley;
 - incised valleys tend to be irregular in their side walls or margins in plan view, while the unincised channels have smooth margins;
 - the incised valleys are a product of complex and multi-stage infilling history, while unincised channel fills tend to contain much simpler internal architecture.
- (2) Recognition of tidal influences
 - tidal influence is clearly visible on the seismic slices, especially in sequences SQ3.
- (3) Evidence for the presence of ancient "big rivers"
 - Before this study, most of the fluvial channels recognized from 3D seismic slices have widths no more than 4 - 5 km (Miall, 2002, 2006, 2014; Darmadi et al., 2007; Wood et al., 2007; Ethridge and Schumm, 2007).
 - Using three-dimensional seismic data in the northern shelf of the South China Sea, this study have spotted giant fluvial channels or incised valleys reaching a maximum width of 16 km (e.g. the C1.1), providing solid evidence for the existence of such giant rivers.

Evolution of Quaternary Buried Fluvial Systems

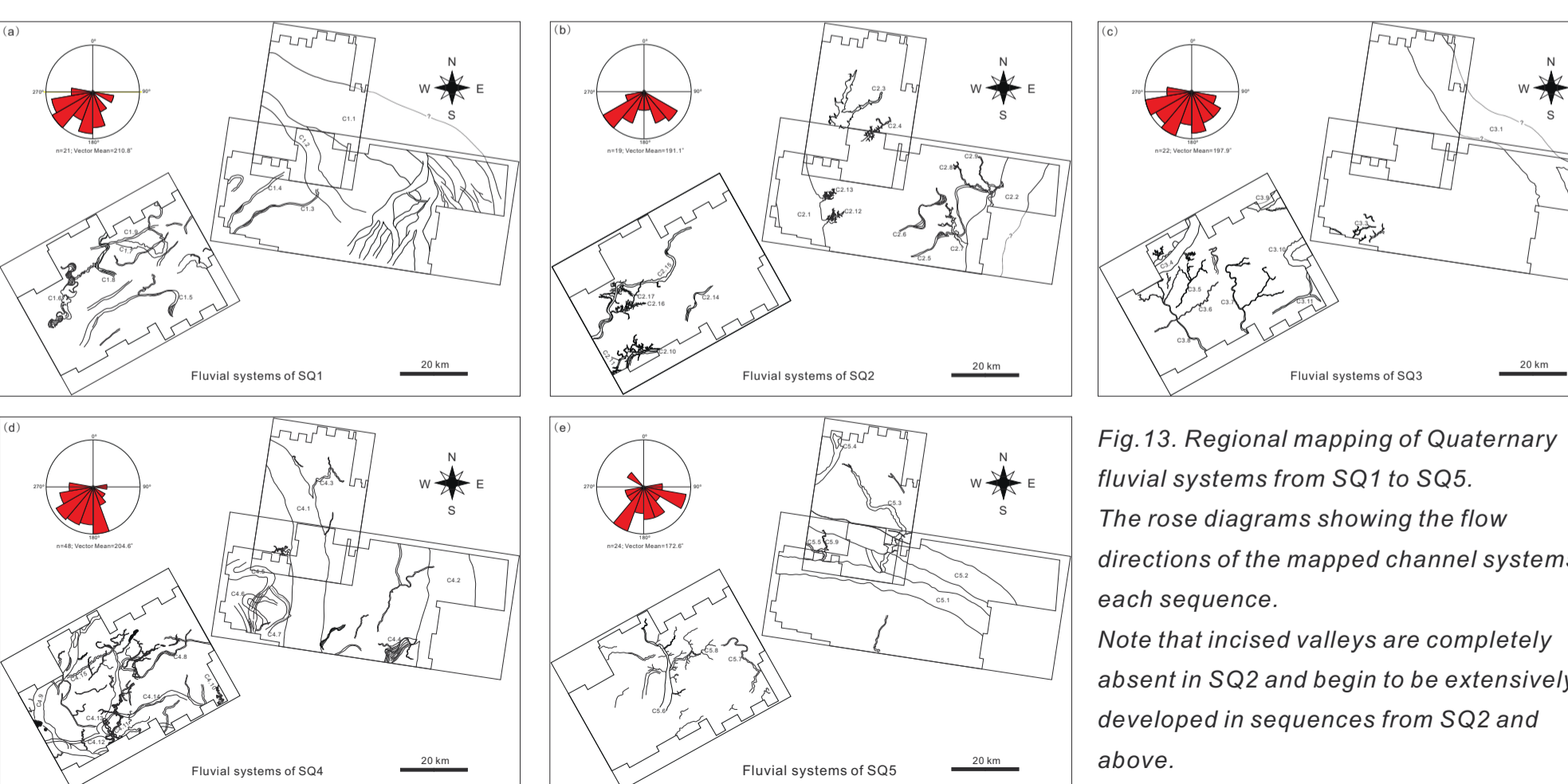


Fig.13. Regional mapping of Quaternary fluvial systems from SQ1 to SQ5. The rose diagrams showing the flow directions of the mapped channel systems in each sequence. Note that incised valleys are completely absent in SQ2 and begin to be extensively developed in sequences from SQ2 and above.

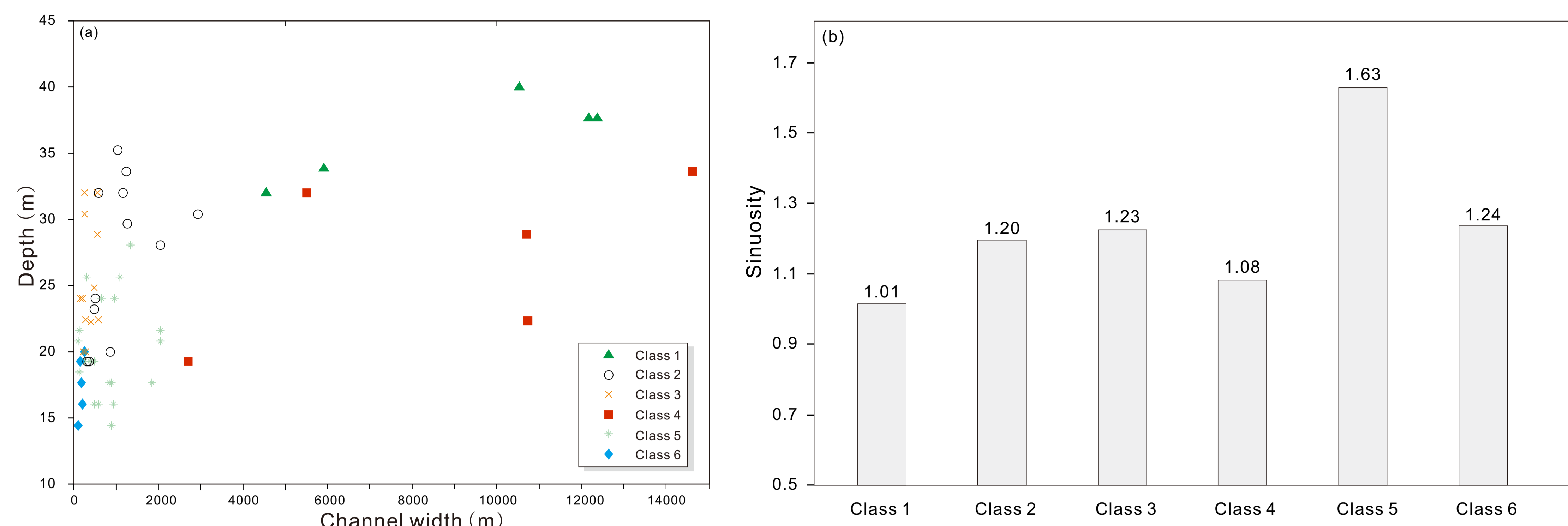


Fig.14. Representative seismic slice and interpretations showing the stable channels of SQ3. This class of channels is small in scale and have none evidence of later migration.

- (1) the incisions of various kinds of valleys tend to be deeper relative to the corresponding types of unincised channels (e.g., Class 1 VS. Class4, Class 2 VS. Class 5, Class 4 VS. Class 6);
- (2) large-scale incised valleys and braided channels have the highest width-to-depth ratio while the incised tributaries and stable channels have the lowest;
- (3) Class 2 valleys and Class 5 migrating channels have the highest sinuosity in all of the fluvial types;
- (4) it is difficult to distinguish incised and unincised systems solely on the basis of channel size.

Origin of Buried Fluvial Systems

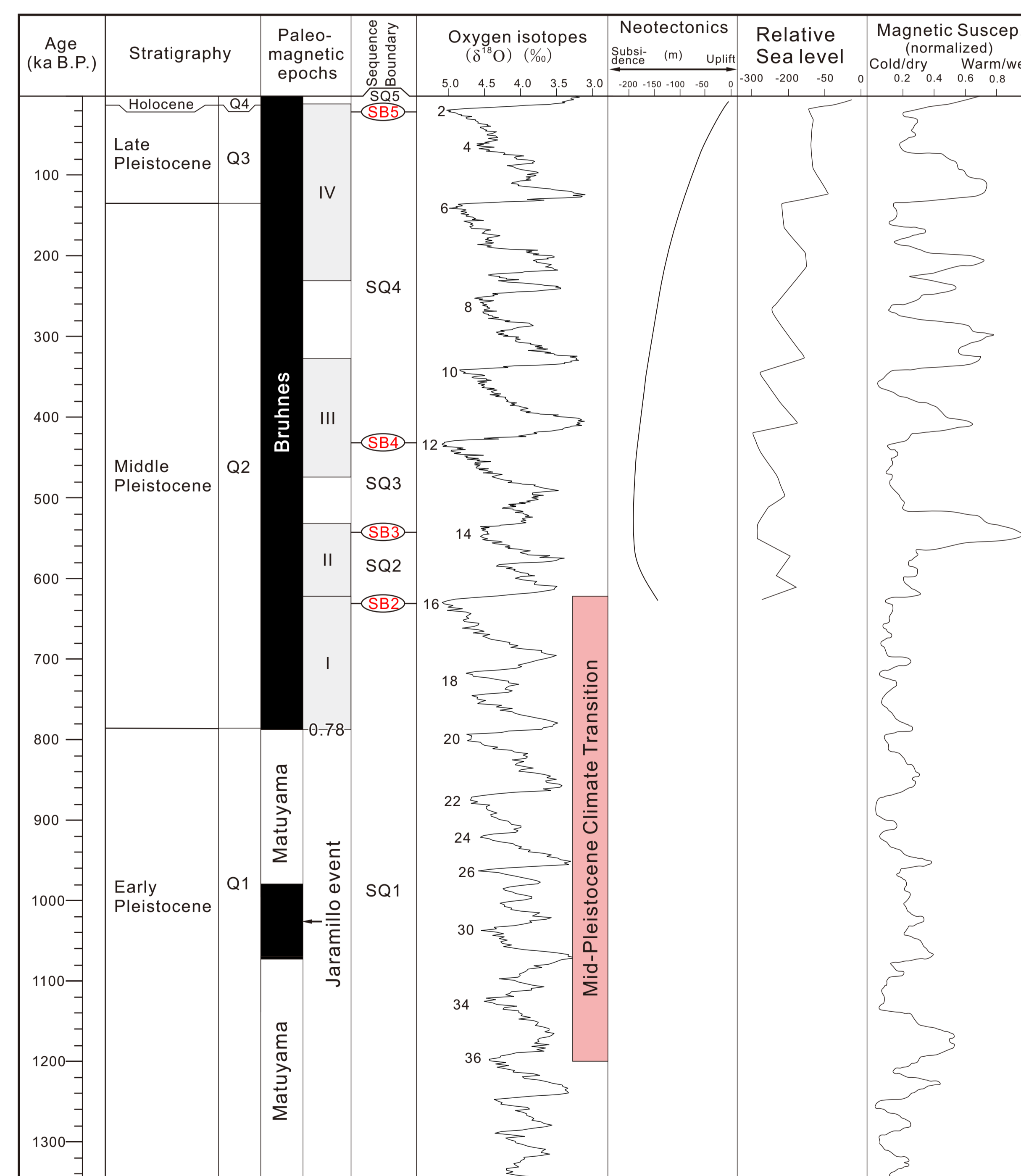


Fig.3. Chronostratigraphic chart of the study area since late Early Pleistocene. I – IV represent the possible range of the sequence boundaries SB2 – SB5, respectively. The oxygen isotope curve is from Lisiecki and Raymo (2005). Neotectonic and relative sea level curve are from Lüdmann et al. (2001). The normalized magnetic susceptibility is derived from Chinese Loess Plateau (Clemens et al., 1996), which serves as an important proxy for the East Asia monsoon intensity.

(1) Downstream versus upstream controls

- the distance to the shelf-break or shoreline was considered as a vital parameter in evaluating the relative contribution from the upstream or the downstream controls;
- the project area in this study is only a few tens of kilometers from the present shelf break, and distant from the shoreline (more than 100 km)

(2) Neotectonics and shelf physiography

- the Dongsha Rise experienced continuous uplift since the Middle Pleistocene;
- sea level fall were significantly accentuated and caused enhanced fluvial incisions during glacio-eustatic cycles since ca. 600 ka (0.6 Ma);
- the NE – SW direction of these fluvial systems was partially controlled by regional tectonic framework;

(3) Mid-Pleistocene Climate Transition (MPT)

- the MPT marks the significant transition of climate periodicity from ca. 41 ky to ca. 100 ky;
- a dramatic increase in the amplitude of eustatic change, perhaps from tens of meters prior to MPT, to over one hundred meters after it, was considered to be a primary trigger for incised fluvial systems.

(4) East Asian monsoon evolution

- the climate of the South China Sea region is significantly influenced by the East Asian monsoon;
- the East Asian monsoon intensification events at ca. 0.9 Ma and 0.6 Ma which lead to cooler and drier climatic conditions and that were also associated with increased magnitude of sea level fall, caused the onset of enhanced fluvial incision about 0.6 Ma;
- driven by strengthened monsoons, vegetation cover was dominated by grassland or liverworts, which were prone to be eroded.

Acknowledgments

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For more information: www.researchgate.net/profile/Haiteng_Zhuo2