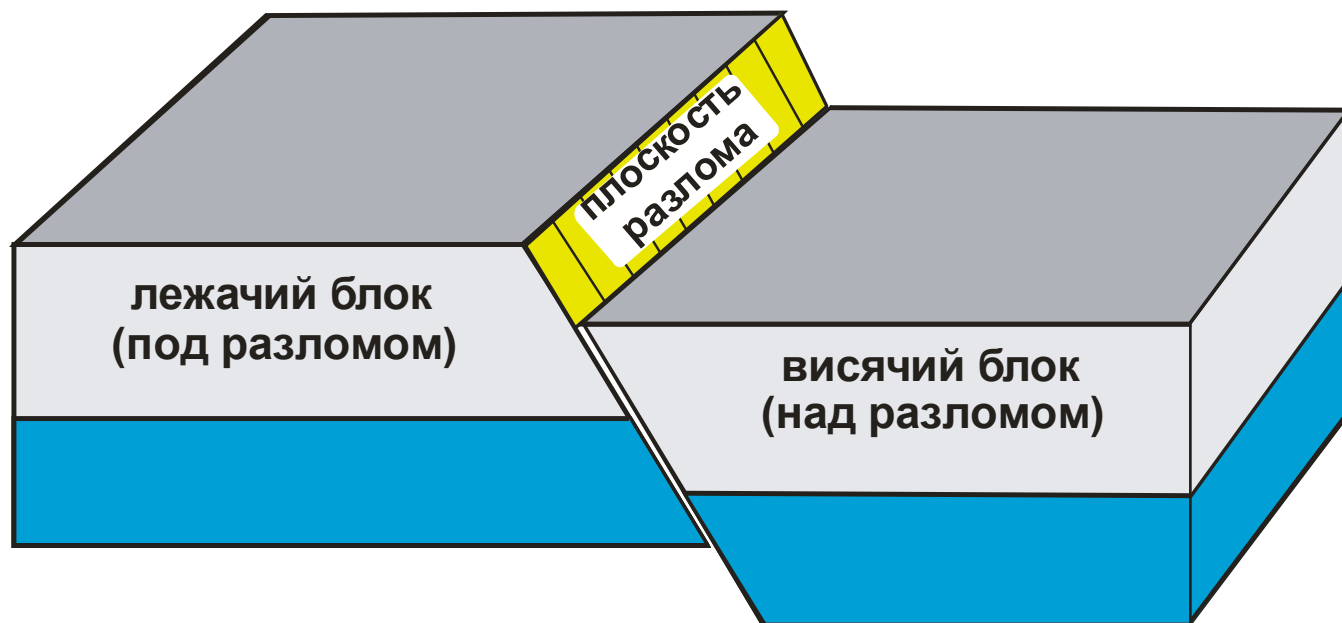
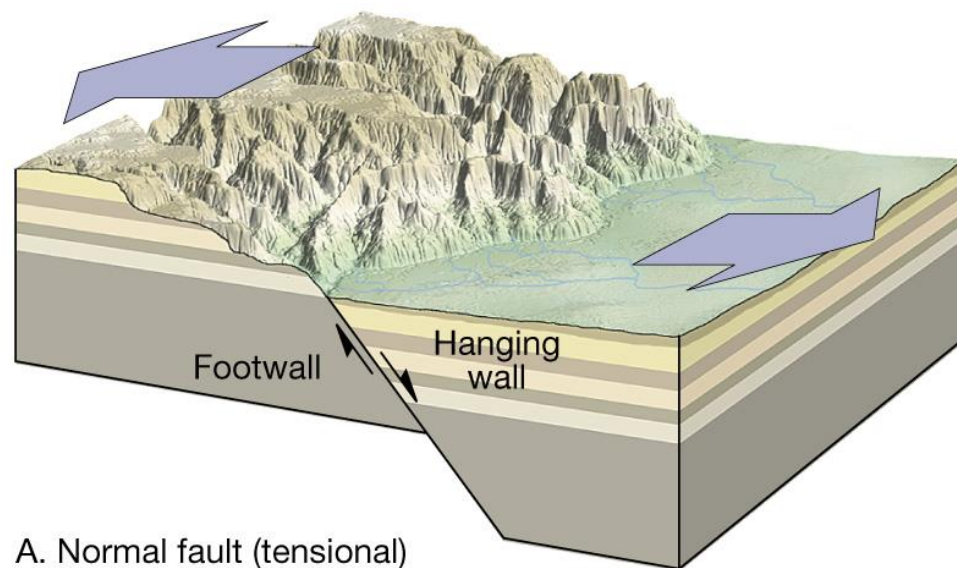
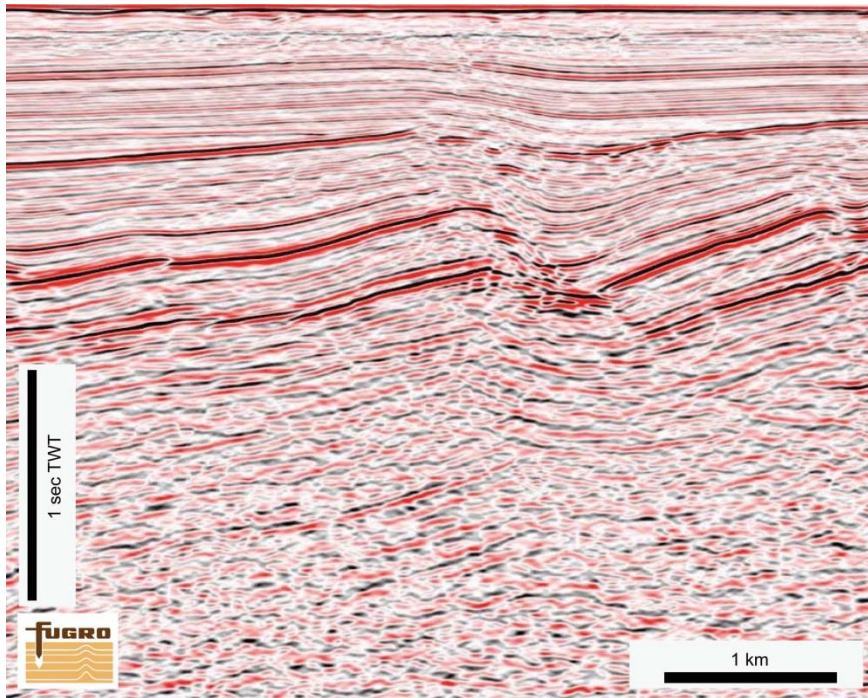
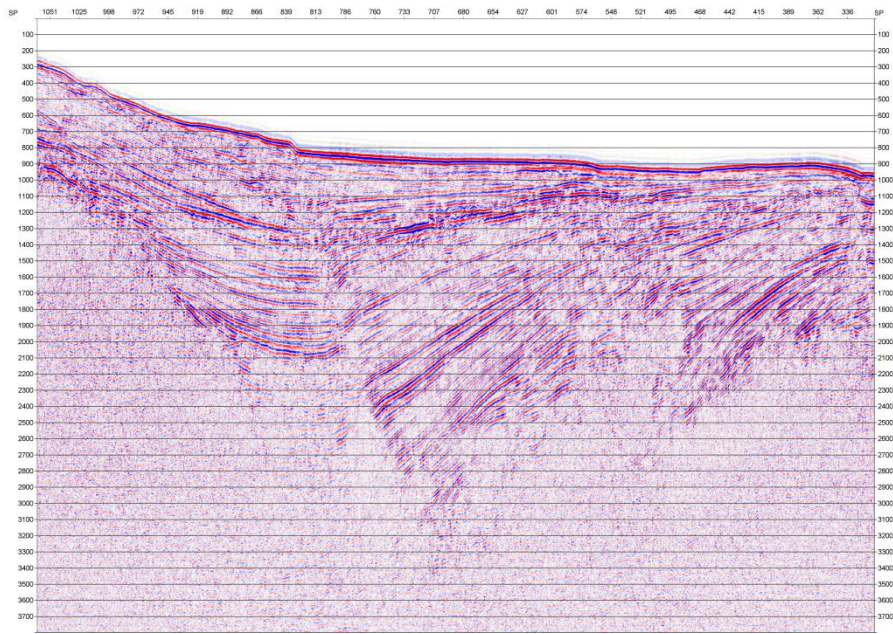


# Сбросы и другие структуры растяжения

А.М. Никишин

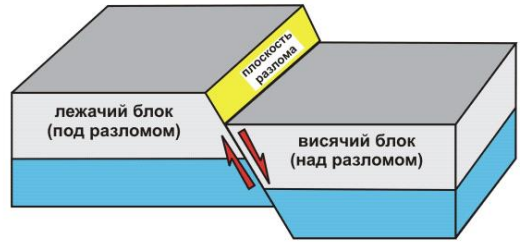




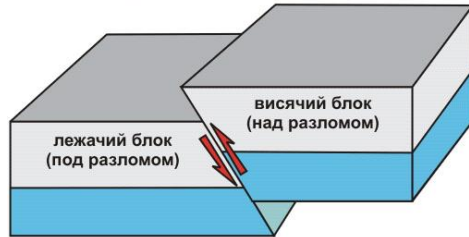


# ОСНОВНЫЕ ТИПЫ РАЗЛОМОВ

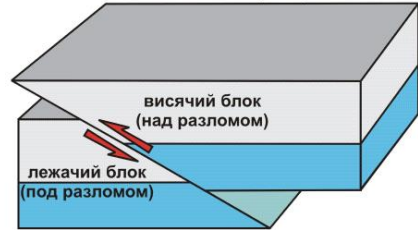
Сброс, *висячий блок относительно опущен*



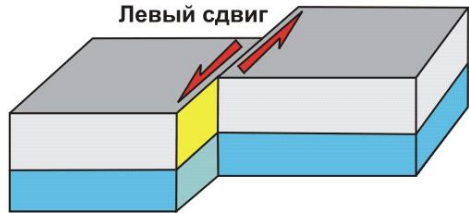
Всброс, *висячий блок относительно поднят*



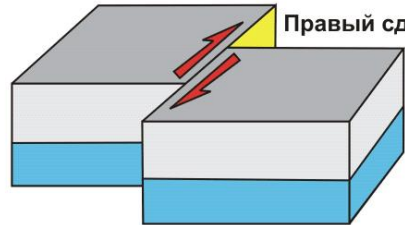
Надвиг, *наклон плоскости сместителя меньше 45 градусов*



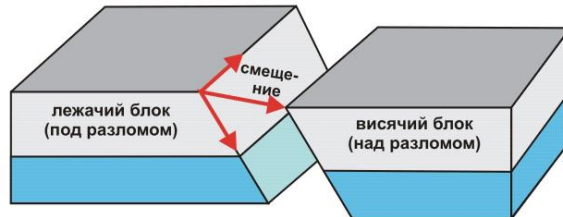
Левый сдвиг



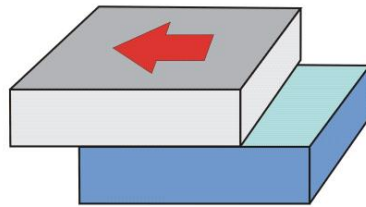
Правый сдвиг

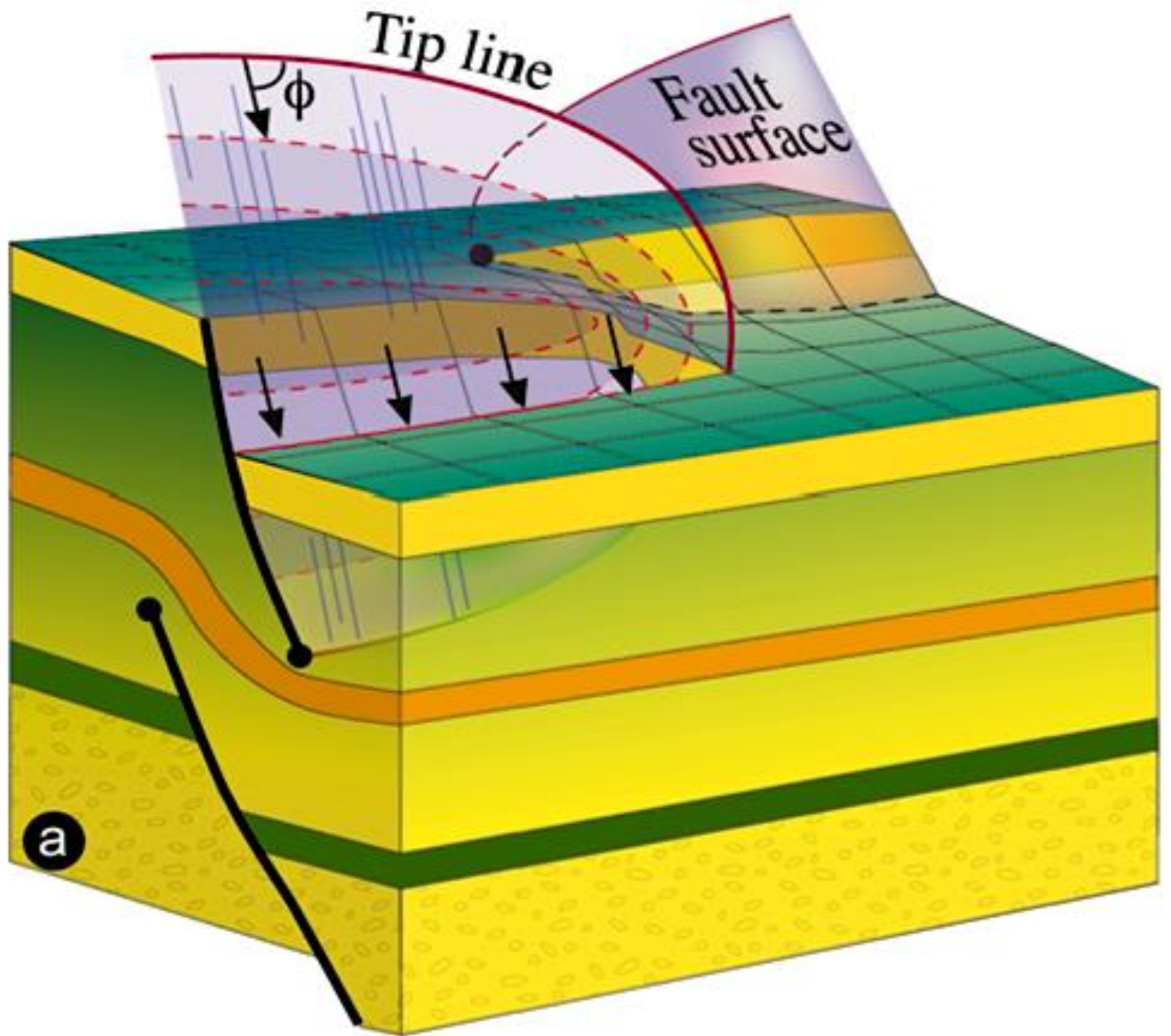


Сочетание сброса и сдвига

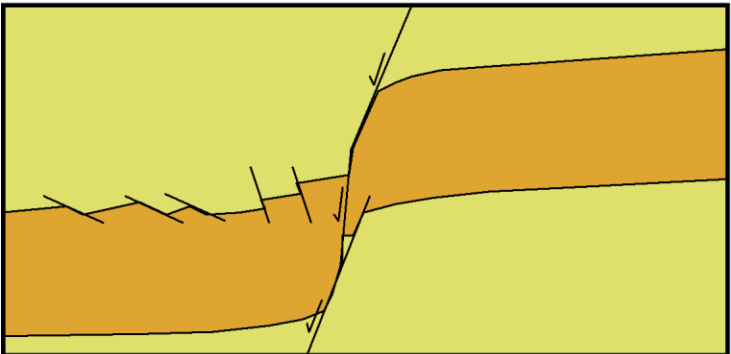
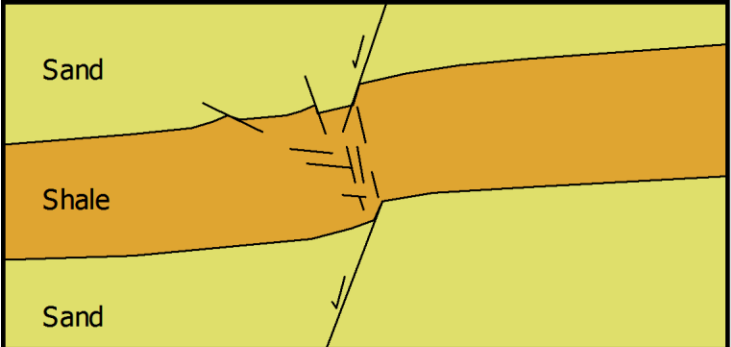
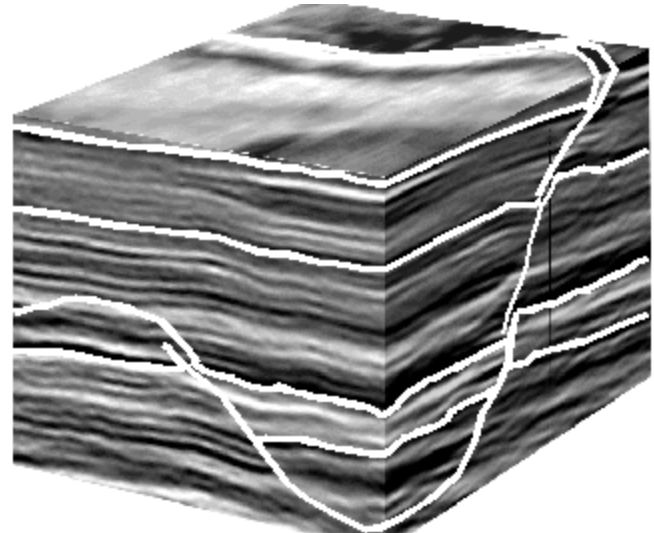


Срыв (детachment)

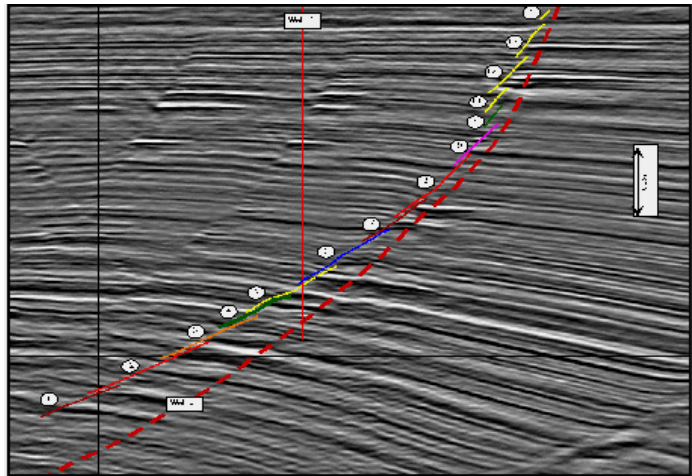


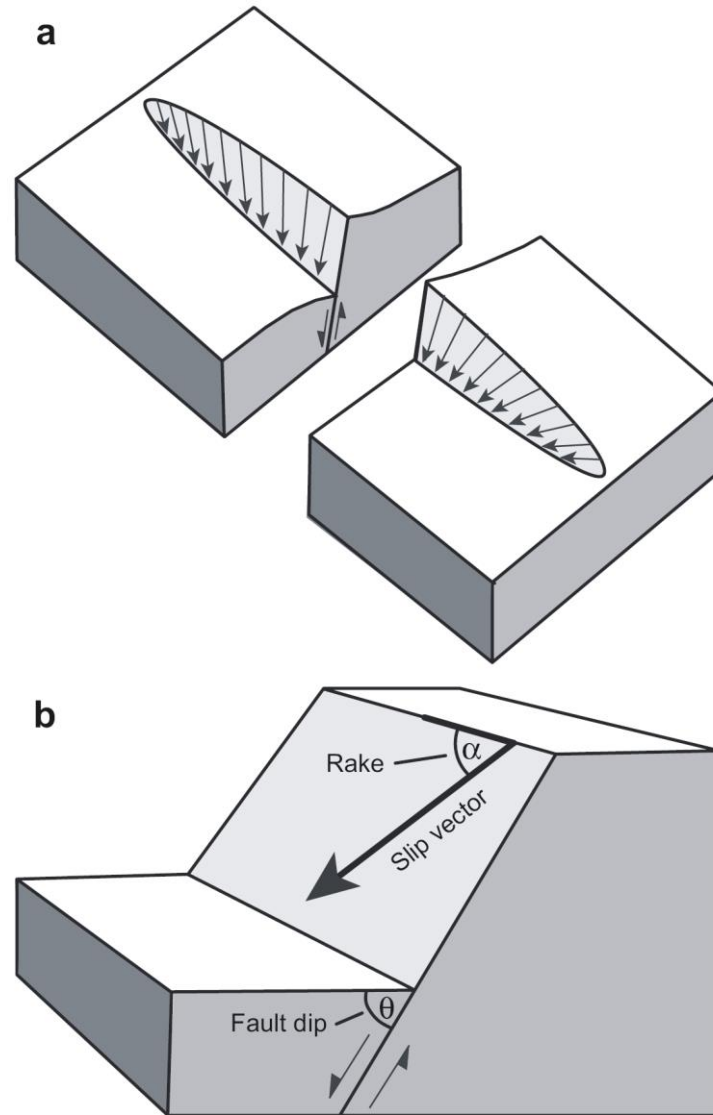


- При моделировании предполагается, что нарушение начинается в интервалах более хрупких пород (с преобладанием песка) и распространяются в более пластичные переслаивающиеся пачки, образуя сквозные сбросовые зоны.

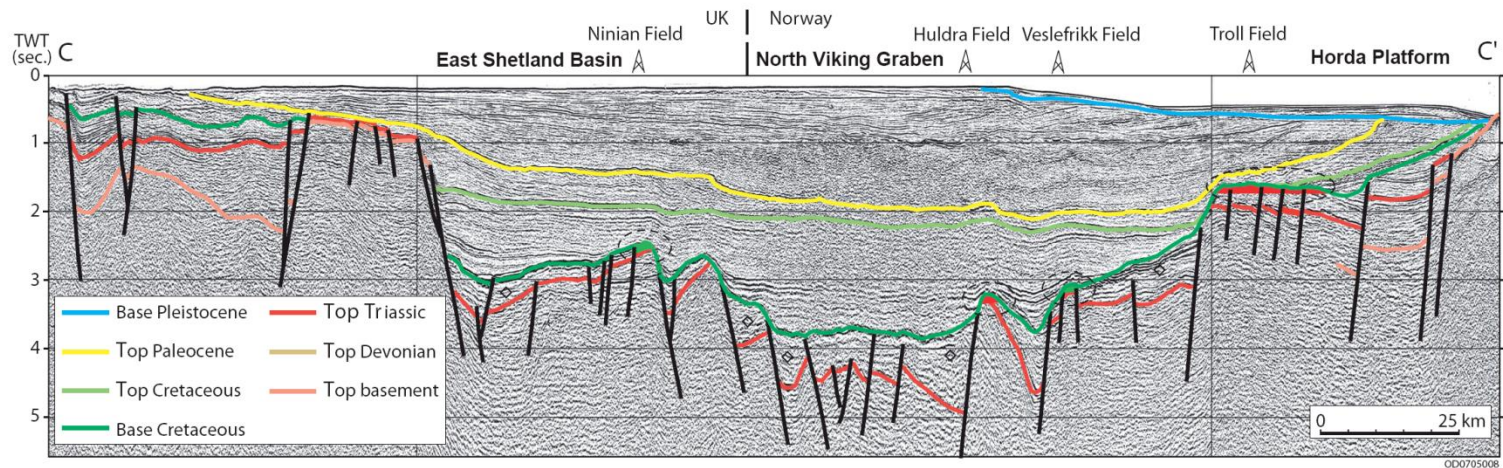
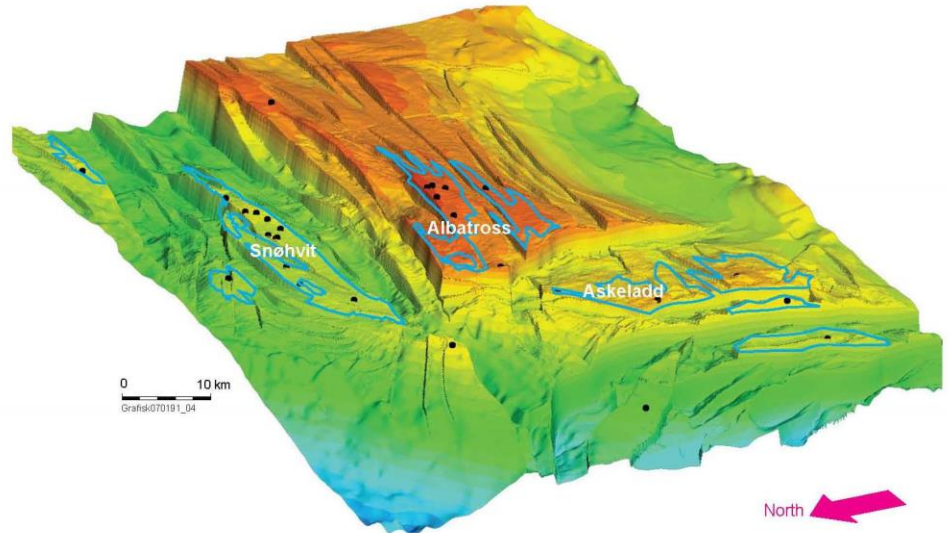
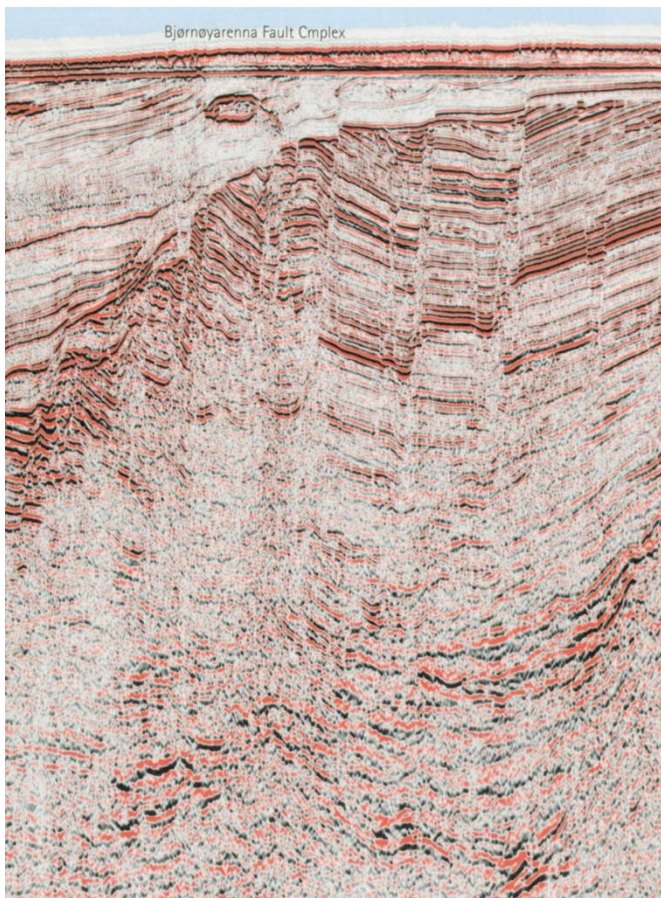


Пример сейсмического профиля в дельте реки Нигер

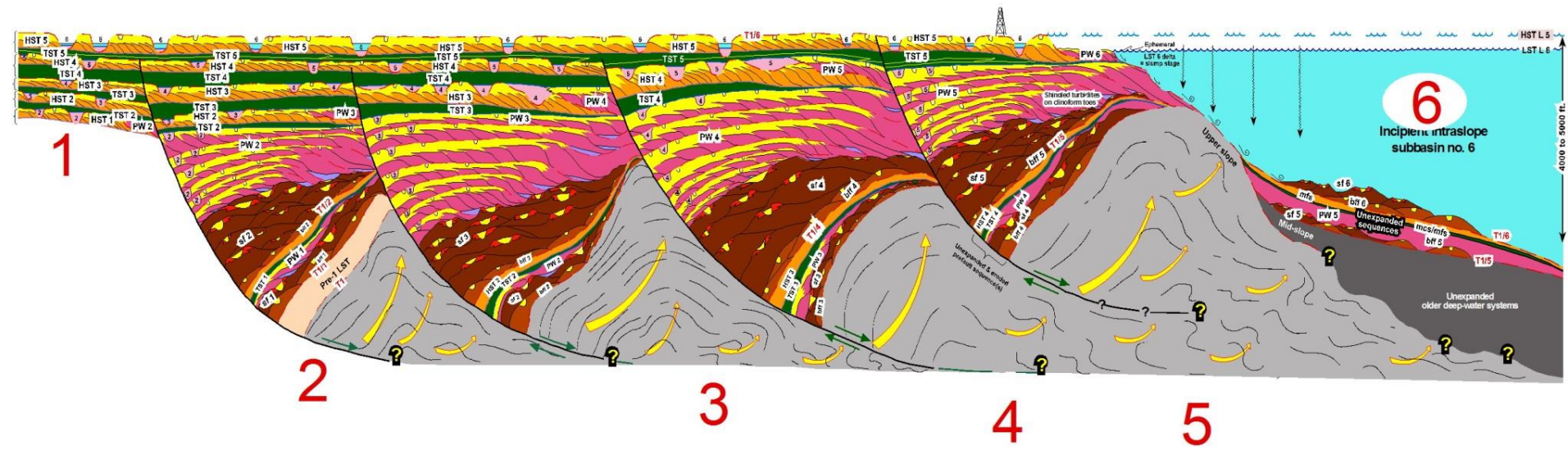
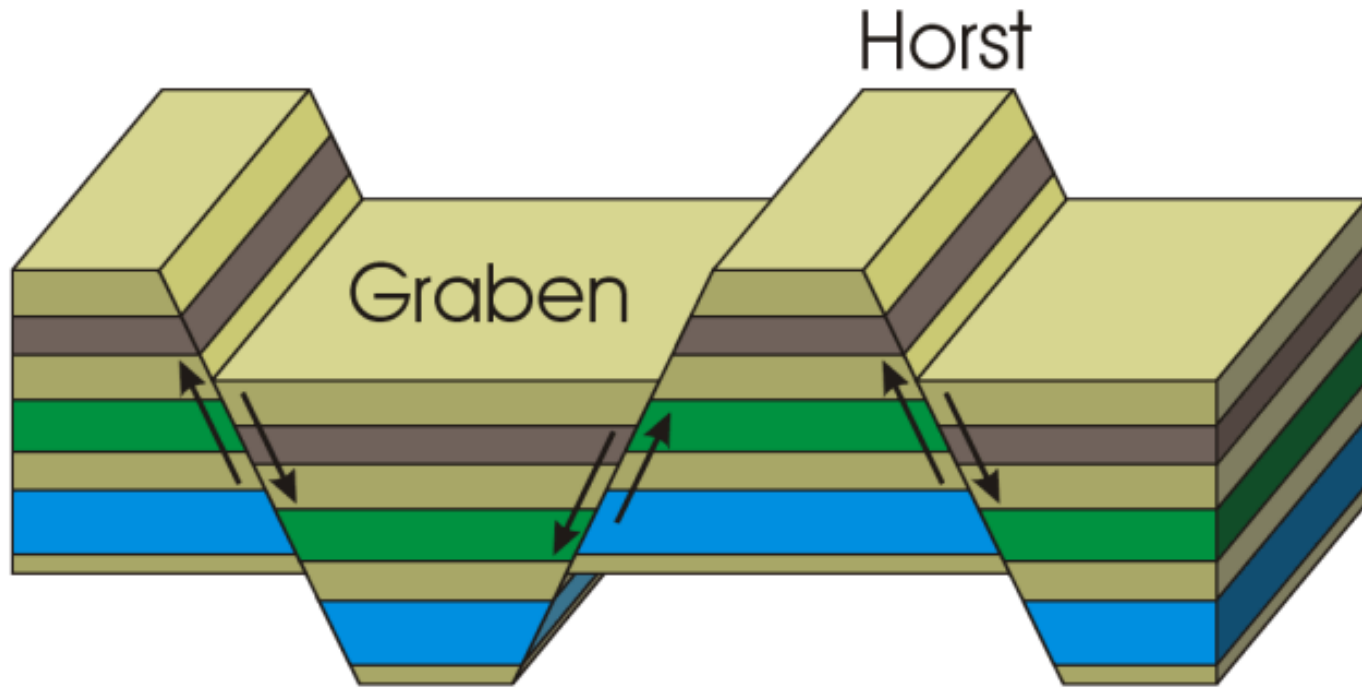




(a) Sketch of a normal fault with a converging slip pattern. With increasing distance from the fault centre, the slip direction becomes oblique (modified from Roberts and Ganas, 2000). (b) The acute angle between fault strike and the slip vector on the fault plane is termed rake  $\alpha$ . The dip angle of the fault is  $\theta$ .





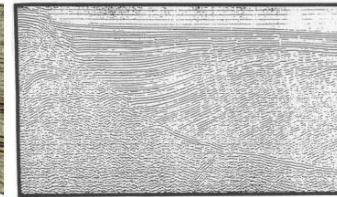


# СБРОСЫ И ГРАБЕНЫ

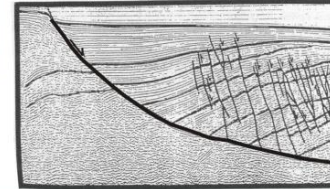
1

## А. Фрагменты сейсмических профилей со сбросами

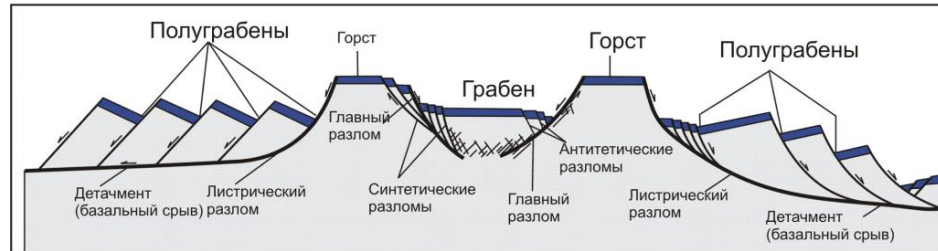
2



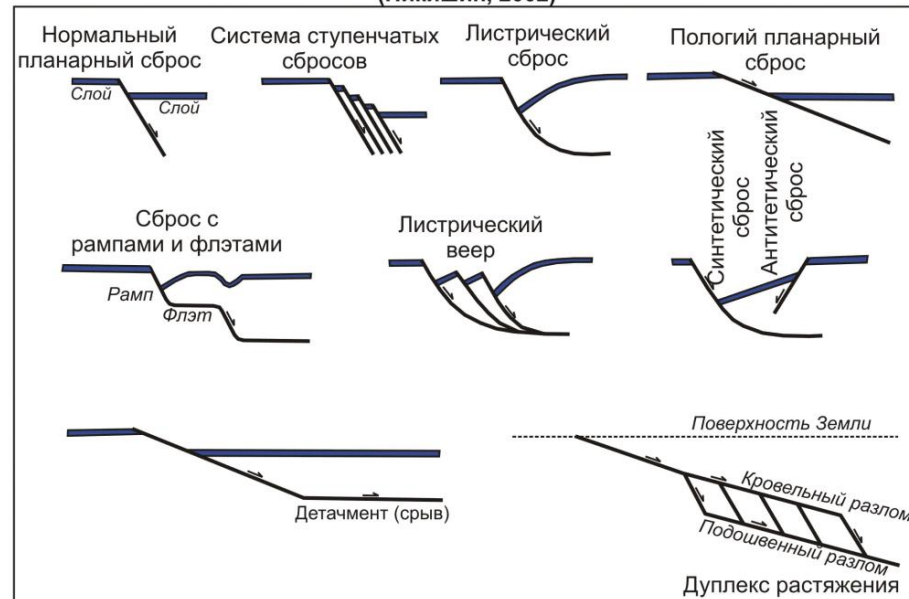
(Twiss, Moores, 1992)



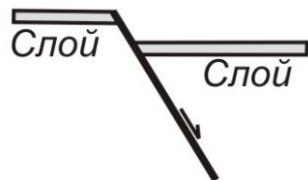
## Б. Структурные элементы сбросовых систем (Twiss, Moores, 1992).



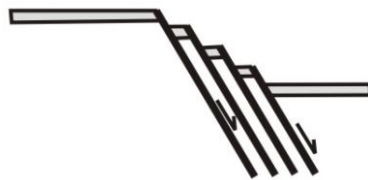
## В. Геометрические характеристики сбросов и применяемая терминология (Никишин, 2002)



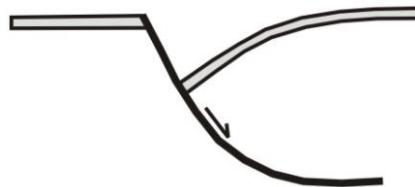
Нормальный  
планарный сброс



Система ступенчатых  
сбросов



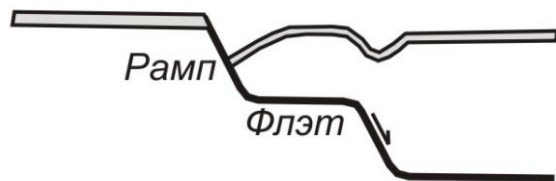
Листрический  
сброс



Пологий планарный  
сброс



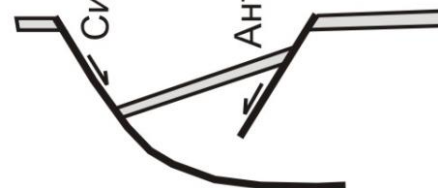
Сброс с  
рампами и флэтами



Листрический  
веер



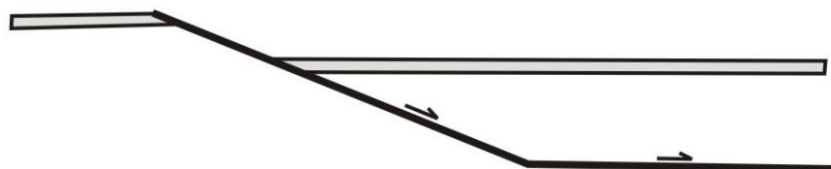
Синтетический  
сброс



Антисинтетический  
сброс

Поверхность Земли

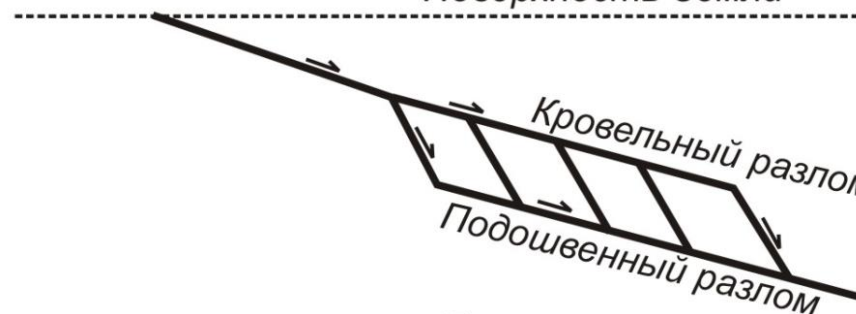
Детачмент (срыв)



Кровельный разлом

Подошвенный разлом

Дуплекс растяжения



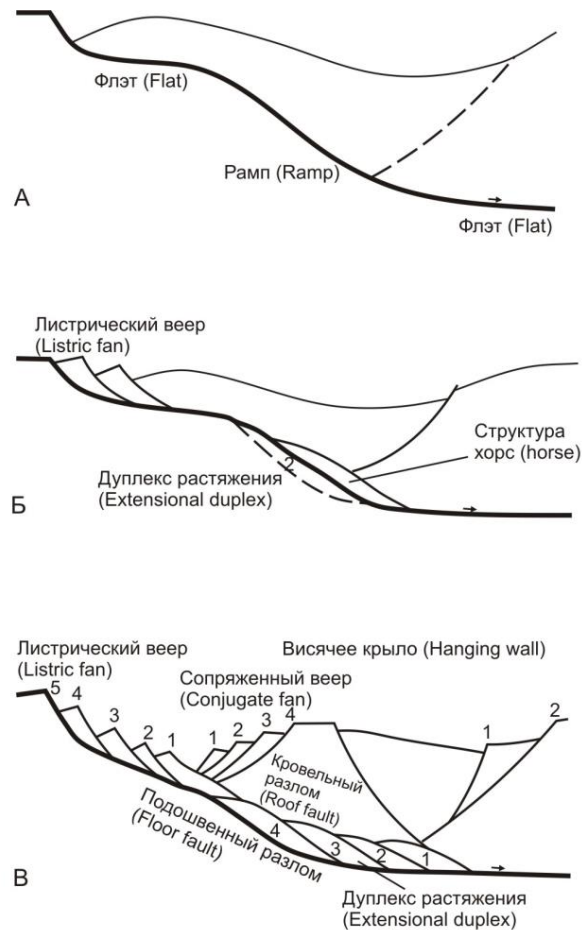
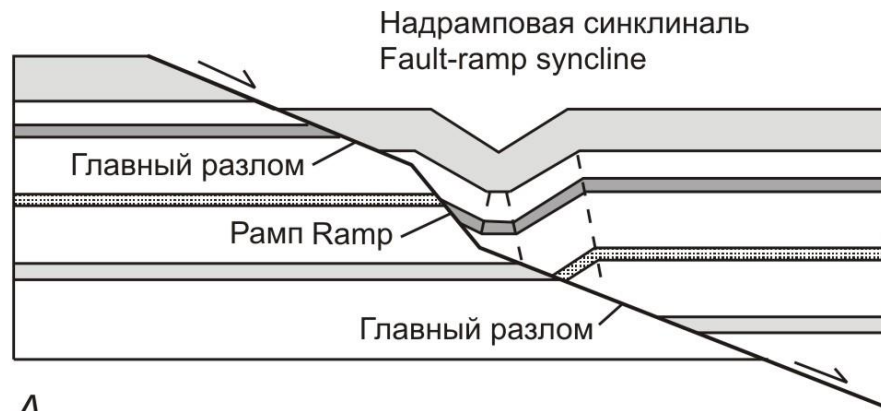
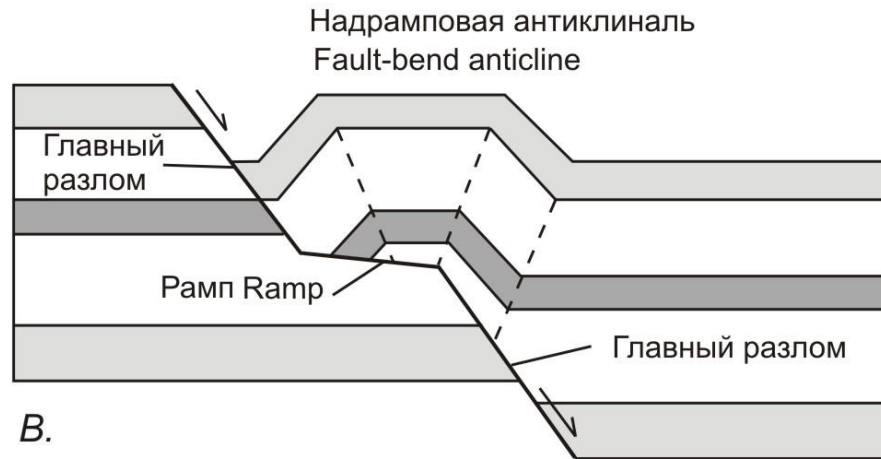


Рис. С-5. Модель последовательного развития листрического веера и сбросового дуплекса растяжения.

(А) Листрический сброс состоит из пологих частей (флэт) и более крутых уступов (рампы). Антиклиналь ролловер и надрамповая синклиналь развиваются в висячем крыле сброса. (Б, В) Дальнейшее последовательное распространение разлома в блок лежащего крыла приводит к образованию листрического веера вблизи поверхности и дуплекса растяжения на глубине. При последующей деформации другие разломы, такие, как сопряженный чешуйчатый веер, развиваются в висячем крыле разлома.

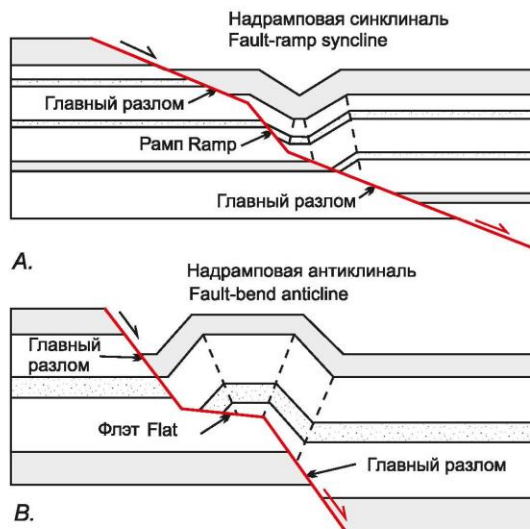
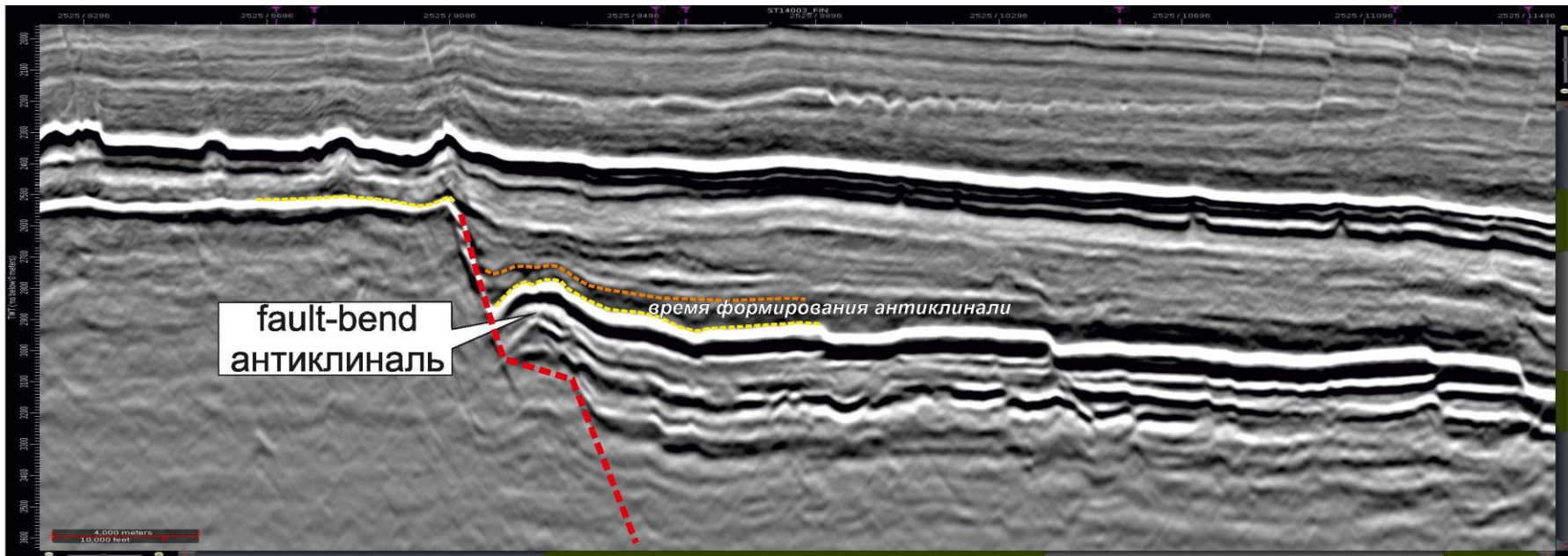


A.

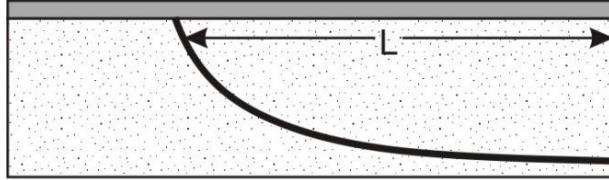


B.

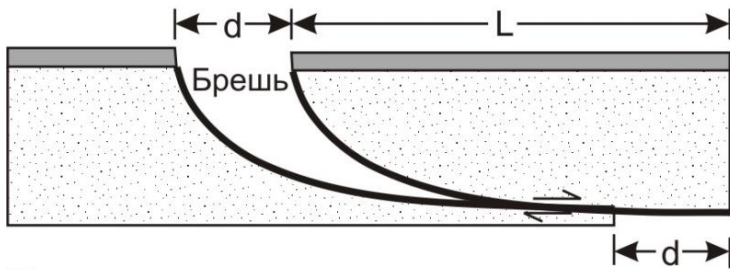
Рис. С-6. Главные типы сбросовых структур ролловер (roll-over). Показаны деформации, развитые в лежащих крыльях сбросов: А - надрамповая синклиналь. Б - надрамповая антиклиналь (по Twiss, Moores, 1992).



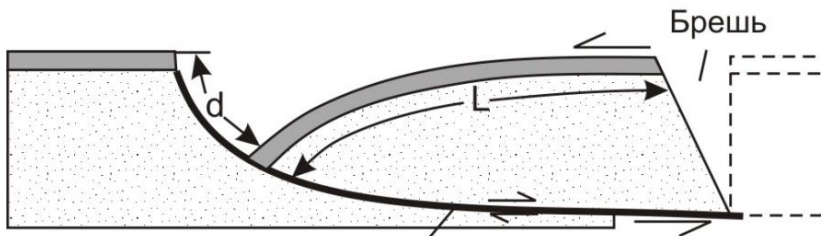
Модели формирования складок над сбросами (Twiss, Moores, 1992)



A

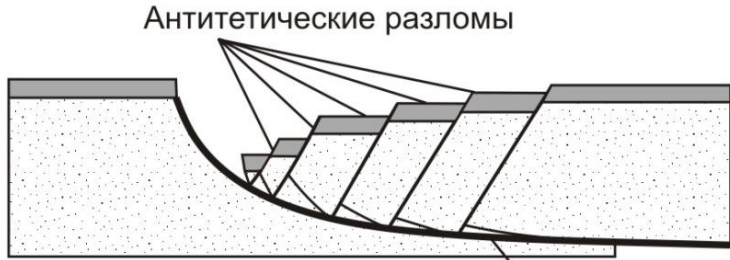


Б



В

Детачмент



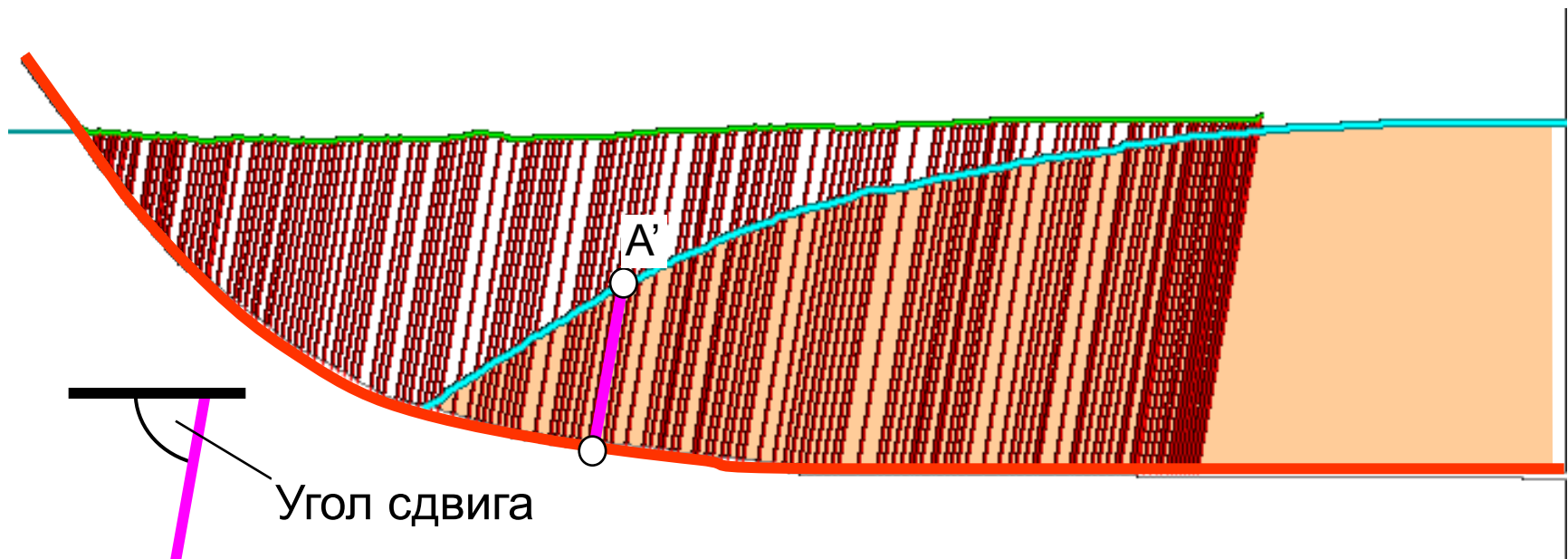
Г

Детачмент

Рис. С-7.

## Методы восстановления – Шеврон

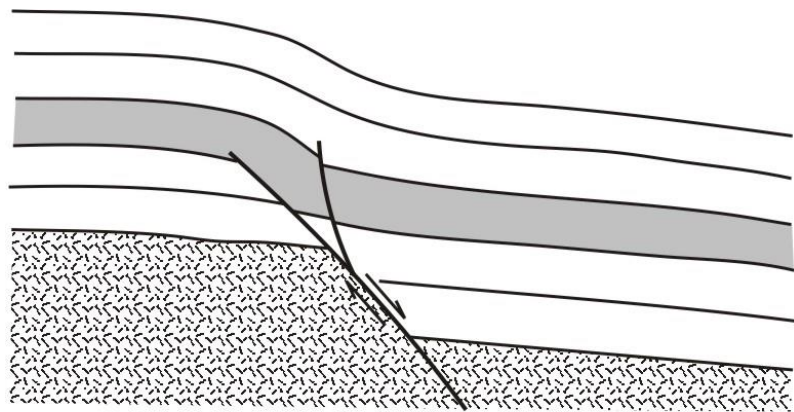
- Когда интерпретация сброса хорошо обоснована, то можно использовать методики восстановления для проверки интерпретации и прогнозирования палеобатиметрии.



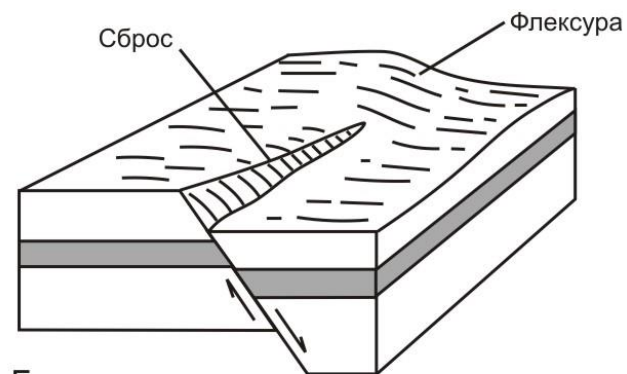


синтетические сбросы

антитетические сбросы



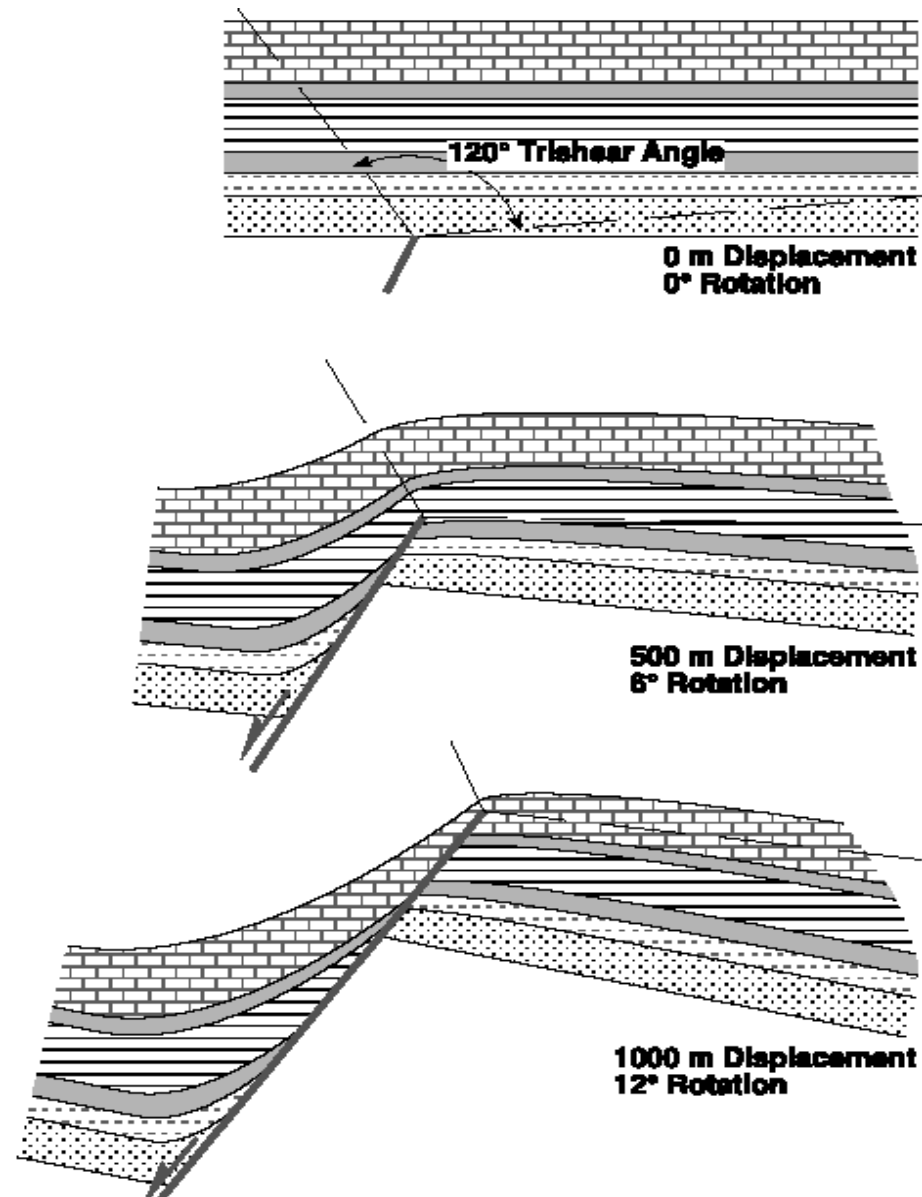
A



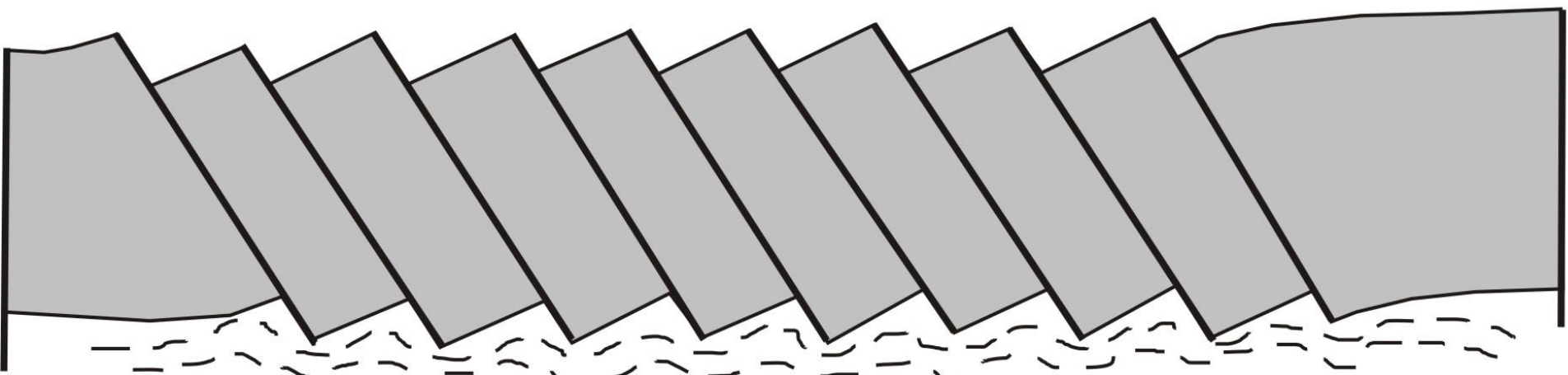
Б

Рис. С-9. (А) Слепой сброс, в верхних горизонтах выраженный флексурой.  
 (Б) Затухающий по латерали сброс, по простиранию переходящий во флексуру.

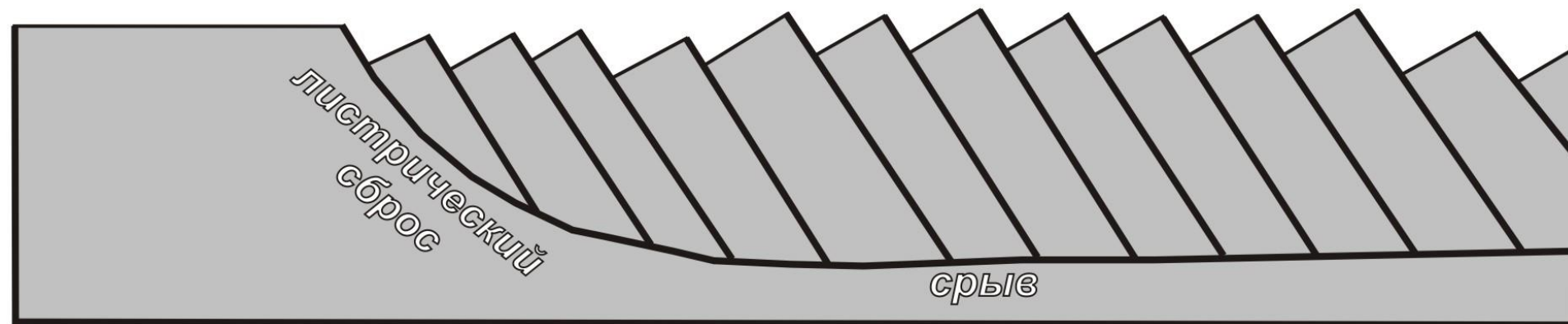
# Распространение сбросов: 2-мерное геометрическое моделирование



# Системы "ДОМИНО"



*пластические деформации*

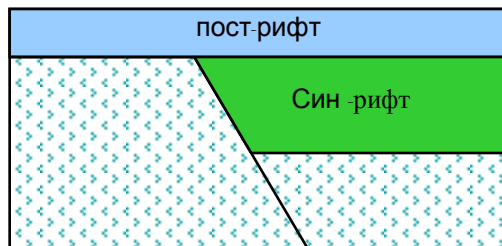


*листрический сброс*

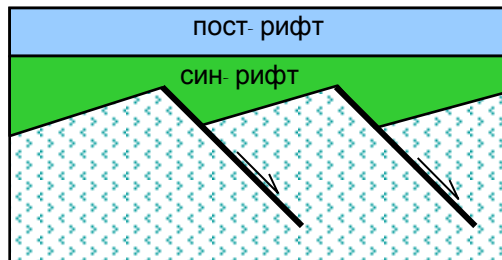
*срыв*

# Геометрические характеристики сбросов в рифтах

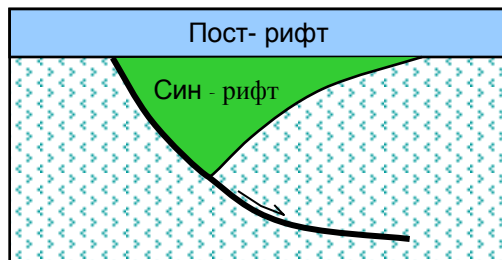
Плоские без вращения



Вращающиеся плоские

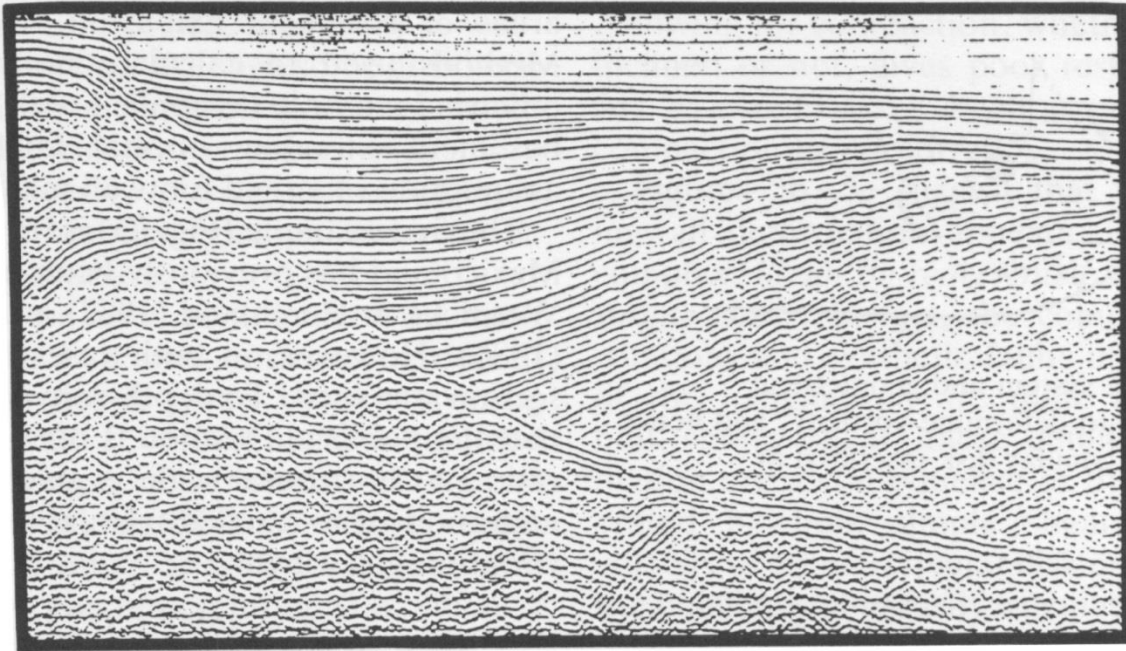


Вращающиеся листрические

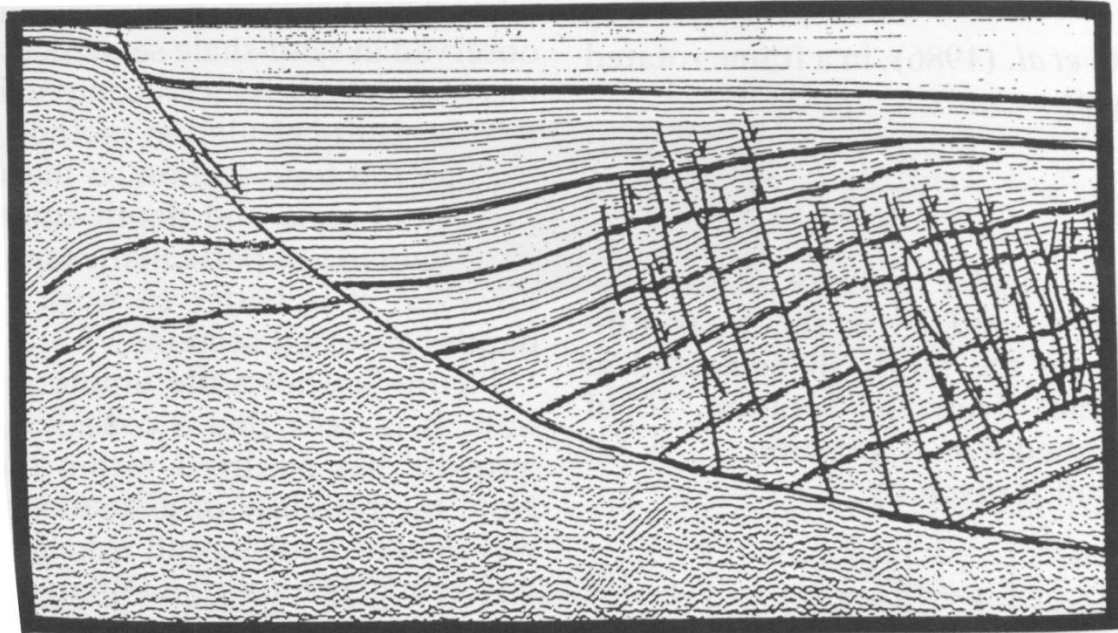


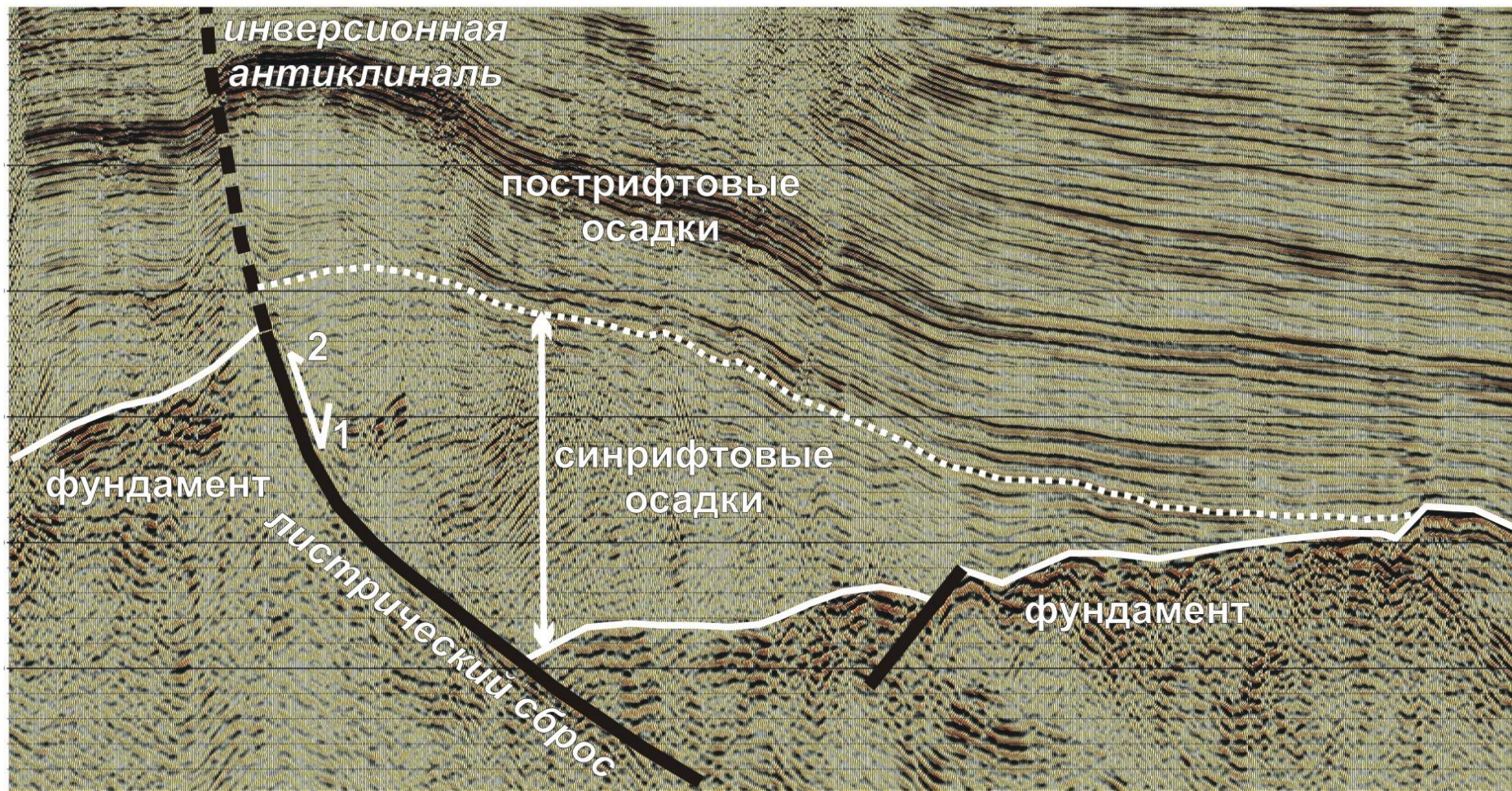
- Возможные геометрические характеристики сбросов растяжения в рифтовых тектонических бассейнах
  - Плоские без вращения
  - Вращающиеся плоские
  - Вращающиеся листрические
- Стратиграфию в пределах системы сбросов можно подразделить на:
  - Пред-рифтовую
  - Син-рифтовую
  - Пост-рифтовую
- Стратиграфию также можно определить как пред-, син- и пост кинематическую.

a

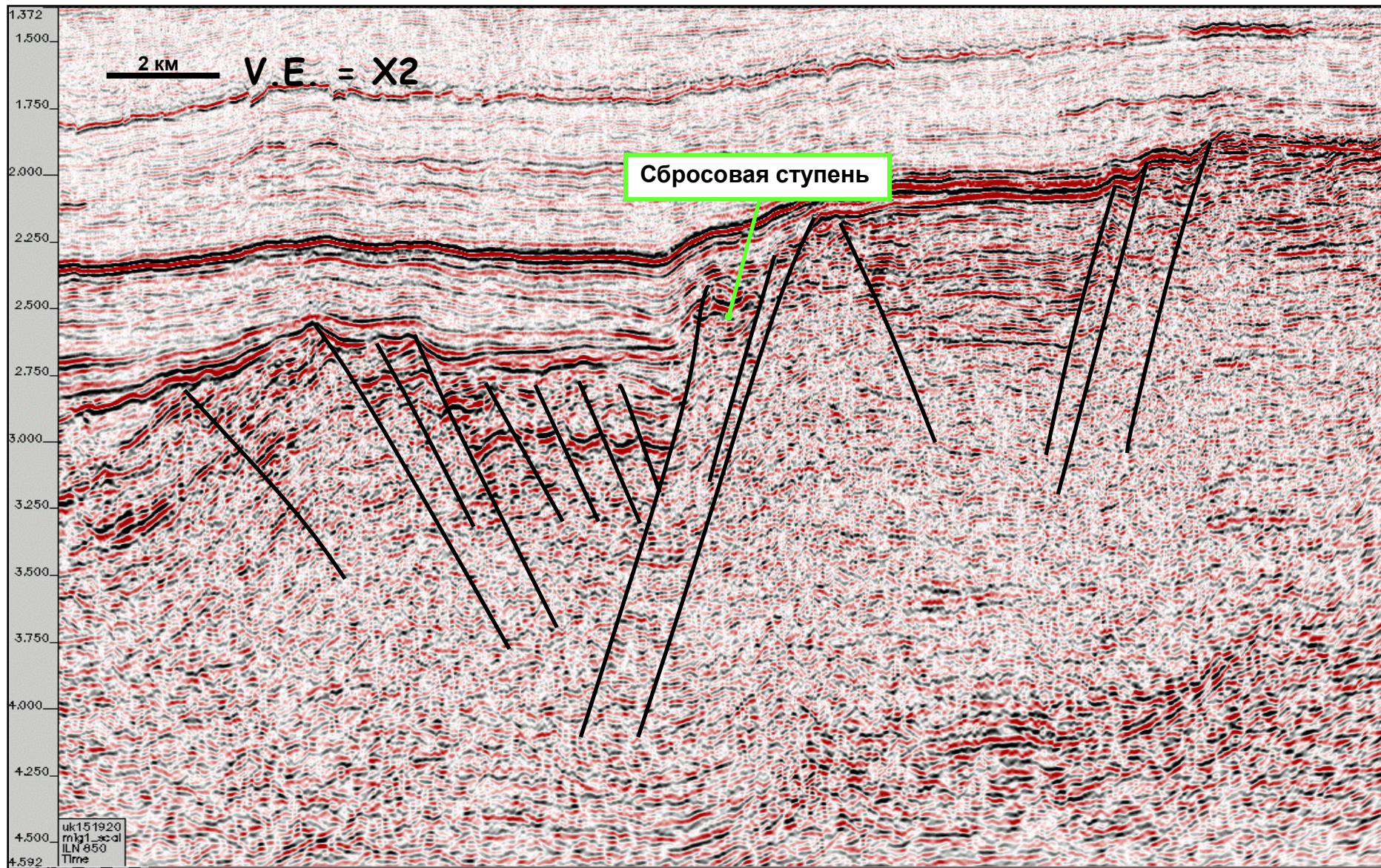


b





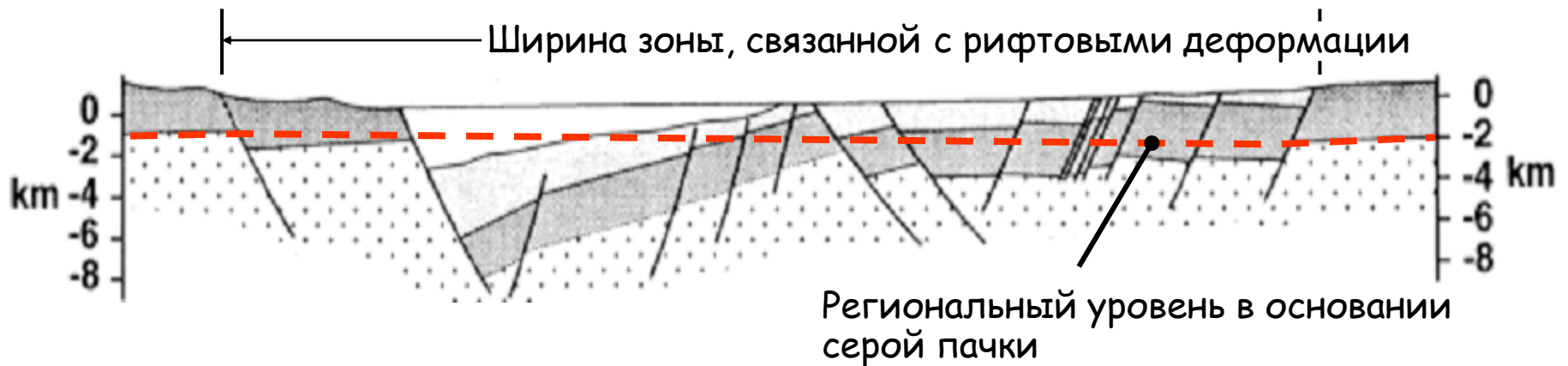
# Сейсмический пример - Северное море





# Региональный уровень

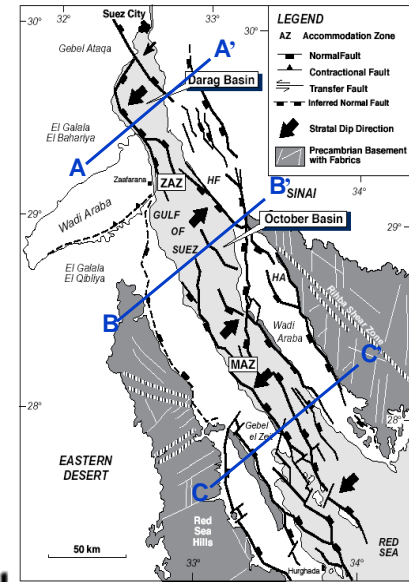
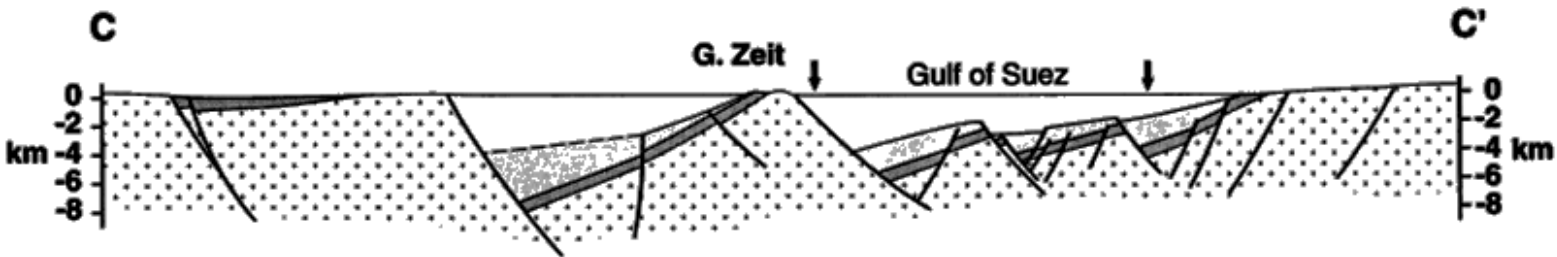
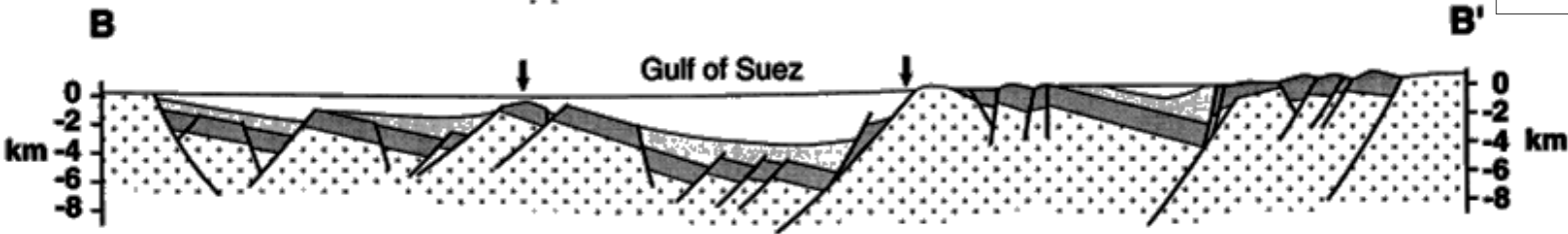
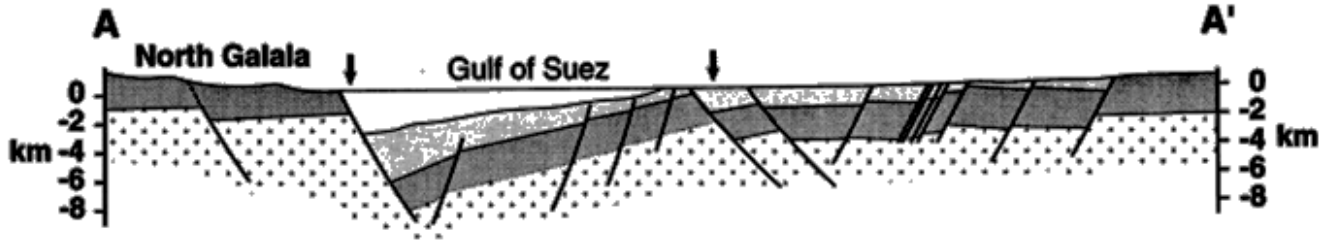
- **Уровень (глубина или высота), на котором слой присутствовал до структурной деформации.**
  - При растяжении деформированные слои обычно смещаются ниже их региональных уровней.
  - В областях сжатия деформированные слои обычно смещены выше их региональных уровней.

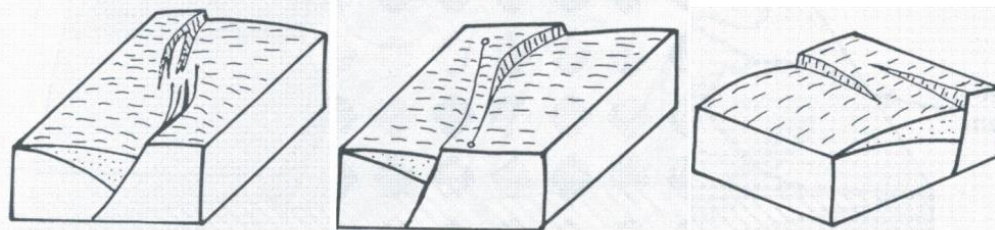


# Рифт в Суэцком заливе

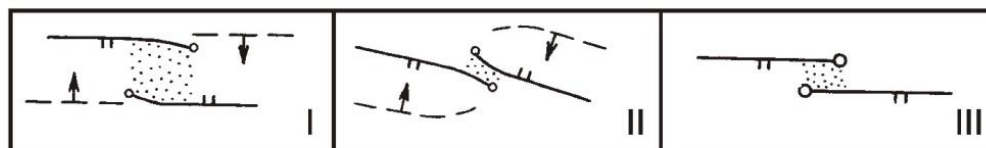
- Упрощенная структурная геометрия рифта Суэцкого залива

- Крупная структура вращения всяческого бока над глубинными листрическими сбросами.





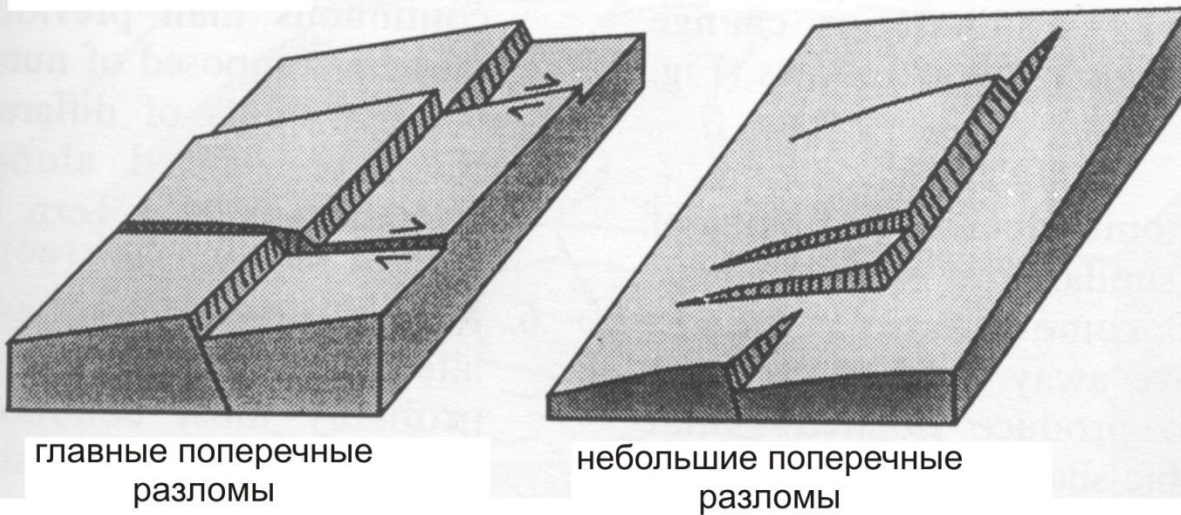
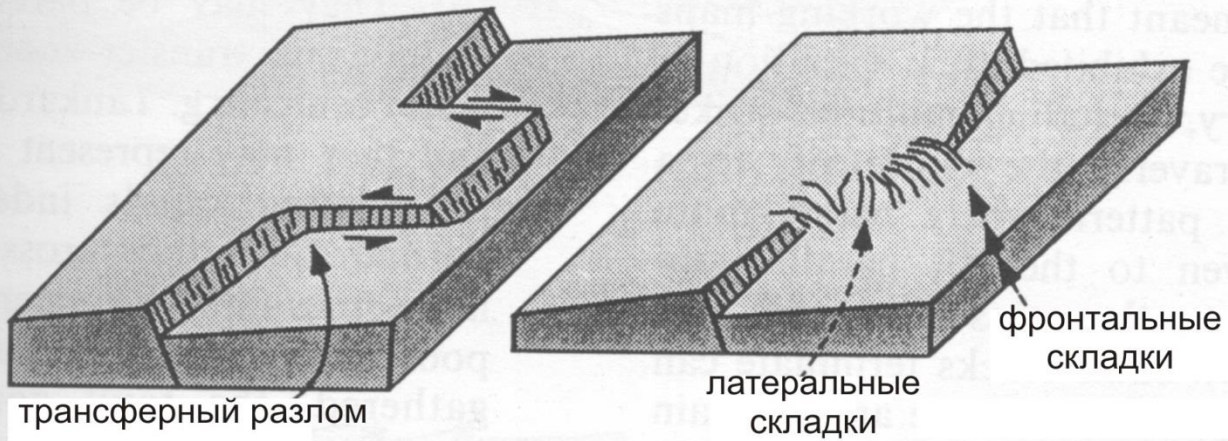
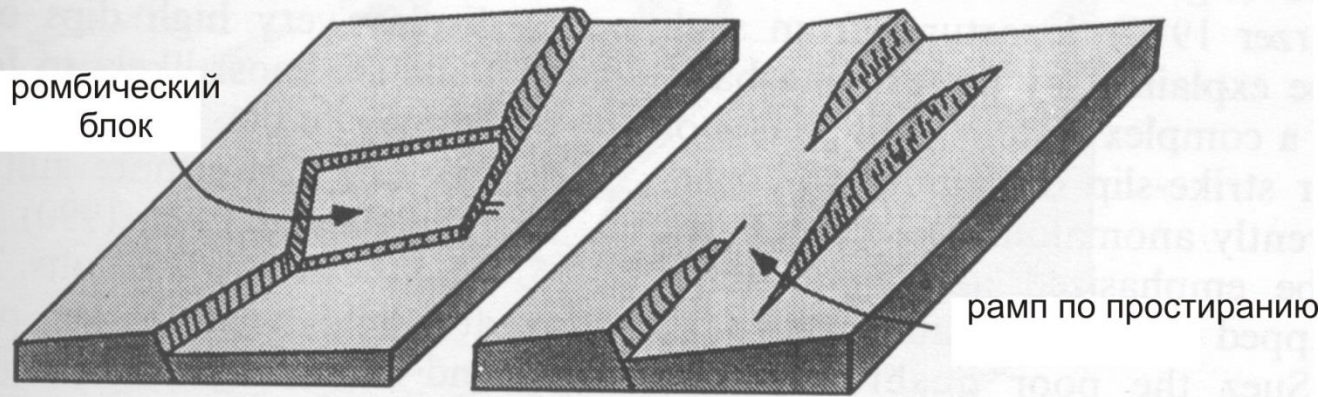
а



б

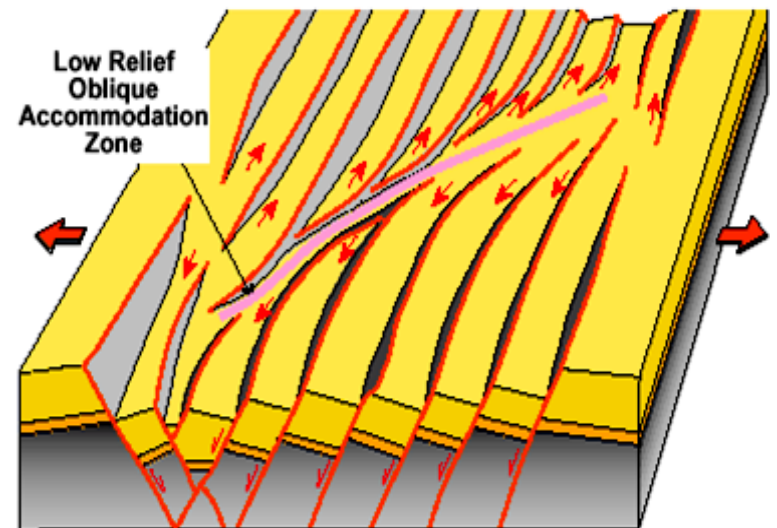
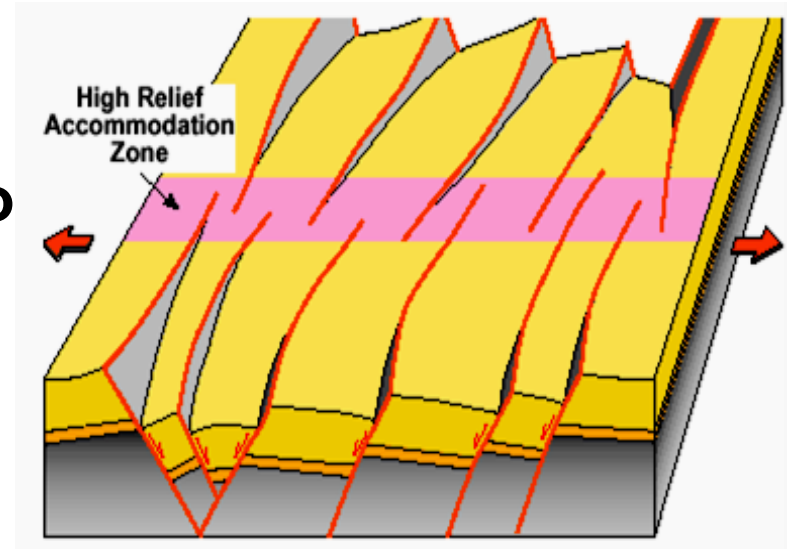
		Встречные		Синтетические
		Конвергентные	Дивергентные	
Сходящиеся				
Перекрывающиеся				
Параллельные				
Коллинеарные				





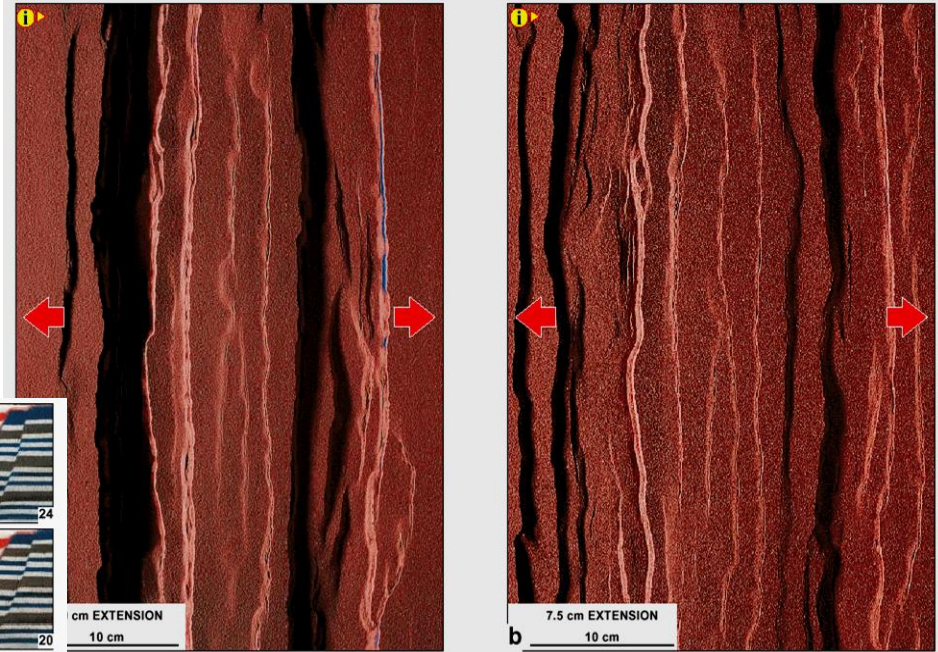
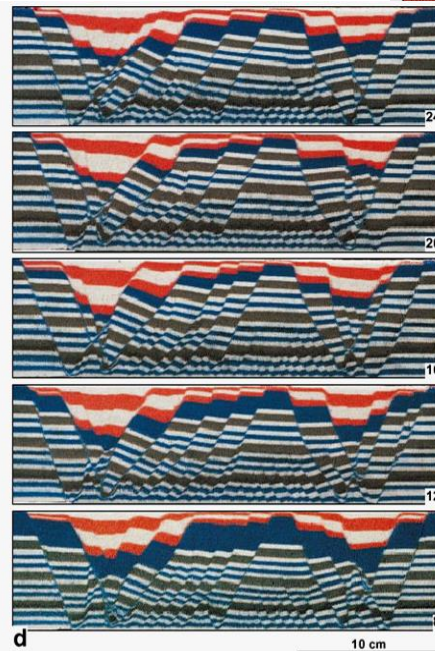
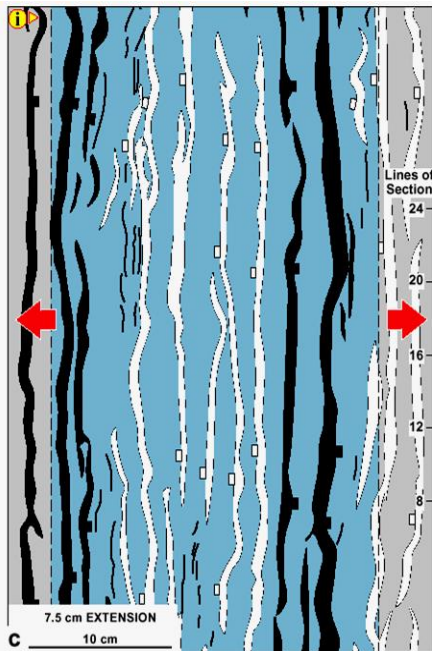
# Асимметрия и полярность рифтов

- Рифты часто подразделены на сегменты, в которых преобладают сбросы данного направления падения.
- Зоны сочленения:
  - Границы рифтовых сегментов
  - Зоны косоугольного сдвига в системе растяжения.
  - Относительные структурные поднятия в погруженном рифтовом бассейне.



# Сбросы простых рифтов

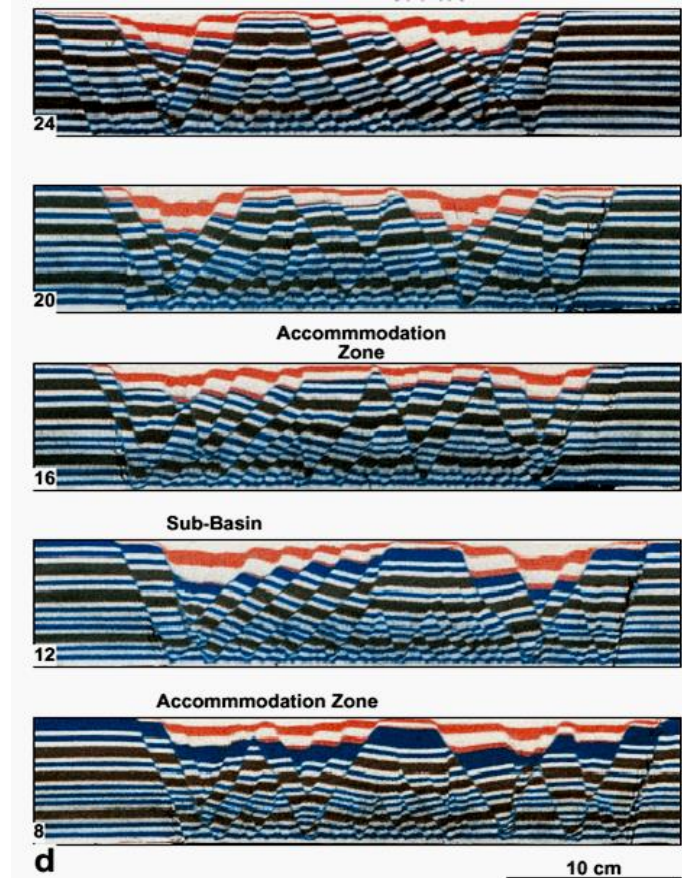
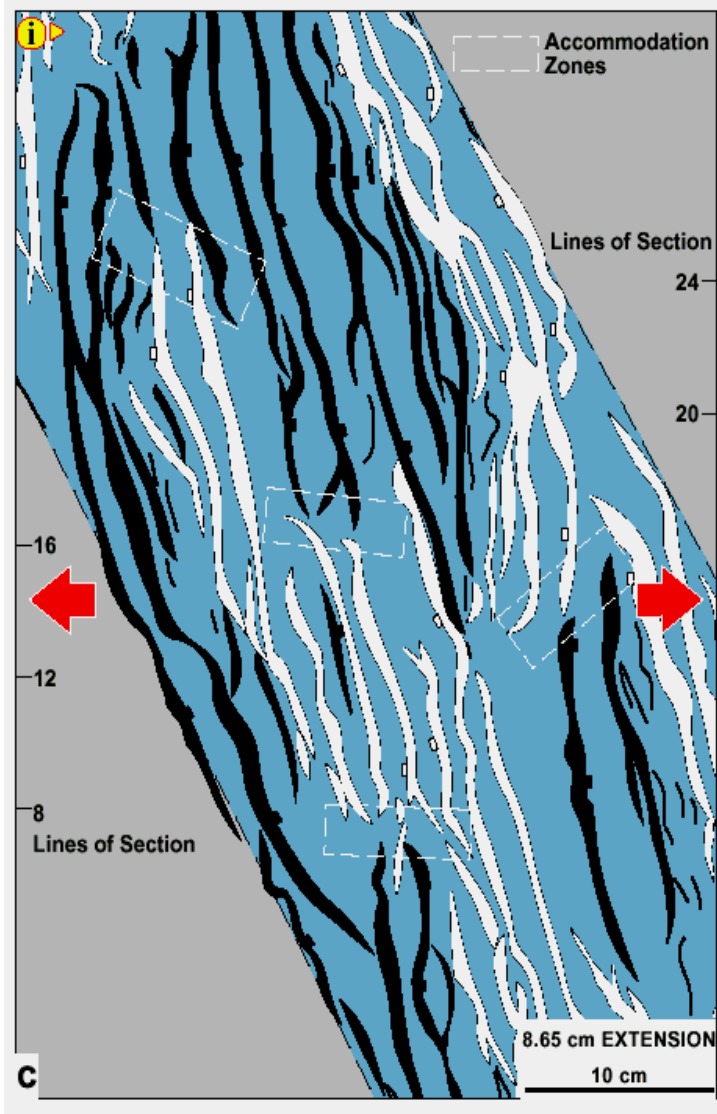
- **Субпараллельные линейные сбросы**
  - Изменения в направлении падения плоскости сбрасывателя поперек модели
  - Падение сопряженных систем по направлению друг к другу.



Изображения физических моделей, реализованных в проекте определения динамических характеристик сбросов, Университет Ройял Холлоуэй, Лондон, Великобритания

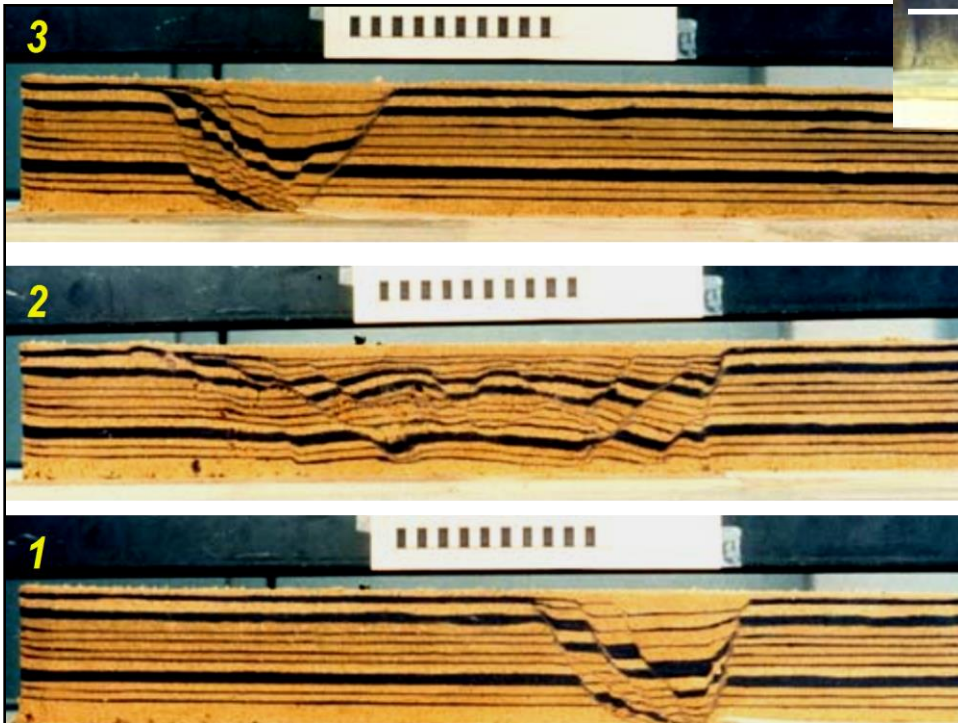
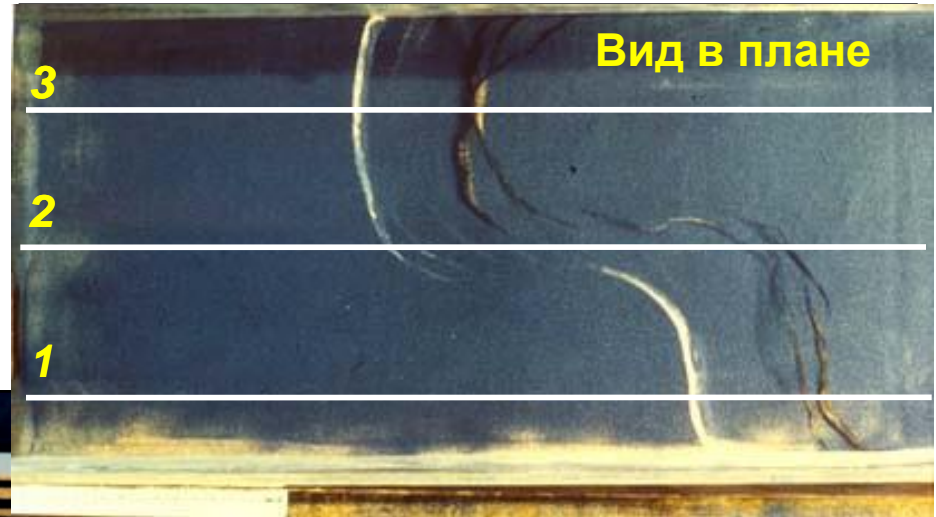
# Картина косых сбросов в рифтах

- Косое растяжение и древние ослабленные структуры коры могут изменить ориентацию распространения сбросов в рифтовом бассейне.



# Геометрия сдвинутого рифта (т.н. перескок)

- Для исследования детальной структурной геометрии в пределах развивающихся рифтовых бассейнов широко применяется аналоговое физическое моделирование (ящик с песком).



- Данная конкретная модель демонстрирует быстрые изменения структурной геометрии и ориентации сбросов, которые могут присутствовать в области рифтового сдвига.



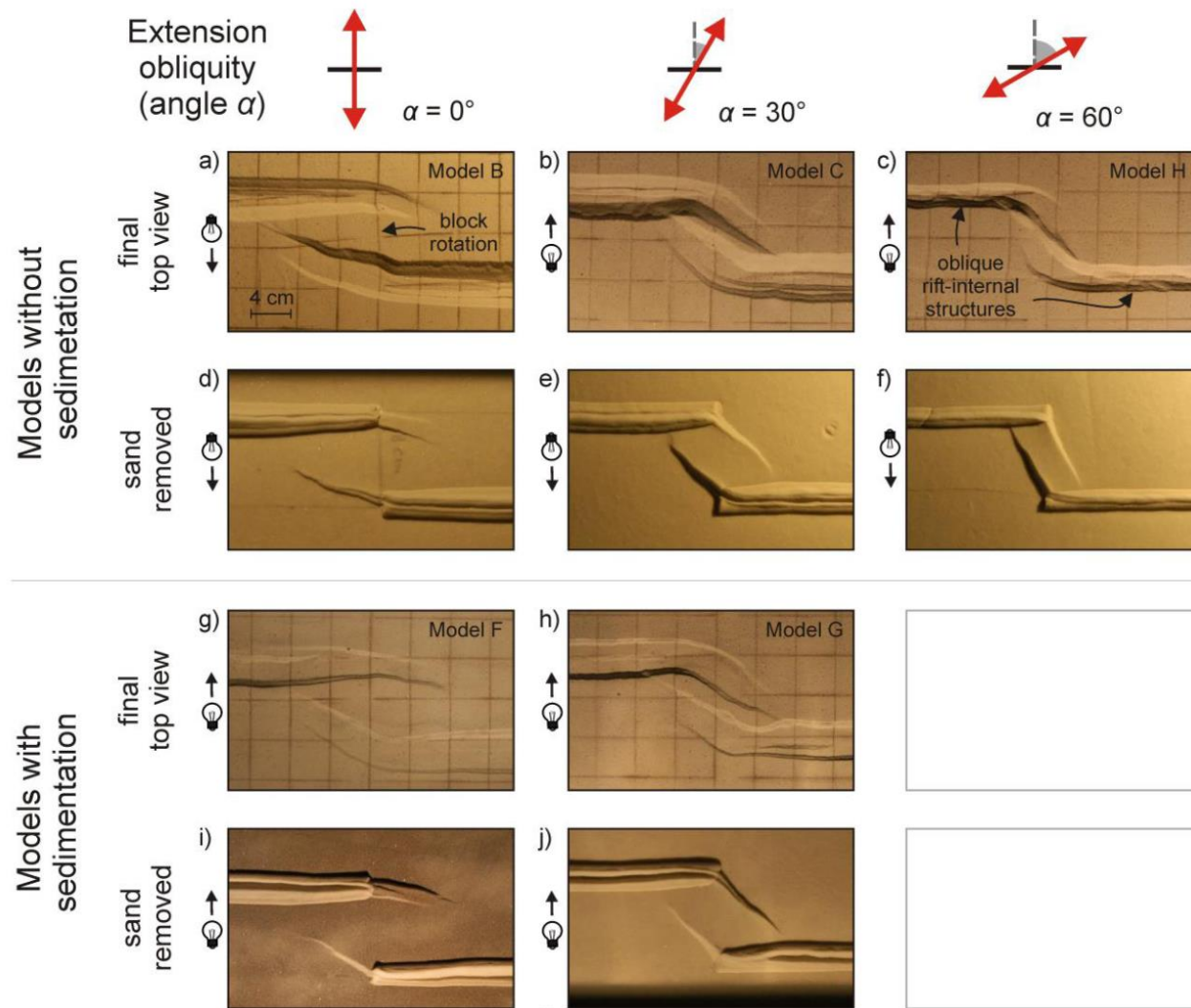
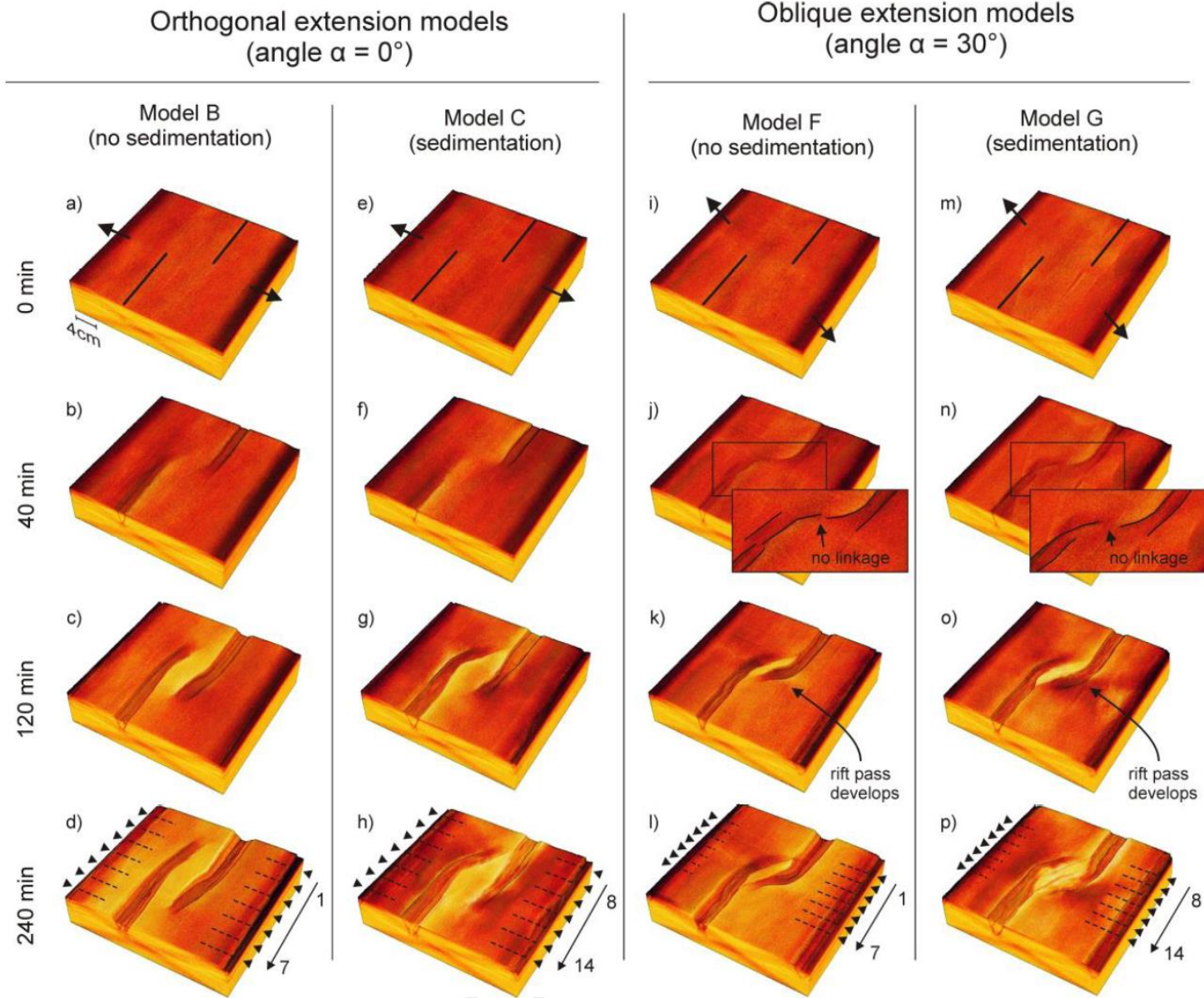


Figure 4

Figure 4.

Top view analysis of series 1 (Models B, C, F, H, and G), illustrating the influence of extension obliquity on transfer zone formation. Removing the sand cover reveals the deformation at the top of the viscous layer. Lighting directions are indicated to the left of each model.

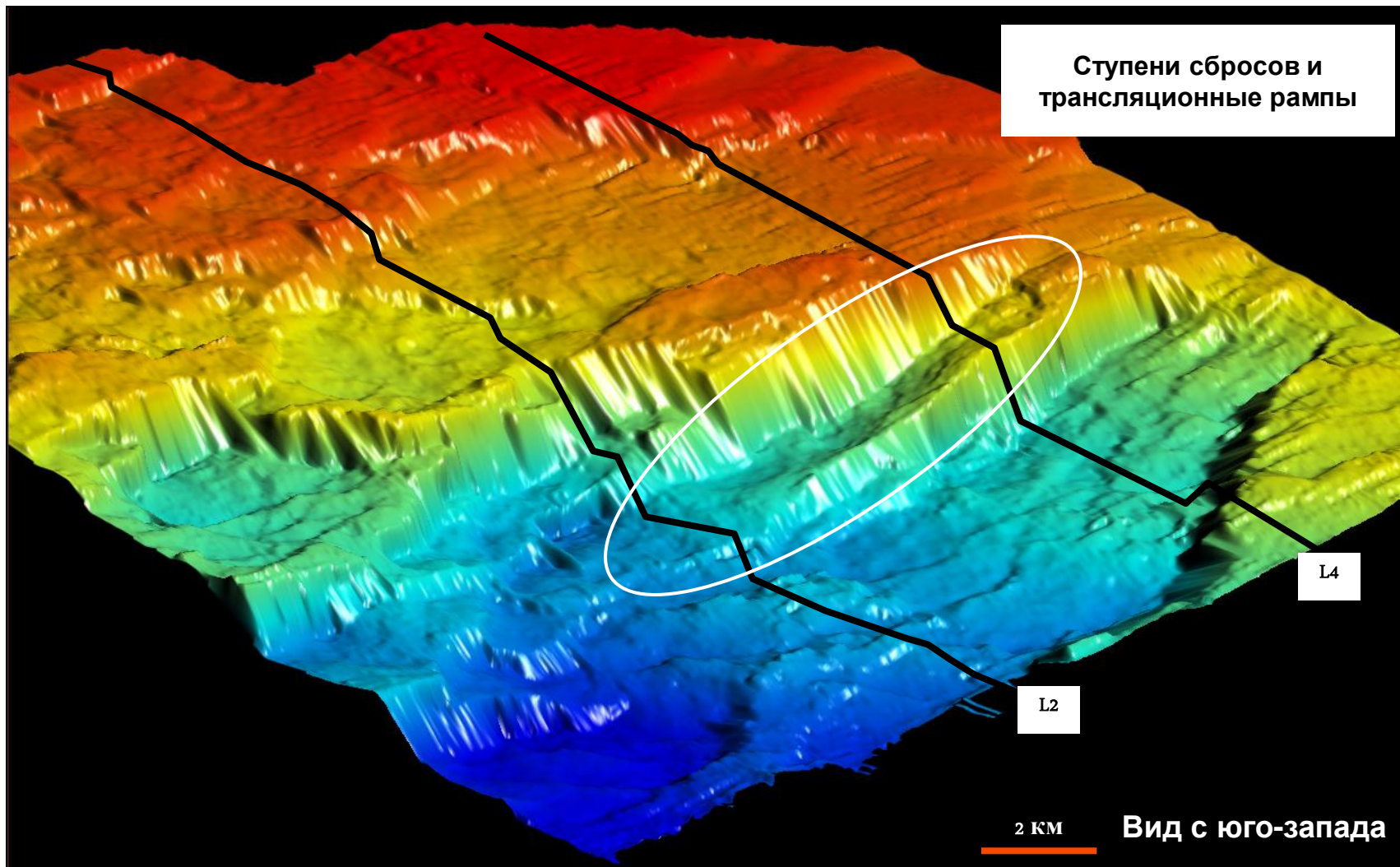


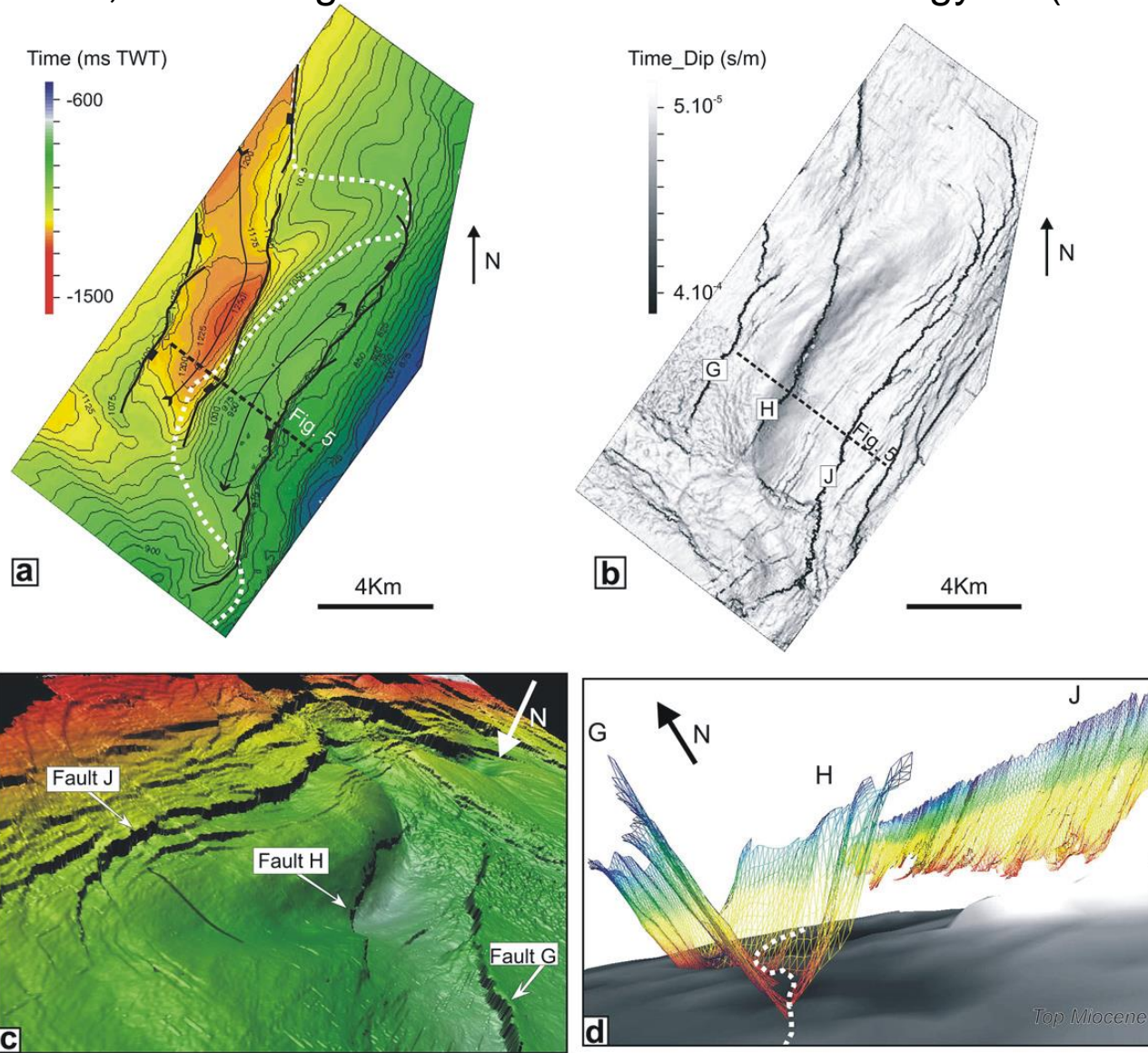
Please cite this article as: Frank Zwaan, Guido Schreurs, Jürgen Adam, Effects of sedimentation on rift segment and transfer zone evolution in orthogonal and oblique extension settings: Insights from analogue models analysed with 4D X-ray computed tomography and digital volume correlation techniques. The address for the corresponding author was captured as affiliation for all authors. Please check if appropriate. Global(2017), doi:[10.1016/j.gloplacha.2017.11.002](https://doi.org/10.1016/j.gloplacha.2017.11.002)

Figure 5

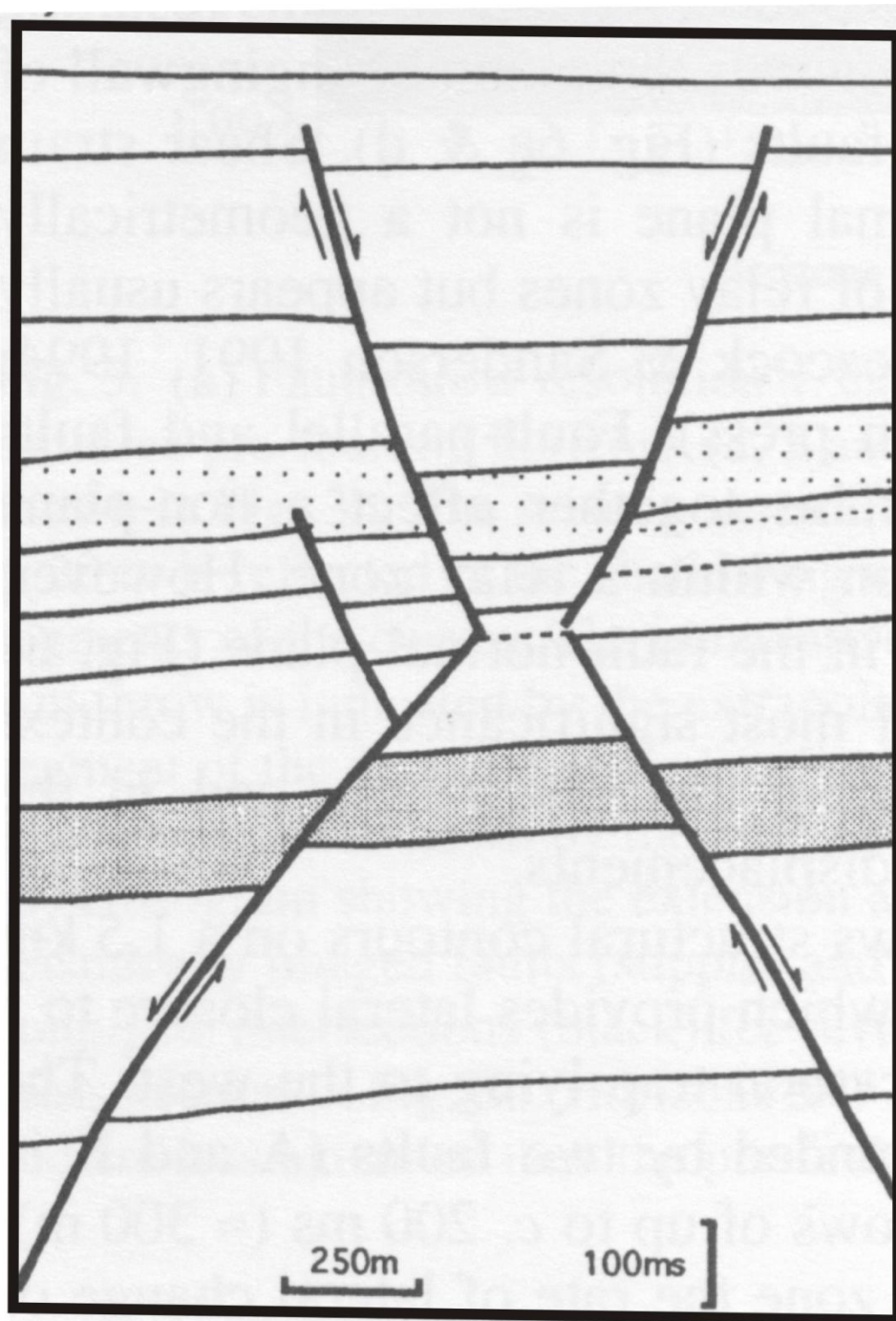
3D CT-derived topography evolution of Models B, C, F and G (series 1). Brighter colours on the model surface represent higher parts of the model, which are therefore more transparent for X-rays and show up as a lighter colour. This provides a qualitative insight into vertical displacement.

# Сейсмический пример - Северное море





Structural map of the area comprising the Kefira graben and the coast-parallel faults based on Pleistocene Horizon Ba (shown in Fig. 5). (a) Two-way time map showing contours spaced at 25 ms TWT with low values in red and high values in blue. The dashed line represents the edge of the Messinian evaporites. Arrows indicate syncline and anticline. (b) Dip map showing the traces of the main Faults G, H and J. (c) Geoviz image of Pleistocene Horizon Ba. (d) Geoviz visualisation of the geometry of Faults G, H and J related to the top Miocene.



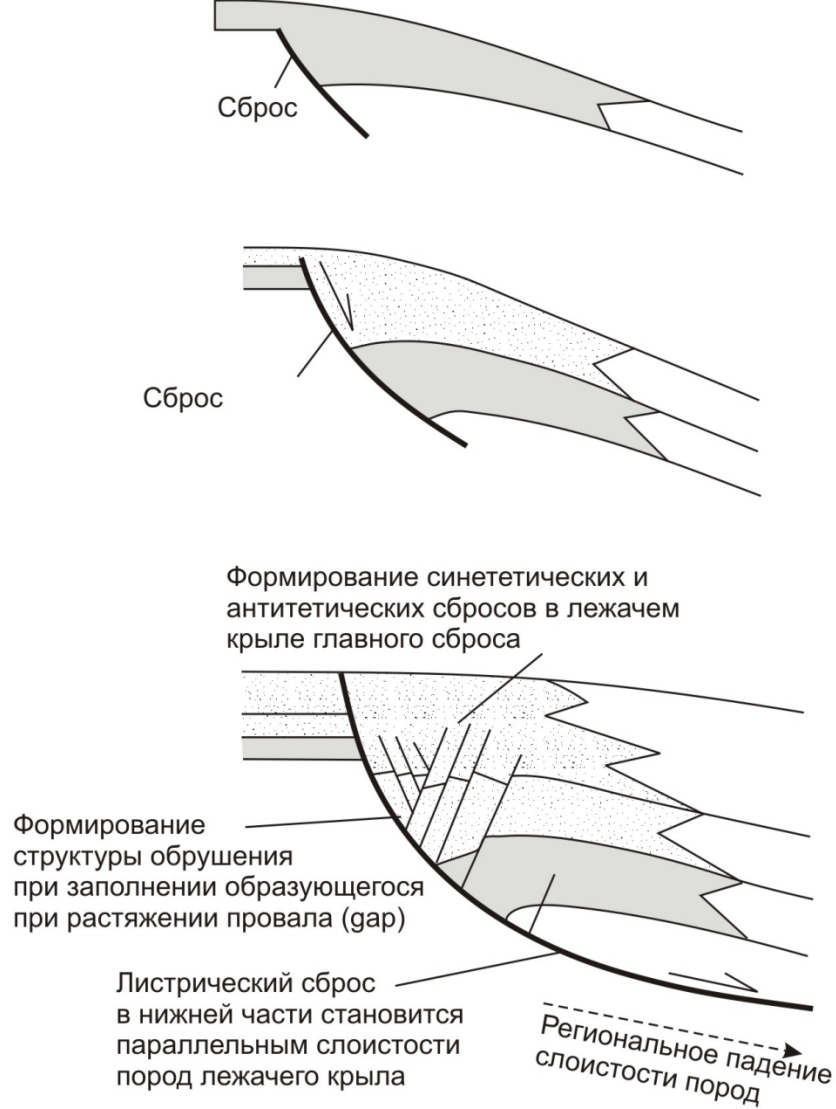
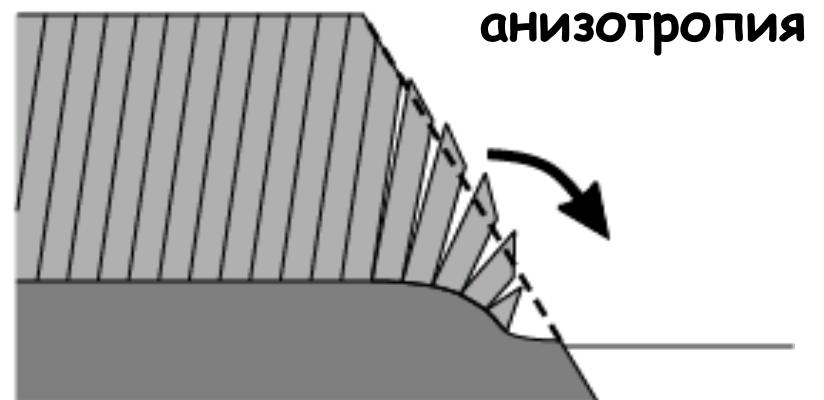
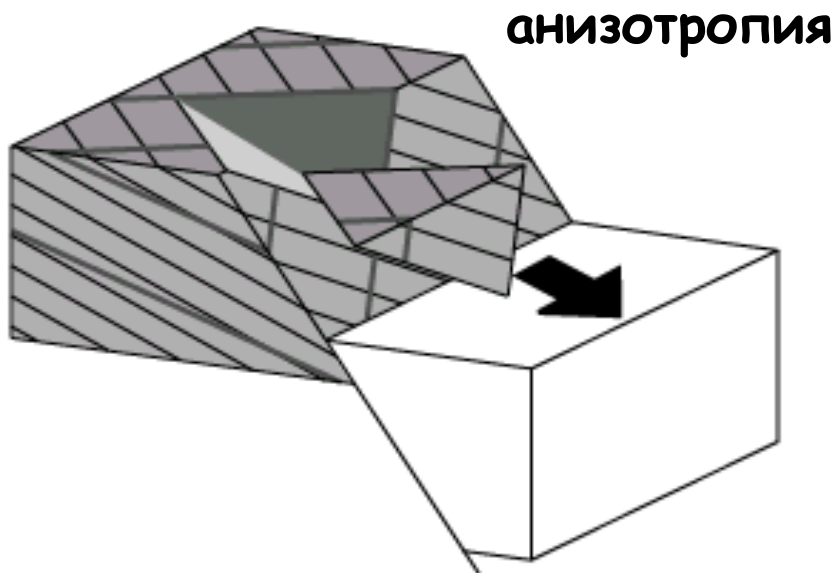
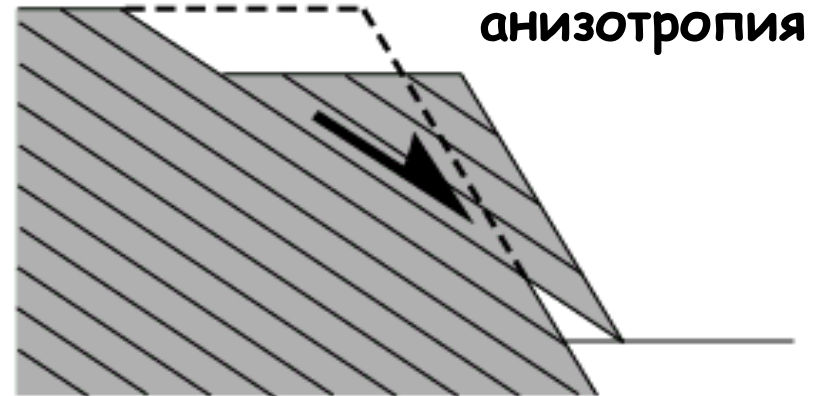
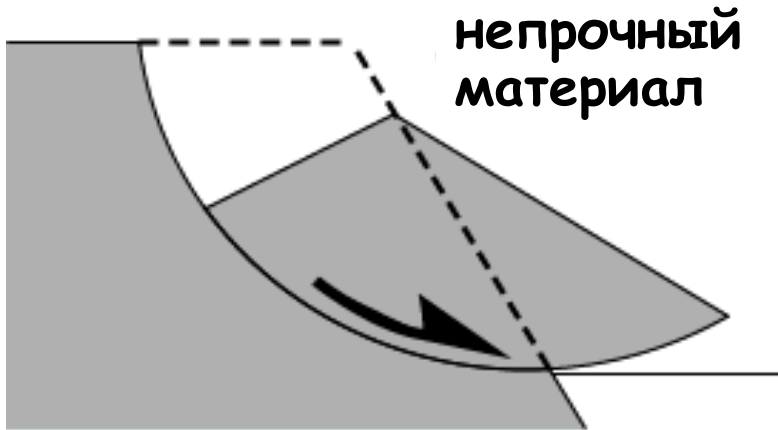
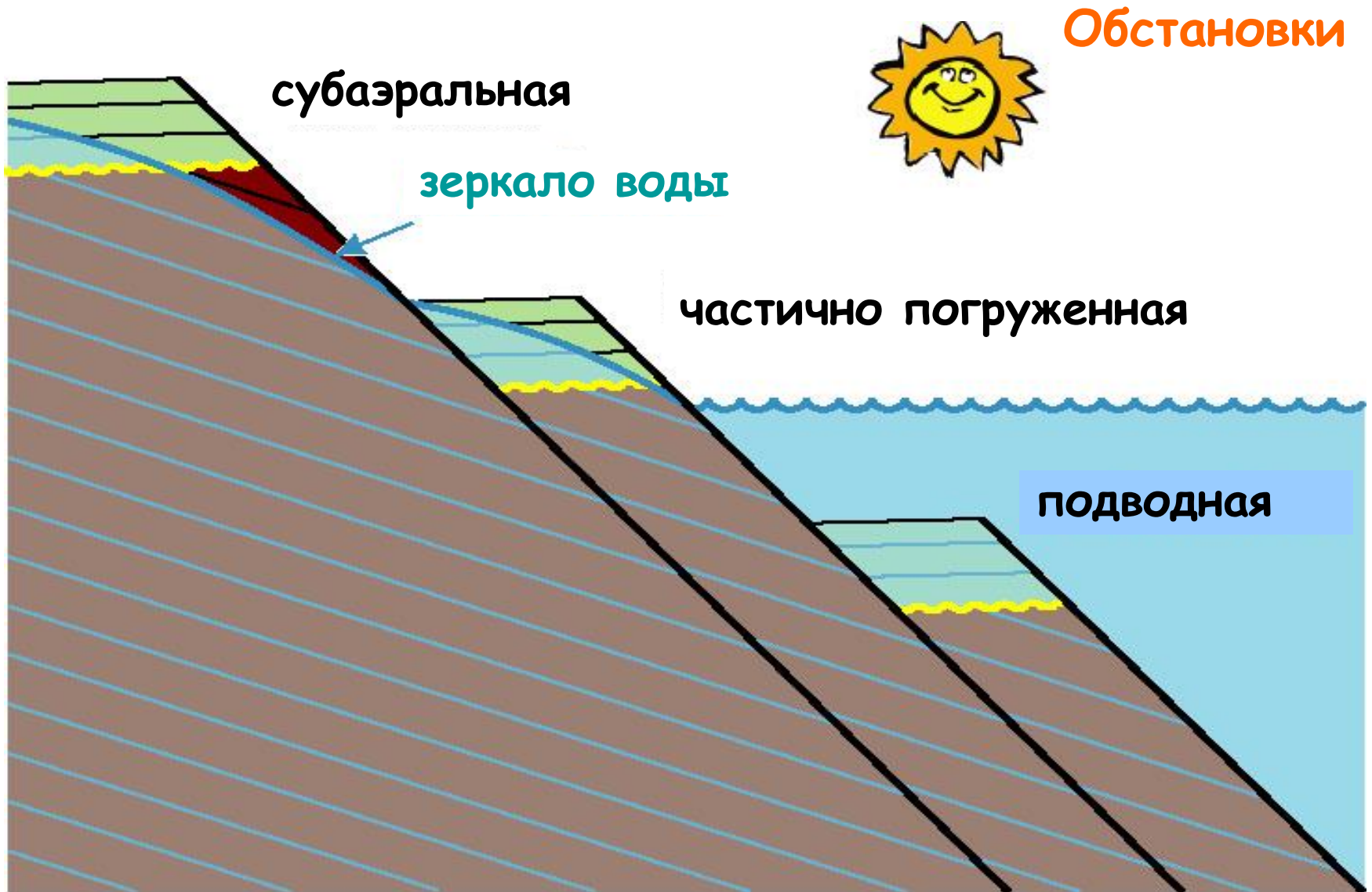


Рис. С-14. Стадии формирования растущих конседиментационных сбросов (growth faults). Смещение по листрическому сбросу происходит в процессе продолжающегося осадконакопления. В результате этого происходит увеличение мощности синхронных отложений (на рисунке - одинакового цвета) в лежащем крыле. На глубине сброс становится параллельным слоистости пород лежащего крыла.

# Типы разрушения сбросового уступа

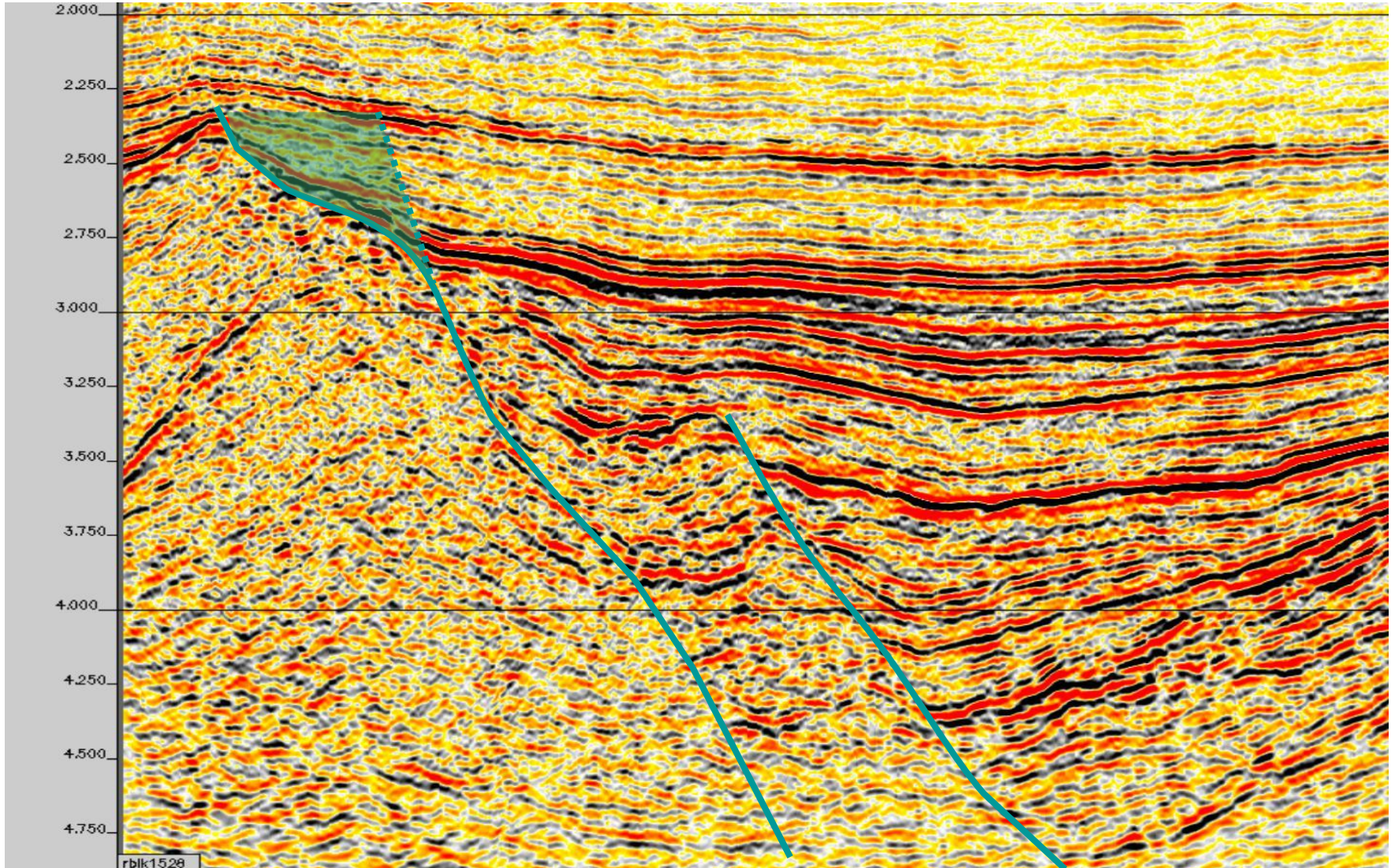


# Воздействия на сбросовый уступ

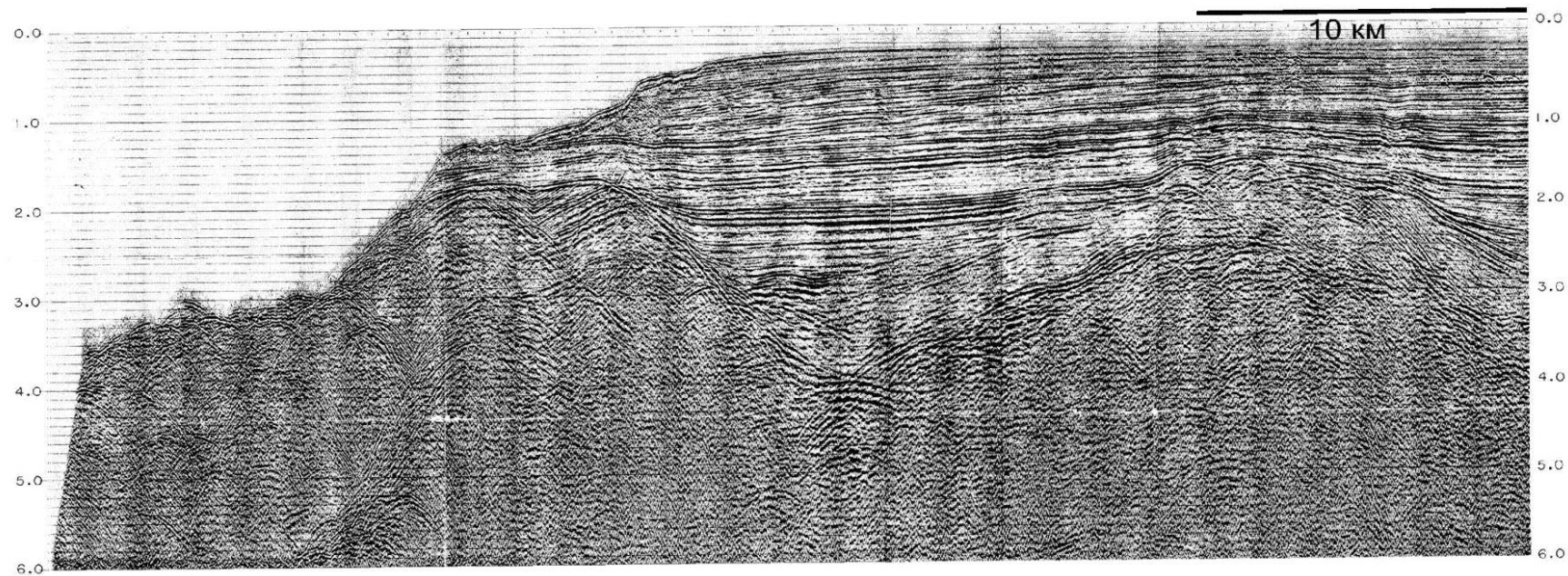
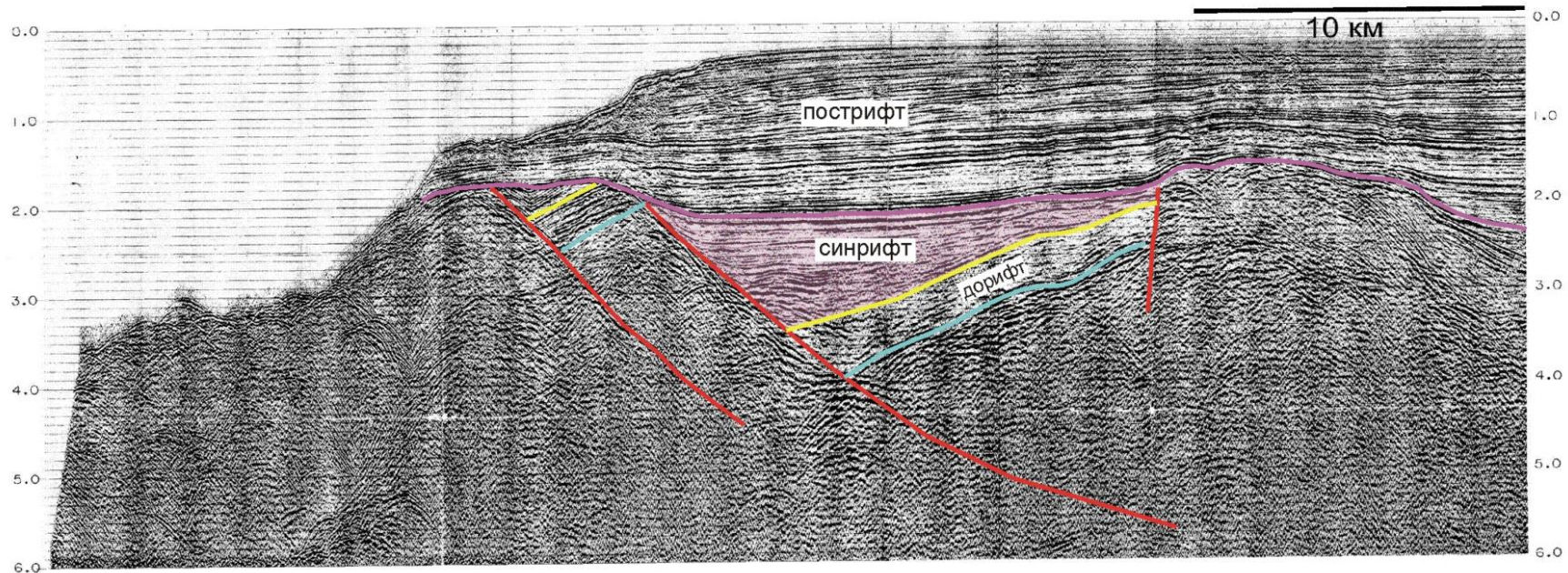




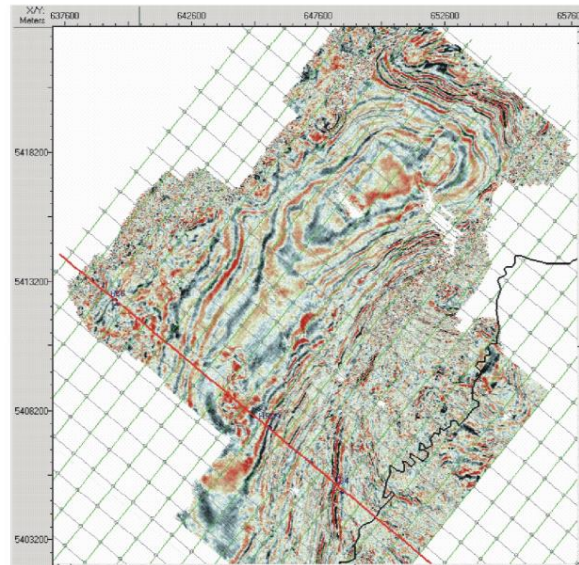
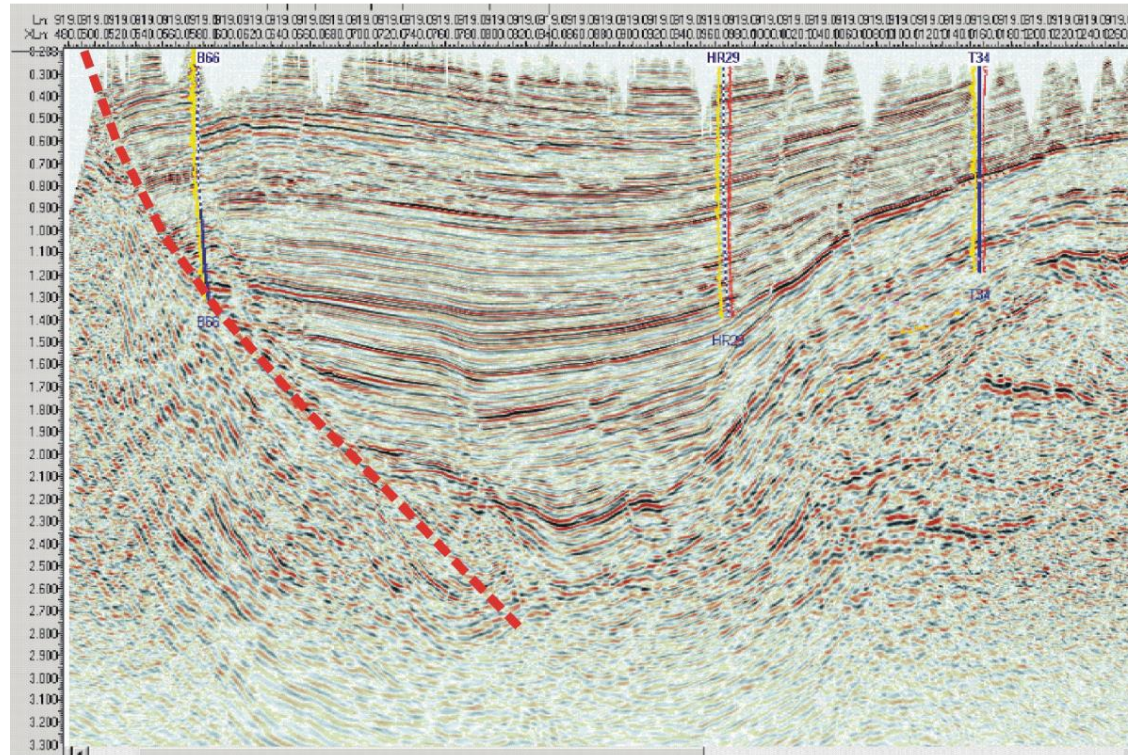
# Разрушение уступа и продолжительность воздействия



# Геометрия грабена Наваринского бассейна

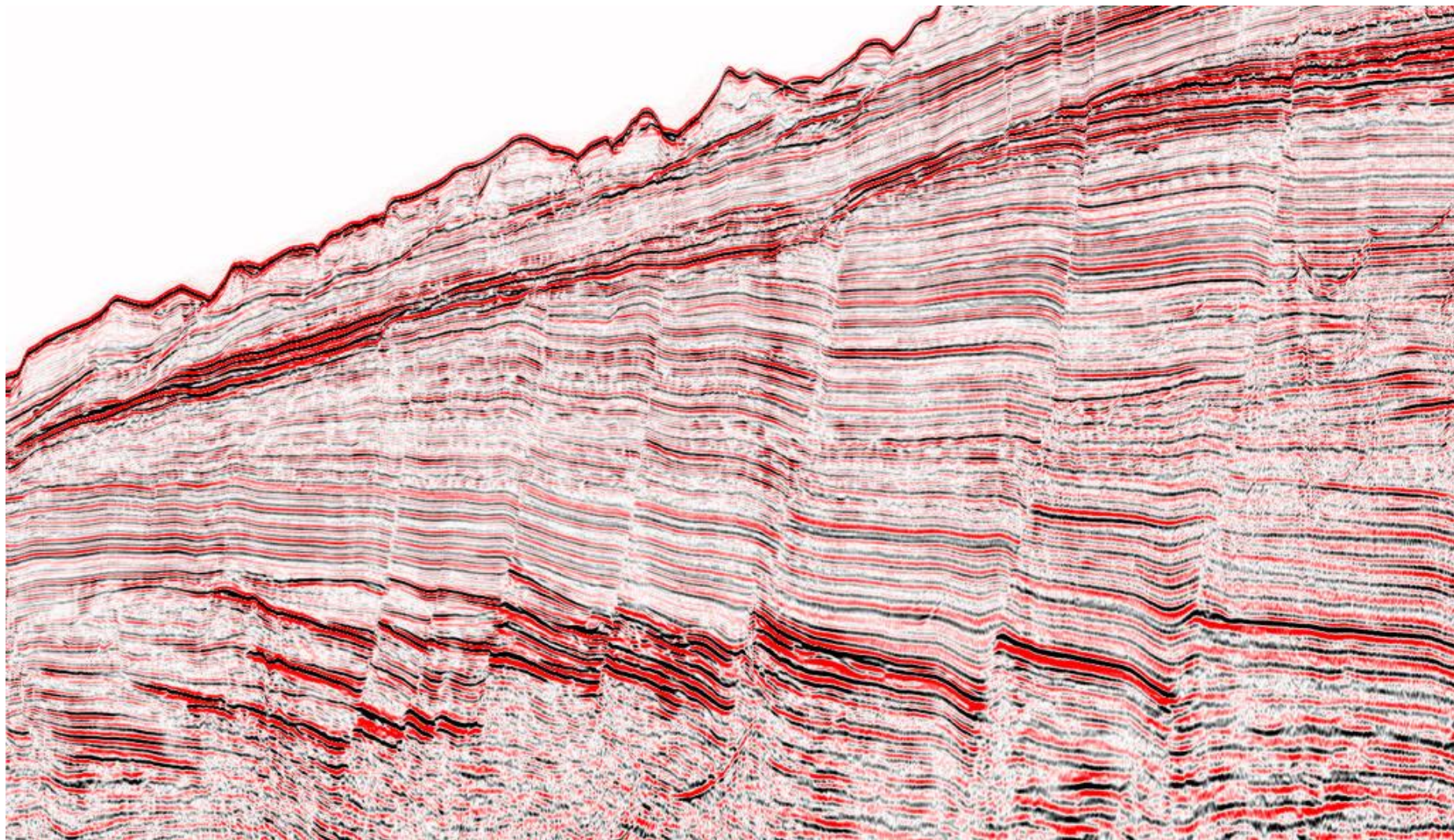


# Vienna Basin



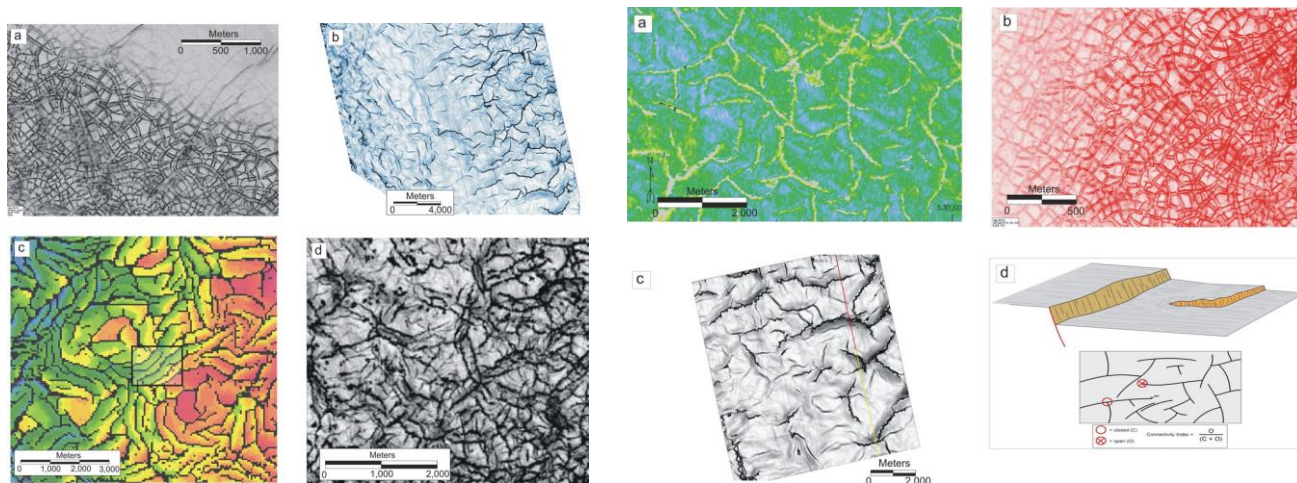
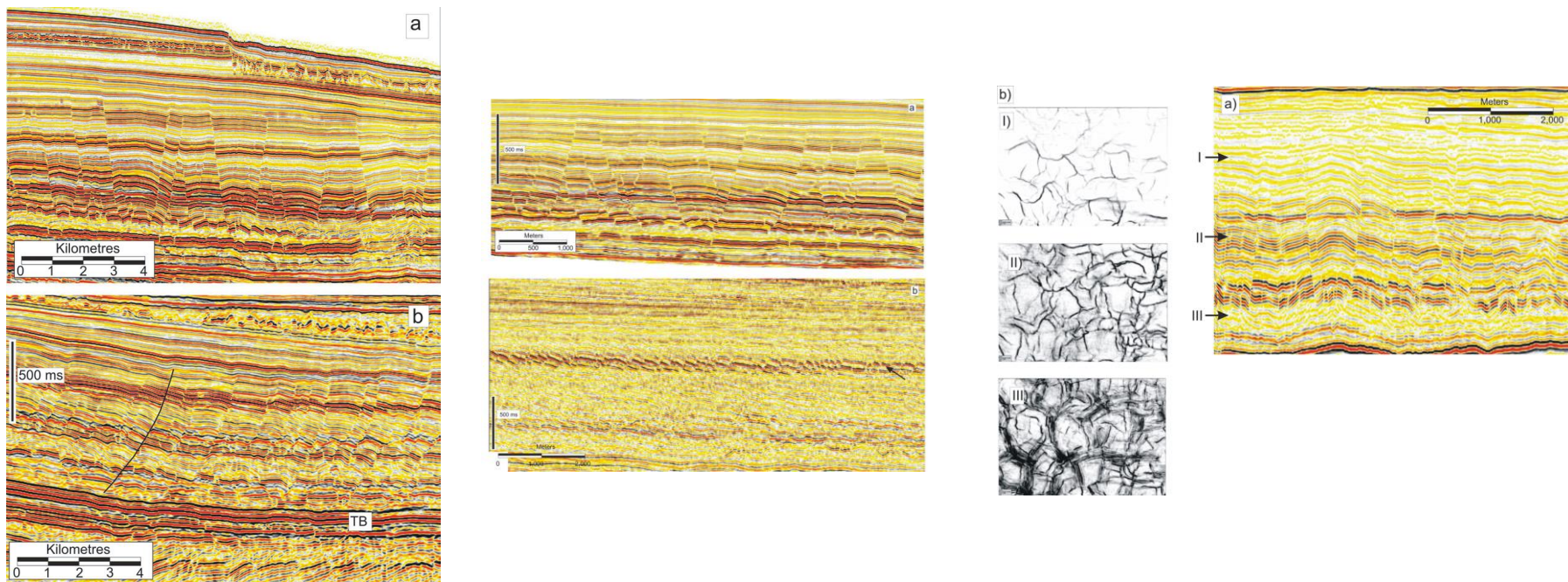
MND data

## Пассивная окраина Западной Сахары



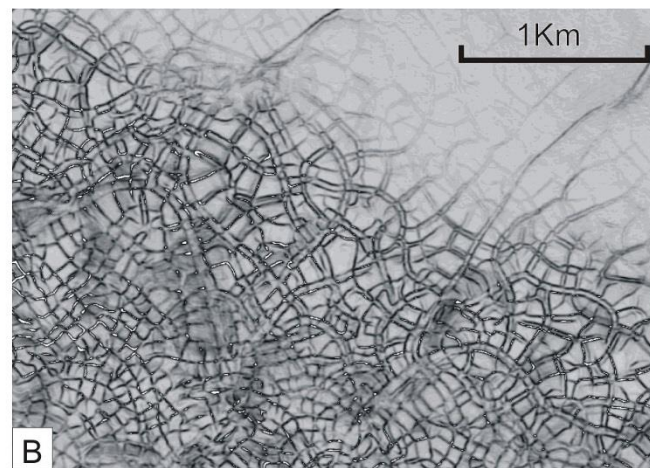
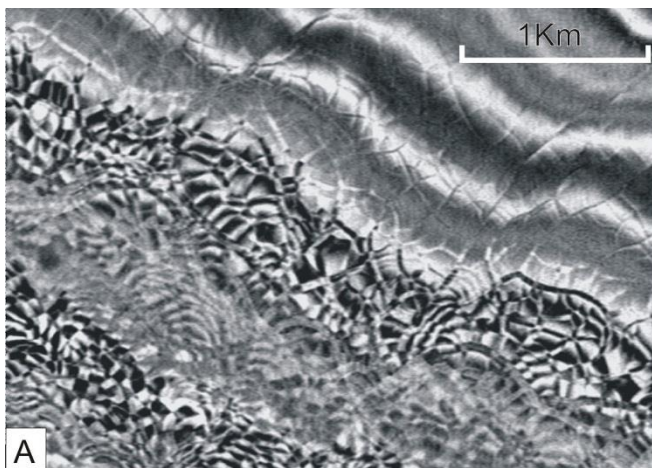
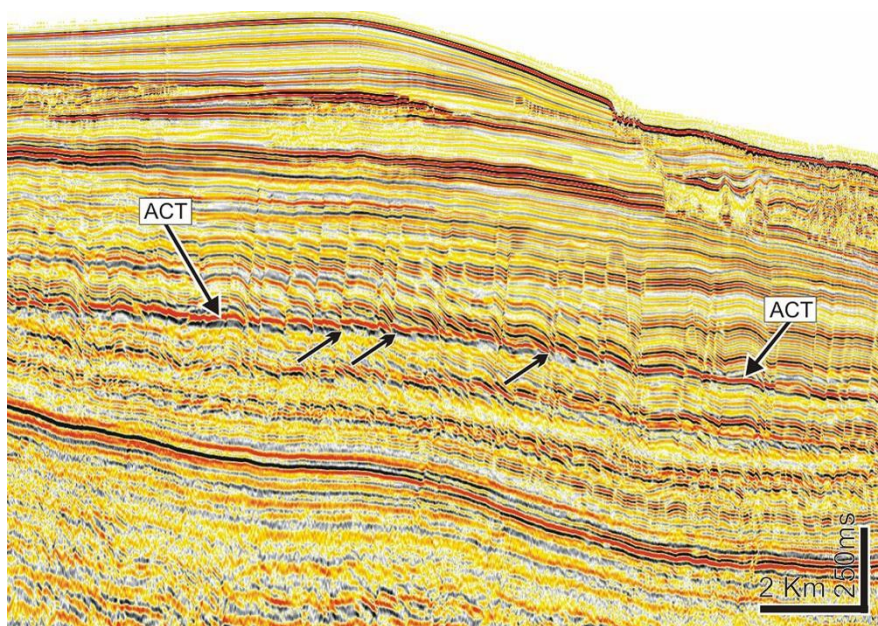
# Полигональные разломы

# Полигональные системы разломов. Представлены в основном сбросами. Наблюдаются в глинах и алевролитах, связаны с процессами диагенеза

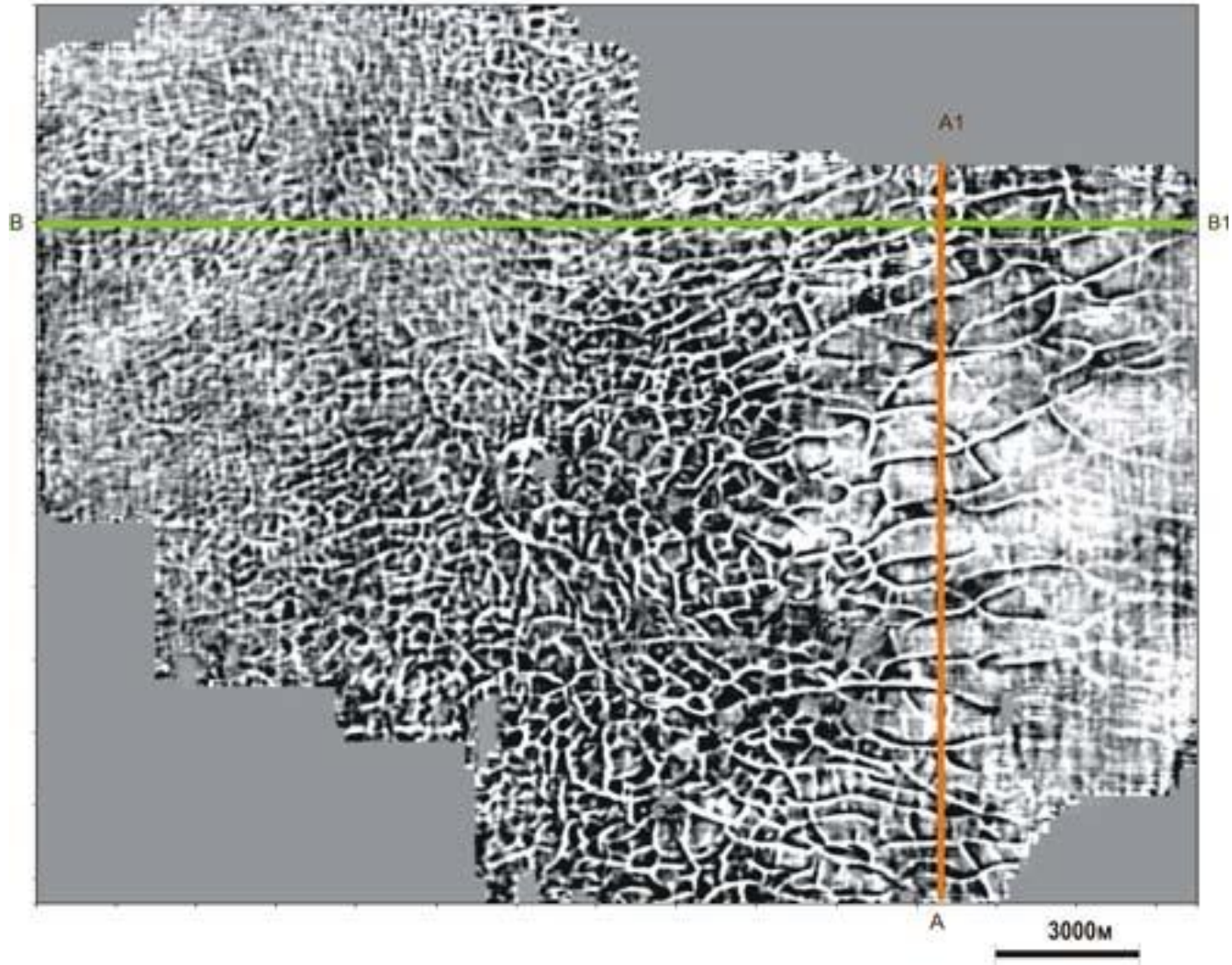


Cartwright, J. Diagenetically induced shear failure of fine grained sediments and the development of polygonal fault systems, *Marine and Petroleum Geology* (2011), doi: 10.1016/j.marpetgeo.2011.06.004

# Полигональные системы разломов

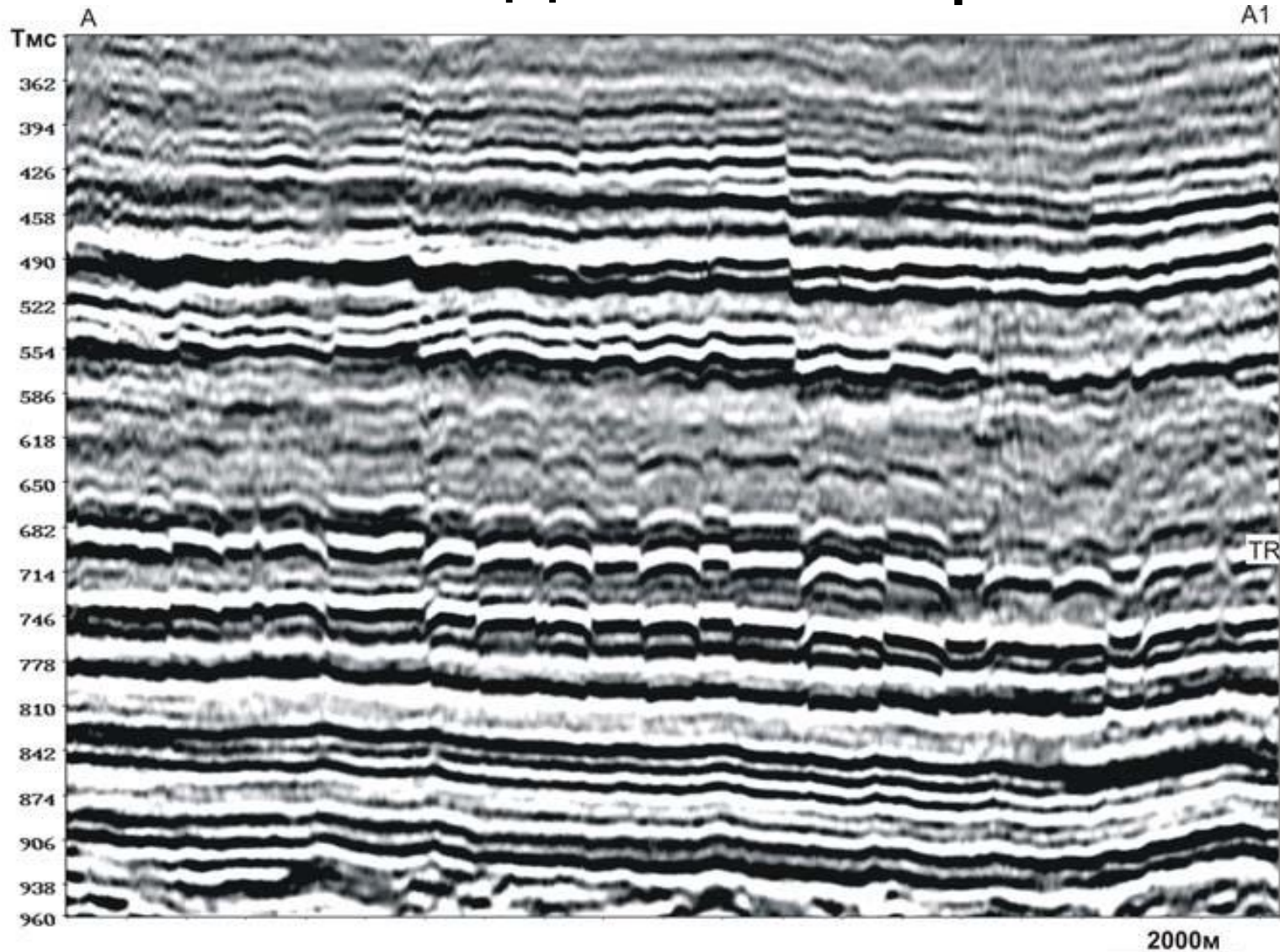


# Полигональные разломы в Западной Сибири (вид на карте)

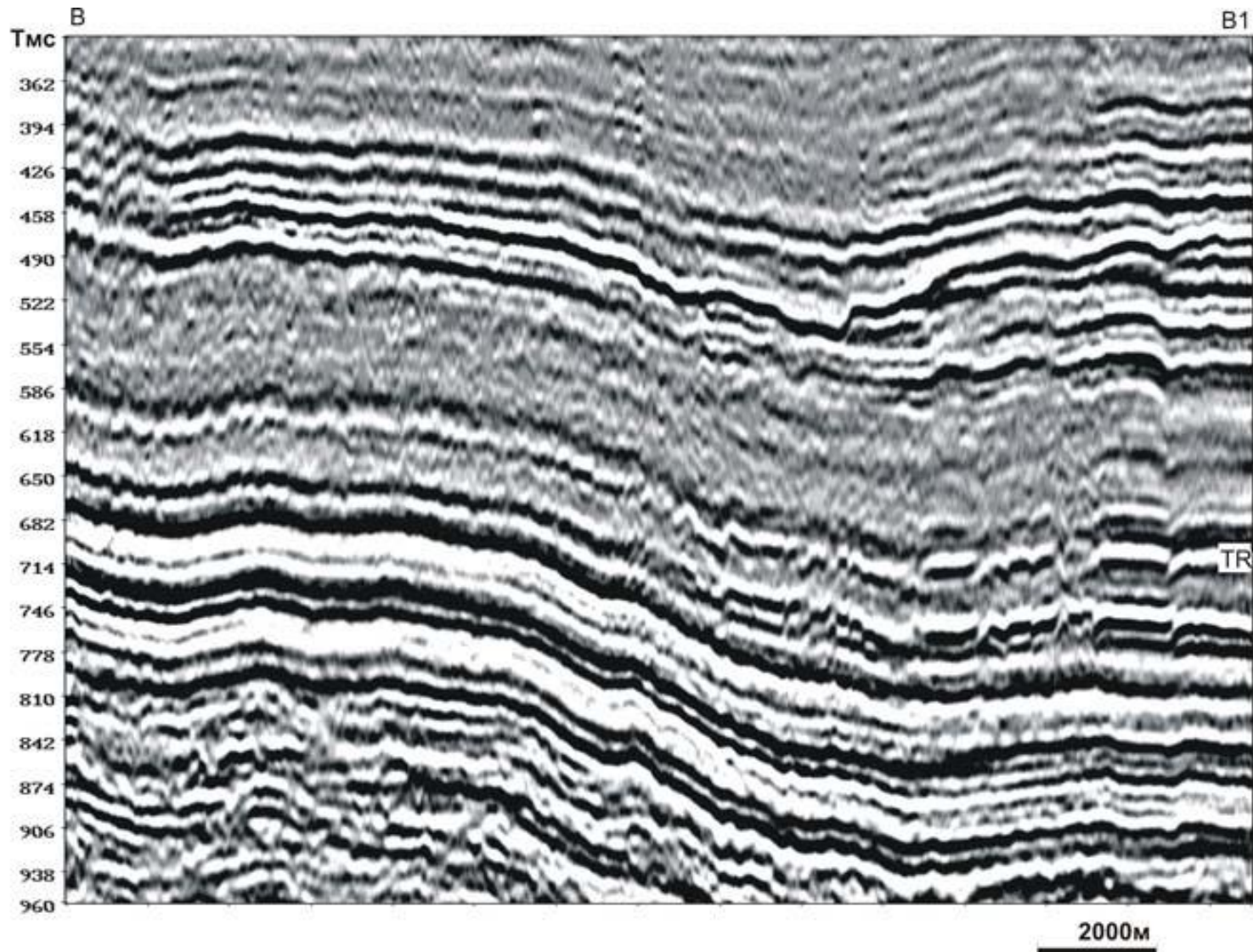




# Полигональные разломы, Западная Сибирь



# Западная Сибирь



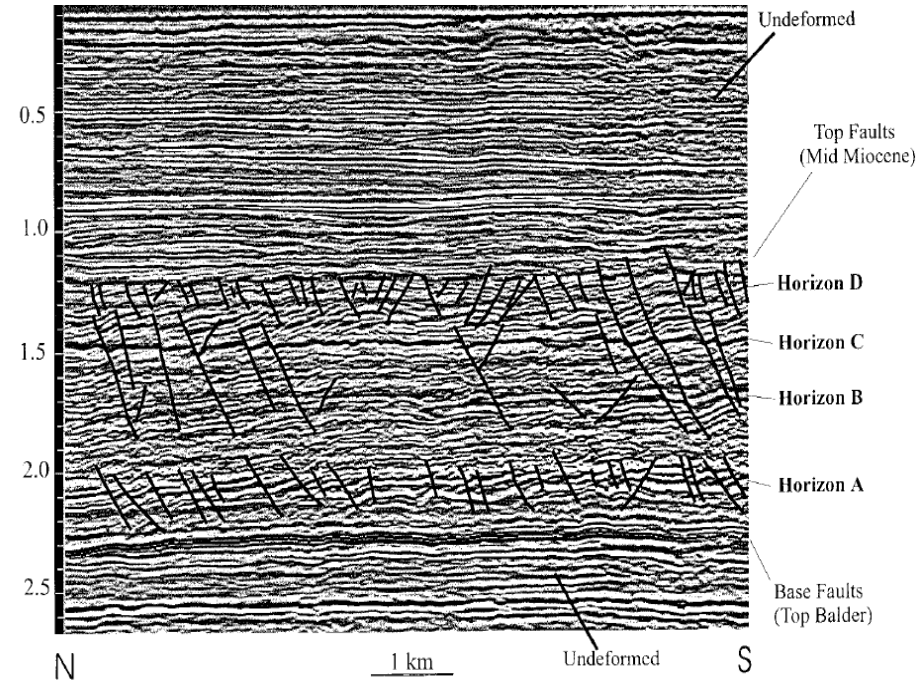
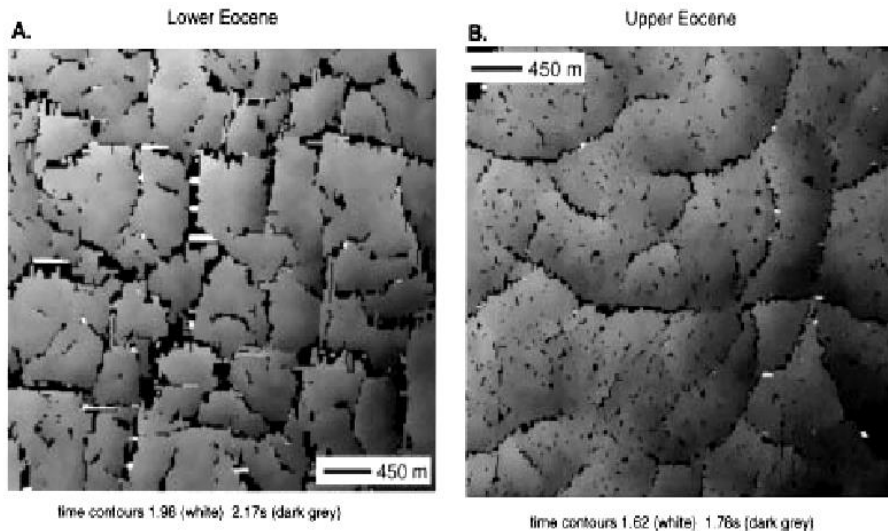
# Полигональные сбросы

- Геометрия сбросов

- Ограниченные определенными слоями регионально распространенные разломы на пассивных окраинах.

- Все варианты дислокаций от “домино” (вверх по восстанию) до полигональных.

- Организация сбросов различается на разных



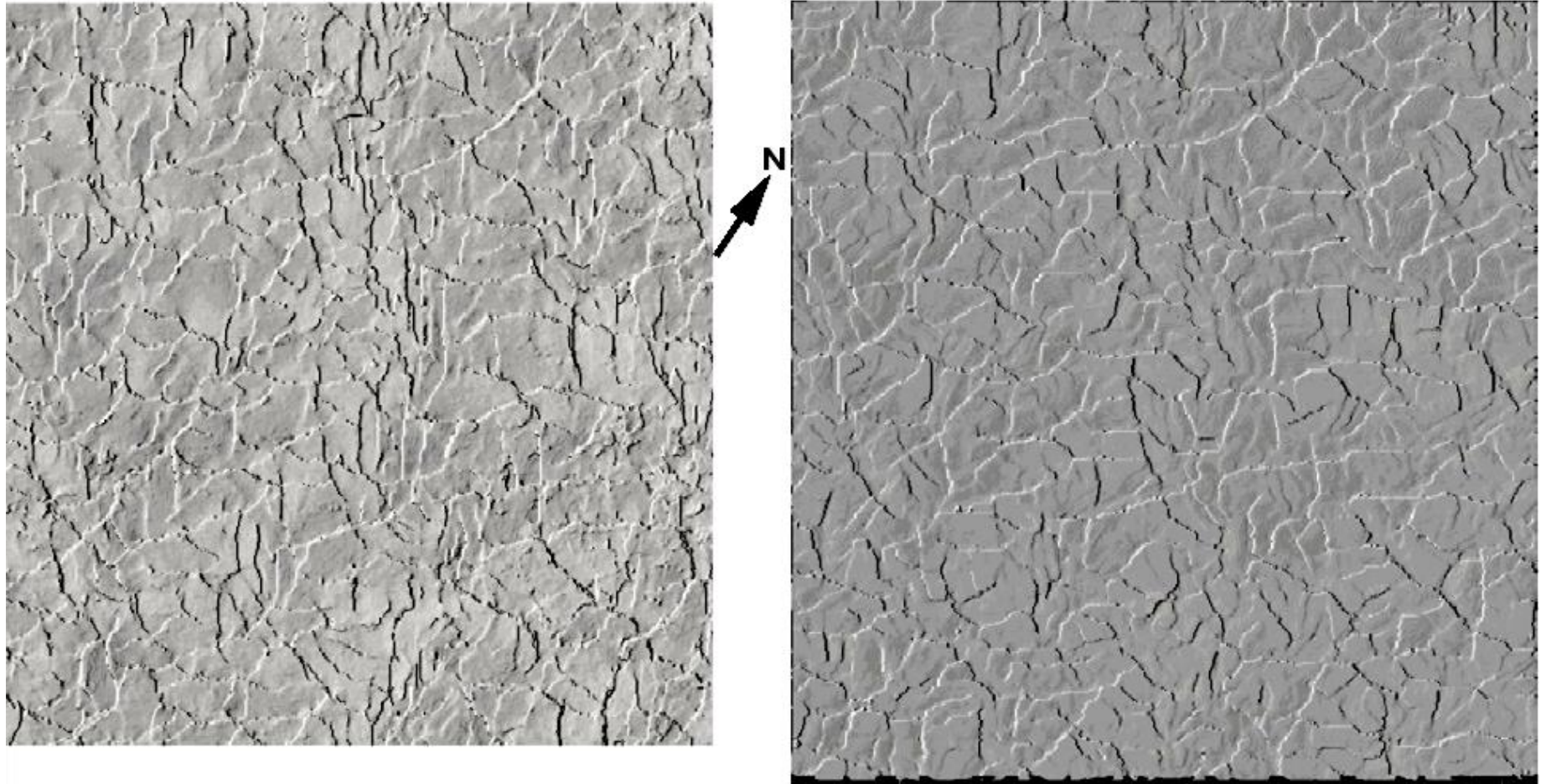
- Масштаб

- Организация в несколько порядков (см – км) величины

- Длина сброса < 2 км

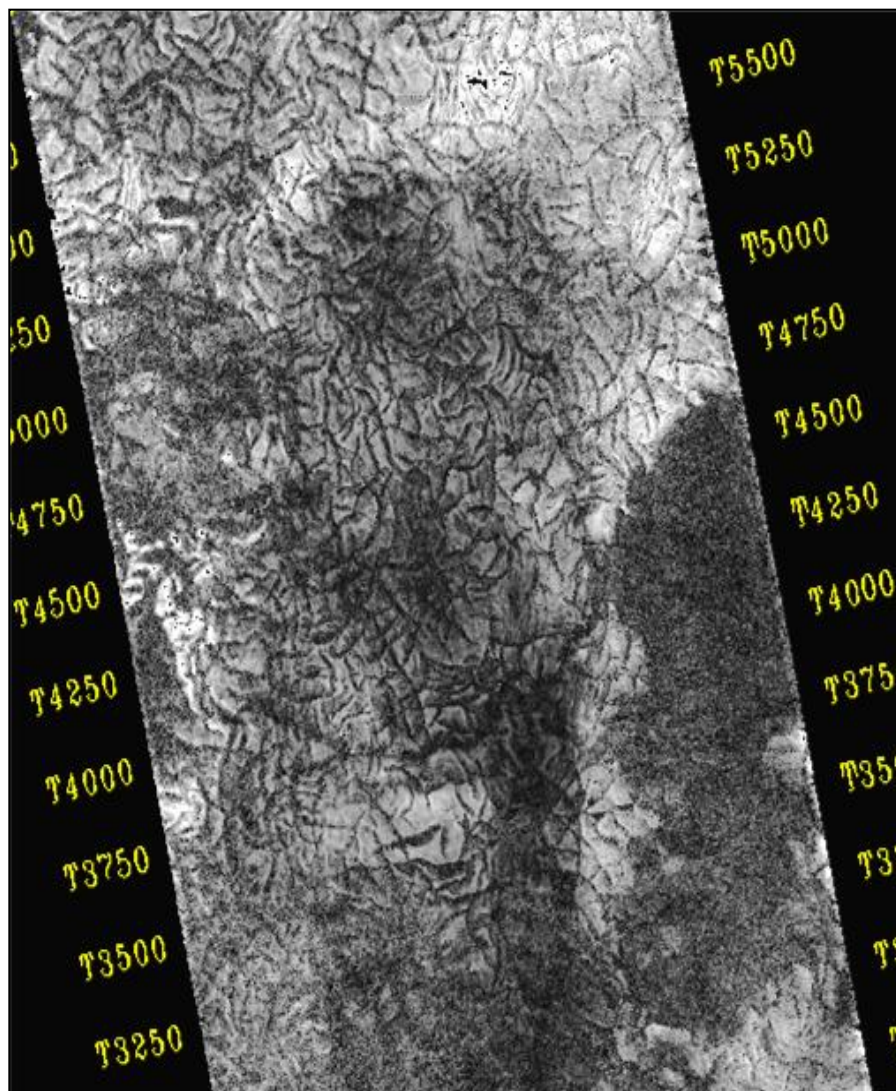
- Смещение сбросов < 200 м

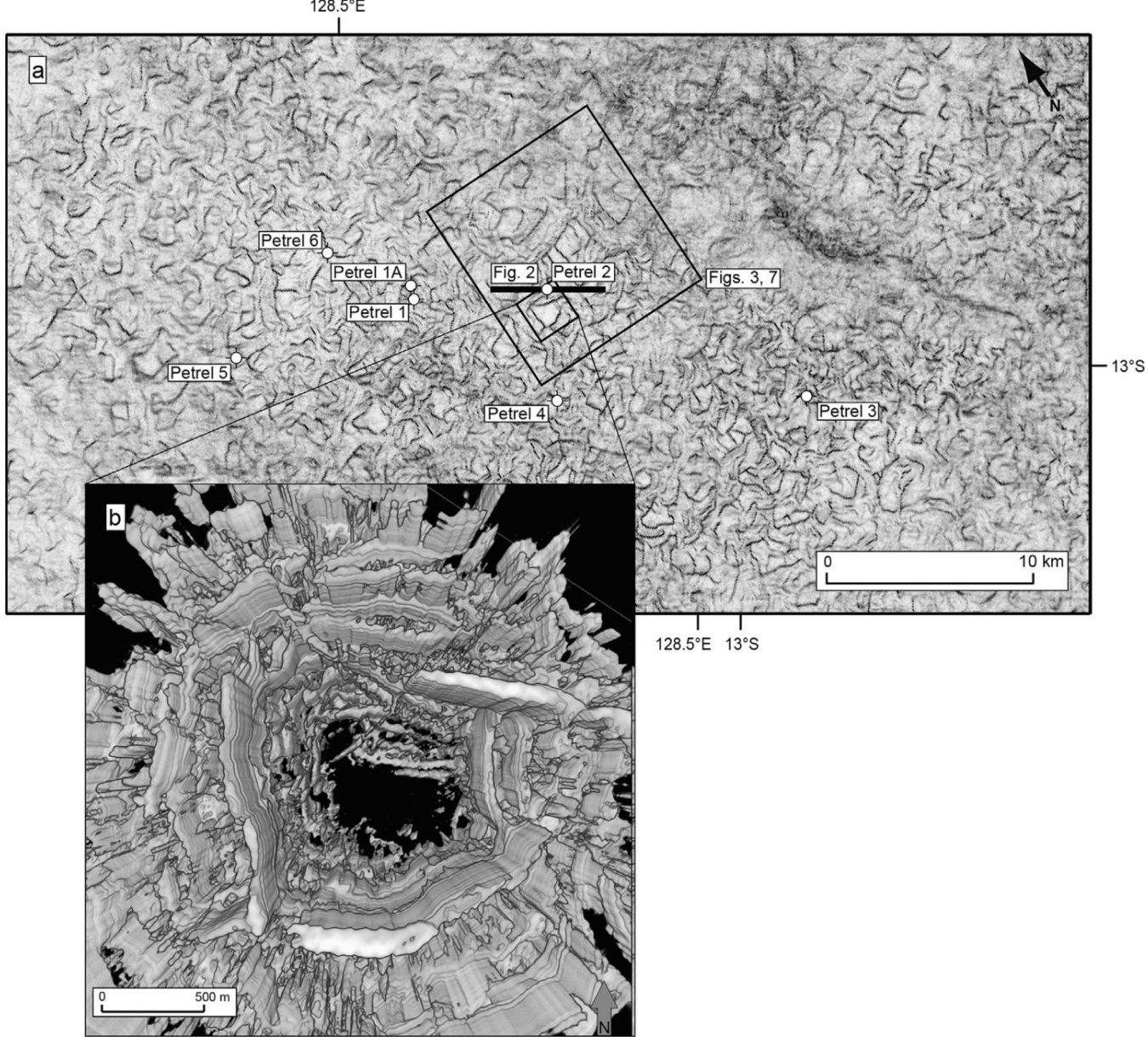
# Поверхность, разбитая полигональными сбросами :



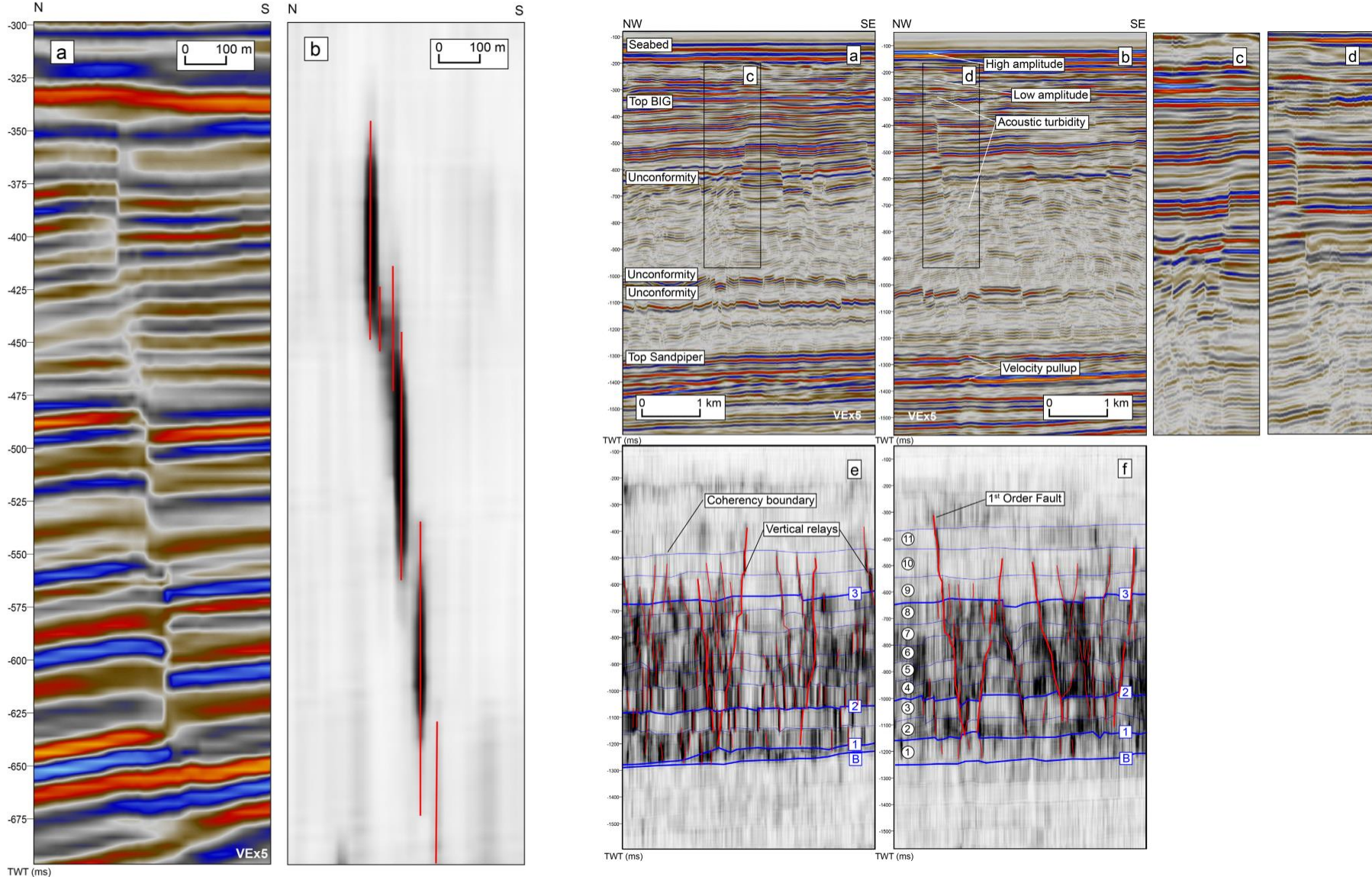
1.25 km

# Полигональные сбросы : Механизмы

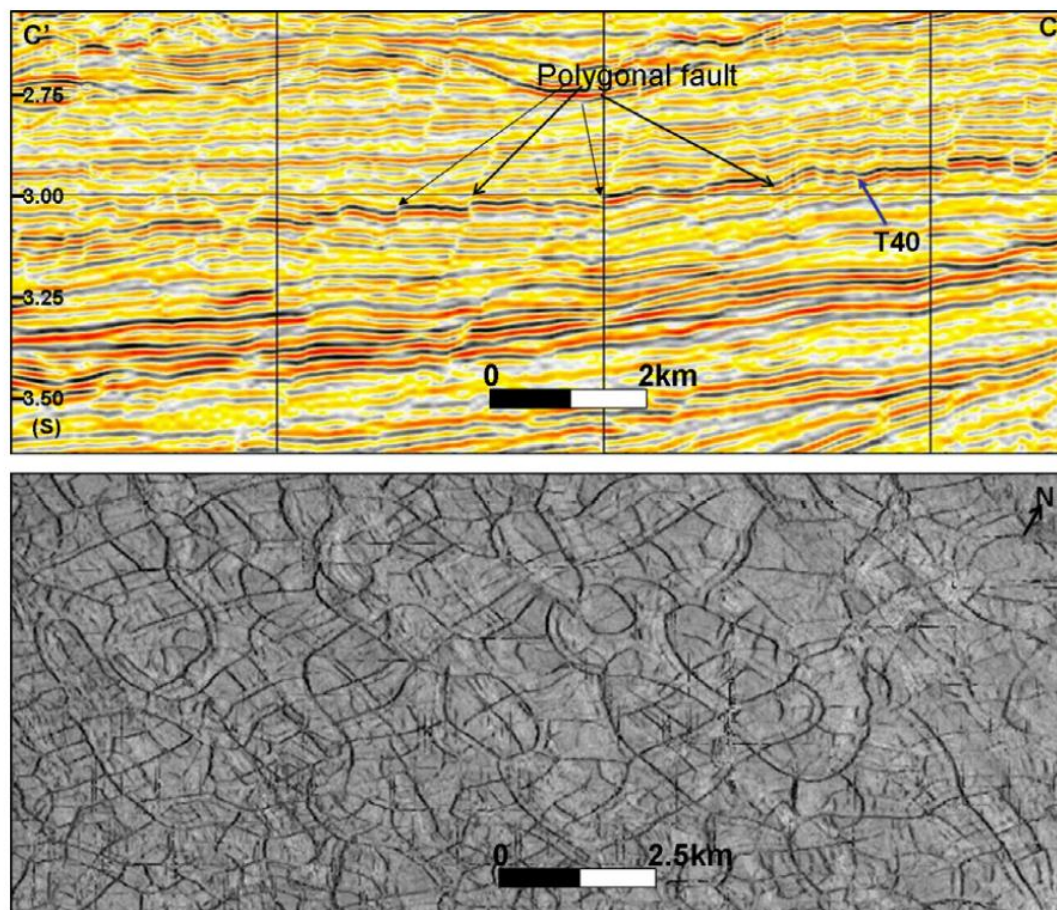




(a) Coherency map showing the polygonal fault system at ~500 ms TWT within the Bathurst Island Group, Petrel Sub-basin, northwest Australia.  
 (b) Interconnected polygonal faults (white and grey polygons derived from coherency cube e reverse colour scheme to (a)) forming a polygonal cell  
 (c) and displayed in 3D view looking downwards.  
 Preliminary volume analysis indicates that the faults are highly connected.



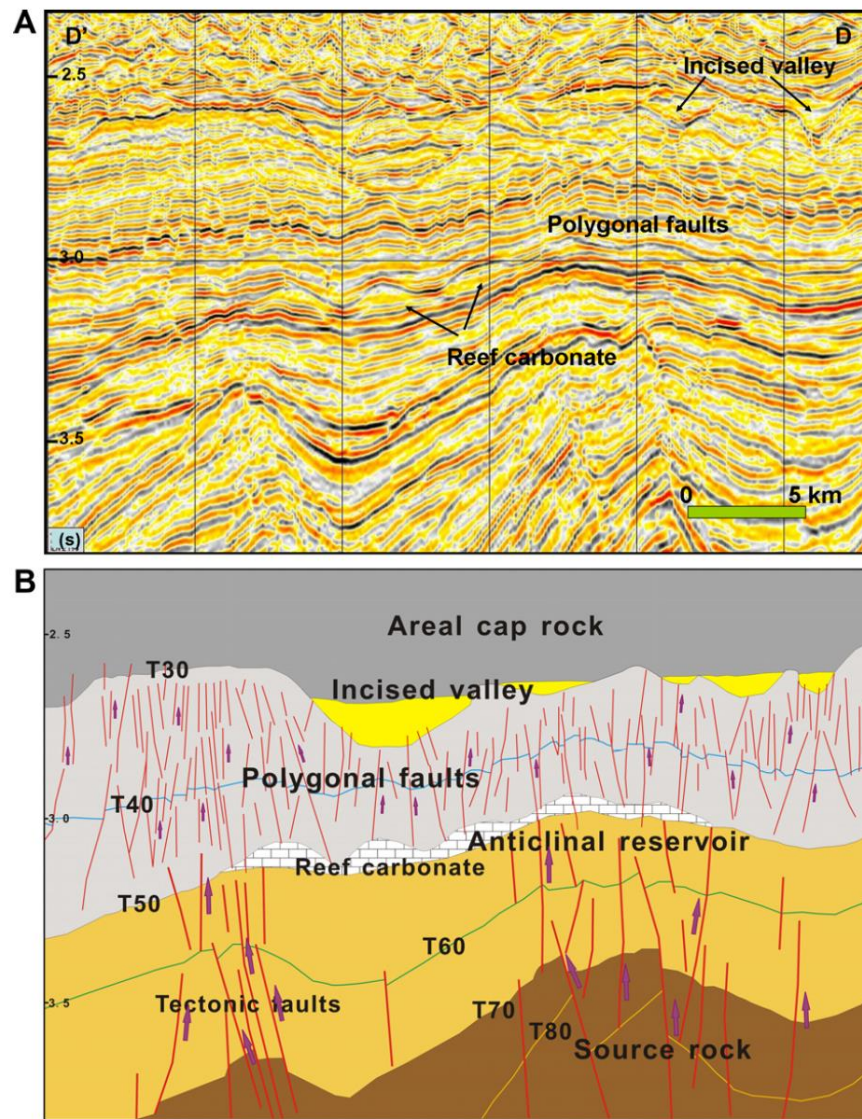
Detailed geometry of a segmented polygonal fault in the upper 350 ms of the faulted interval. a) Seismic reflection profile. b) Coherency attribute with fault interpretation (red vertical lines). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)



**Fig. 5.** Planimetric and sectional characteristics of polygonal faults. Top: development of polygonal faults is mostly confined between 2.75 and 3.25 TWT(s) and are very representative along T40, See position in Fig. 1, C–C'; Bottom: coherent attribute map images the geometrical characteristics of the polygonal faults. See position in Fig. 1.



Южно-Китайское море



**Fig. 10.** A: a representative seismic profile for new model of petroleum system of Qiongdongnan Basin. B: the interpretation profile of A. Yacheng Formation and Lingtou Formation below T70 provide the source rocks. Lingshui Formation and Sanya Formation between T50 and T70 are the regional reservoirs with anticlinal traps developed. Reef carbonate reservoir developed above T50 in lower Meishan Formation. Tectonic faults mainly formed in rifted stage below T50. Polygonal faults developed above anticlinal traps in upper Meishan Formation and Huangliu Formation between T30 and T50 and may form a migration pathway in the post-rifted stage. Coarse sandstone deposited in composite valleys above T30 (base of the Yinggehai Formation) form the reservoirs in the post-rifted stage. The Yinggehai Formation is the areal cap rock. See location in Fig. 1, D–D'.

# Баренцево море

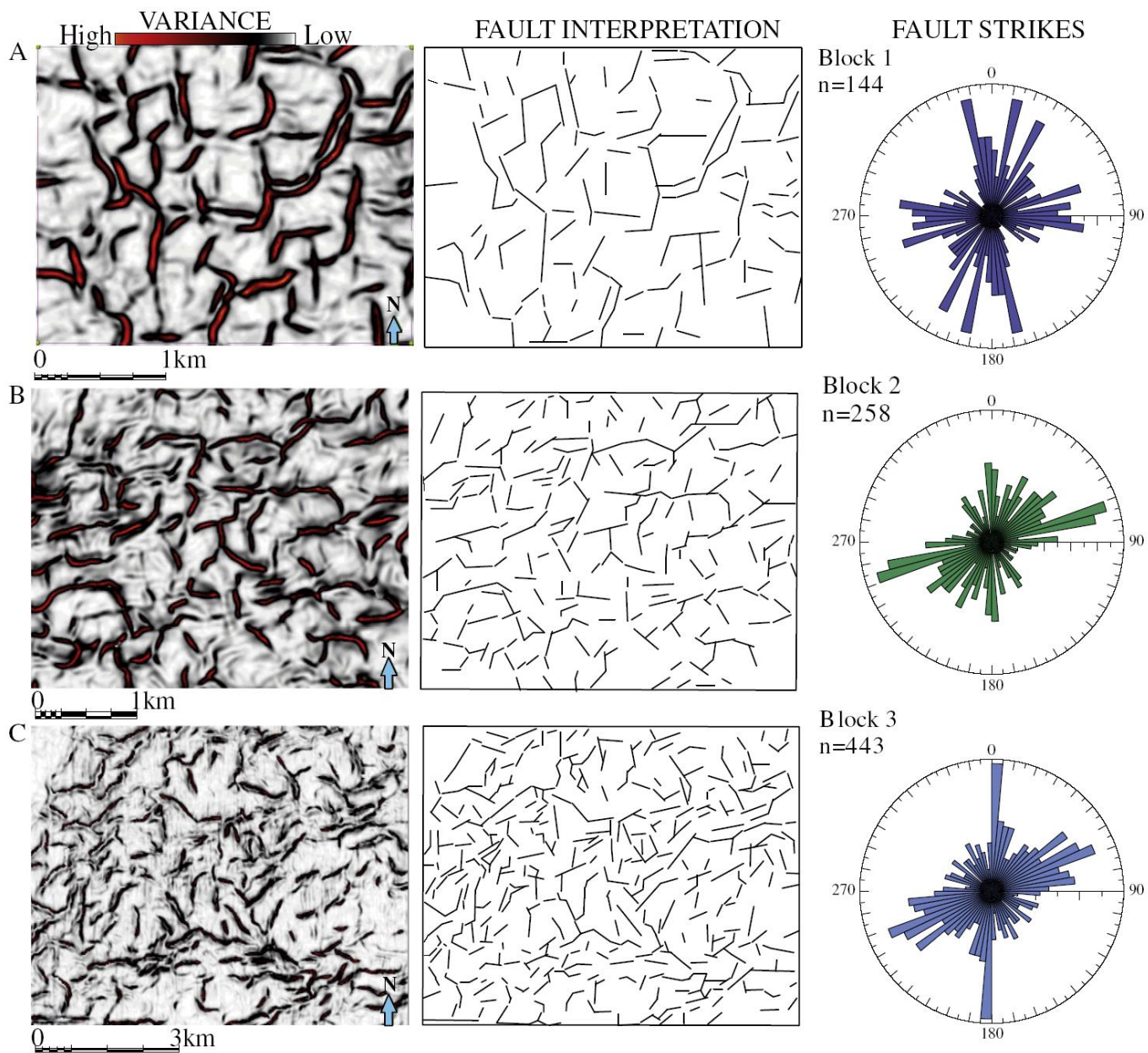
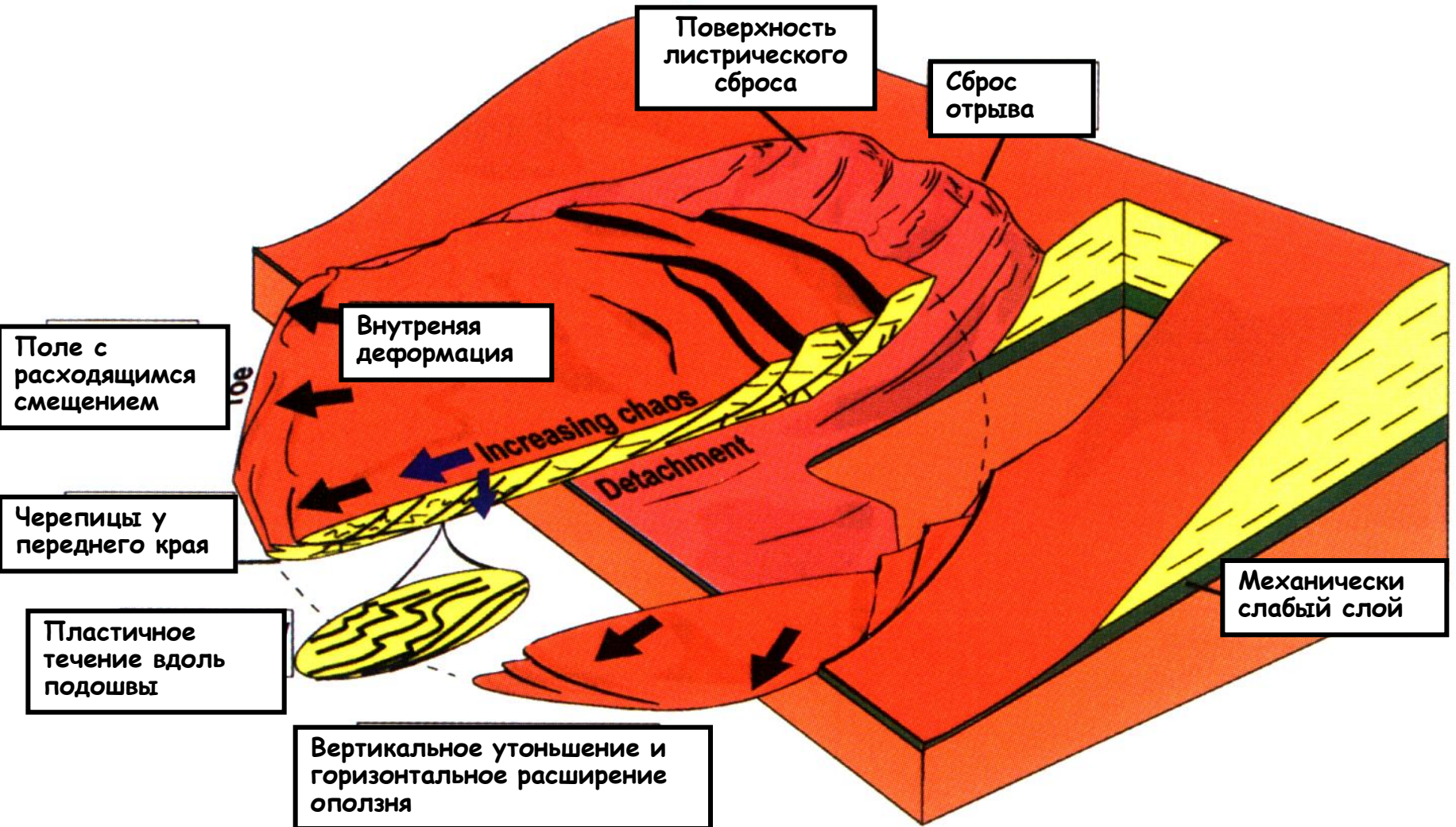


Fig. 6. Insets showing a small sample area of polygonal faults for each of the network blocks 1, 2 and 3. See Fig. 5 for location and text for further details.

# Примеры для дискуссии

# Связанный массовый поток



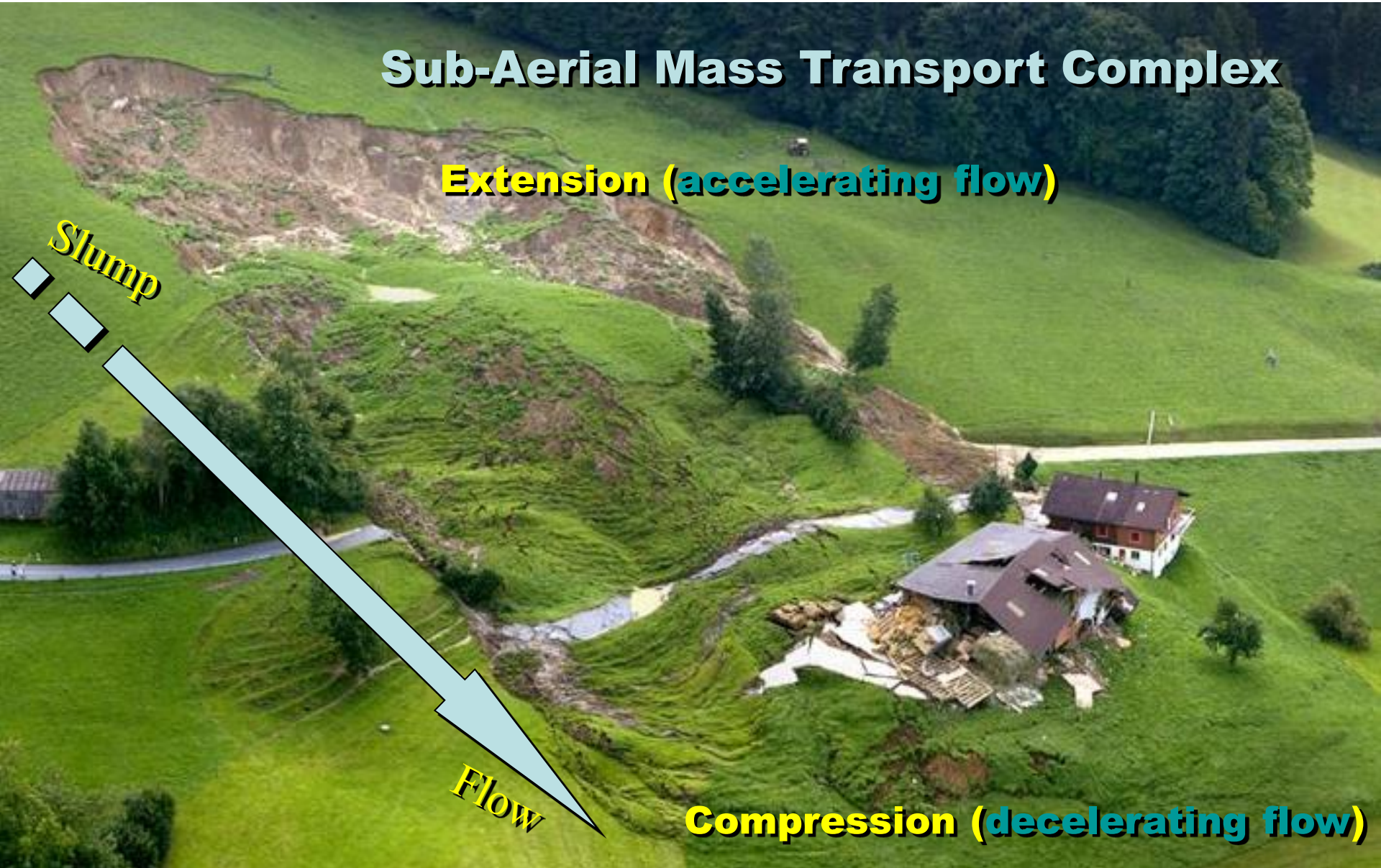
# Sub-Aerial Mass Transport Complex

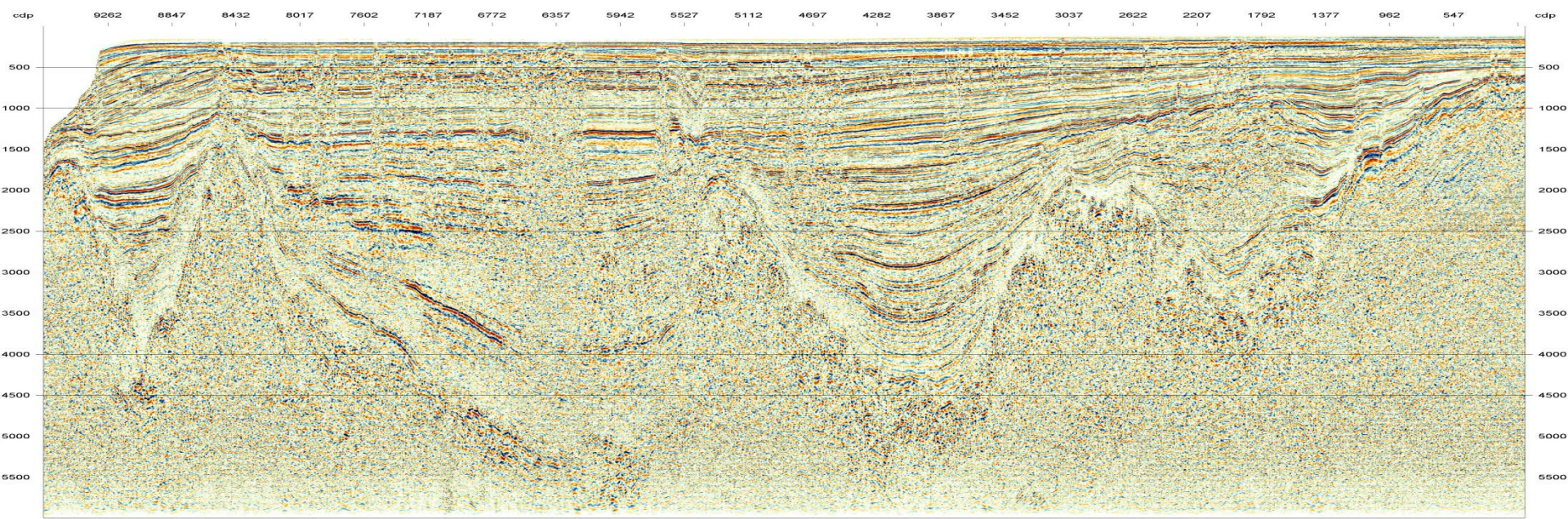
**Extension (accelerating flow)**

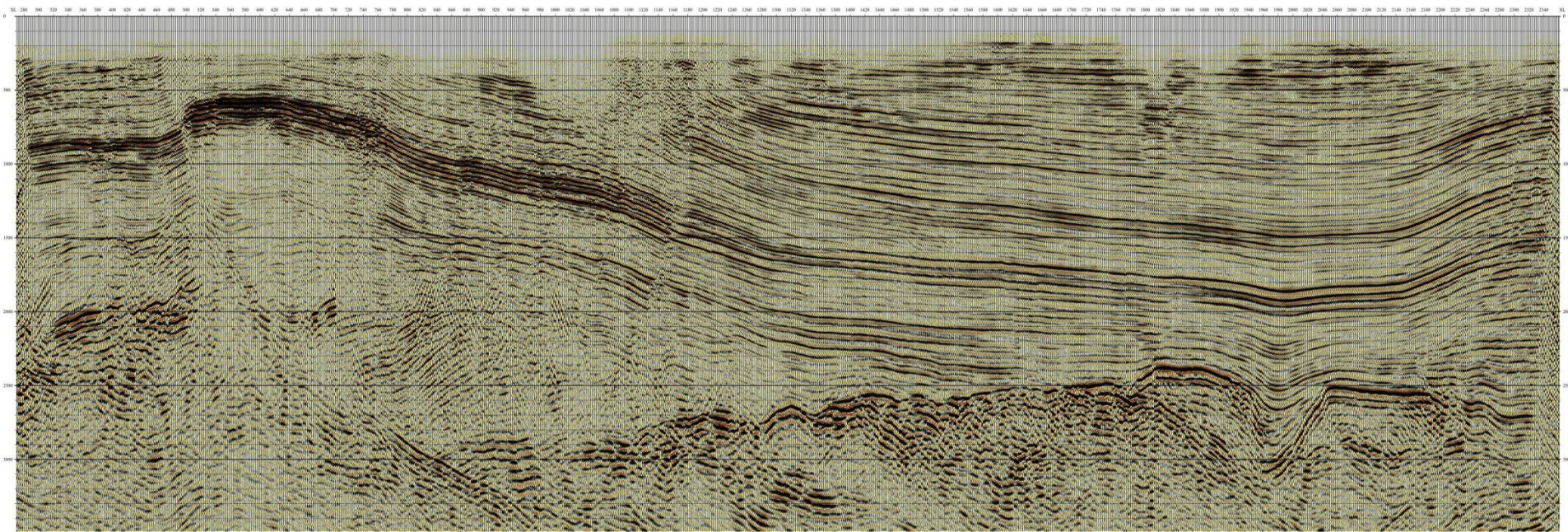
**Slump**

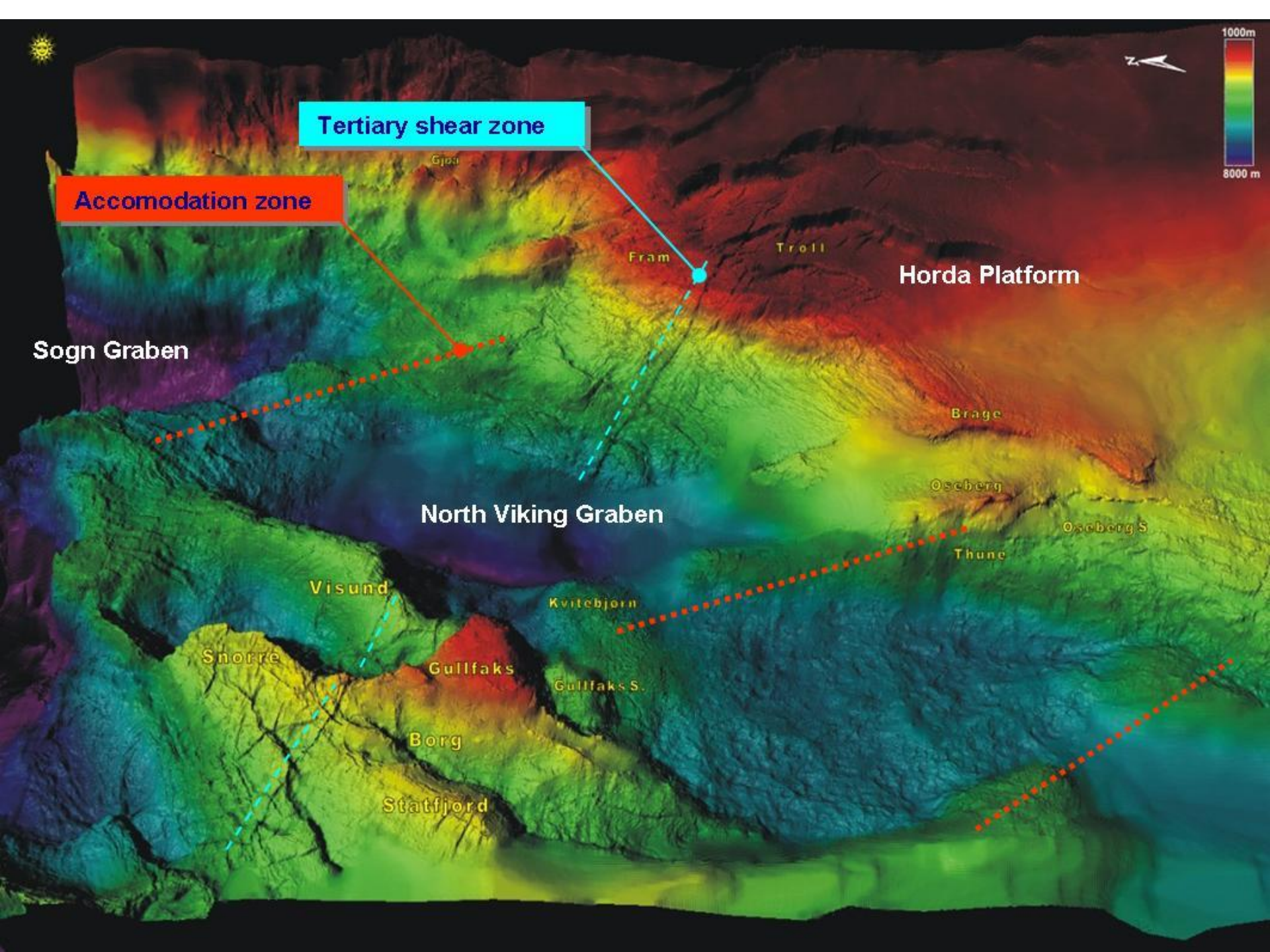
**Flow**

**Compression (decelerating flow)**

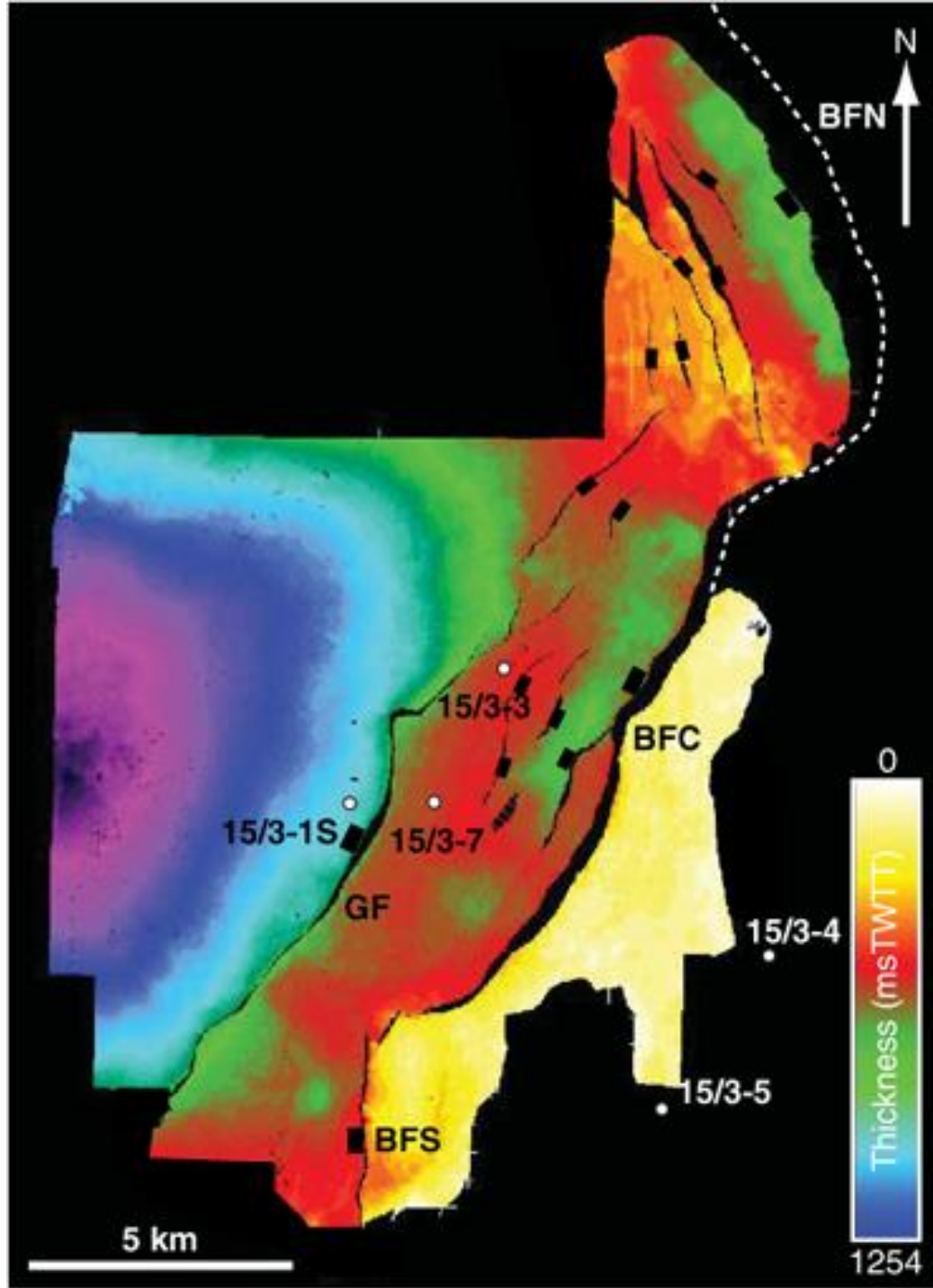


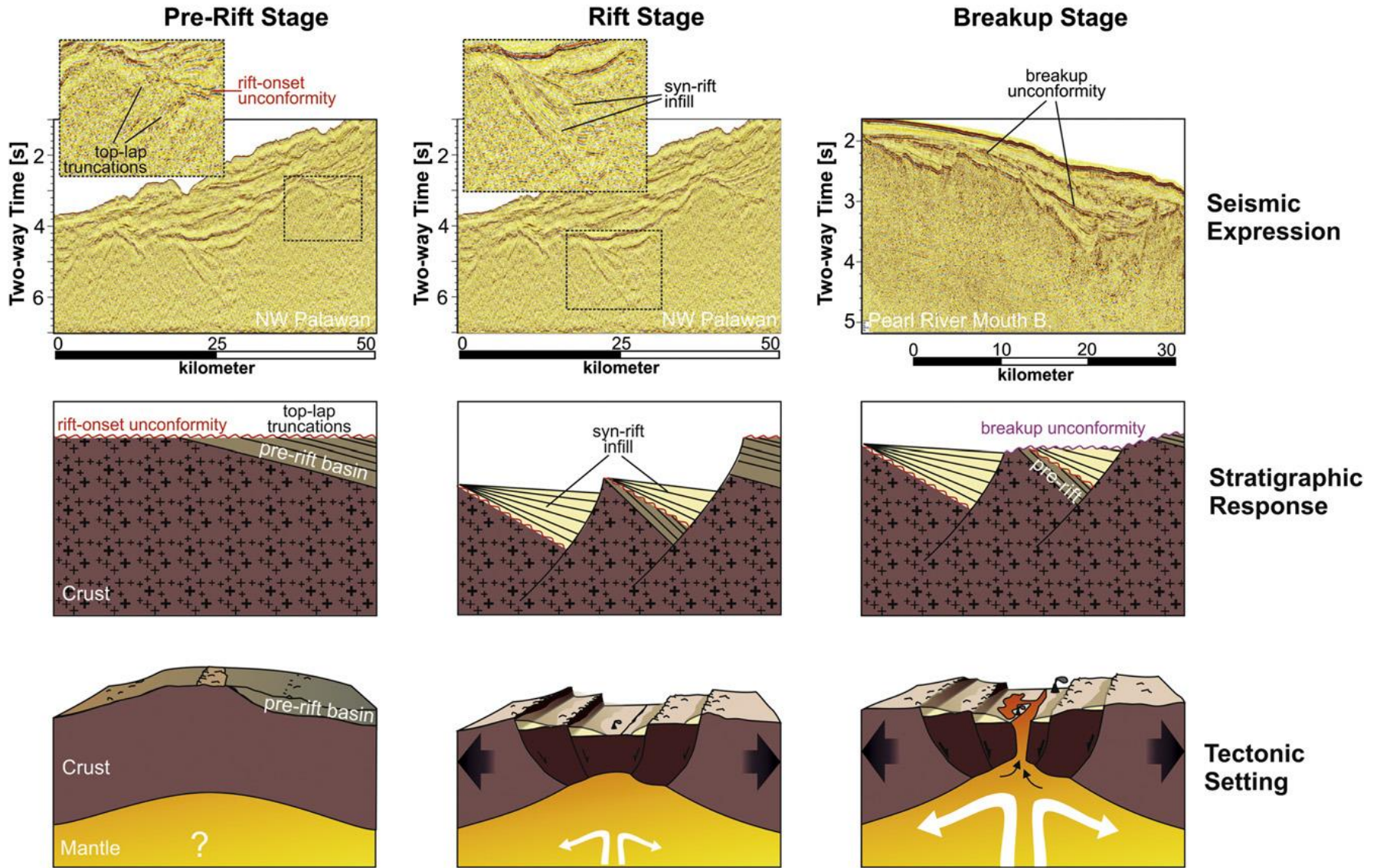




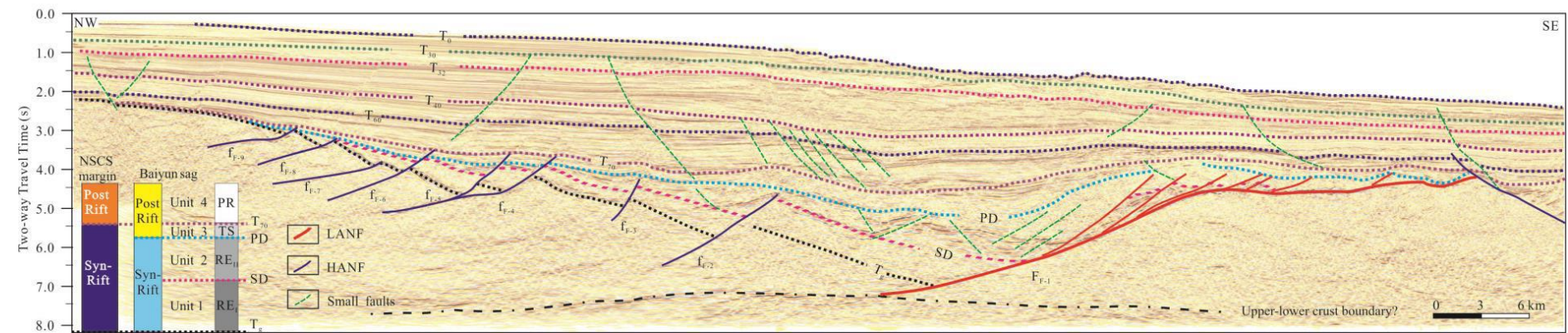
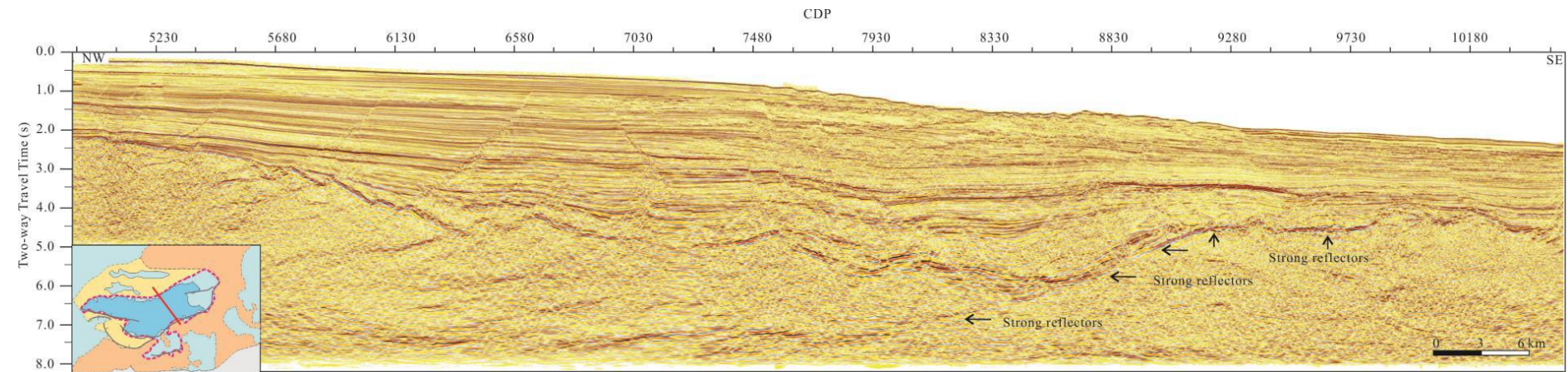




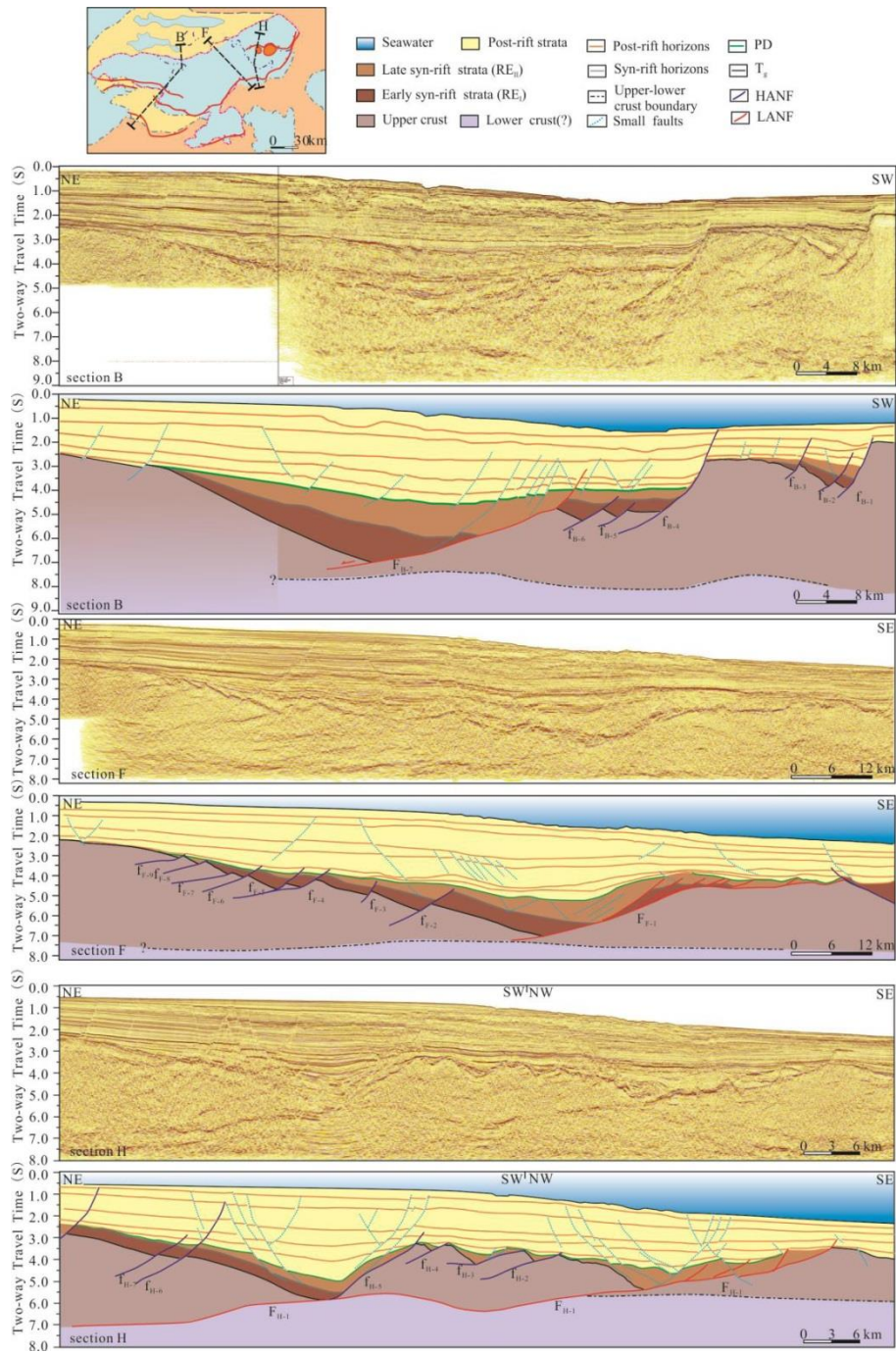




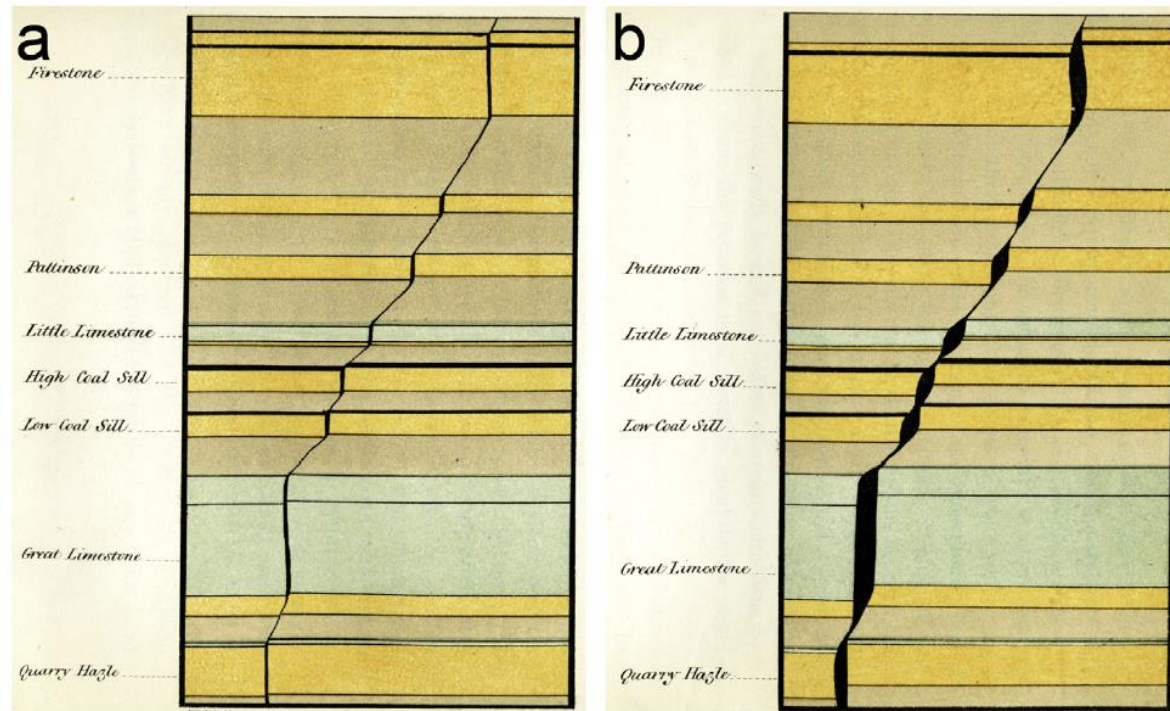
Schematic cross section, a seismic data example and the tectonic setting illustrating the pre-rift erosion, the rift sedimentation, and the breakup stages. During pre- or syn-rift doming erosion a rift-onset unconformity (ROU) forms, which in seismic data often is recognized as angular unconformity with top-lap truncations of seismic reflectors from below. A syn-rift infill typically shows wedge shaped reflector packages with the thin end of the wedge lying on the hangingwall dip-slope. The seismic section shows two subsequent rift deposits before subsidence did outpace sedimentation, resulting in a different relief. This indicates the time of maximum displacement, the rift climax (Prosser, 1993). At continental breakup, a flexural rebound results in uplift of the rift shoulders. This frequently results in the formation of a breakup unconformity (BU), truncating the wedge-shaped syn-rift sediments in the rift basins from the draped post-rift sediments. At the basins outer margins the BU is expected to form an amalgamation with the rift-onset unconformity.



Please cite this article as: Zhao, Y., Ren, J., Pang, X., Yang, L., Zheng, J., Structural style, formation of low angle normal fault and its controls on the evolution of Baiyun Rift, northern margin of the South China Sea, *Marine and Petroleum Geology* (2017), doi: 10.1016/j.marpetgeo.2017.11.001.



Please cite this article as: Zhao, Y., Ren, J., Pang, X., Yang, L., Zheng, J., Structural style, formation of low angle normal fault and its controls on the evolution of Baiyun Rift, northern margin of the South China Sea, *Marine and Petroleum Geology* (2017), doi: 10.1016/j.marpetgeo.2017.11.001.

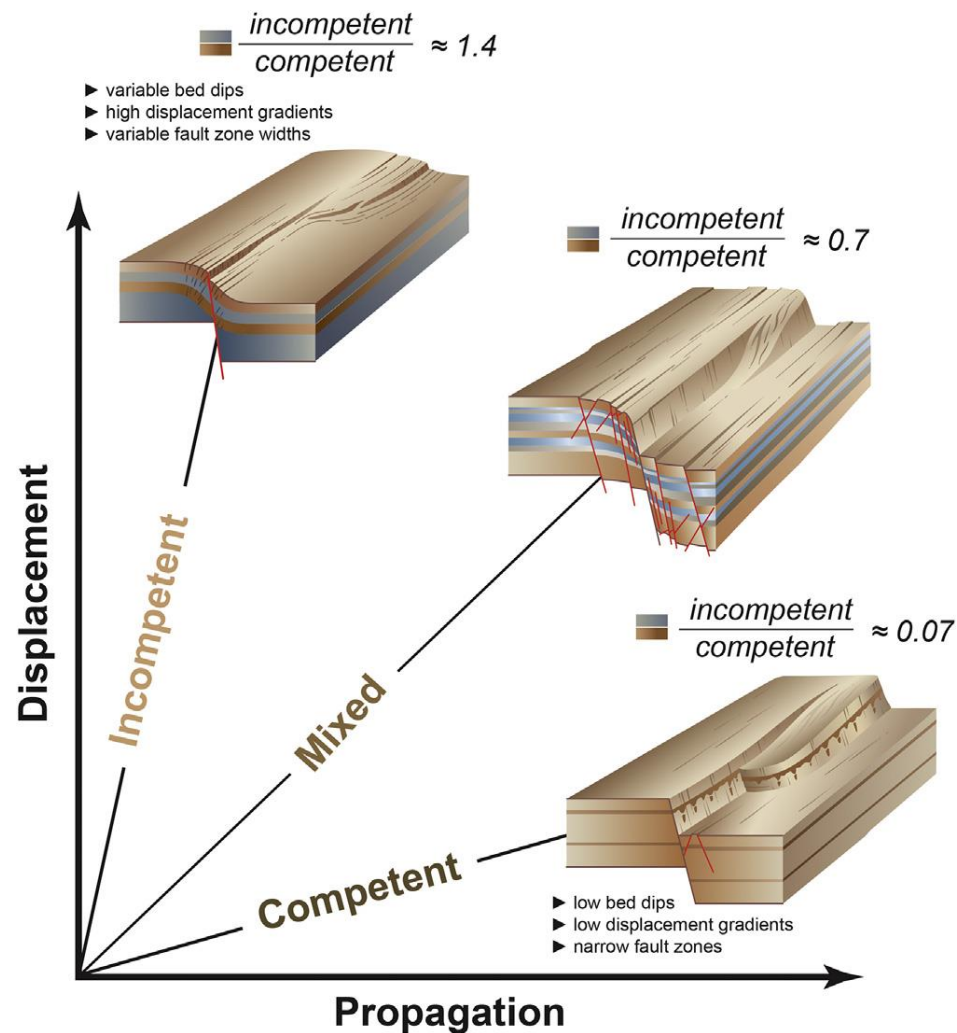


**Fig. 9.** Cross-section through Northern Pennine Orefield fissure vein (dilational normal fault) at two displacement magnitudes from Wallace (1861). Near vertical fault segments through limestones (blue-green) and sandstones (orange) are linked by moderately dipping fault segments through shale (tan/brown) and coal (horizontal black layers) (see legend in Fig. 10). Dilation of steep fault segments during fault slip produced void space that hosts mineralization, and the narrower fault zones through shale and coal were described by Wallace (1861) as fluid flow pathways for mineralization and for vertical movement of groundwater during mining. The total stratigraphic section in the figure is approximately 90 m.

## Mechanical stratigraphy and normal faulting

David A. Ferrill<sup>\*</sup>, Alan P. Morris, Ronald N. McGinnis, Kevin J. Smart, Sarah S. Wigginton, Nicola J. Hill

Department of Earth, Material, and Planetary Sciences, Geosciences and Engineering Division, Southwest Research Institute<sup>\*</sup>, 6220 Culebra Road, San Antonio, TX 78238-5166, USA

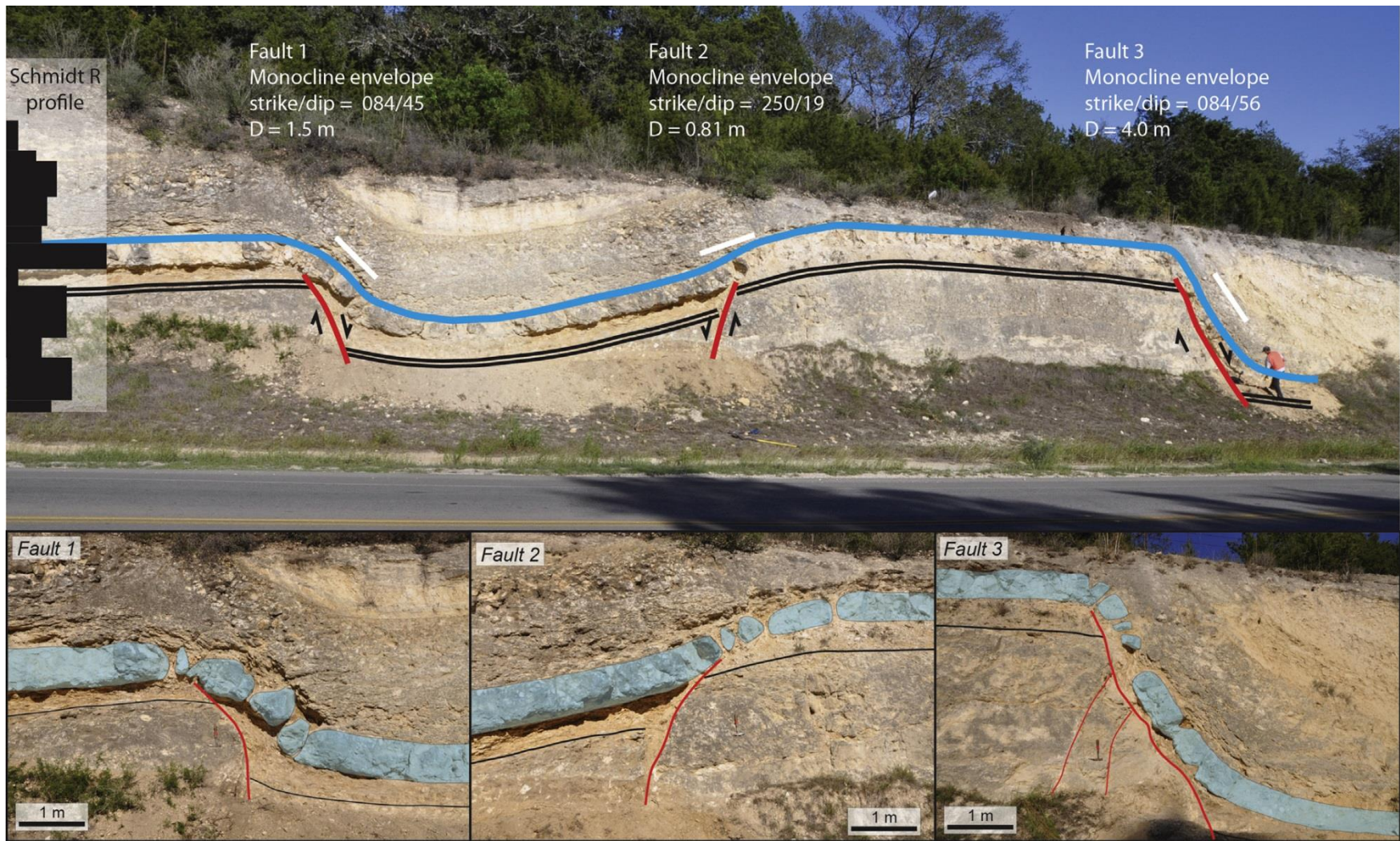


**Fig. 12.** Illustration of the influence of mechanical stratigraphy on fault propagation versus fault displacement for mechanical stratigraphic units with different incompetent to competent thickness ratios. Averaged over time, or multiple slip events, faults developed in mechanically competent layers tend to experience rapid propagation relative to displacement accumulation. Thus, for mechanical stratigraphies with low incompetent to competent thickness ratios (e.g., 0.07), displacement to propagation ratios, and displacement gradients will be low. In contrast, high incompetent to competent thickness ratios (e.g., 1.4), will be characterized by high displacement to propagation ratios, and high displacement gradients. Mechanical stratigraphies with intermediate incompetent to competent thickness ratios may show a range of behavior depending on the local conditions. From Ferrill and Morris (2008).

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Department of Earth, Material, and Planetary Sciences, Geosciences and Engineering Division, Southwest Research Institute\*, 6220 Culebra Road, San Antonio, TX 78238-5166, USA

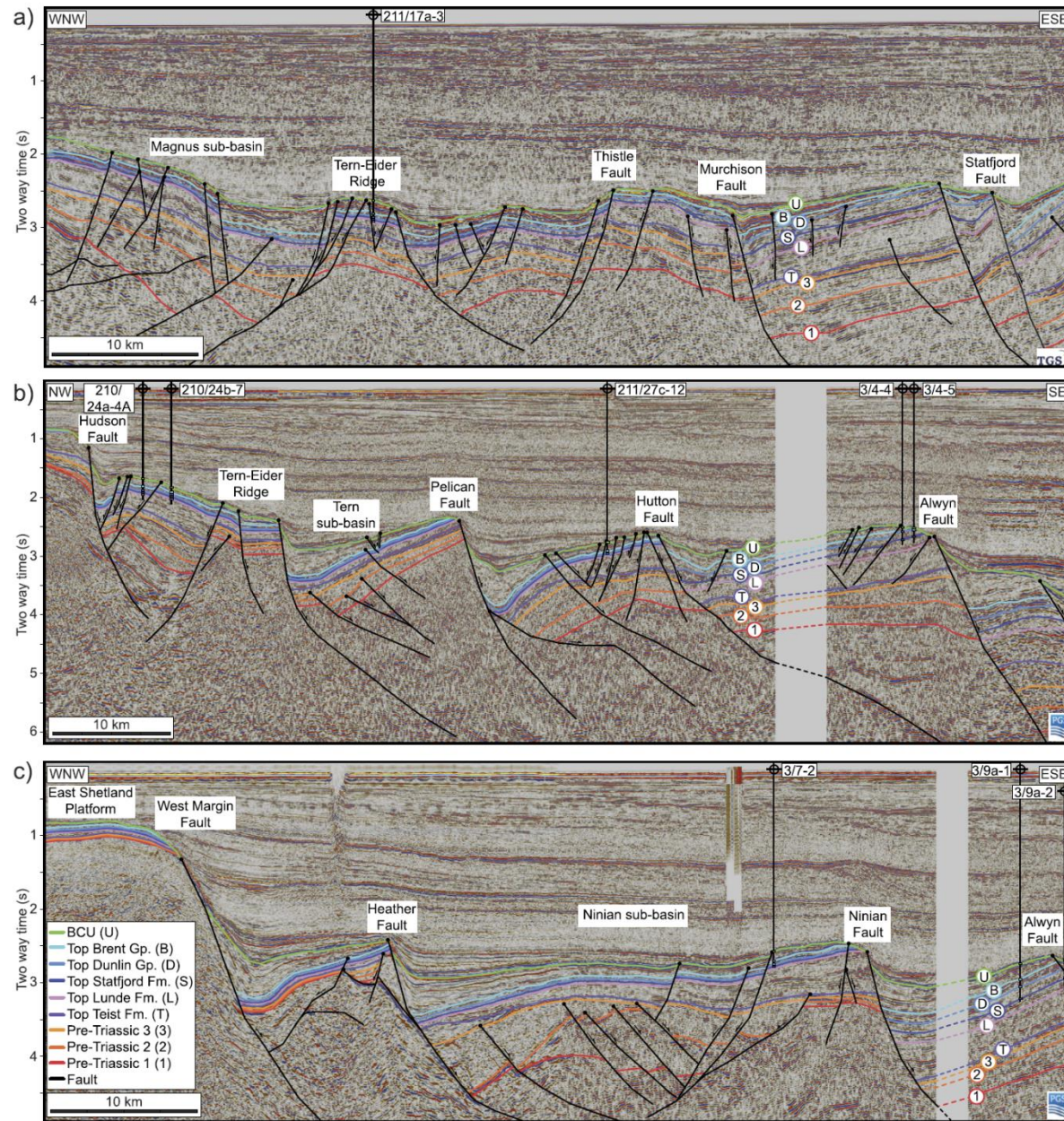


**Fig. 14.** (Top) Annotated field photograph of roadcut exposure (Green Mountain Road, San Antonio, Texas, USA) of massive Austin Chalk and overlying argillaceous and mechanically layered Pecan Gap Formation showing the principal structural elements. The three faults that cut the top of the Austin Chalk (black bedding form line) are from left-to-right fault 1, fault 2, and fault 3. On the left is the outline of the Schmidt R profile matched against the stratigraphy. Note geologist wearing orange vest near fault 3 for scale. Viewing direction is to the ENE along fault strike. Three photographs below illustrate (viewed looking along strike to the east-northeast) structural style including tilting, extension fracturing, and boudinage of competent limestone bed (blue tinted layer that is highest rebound, R, or most competent layer in profile) sandwiched between clay shale beneath and argillaceous limestone (marl) above (from Ferrill et al., 2012b).

### Mechanical stratigraphy and normal faulting

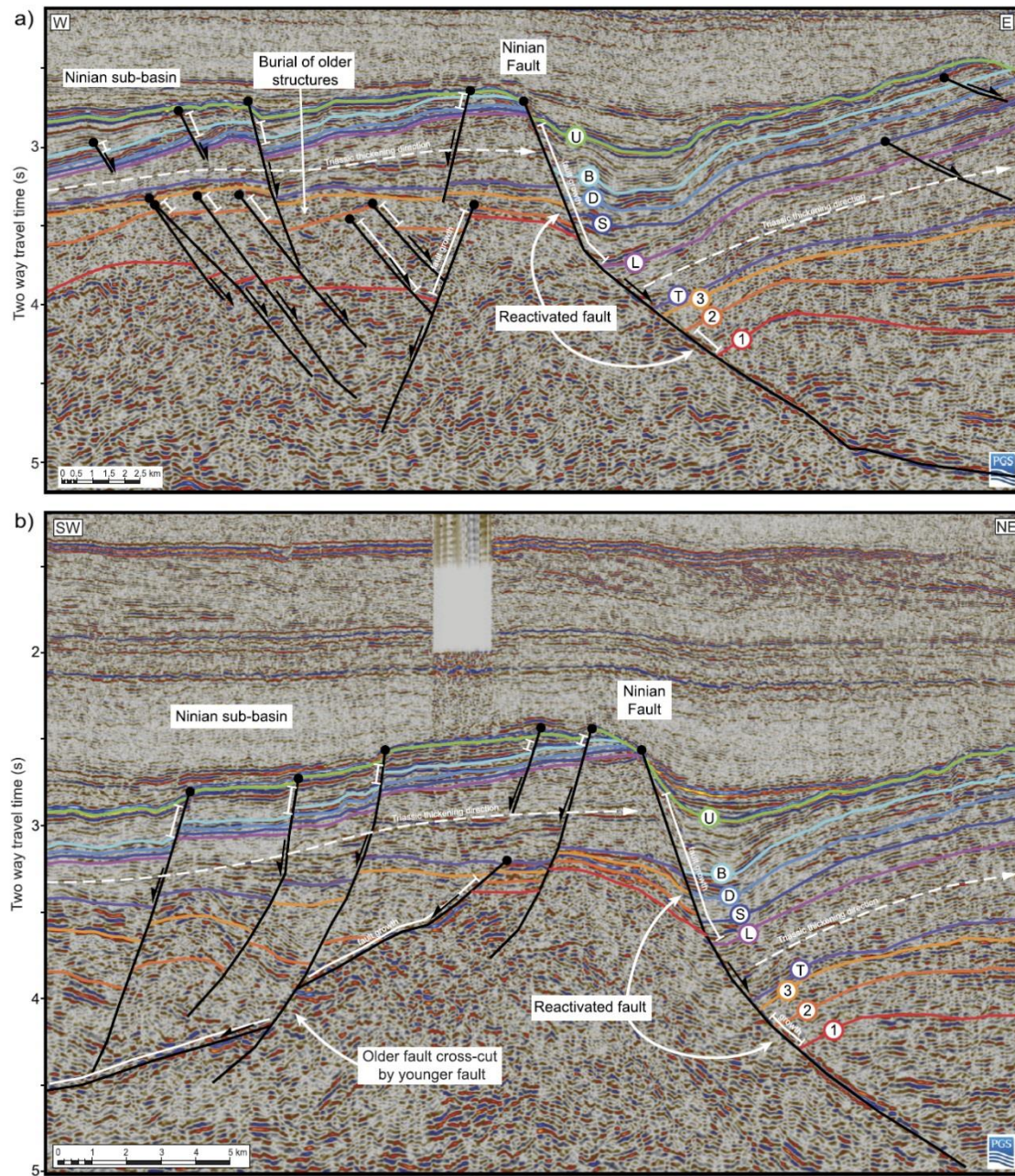
David A. Ferrill\*, Alan P. Morris, Ronald N. McGinnis, Kevin J. Smart, Sarah S. Wigginton, Nicola J. Hill

Department of Earth, Material, and Planetary Sciences, Geosciences and Engineering Division, Southwest Research Institute\*, 6220 Culebra Road, San Antonio, TX 78238-5166, USA

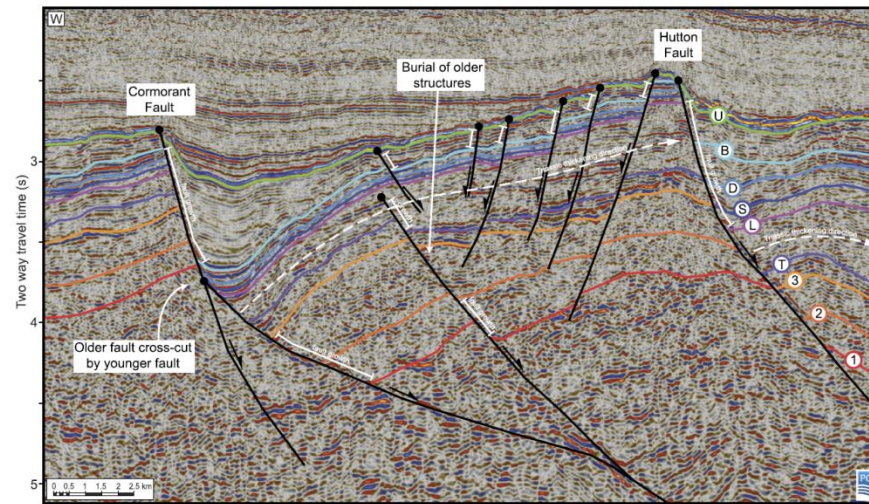


**Fig. 3.** Three interpreted 2D time-migrated seismic reflection profiles crossing the study area in the a) north, b) centre, and c) south. The seismic profiles including well penetrations and major faults and structural features. See Fig. 1b for locations.

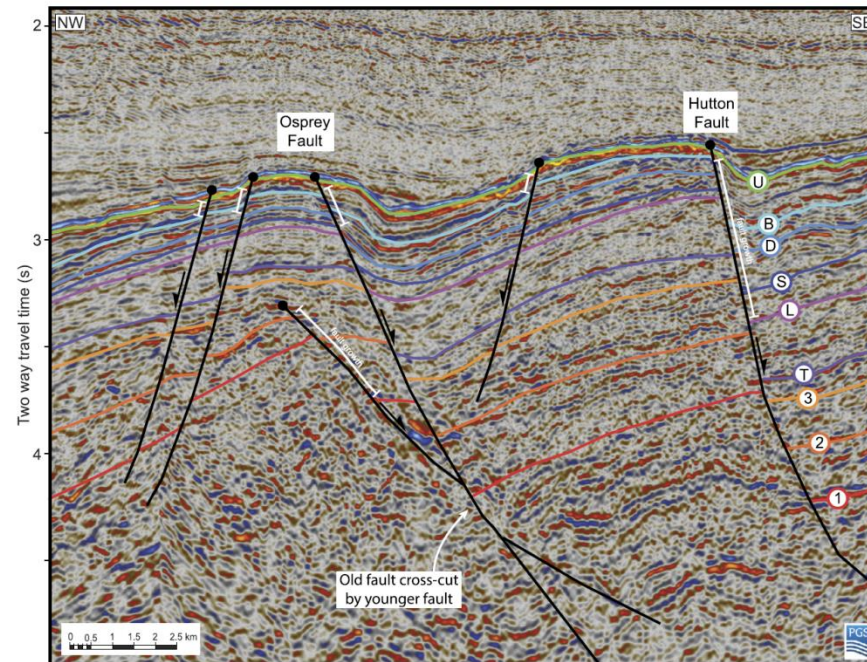




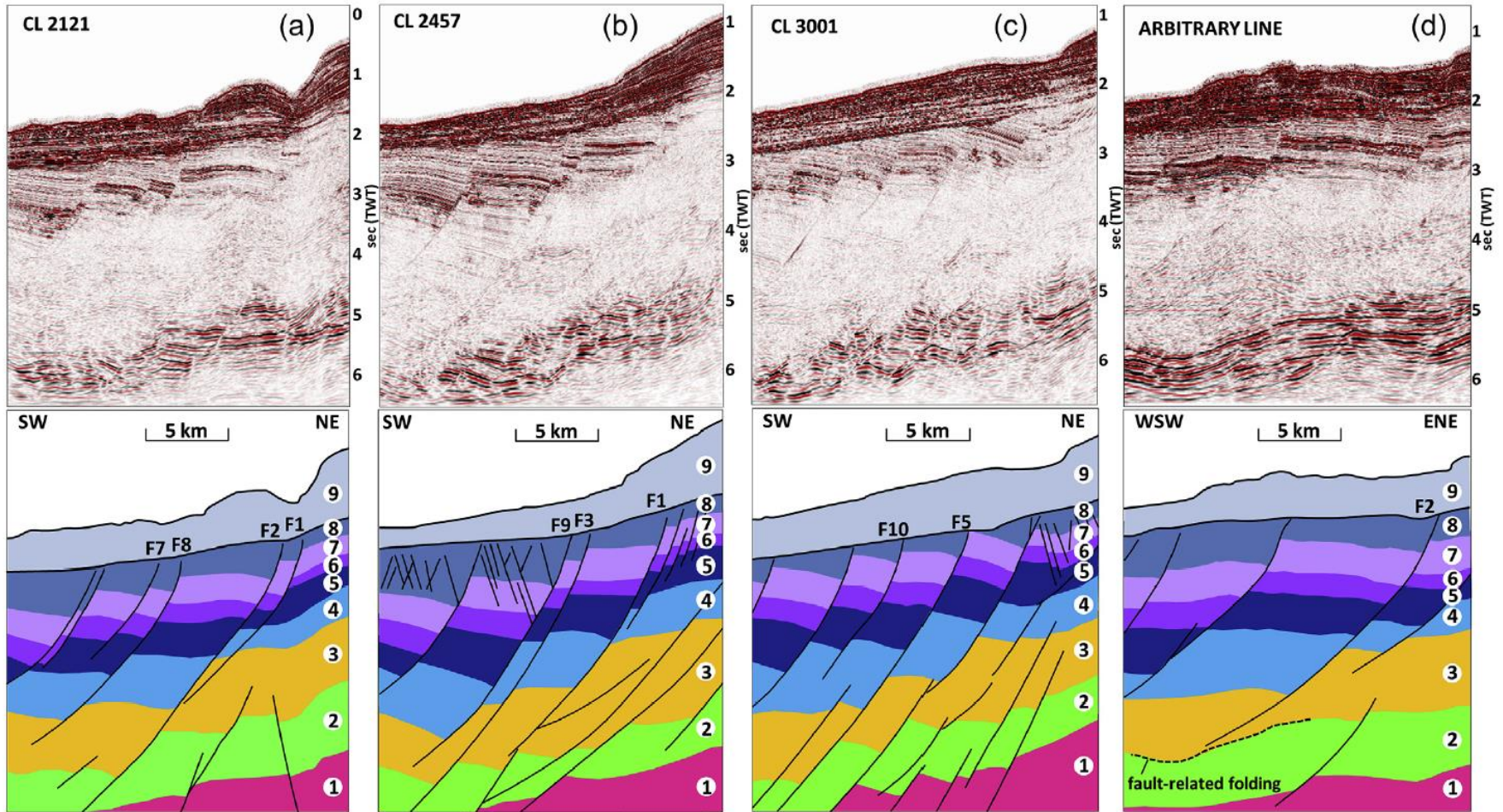
**Fig. 6.** a) Seismic section crossing the Ninian sub-basin and the reactivated Ninian Fault showing an example of the burial of older structures. b) Seismic section crossing the Ninian sub-basin and reactivated Ninian Fault showing an older fault cross-cut by a younger fault. Growth periods are marked by white lines, and the eastward Triassic thickening direction is marked by the white dashed arrows. For location see Fig. 1c, and for horizon abbreviations see Fig. 3.



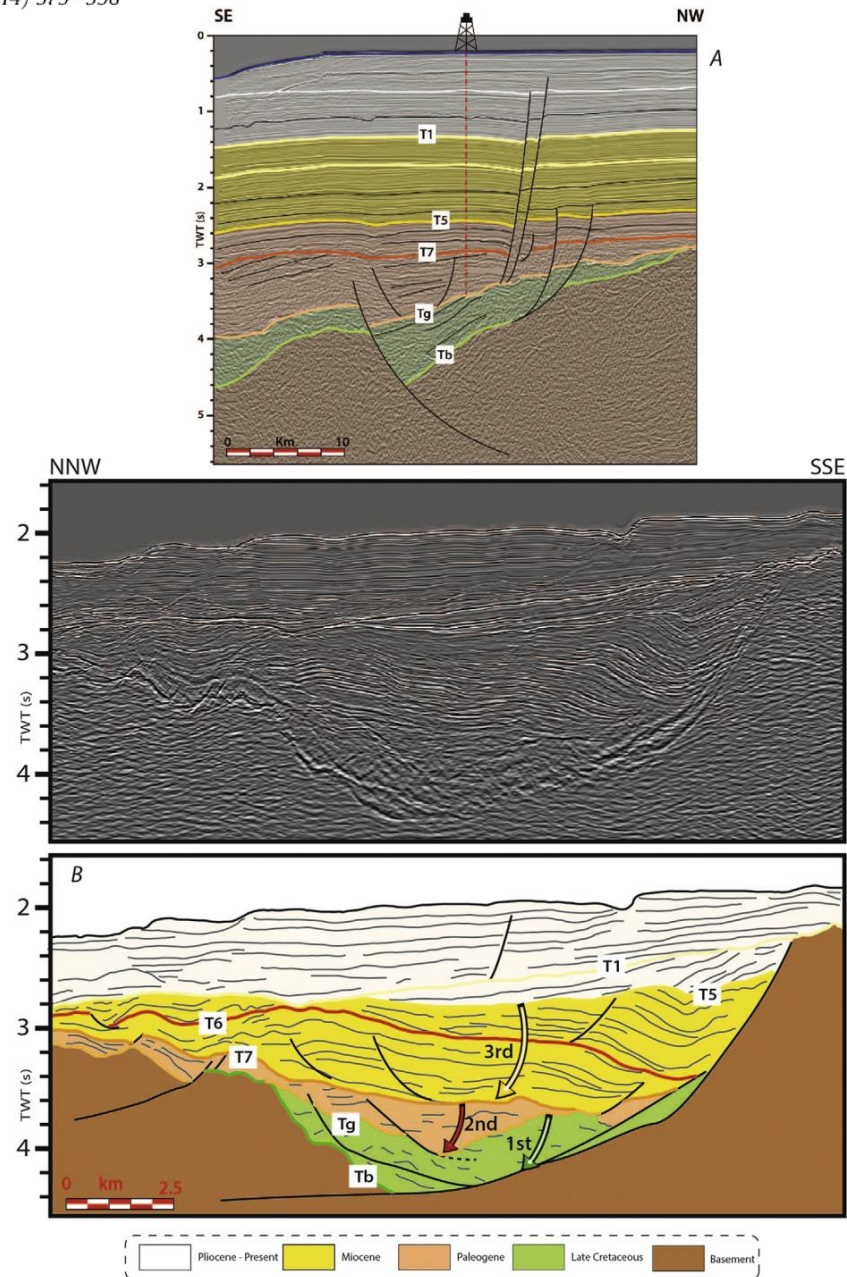
**Fig. 7.** Seismic section crossing the Cormorant and Hutton faults showing an older fault cross-cut by a younger fault and burial of older structures. Growth periods are marked by white lines, and the eastward Triassic thickening direction is marked by white dashed arrows. For location see Fig. 1c, and for horizon abbreviations see Fig. 3.



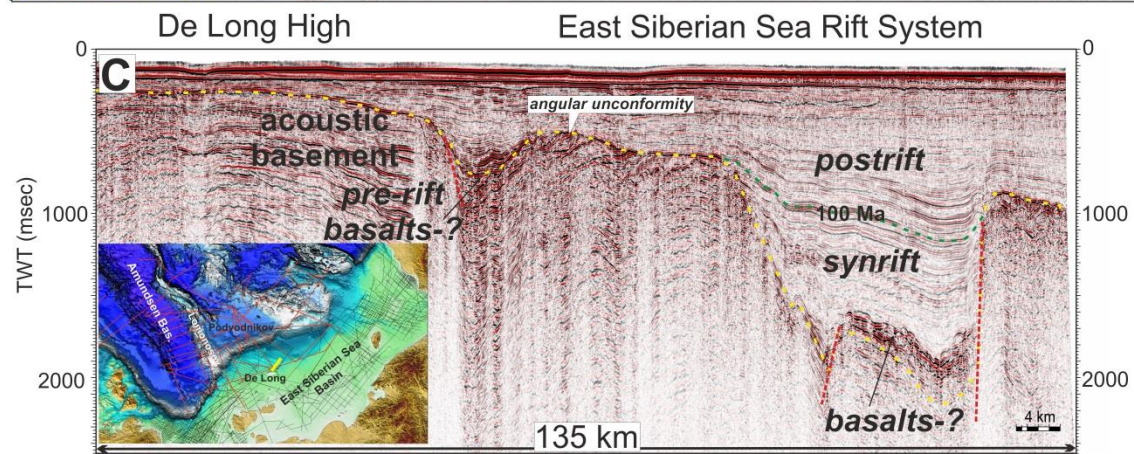
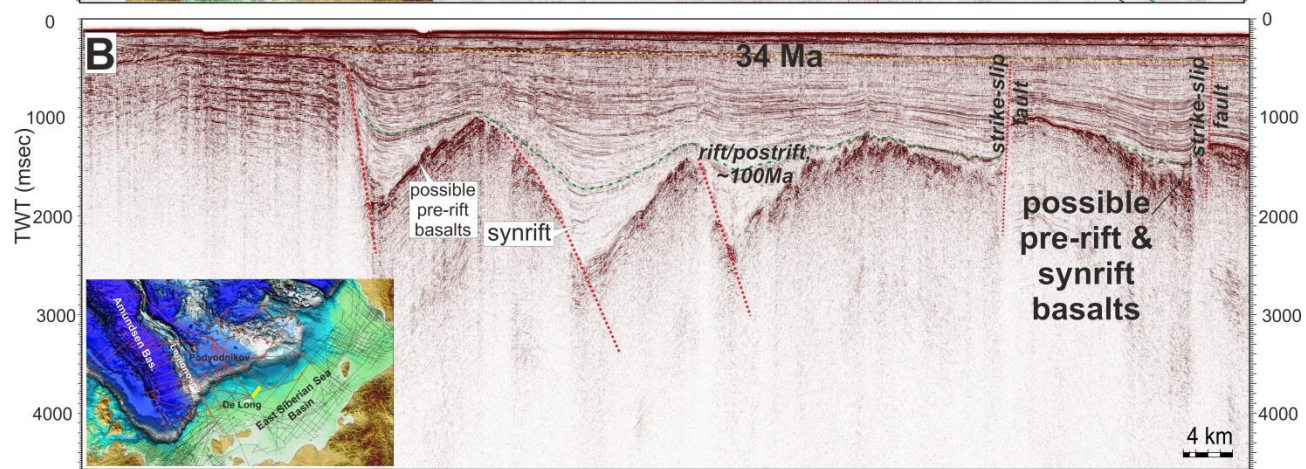
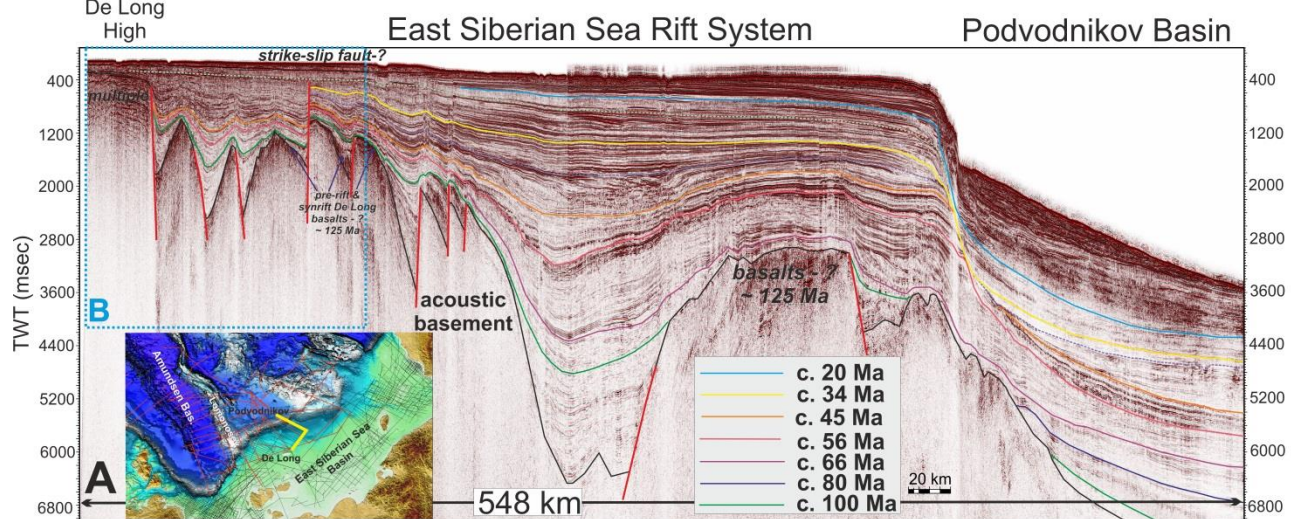
**Fig. 8.** Seismic section crossing the Osprey and Hutton faults showing an older fault cross-cut by a younger fault. Growth periods are marked by white lines. For location see Fig. 1c, and for horizon abbreviations see Fig. 3.

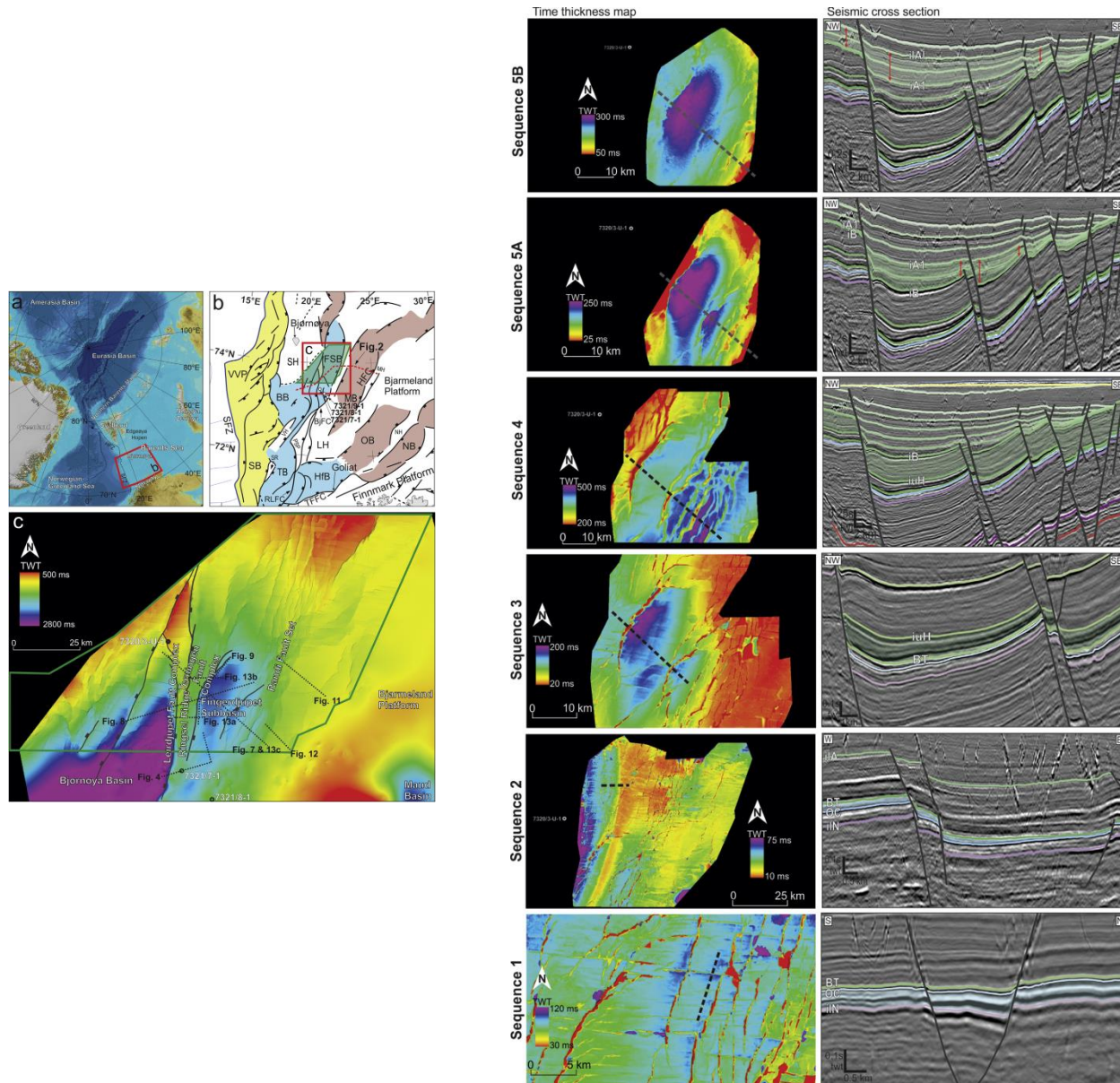


**Fig. 3.** Seismic crosslines 2121 (a), 2457 (b), 3001 (c) and an arbitrary line (d) from Amrit 3D, with seismic interpretation displayed below, including stratal units and faults used for this study labelled. Note faults 1, 2 and 5 all penetrating deeper than the 3D survey and dip-linking with basement-involved faults and more basinward faults 7, 8, 9 and 10 all contained within the 3D survey, displaying no linkage to basement. Also note the fault-related folding at the top of stratal unit 2 (d). The location of these crosslines is shown in Fig. 1(c).

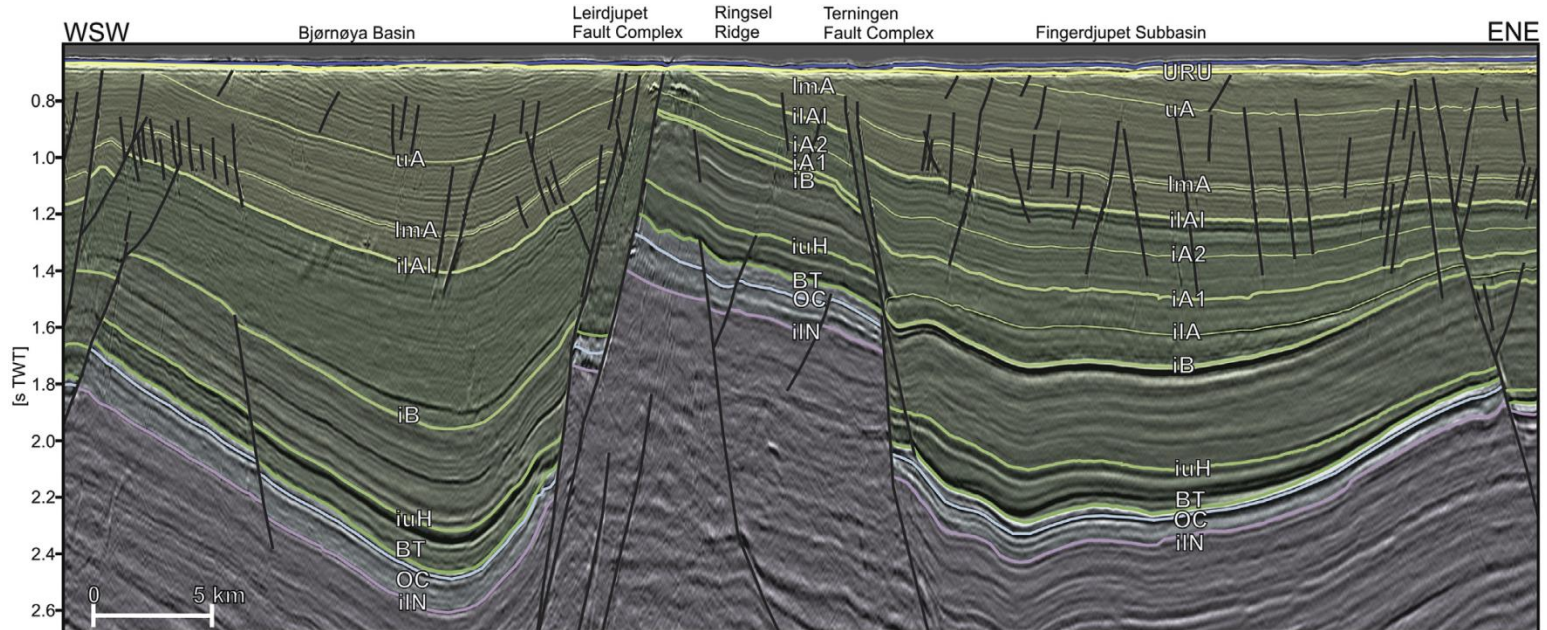
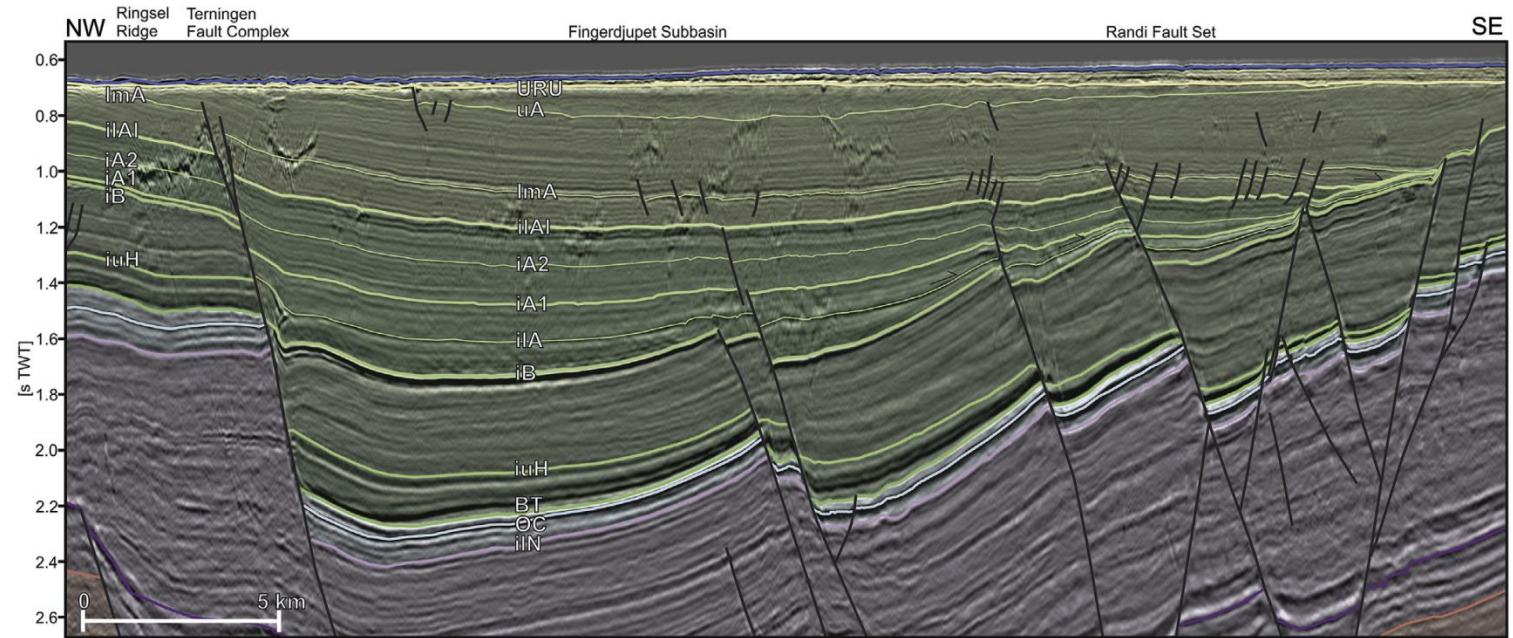


**Figure 6.** A: seismic-well calibration allowing to calibrate seismic horizon from the South China Sea rift Onset (Tg) to the Recent. B: Graben filling with 3 main stages: the first during Upper Cretaceous (green), the second from Eocene to Late Oligocene (orange) and the third during Early Miocene (yellow). Tb: Top basement; T7: Late Oligocene (32 Ma); T6: Late Oligocene-Early Miocene (23 Ma), T5: Mid Miocene (15.5 Ma) and T1: Mid Miocene-Late Miocene (10.5 Ma).





**Fig. 6.** Time thickness maps and seismic sections for sequences 1, 2, 3, 4, 5A and 5B. Wedge-shaped seismic packages consistent with syn-tectonic deposition are seen for sequences 1 (Intra lower Norian – Oxfordian-Callovian), 3 (Berriasian-Tithonian – intra upper Hauterivian) and 5 (Intra Barremian – intra lower Albian). Red arrows indicate thickness variations for the sequences. Seismic profile locations are indicated in the respective time thickness maps. Seismic data courtesy of TGS.



Некоторые примеры



