PSUnravelling the Influence of Throw and Stratigraphy in Controlling Sub-Seismic Fault Architecture of Fold-Thrust Belts: An Example from the Qaidam Basin, Northeast Tibetan Plateau*

Yangwen Pei[1,2], Douglas Paton[2], Rob Knipe[2], K. Wu[1], and L. Xie[1]

Search and Discovery Article #30524 (2017)**
Posted October 16, 2017

*Adapted from poster presentation given at 2017 AAPG Annual Convention & Exhibition, Houston, Texas, April 2-5, 2017

[1]School of Geosciences, China University of Petroleum, Qingdao, China (peiyangwen@upc.edu.cn)
[2]School of Earth & Environment, University of Leeds, Leeds, United Kingdom

Abstract

Understanding fault architecture at an outcrop scale is fundamental as it controls the fault zone compartmentalization which plays important control on fluid flow properties across fault zones. Although previous studies have investigated the relationship between faults and folds developed within compressional systems, the detailed fault architecture of thrust faults remain poorly constrained, particularly at the meso-scale. Not only are sub-seismic faults poorly imaged but even seismically resolvable structures are poorly imaged because of the steep dipping nature of reflections, which makes it difficult to predict the fault zone geometry in detail.

The detailed fault architecture analysis of an exceptionally well-exposed fold-thrust belt in the Qaidam Basin is reported. The Lenghu5 fold-thrust belt, with well-exposed outcrops, is selected for high-resolution fieldwork to collect multiple scale data, including stratigraphy, dips and cross sections. The detailed stratigraphic logging and high-resolution cross sections allow us to quantitatively evaluate the fault throw distribution along the fault zone, both in section view and plan view. Integrating the high-resolution fault system mapping, it is identified that the main thrust fault accounts for between 80 and 85% of the cumulative throw of the fault zone, while the fault splays (15-20% of the cumulative throw) lead to the development of small-scale structures, e.g. small pair of syncline/anticline in the footwall and small accommodation faults in the hanging-wall. The 3D geospatial model, integrating multi-scale data based on high-resolution fieldwork, enables the investigation on the detailed fault zone architecture of a natural fold-thrust belt. The non-uniform fault throw along the fault zone leads to a high degree of lateral structural variation at the regional scale, whereas the local stratigraphy may control the development of minor structures in both the hanging wall and footwall at smaller scales. The Lenghu5 geometry is directly comparable with some well-studied subsurface examples, such as the Niger Delta, and therefore provides invaluable insights into the geometry of faults in poorly imaged fold-thrust systems.

Unravelling the influence of throw and stratigraphy in controlling sub-seismic fault architecture of fold-thrust belts

中国石油大学(华东) CHINA UNIVERSITY OF PETROLEUM

Yangwen Pei*[1,2], D. Paton[2], R. J. Knipe[2], K. Wu[1], L. Xie[1] *peiyangwen@upc.edu.cn

[1]School of Geosciences, China University of Petroleum, Qingdao, China. [2]School of Earth & Environment, University of Leeds, Leeds, UK.

UNIVERSITY OF LEEDS

Introduction

- Understanding fault architecture at an outcrop scale is fundamental as it controls the fault zone compartmentalization which plays important control on fluid flow properties across fault zones. Although previous studies have investigated the relationship between faults and folds developed within compressional systems, the detailed fault architecture of thrust faults remain poorly constrained, particularly at meso-scale. Not only are sub-seismic faults poorly imaged but even seismically resolvable structures are poorly imaged because of steep dipping nature of reflections, which makes it difficult to predict the fault zone geometry in detail. The detailed fault architecture analysis of an exceptionally well-exposed fold-thrust belt in the Qaidam Basin is reported.

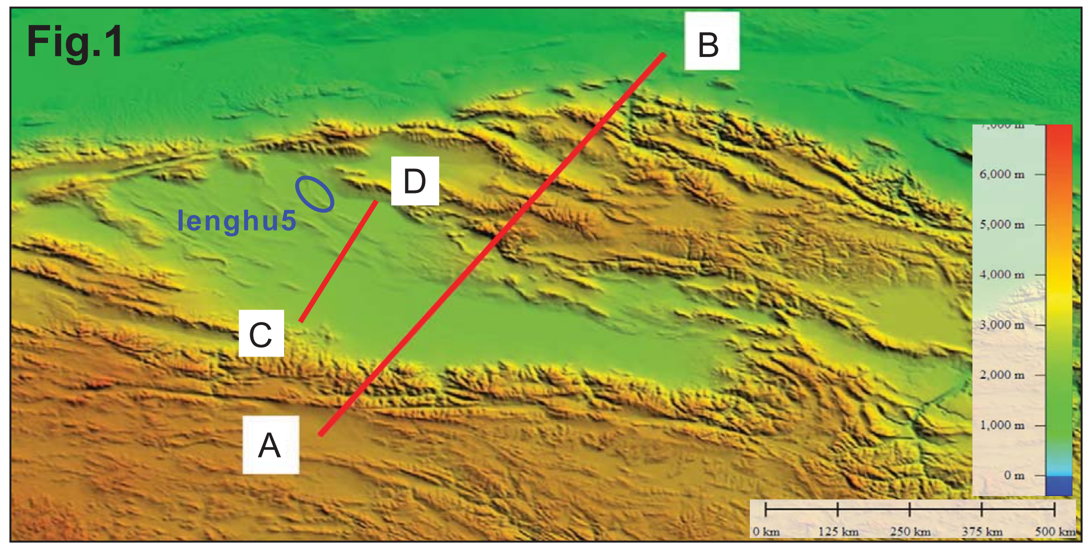
Objectives

- To quantitatively evaluate the fault throw distribution along the fault zone, both in section view and plan view.
- To identify the critical parameters which contribute to the detailed fault zone architecture of a natural fold-thrust belt.
- To provide insights into the geometry of faults in poorly imaged fold-thrust systems, based on analogue comparison.

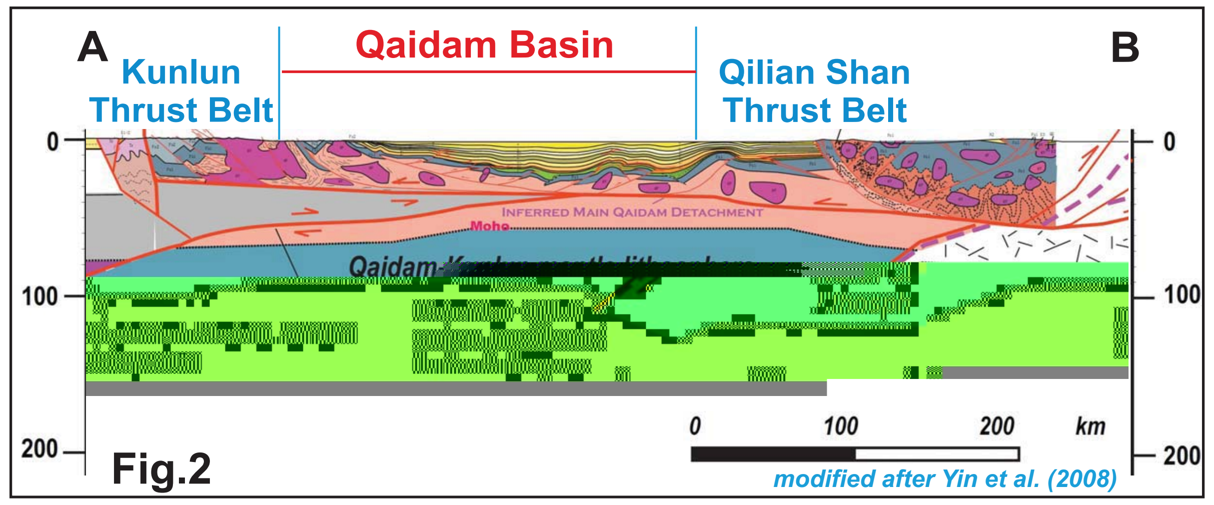
Methodology

- 1) Stratigraphy logging: to constrain the detailed stratigraphy within the Lenghu5 fold-thrust belt three well exposed traverses (2150 m total stratigraphic thickness) across the structure were logged.
- 2) Cross section construction: to investigate the spatial distribution in throw along the fault zone and the anticline geometry in the hanging-wall, ten parallel sections were created by detailed structural measurements and ground-truthed satellite image interpretation.
- 3) 3D geospatial modeling: 3D geospatial models were constructed by integrating the field-scale observation and cross sections. The spatial distribution of fault throw and the lateral variation of hanging wall anticline were then quantitatively analysed to understand the 3D fault architecture of the Lenghu5 fold-thrust belt.
- 4) Sub-surface equivalent: A geometrically and scale equivalent example from the Niger Delta was used to compare the field-scale observation from the Lenghu5 fold-thrust belt. In particular we focus on prediction of sub-seismic fault architecture within a fault zone.

Geological Settings

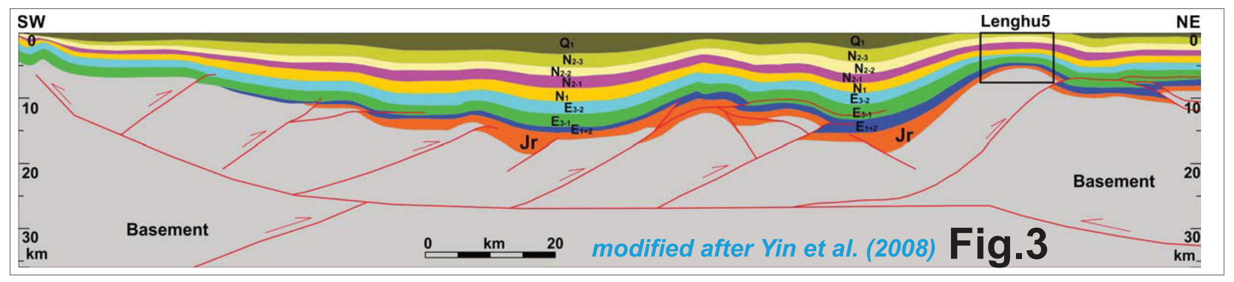


- The Qaidam basin (N Tibetan Plateau) was induced by collision between the Indian and Eurasia.
- A Mesozoic-Cenozoic sedimentary basin with abundant hydrocarbon resources.



- Tectonically dominated by the extension during Jurassic-Cretaceous and then inverted by the contraction during Paleocene-present.

Macro-scale Thrust Fault Architecture



- Mesozoic sediments controlled by normal faults, while Cenozoic sediments controlled by thrust faults;
- The shortening decreases eastward;
- Shortening 18.3km & average-shortening rate 0.28mm/yr;

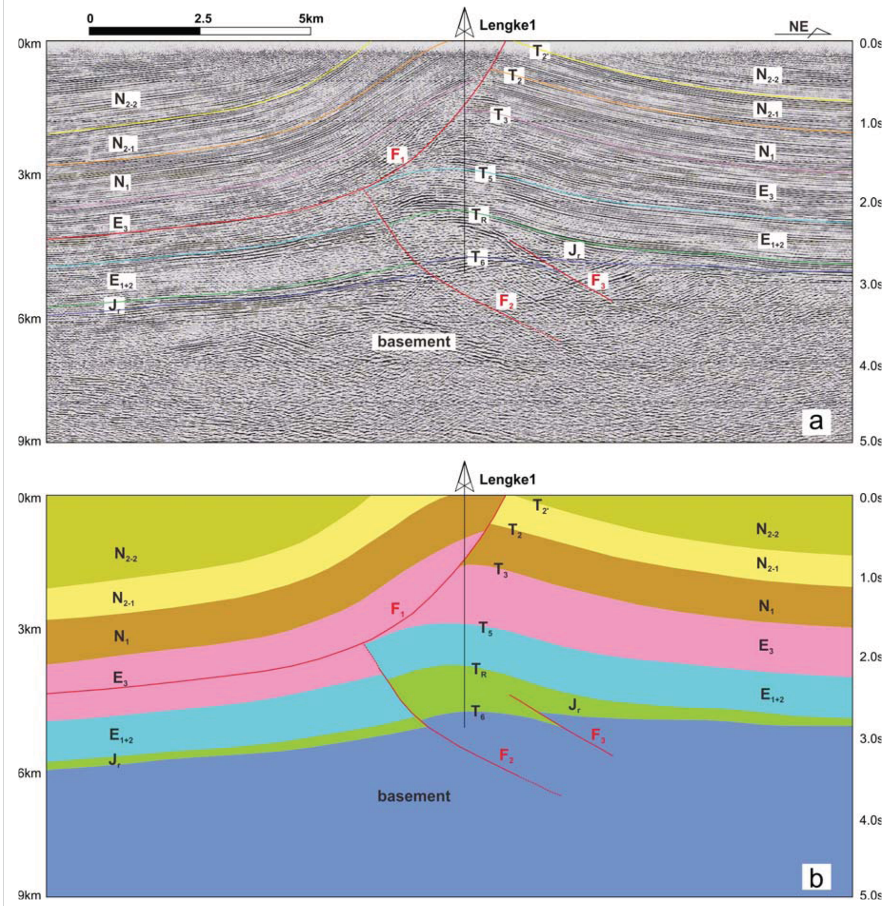


Fig.4

- An interpreted seismic section across the Lenghu5 fold-and-thrust belt.
- The Lenghu5 fold-and-thrust belt (N Qaidam basin), was selected as the study area for the following regional-meso scale studies.

Regional Thrust Fault Architecture

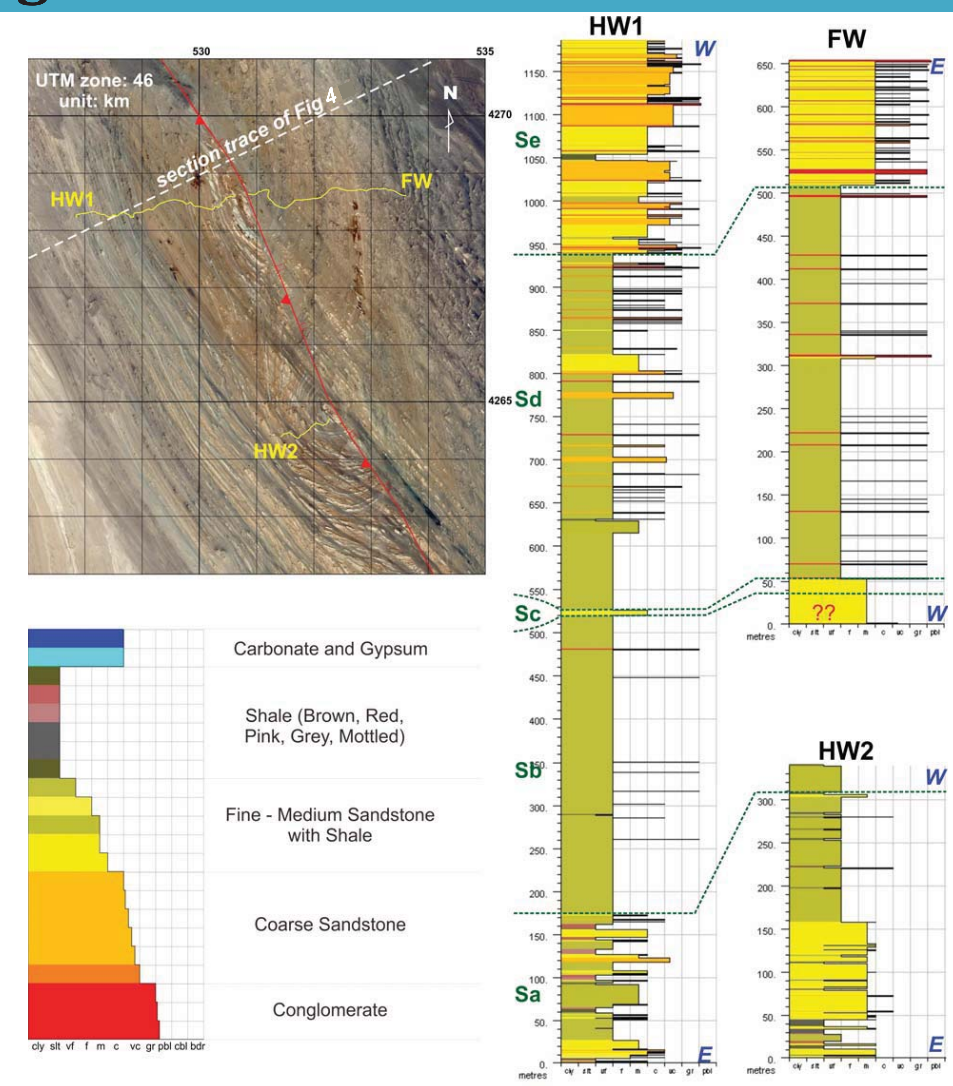


Fig.5

- The stratigraphy (N_2) is dominated by sandstones, silt-stones and mudstones. The mechanical heterogeneity is low-moderate.

Key References Cited

1. Allen, M. B., and S. J. Vincent, 1997, Fault reactivation in the Junggar region, northwest China: the role of basement structures during Mesozoic-Cenozoic compression: Journal of the Geological Society, v. 154, p. 151-155.
2. Cowgill, E., A. Yin, W. X. Feng, and Z. Qing, 2000, Is the North Altyn fault part of a strike-slip duplex along the Altyn Tagh fault system?: Geology, v. 28, p. 255-258.
3. Kostenko, O. V., S. J. Naruk, W. Hack, M. Poupon, H.-J. Meyer, M. Mora-Glukstad, C. Anowai, and M. Mordi, 2008, Structural evaluation of column-height controls at a toe-thrust discovery, deep-water Niger Delta: AAPG, v. 92, p. 1615-1638.
4. Molnar, P., and P. Tapponnier, 1975, Cenozoic Tectonics of Asia - Effects of a Continental Collision: Science, v. 189, p. 419-426.

geori.upc.edu.cn

Unravelling the influence of throw and stratigraphy in controlling sub-seismic fault architecture of fold-thrust belts

Yangwen Pei*[1,2], D. Paton[2], R. J. Knipe[2], K. Wu[1], L. Xie[1] *peiyangwen@upc.edu.cn
[1]School of Geosciences, China University of Petroleum, Qingdao, China. [2]School of Earth & Environment, University of Leeds, Leeds, UK.

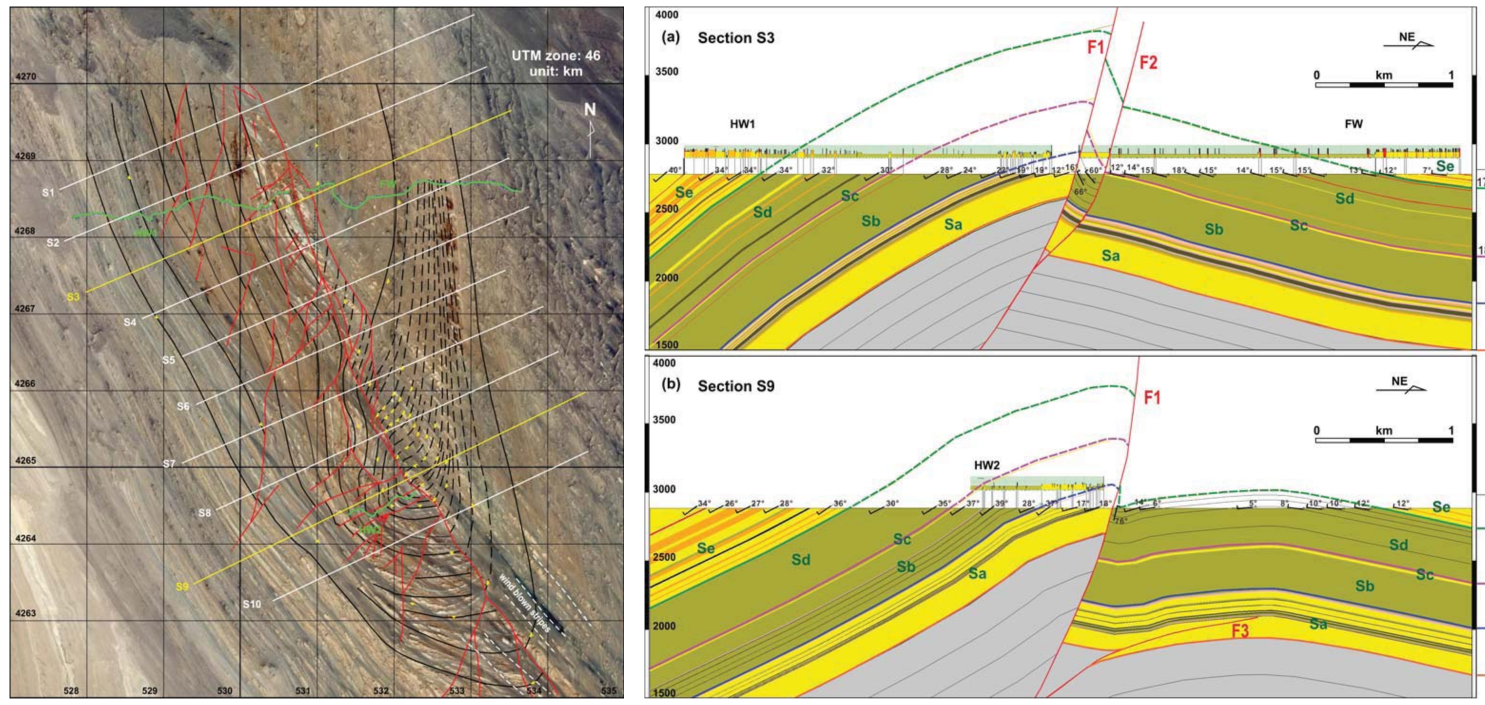


Fig.6

- Transects based on field data are used to evaulate the fault throw distribution.
- The transects show non-uniform displacement along the fault zone.

3D Fault Architecture: spatial distribution of fault throw

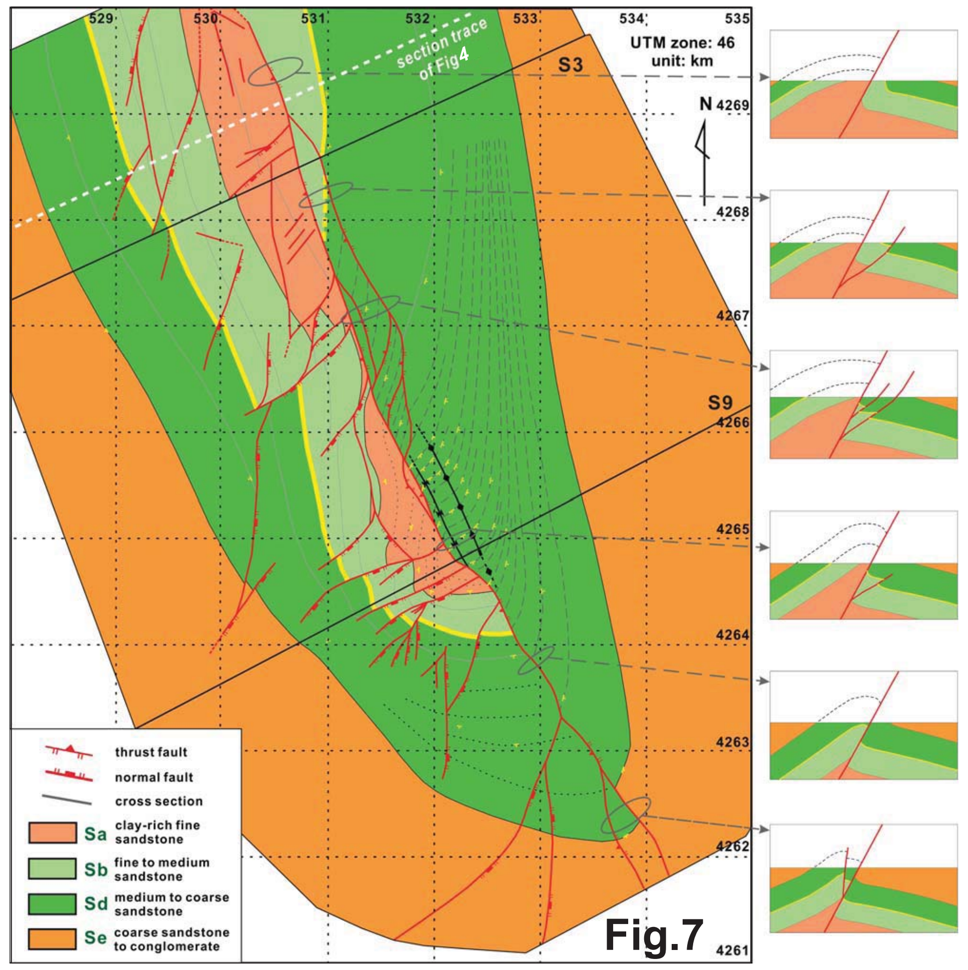


Fig.7

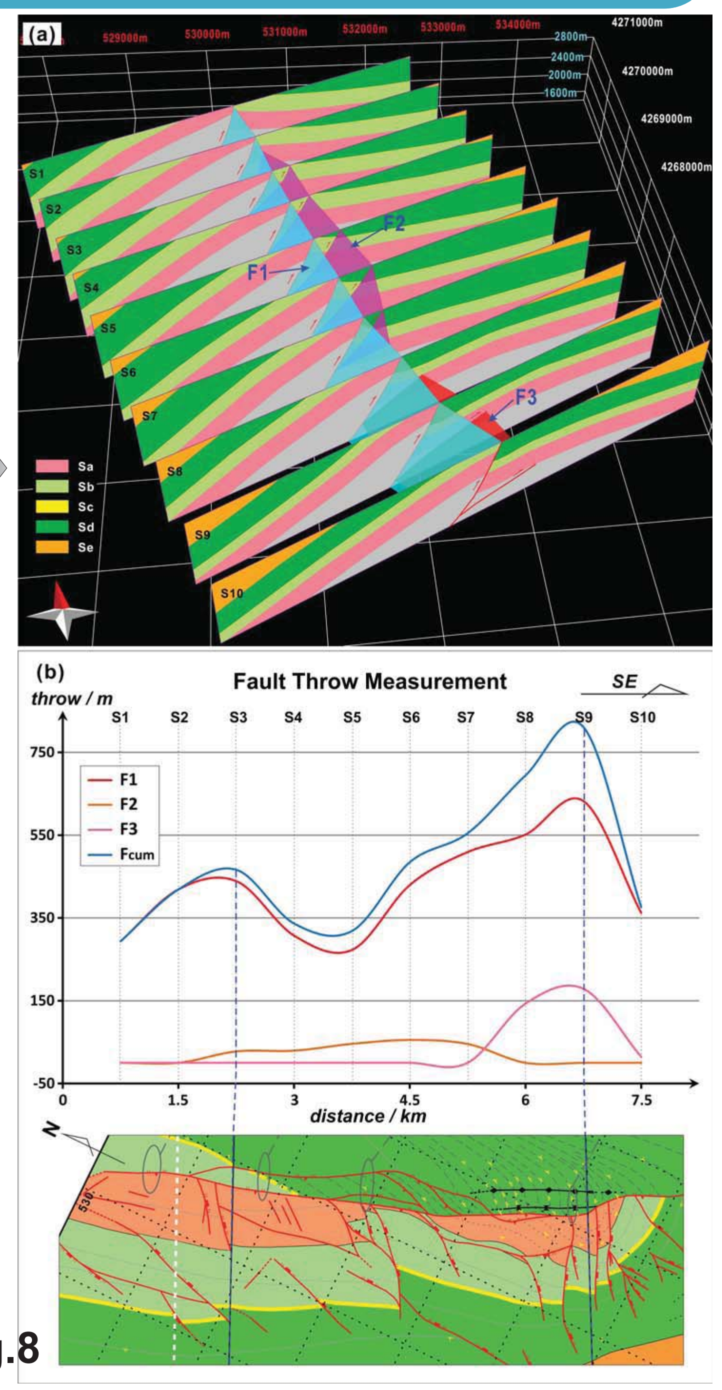


Fig.8

- 3D structural model of the Lenghu5 fold-thrust belt and the fault throw measurement along the Lenghu5 fault zone (the Fcum represents cumulative fault throw of the fault zone, Fig.8).
- The peaks and valleys in the fault throw curve corresponds to positions with high degree of lateral structural variation.

3D Fault Architecture: lateral variation

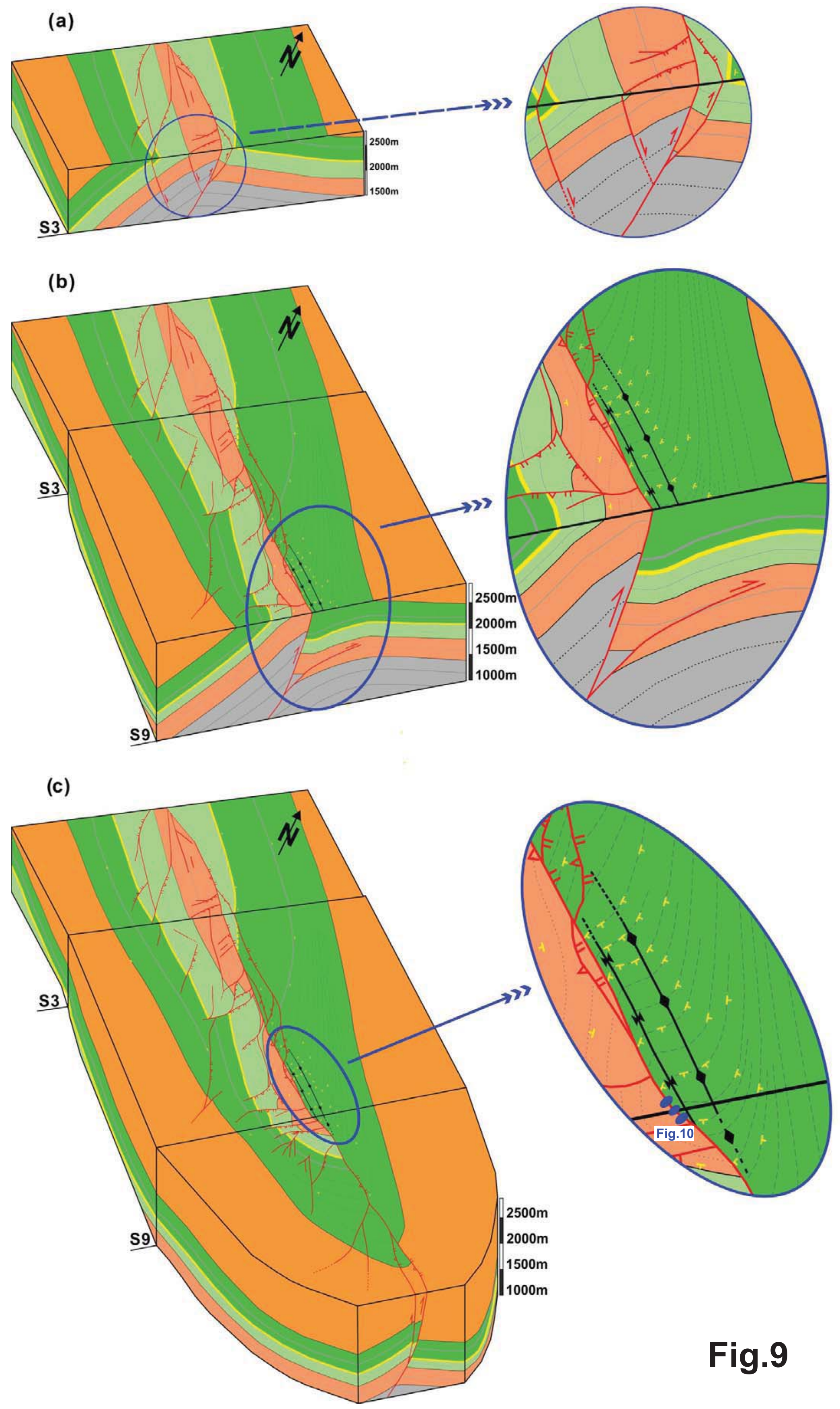


Fig.9

- 3D models integrating multi-scale structures to demonstrate the structural geometry and lateral variation of the Lenghu5 fold-thrust belt. The nonuniform fault throw anong the fault zone leads to high degree of lateral structural variation.
- The overall structural style is determined by the main thrust fault, while the small-scale structures (e.g., small folds and faults) are developed as a result of the fault splays.

3D Fault Architecture: missed strain at a smaller scale

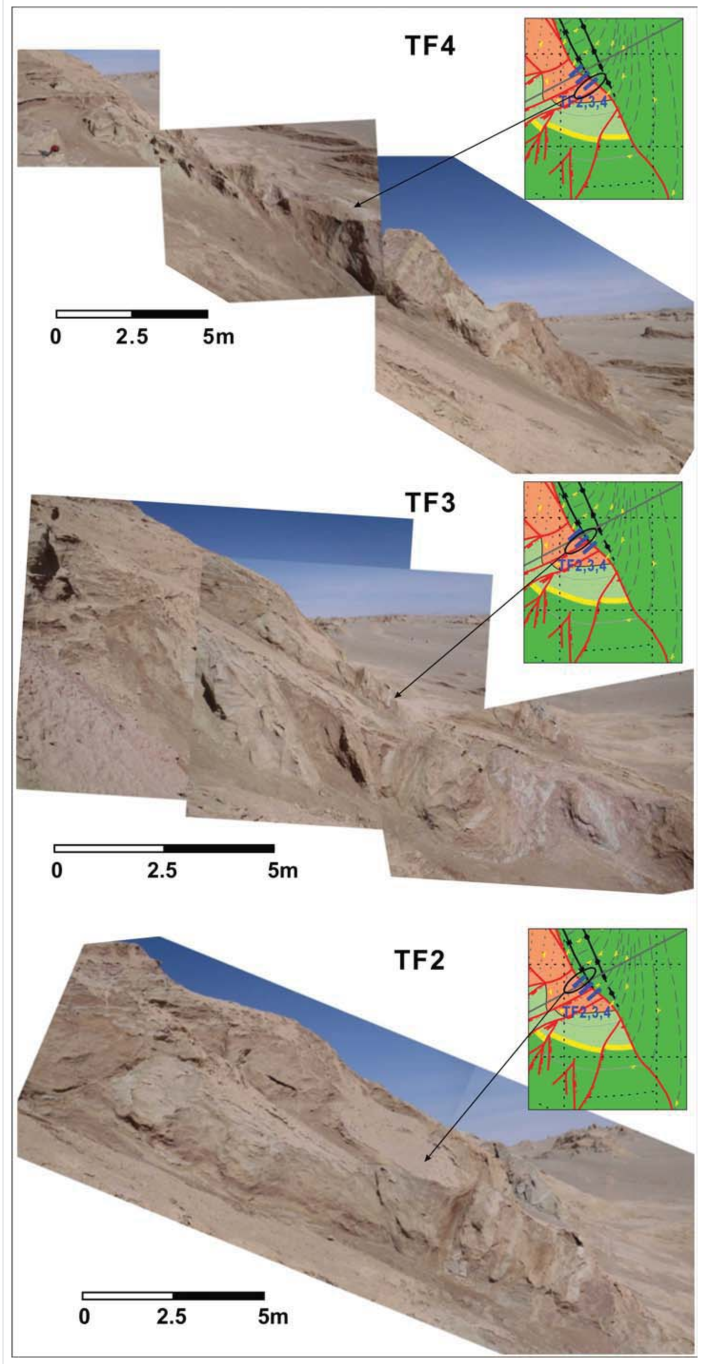


Fig.10

- The detailed outcrop map of TF2, TF3 and TF4. An anticline can be found in the left-top part of these outcrops.
- In the right-bottom part, the core of the main reverse fault is just next to the anti-cline on the left.
- The detailed outcrop maps show the latera structurall variation of the Lenghu5 thrust fault zone. These fault zone outcrops present similar structural geo-metries, however, lat-eral structural variation can be observed when focusing on smaller-scale deformation features (Fig.11).

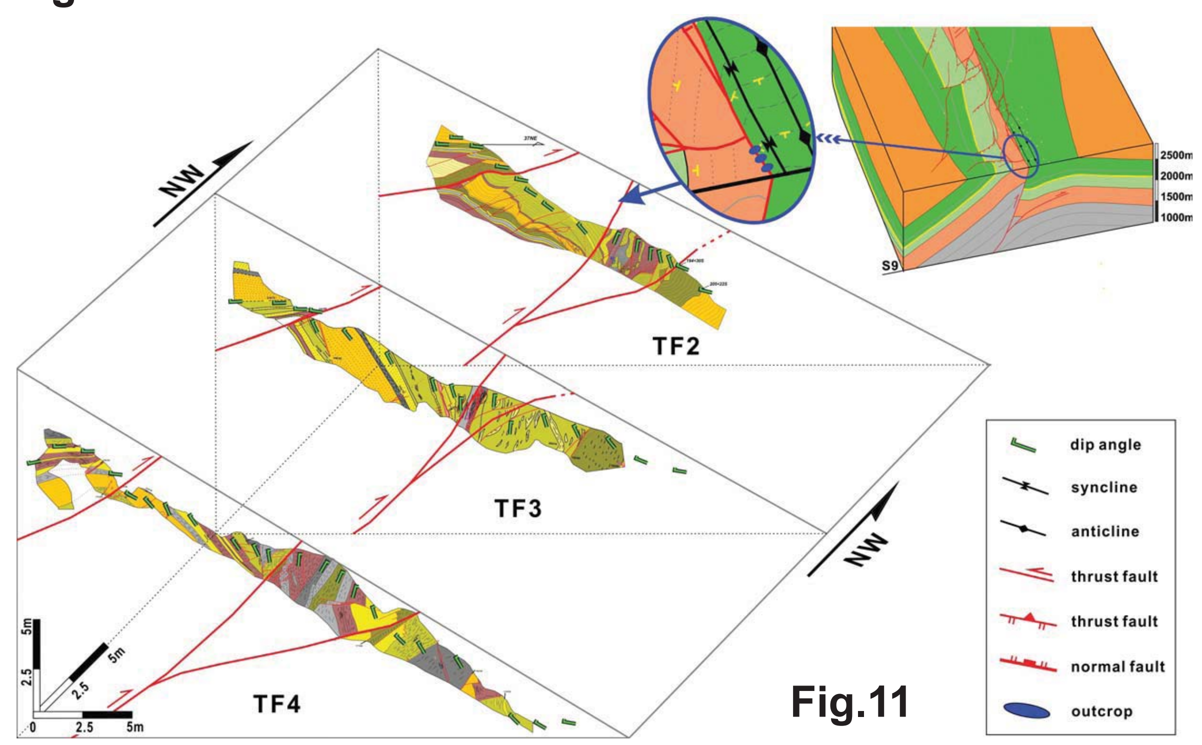


Fig.11

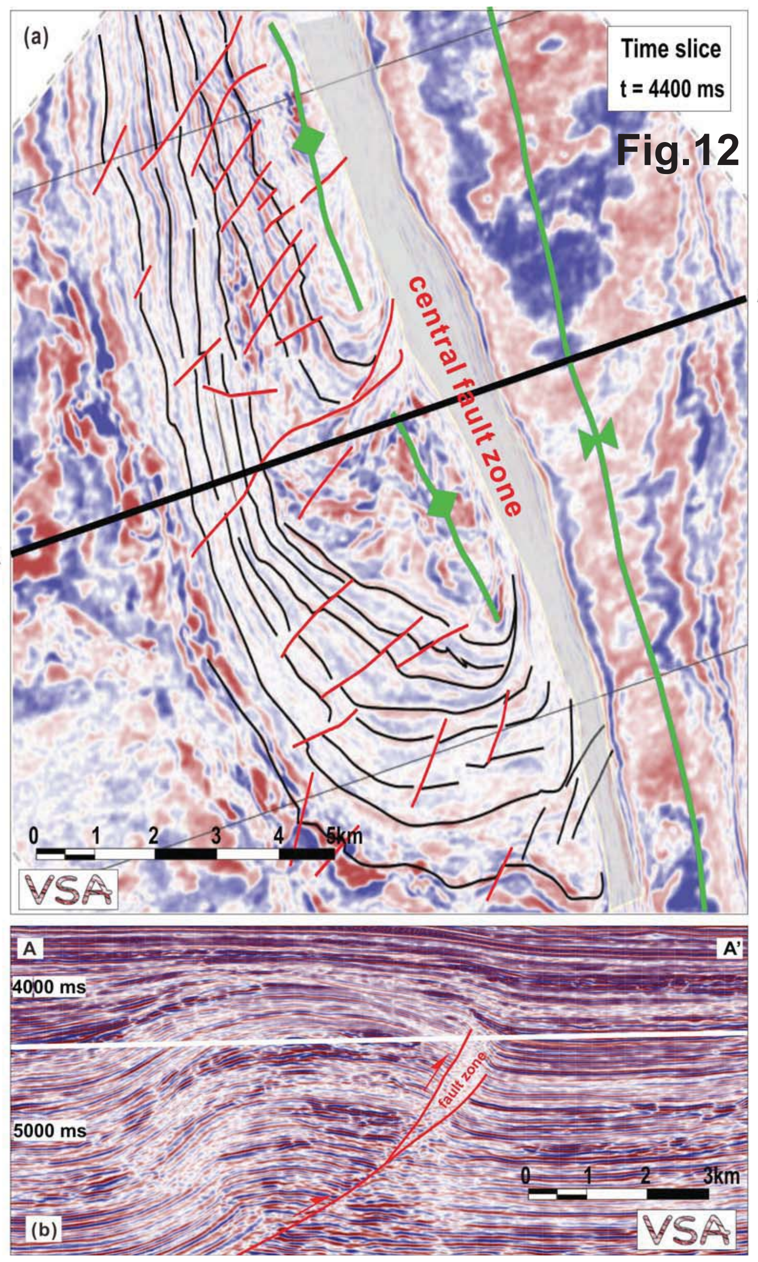
Key References Cited (continued)
5. Morley, C., 2009, Geometry of an oblique thrust fault zone in a deepwater fold belt from 3D seismic data: Journal of Structural Geology, v. 31, p. 1540-1555.
6. Paton, D., M. Carr, B. Trudgill, H. Ortner, and D. A. Medwedeff, 2007, Alpine-scale 3D geospatial modeling: Applying new techniques to old problems: Geosphere, v. 3, p. 527-549.
7. Pei, Y., D. A. Paton, and R. J. Knipe, 2014, Defining a 3-dimensional trishear parameter space to understand the temporal evolution of fault propagation folds: Journal of Structural Geology, v. 66, p. 284-297.
8. Yin, A., Y. Q. Dang, M. Zhang, X. H. Chen, and M. W. McRivette, 2008, Cenozoic tectonic evolution of the Qaidam basin and its surrounding regions (Part 3): GSA, v. 120, p. 847-876.

geori.upc.edu.cn

Unravelling the influence of throw and stratigraphy in controlling sub-seismic fault architecture of fold-thrust belts

Yangwen Pei*[1,2], D. Paton[2], R. J. Knipe[2], K. Wu[1], L. Xie[1]   *peiyangwen@upc.edu.cn
[1]School of Geosciences, China University of Petroleum, Qingdao, China.   [2]School of Earth & Environment, University of Leeds, Leeds, UK.
中国石油大学(华东) CHINA UNIVERSITY OF PETROLEUM
UNIVERSITY OF LEEDS

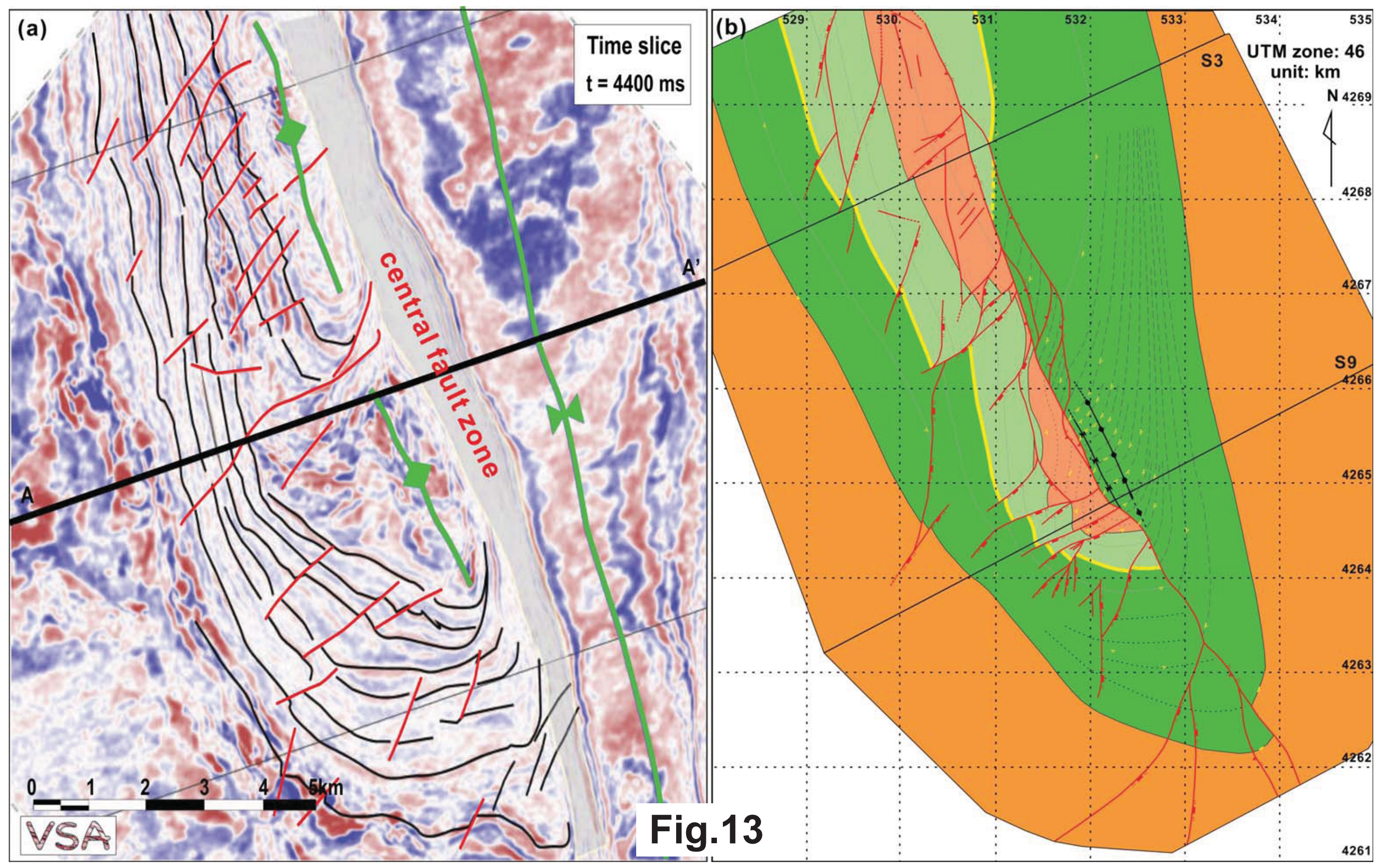
Sub-surface Equivalent - application to exploration in DWFTBs

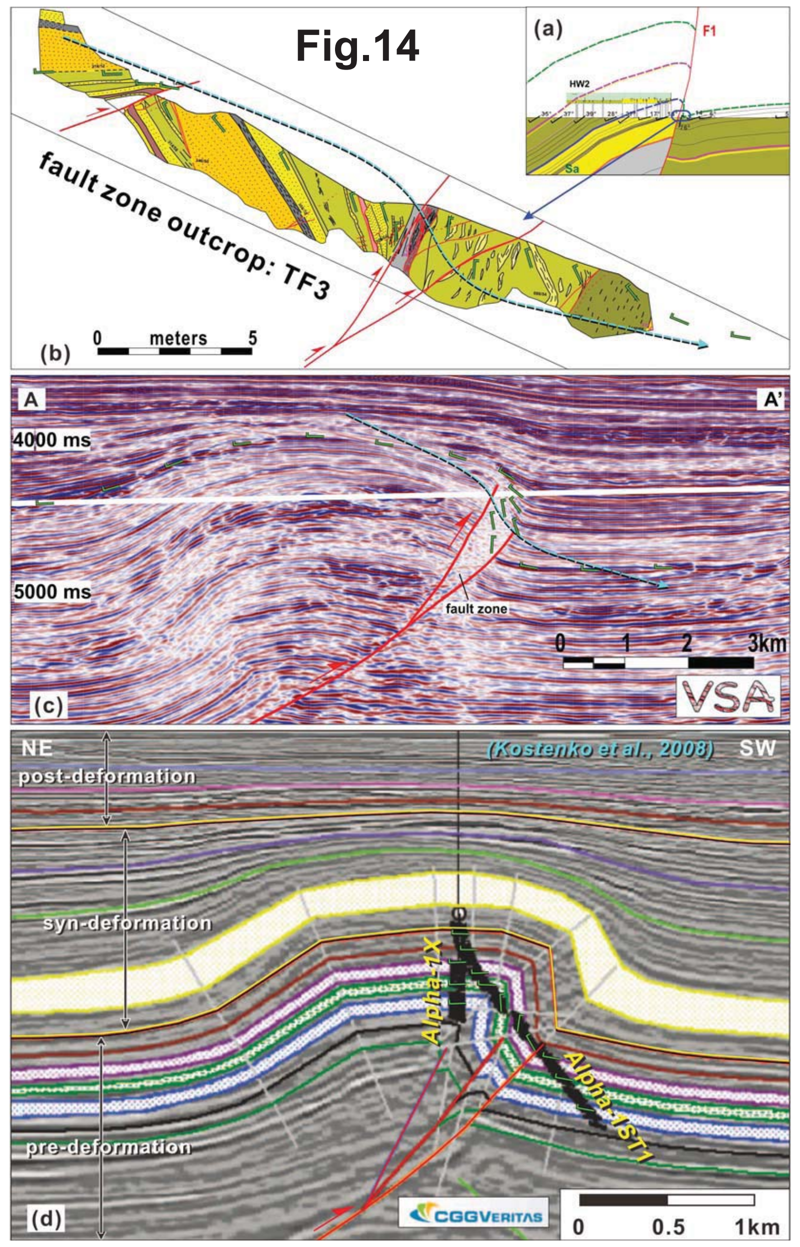


♦ An example from the Niger Delta (seismic data from VSA). (a) A time slice (t=4400 ms) showing folds and fault arrays in plan view. (b) A seismic section showing fold and fault geometry. *modified after Kostenko et al. (2008)*

♦ Comparison between the Lenghu5 fold-thrust belt and the Niger Delta seismic time slice (from VSA).

♦ The good accordance between the two may suggest the potential prediction of small scale structures based on the lateral structural variation.The sandstone dominated sequences are prone to form fractures/faults while mudstone dominated sequences form clay smears.





♦ Comparison of fault architecture and structural geometry between the Lenghu5 fold-thrust belt (a, b) and an seismic example from the Niger Delta (c).

♦ The good correlation between the two demonstrate that the overall geometry of a structural is dominated by the fault throw, whereas the small scale deformation features are more likely to be controlled by the local stratigraphy.

♦ The dip variation of the frontal limb (d) indicates the complexity of structural geometry within the no-seismic-image triangle zone, rather than a simple composition of fault gouges, fault lenses and fault breccias.

Discussion

(1). Control of Fault Throw on Lateral Structural Variation

High degree lateral variation are all located in the positions where the fault throw changes rapidly between peaks and valleys in the throw vs distance curves.

(2). Controls on fault splays and small scale stuctures: influence of stratigrpahy

There is significant variation in splay geometry along trend that appears to have limited correlation with fault throw rather than the stratigraphy. Stratigraphy heterogeneity determines the detailed fault architecture at meso-scale and micro-scale.

(3). Scale-dependant Effects of Fault Throw and Stratigraphy

The fault throw controls the structural geometry and fault architecture at regional scale, whereas the stratigraphy can impact on the deformation features at smaller scale, i.e., meso-scale.

Conclusions

Based on the detailed analyses of fault zone architecture in this study, we can draw the following conclusions:

(1). According to quantitative evaluation of the fault throw distribution along the fault zone, it is indentified that the main thrust and splays account for 80-85% and 10-15% of the cumulative throw, respectively.

(2). The hanging-wall anticlines and fault zone in Lenghu5 fold-thrust belt present a high degree of lateral structural variation, which is mainly controlled by the nonuniform fault throw along the strike of the structure. The stratigraphy also plays an important control on the fault zone architecture. The higher mechanical heterogeneity of the stratigraphy, the higher complexity of the fault zone.

(3). Although both fault throw and stratigraphy are all influencing fault zone architecture, they play their controls at different scales. The fault throw usually controls regional scale structure (>1km) whereas the stratigraphy controls small scale structure (10m-100m).

(4). The fault architecture models at outcrop scale can potentially be used to predict the detailed structural styles and strain within a fold-thrust belt that is beyond the resolution of seismic surveys.

Acknowledgements

PetroChina · Rock Deformation Research · Midland Valley · National Natural Science Foundation of China NO.41502192 NO.41272142 NO.41602143

Contacts
Dr. Yangwen Pei   China University of Petroleum   peiyangwen@ upc.edu.cn
Dr. Douglas Paton   University of Leeds   d.a.paton@leeds.ac.uk
Prof. Rob Knipe   University of Leeds & RDR   rjk@rdrgroup.co.uk

geori.upc.edu.cn