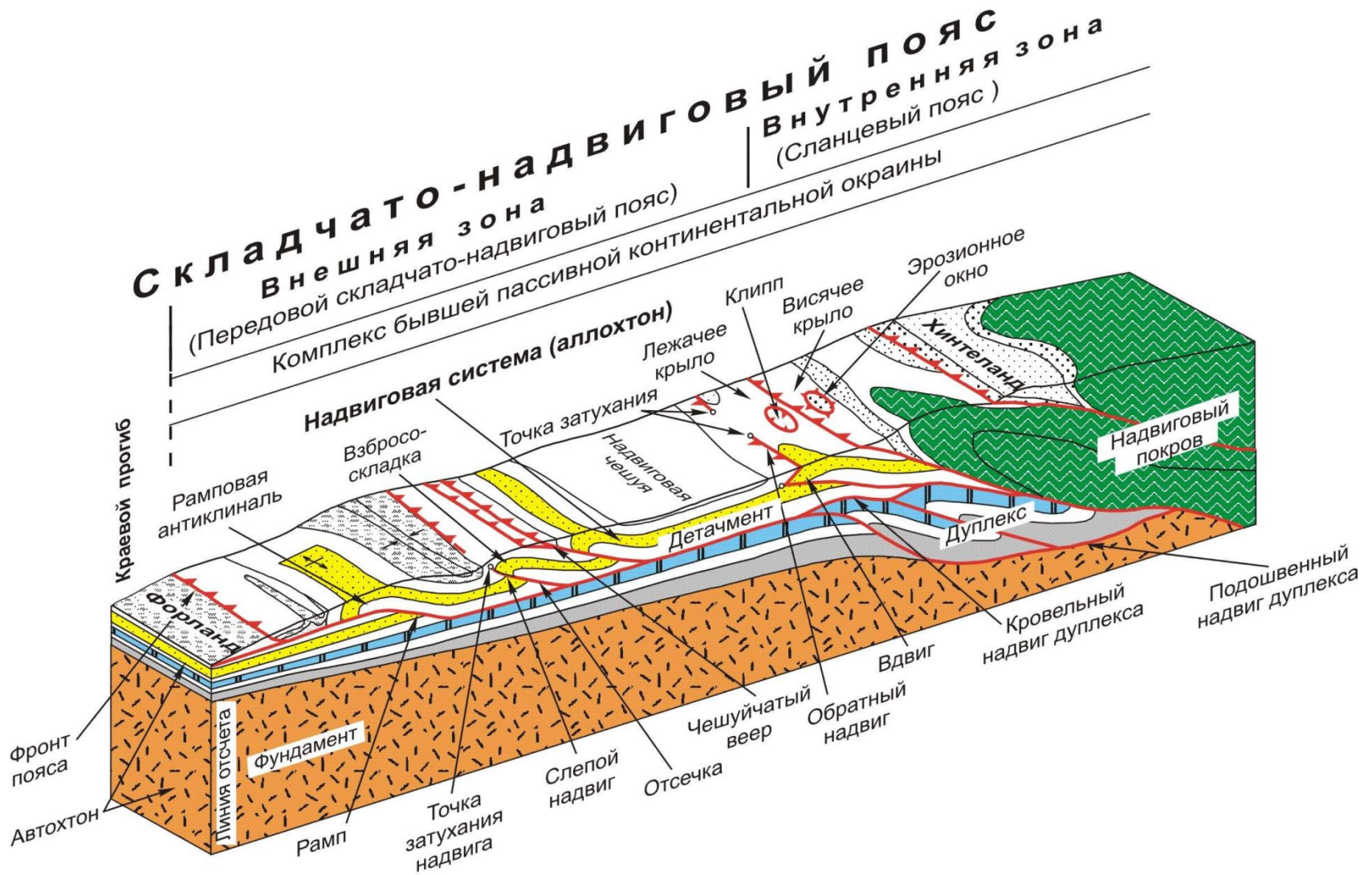


А.М. Никишин
Надвиги, взбросы,
и связанные с ними складки

Общие вопросы

НАДВИГИ И ВЗРОСЫ В СКЛАДЧАТО-НАДВИГОВЫХ ПОЯСАХ



Структурные элементы надвигового пояса (De Paor, 1988, Прокопьев и др., 2004).

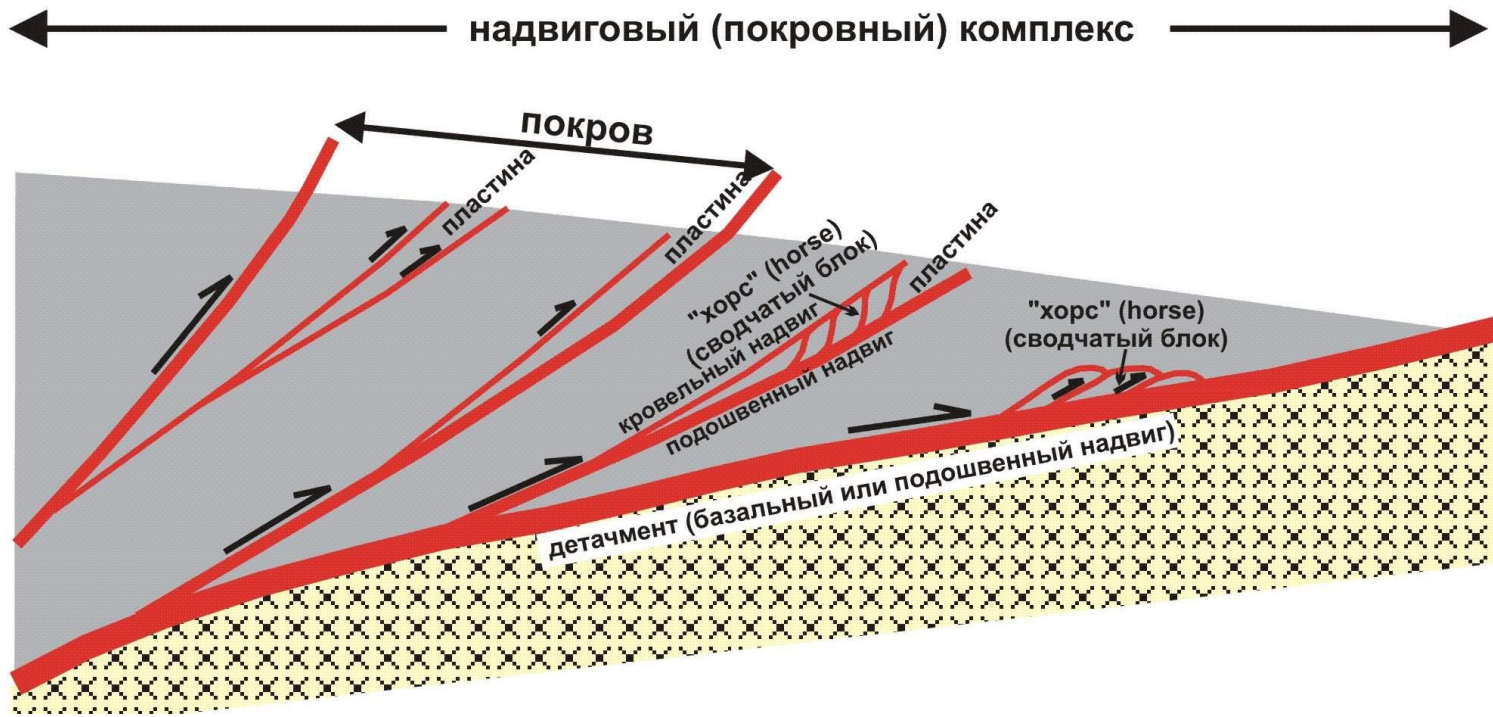
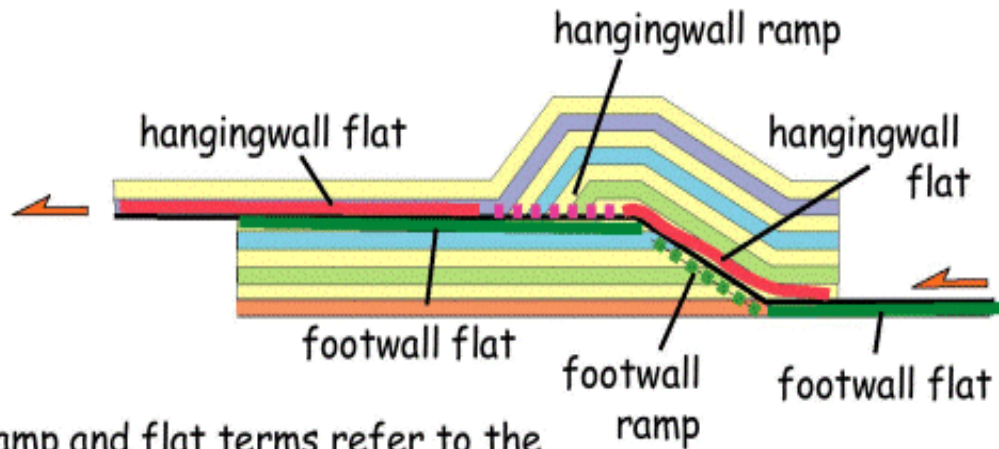


Схема строения надвигового комплекса (Составил А.М. Никишин).

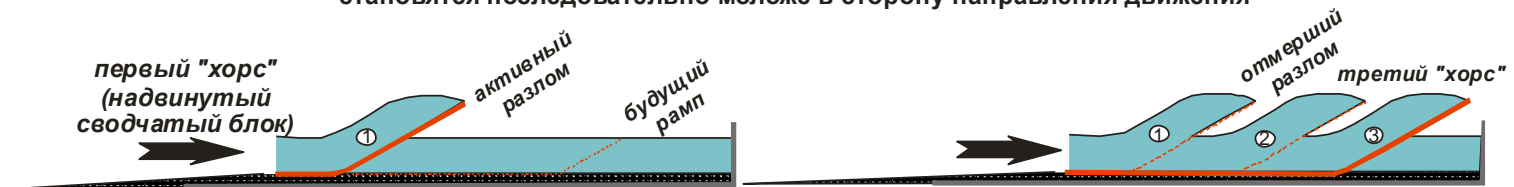
Подошвенный надвиг, флэт, рамп и хорс



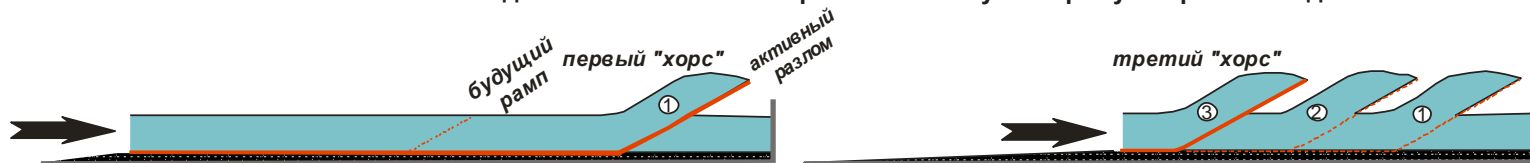
ramp and flat terms refer to the ORIGINAL state - and hence are in a bedding reference frame

Два основных типа последовательности формирования надвигов

А. Нормальная (фронтальная) последовательность формирования надвигов. Рампы (надвиги) становятся последовательно моложе в сторону направления движения

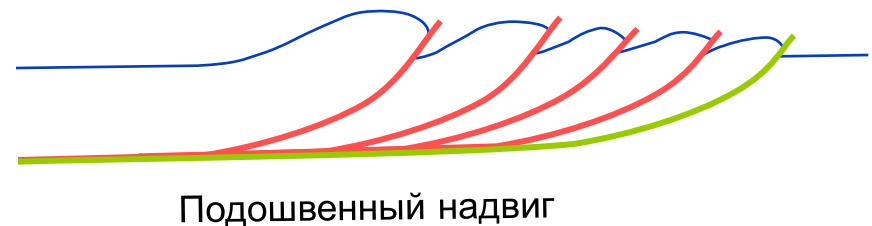
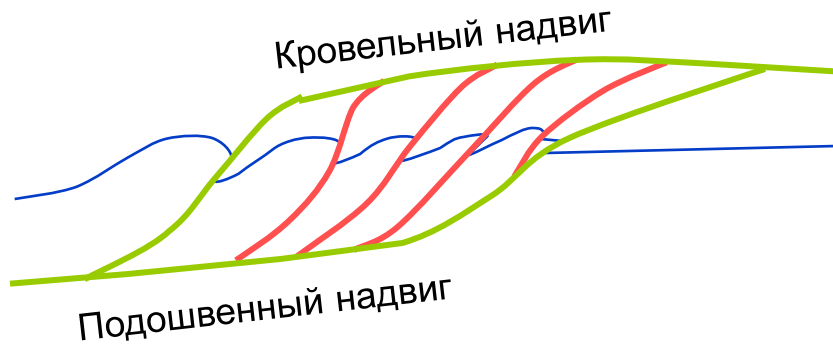


Б. Обратная (тыловая) последовательность формирования надвигов. Рампы (надвиги) становятся последовательно моложе в противоположную сторону направления движения



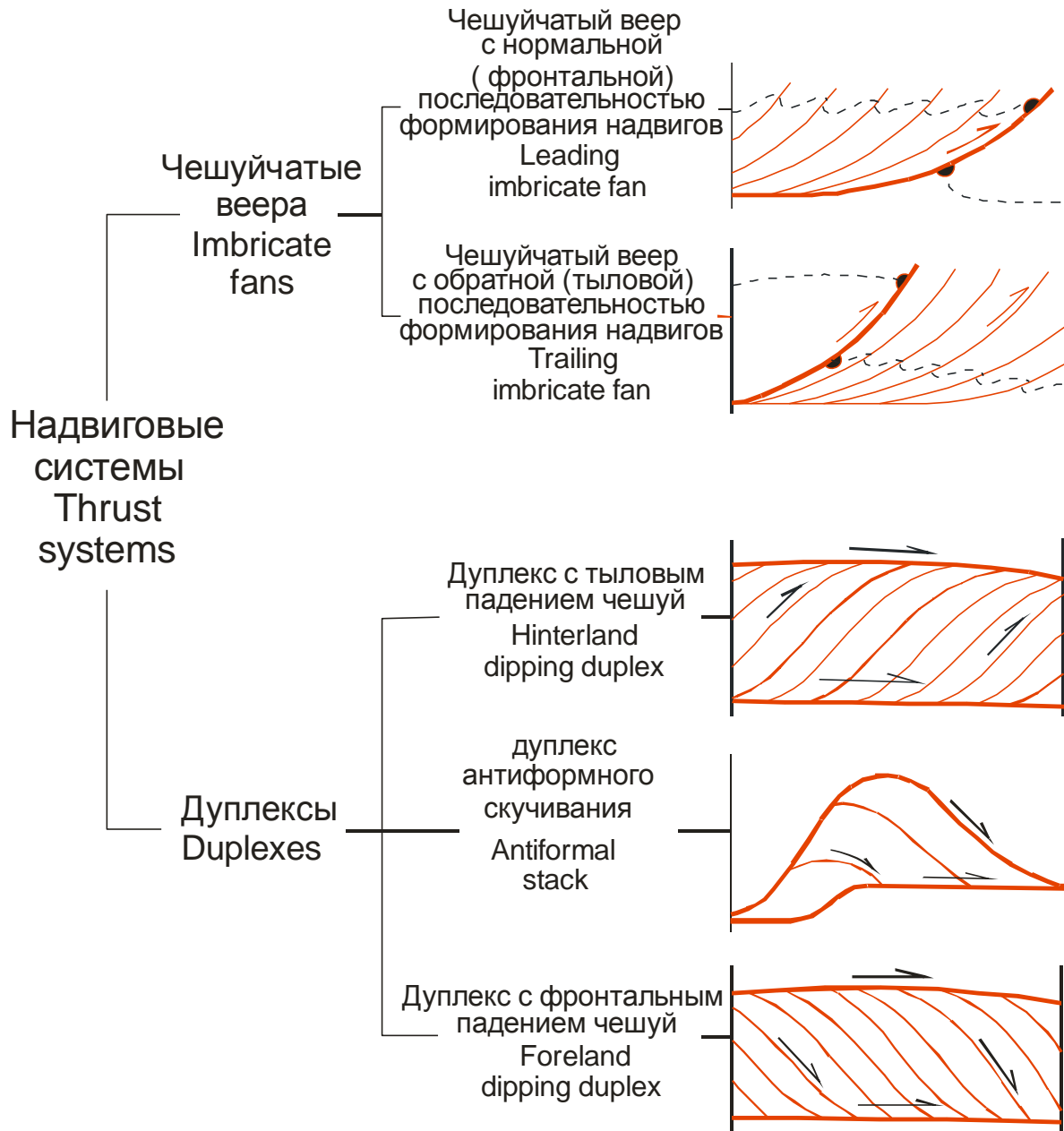
Имбрикационные вееры и дуплексы

- Имбрикационный веер
 - Система надвигов связана с общим базальным детачментом



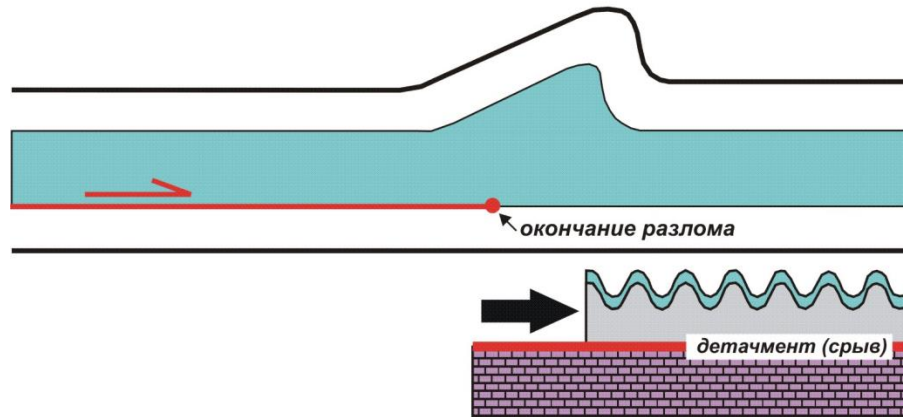
- Дуплекс
 - Система надвигов связана с кровельным и подошвенным детачментами

КЛАССИФИКАЦИИ НАДВИГОВЫХ СИСТЕМ (Boyer, Elliot, 1982; McClay, 1992)

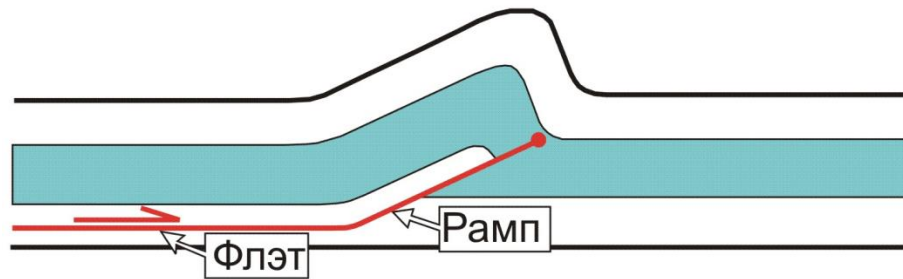


Три типа соотношений складок и разломов

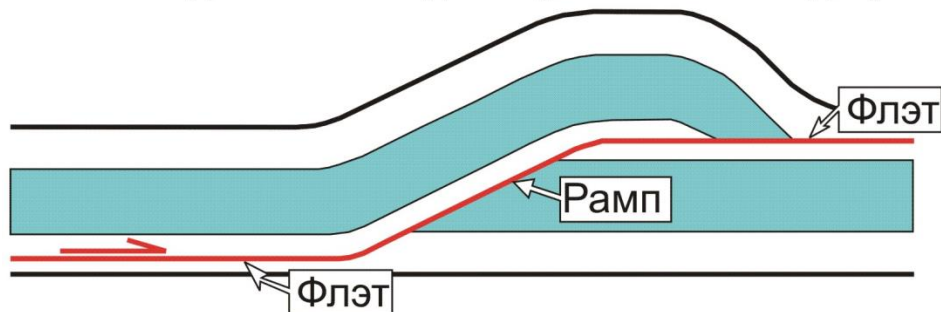
Три типа сочетаний надвигов и складок складки срыва



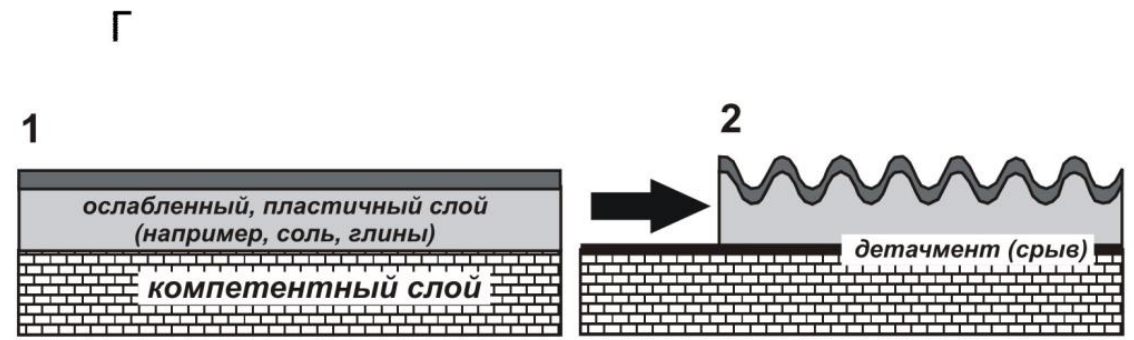
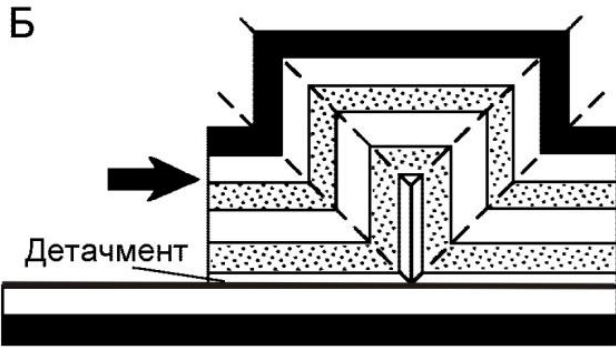
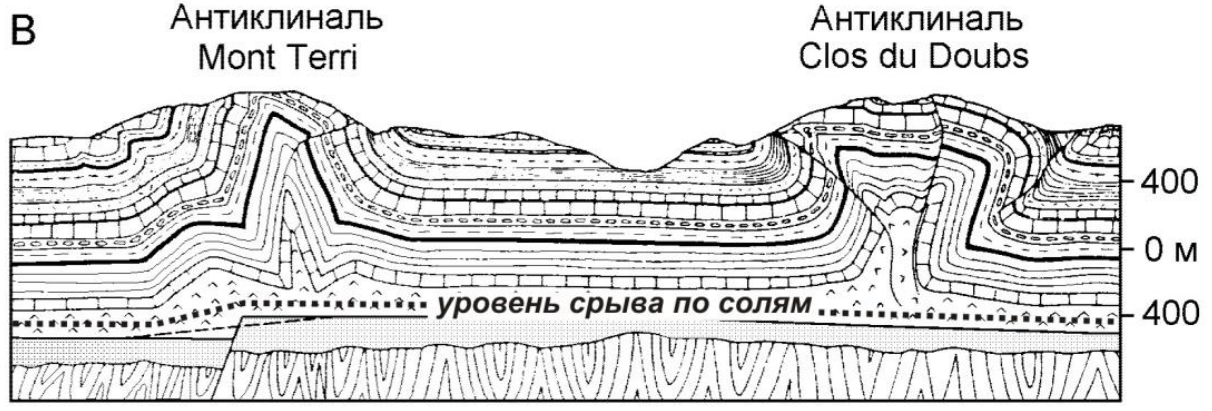
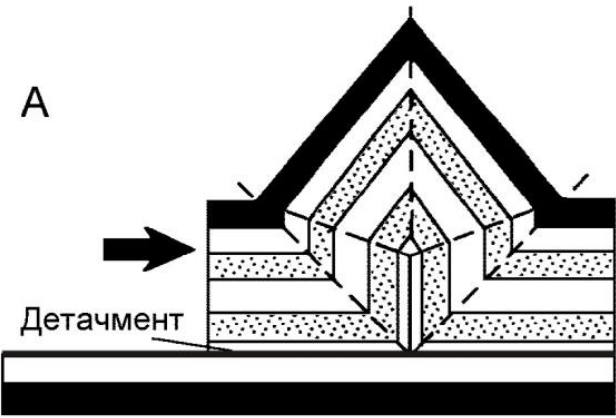
складки продвижения (пропагации) разлома



складки изгиба-надвига (рамповые складки)

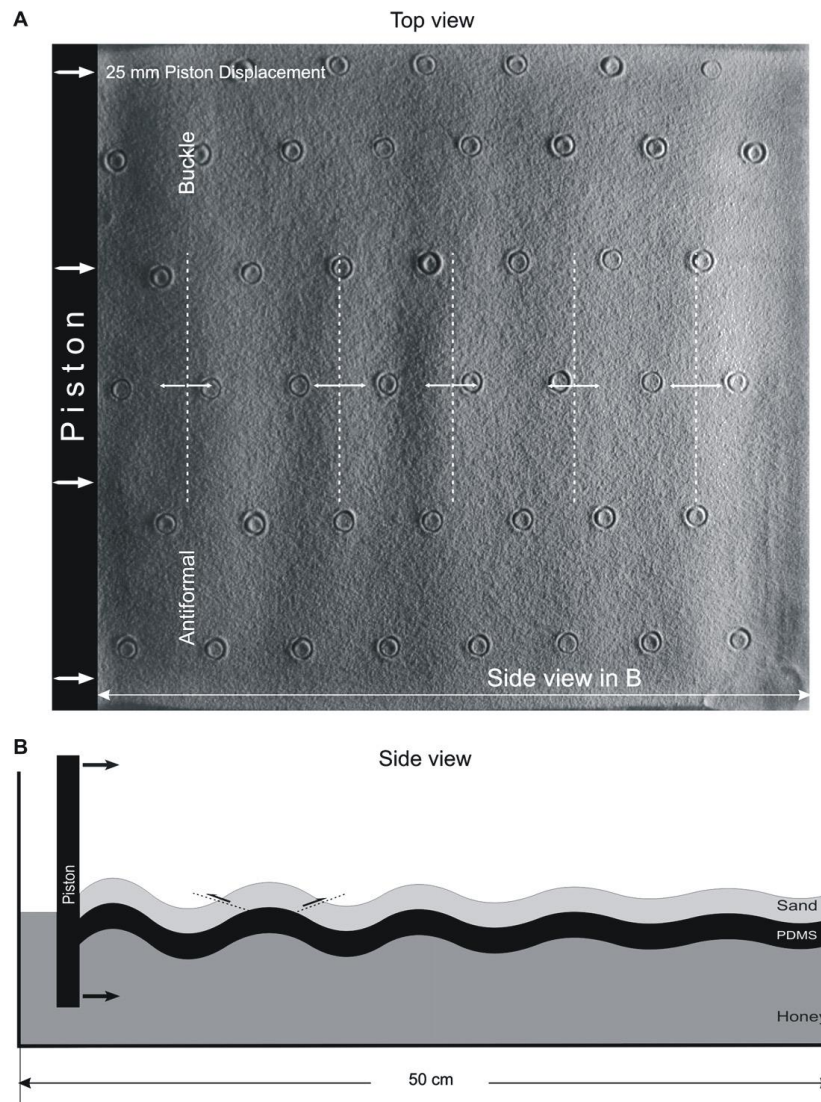


Jamison, 1987



Геометрические модели шевронных (А) и коробчатых складок (Б) срыва (Mitra, Namson, 1989) и их природные аналоги в Юрских горах (Woodward et al., 1985) (В).

(Г) – схематическая модель складчатости срыва с мощным слоем пластичных пород, в основании которых формируется детачмент (1, 2 - стадии процесса).

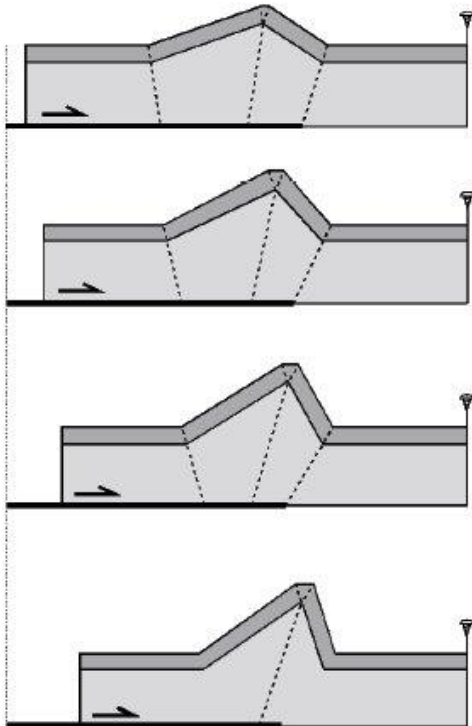


Deformation after 25 mm piston displacement, in fold-first mode. Rectilinear piston moved from left to right at steady velocity. (A) Plan view photograph (under low-angle lighting from the right) shows structures at upper surface of model. Free surface was initially flat and horizontal, and there was no erosion or sedimentation during the run. Buckling propagated from left to right and died out in the same sense. (B) Sketch of side view.

Складки срыва

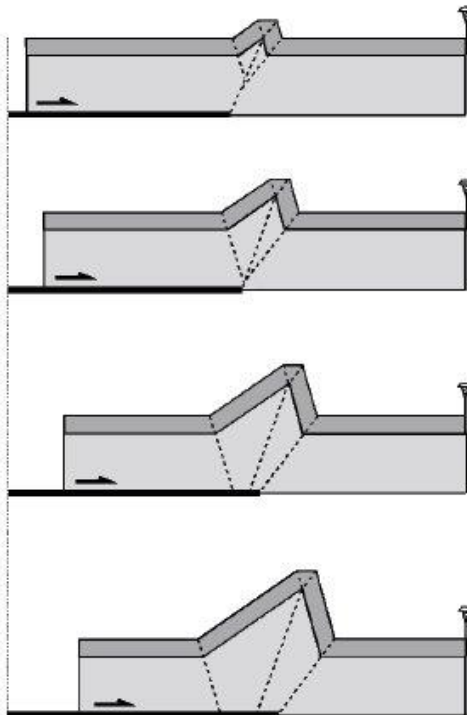
1) Вращение крыльев

*Изменение наклона крыльев
Сохранение длины крыльев*



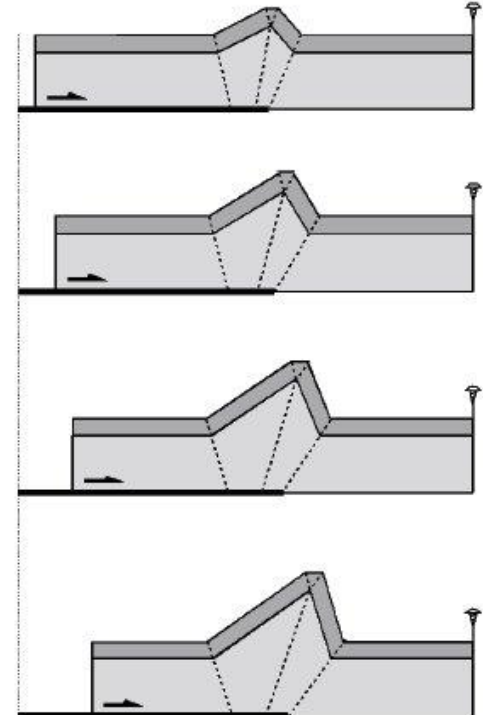
2) Миграция кинк-бандов

*Сохранение наклона крыльев
Изменение длины крыльев*



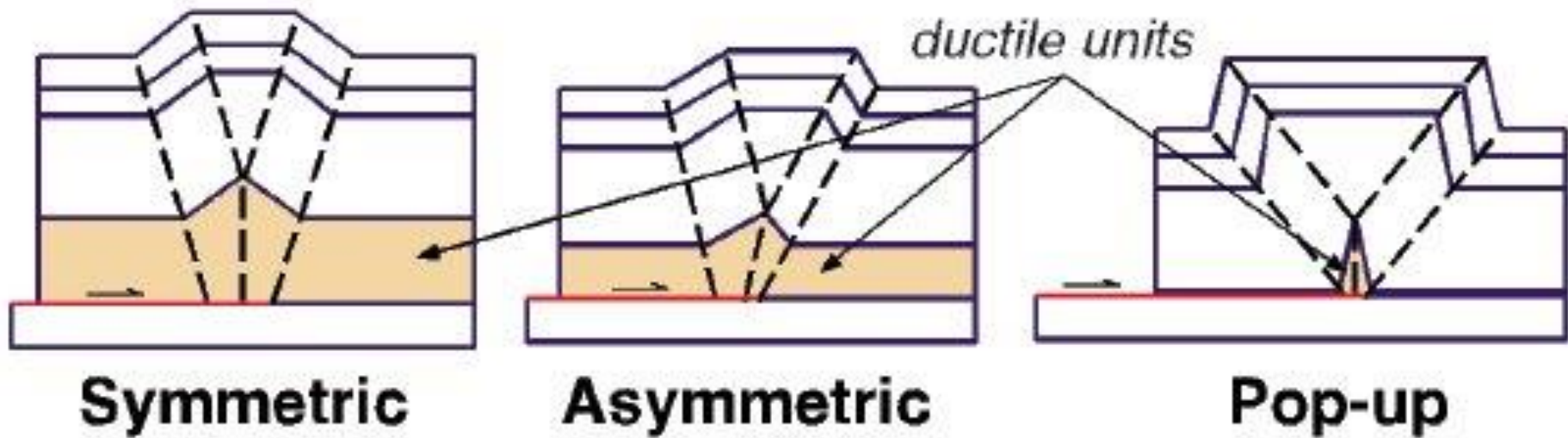
3) Вращение крыльев и миграция кинк-бандов

*Изменение наклона крыльев
Изменение длины крыльев*



modified from Poblet and McClay (1996)

Складки срыва. Кинематические модели складок срыва включают вращение крыльев, миграцию кинк-бандов или комбинацию этих процессов. Чаще реализуется модель с вращением крыльев. From Shaw et al. (2005), after Poblet and McClay (1996).



Складки срыва. From Shaw et al. (2005), after many others.

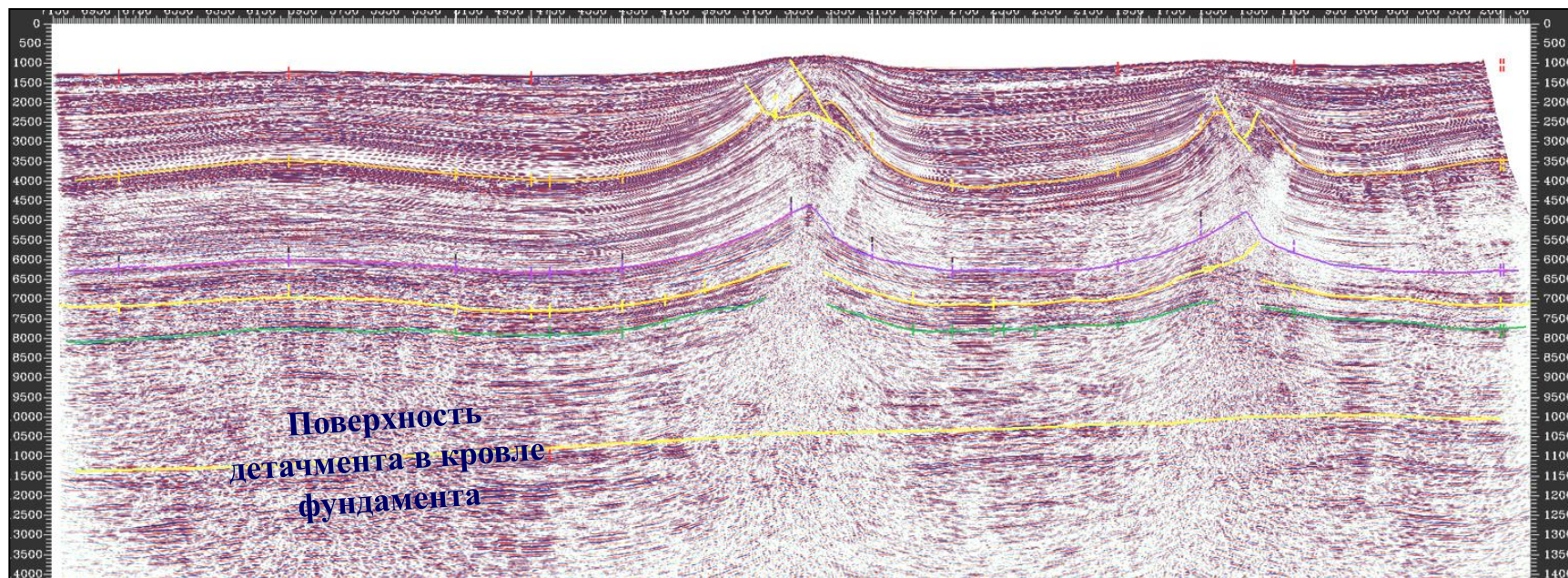
Складки срыва

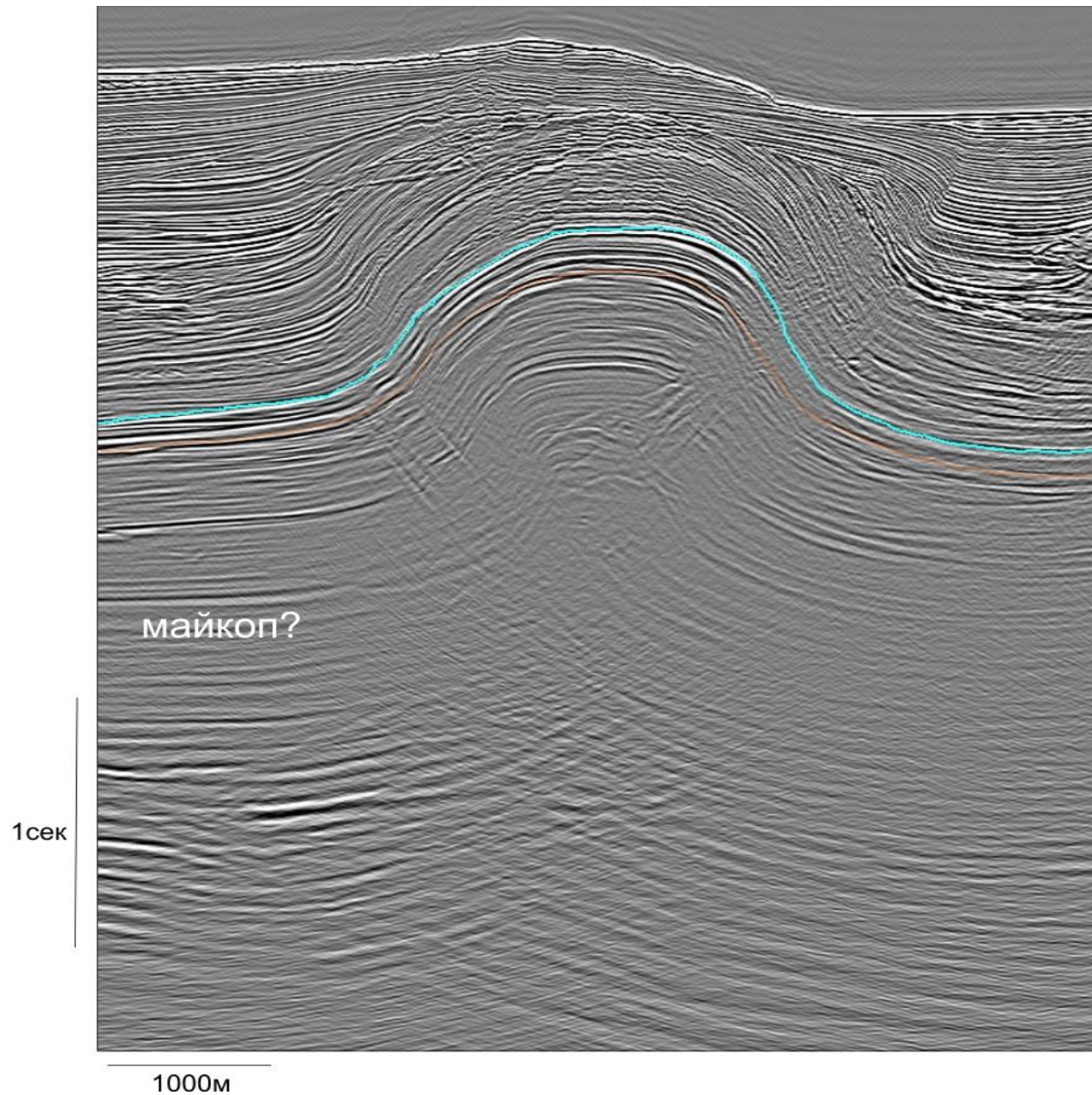
- Южно-Каспийский бассейн
(20-сек. сейсмопрофиль)

- Два основных уровня detachmentов:
кровля фундамента и майкоп

NW

SE



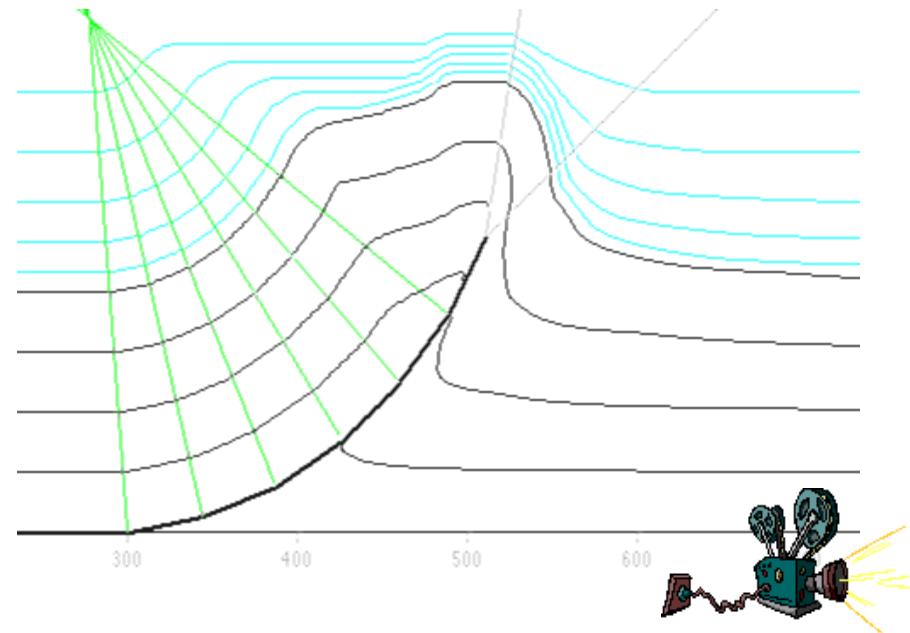
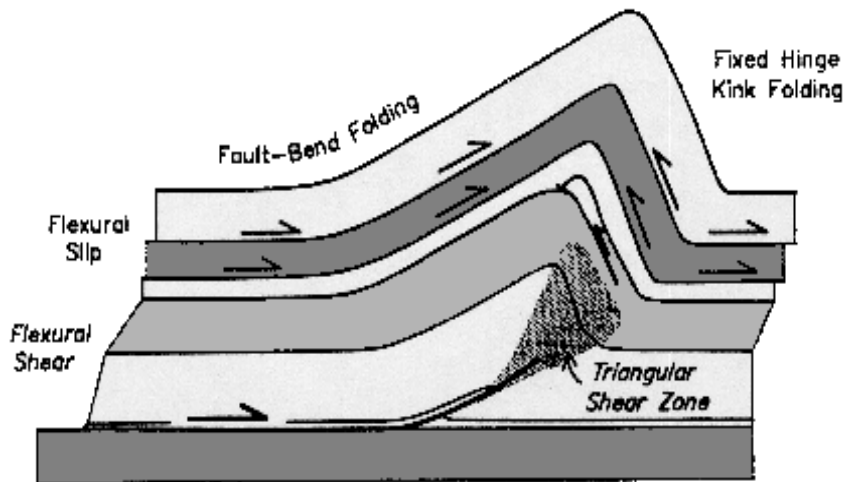


Пример предполагаемой складки срыва (Альмендингер, 2011)

Fault Propagation Folds

Складки пропагации разлома

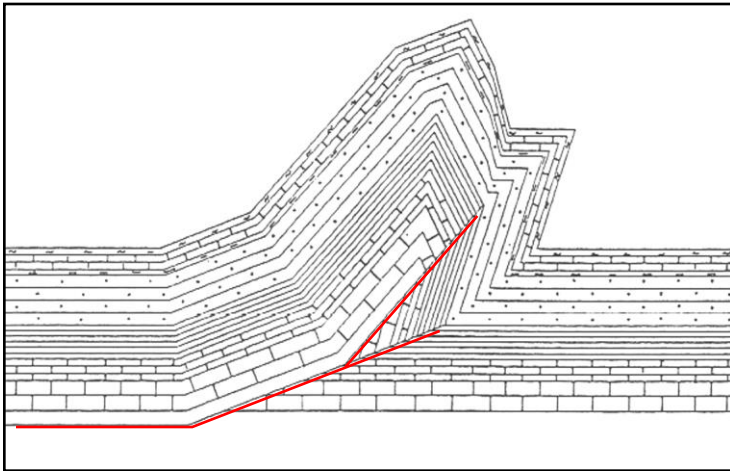
- Структуры формируются на окончании растущего разлома
- Складки образуются как реакция на торможение скольжения вдоль надвигового рампа по направлению к окончанию разлома



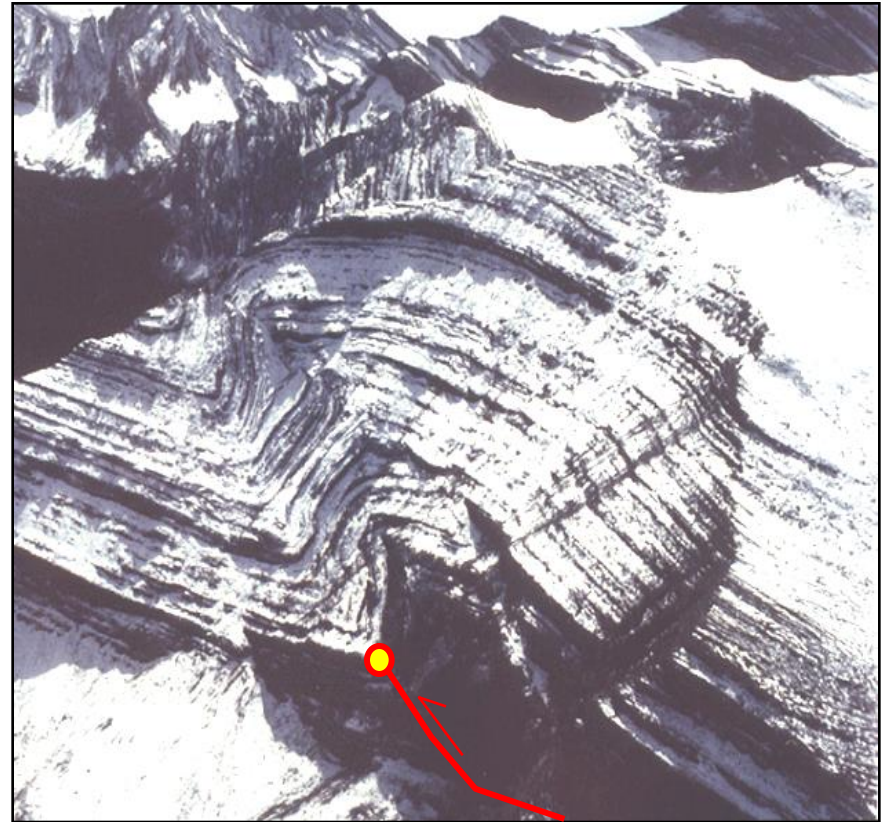
- Складки часто характеризуются крутыми и перевернутыми крыльями
 - Animation developed by Rick Allmendinger, Cornell Univ., USA

Складки пропагации разлома

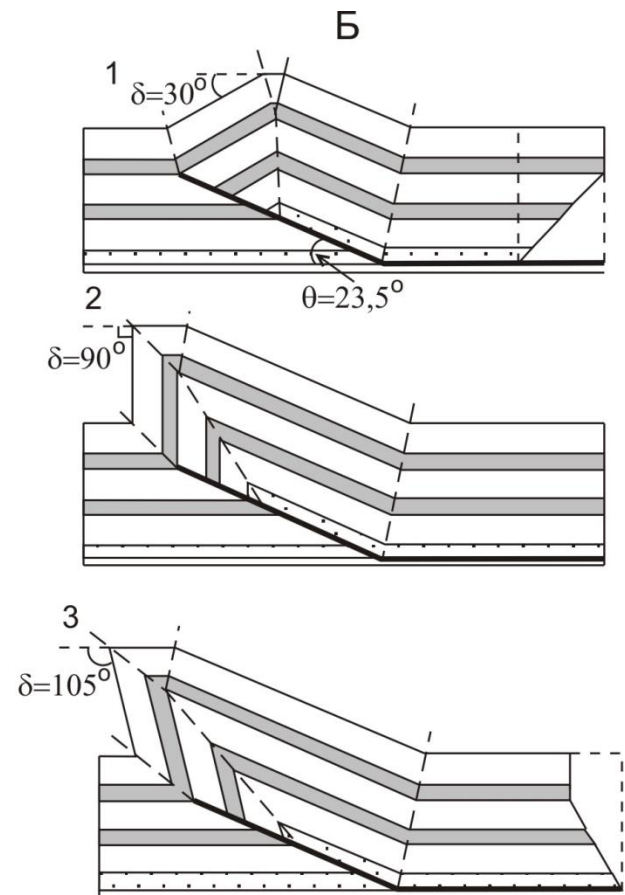
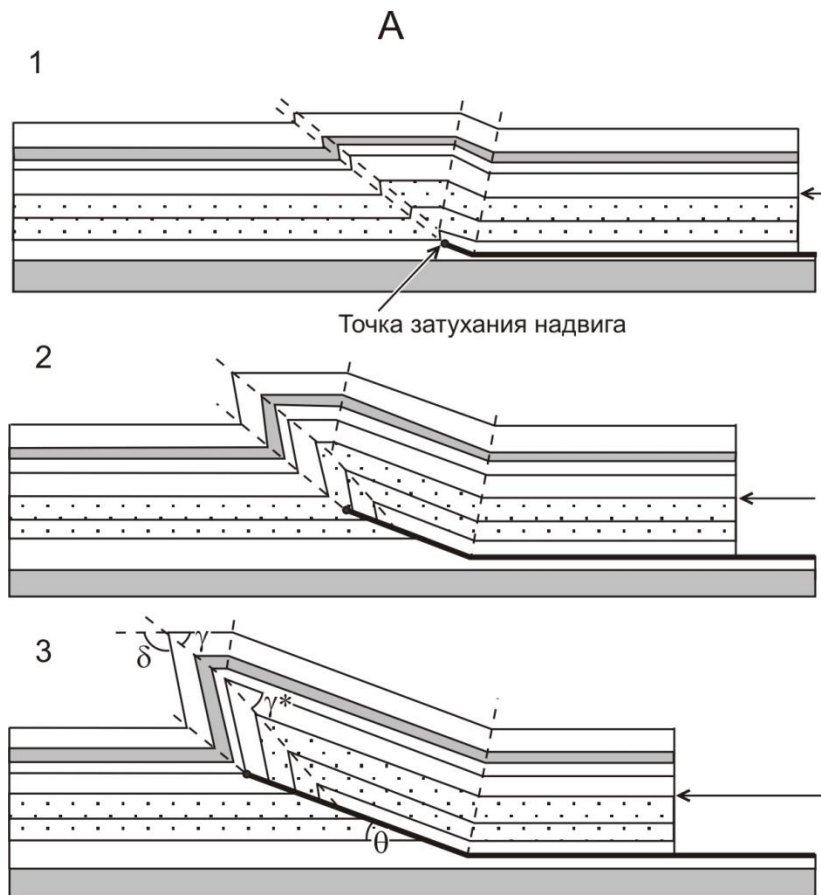
- Часто формируются крупные антиклинали
- Складки часто являются хорошими резервуарами



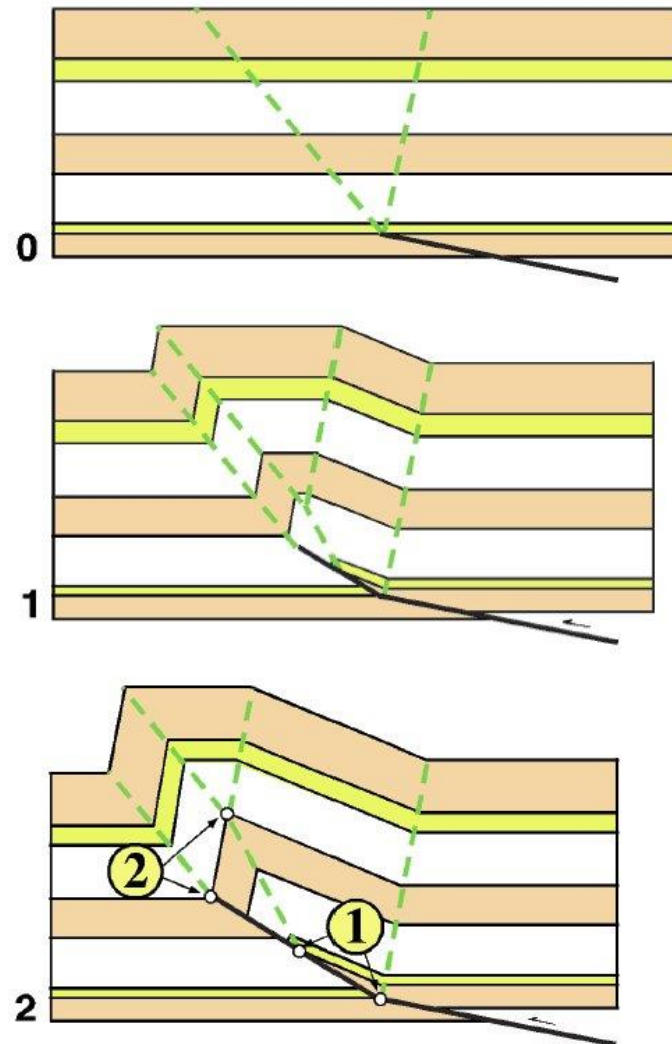
Атлас, северное Морокко (Al Saffar, 1990)



Скалистые горы, Канада



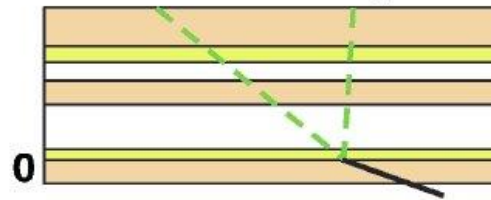
Геометрия взбросо-складок (складок продвижения надвига). А - модель формирования взбросо-складки при отсутствии межслоевого сдвига (Suppe, 1985). Б - морфология взбросо-складок с разными видами межслоевого сдвига при одинаковом угле лежащей отсечки (Θ) (Mitra, 1990). 1 – 3 – стадии формирования складок.



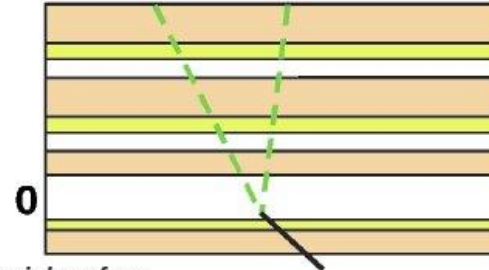
Constant-thickness fault-propagation fold. In this model, the fault propagates up through the section, with a growing fault accommodating shortening above the ramp. The intersection of the crestal axial traces defines the stratigraphic position of the fault tip, which is located along the synclinal axial trace. From Shaw et al. (2005), after Suppe and Medwedeff (1990).

Kinematic Models

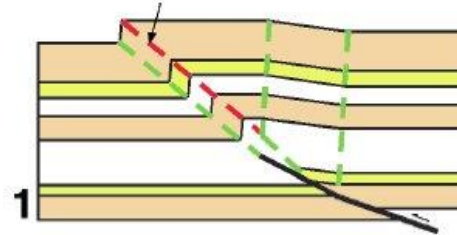
with forelimb thickening



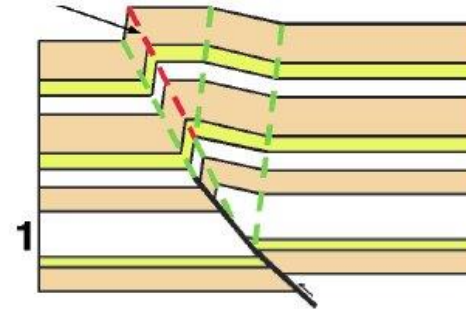
with forelimb thinning



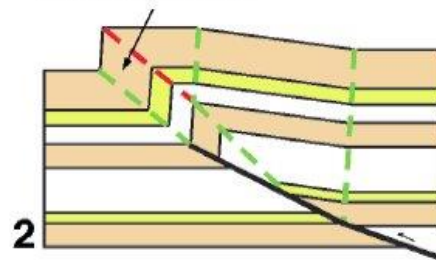
fixed axial surface



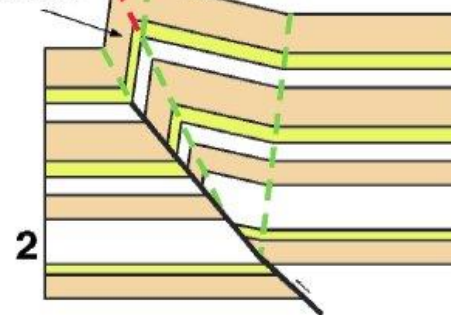
fixed axial surface



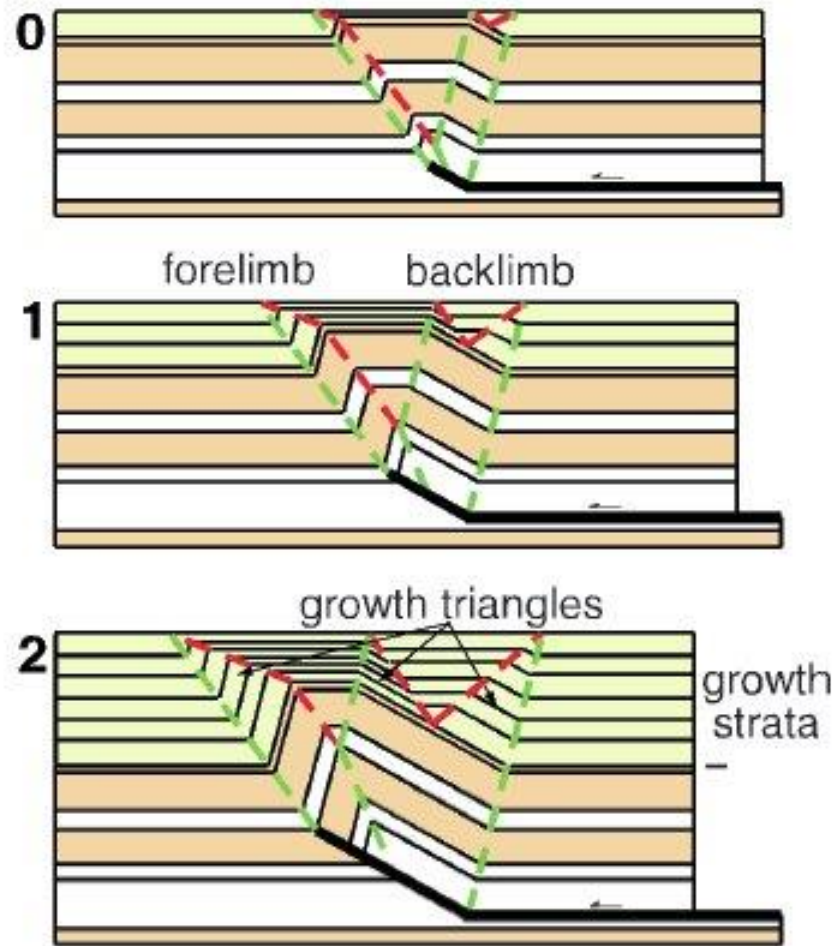
forelimb thickens



forelimb thins

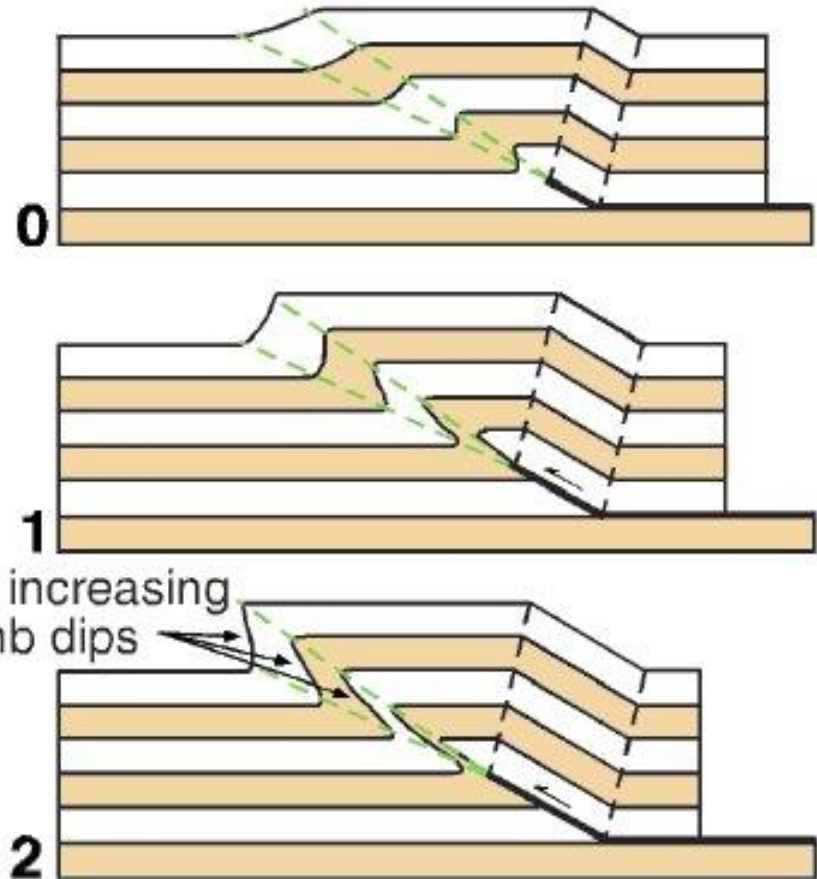
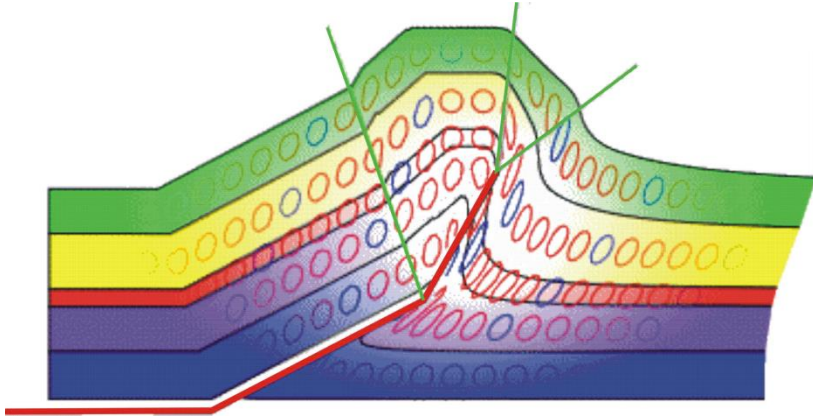


Fixed-axis fault-propagation folds. An alternative model allows the forelimb strata to either thicken or thin during deformation, resulting in different fold and axial-trace geometries. From Shaw et al. (2005), after Suppe and Medwedeff (1990).

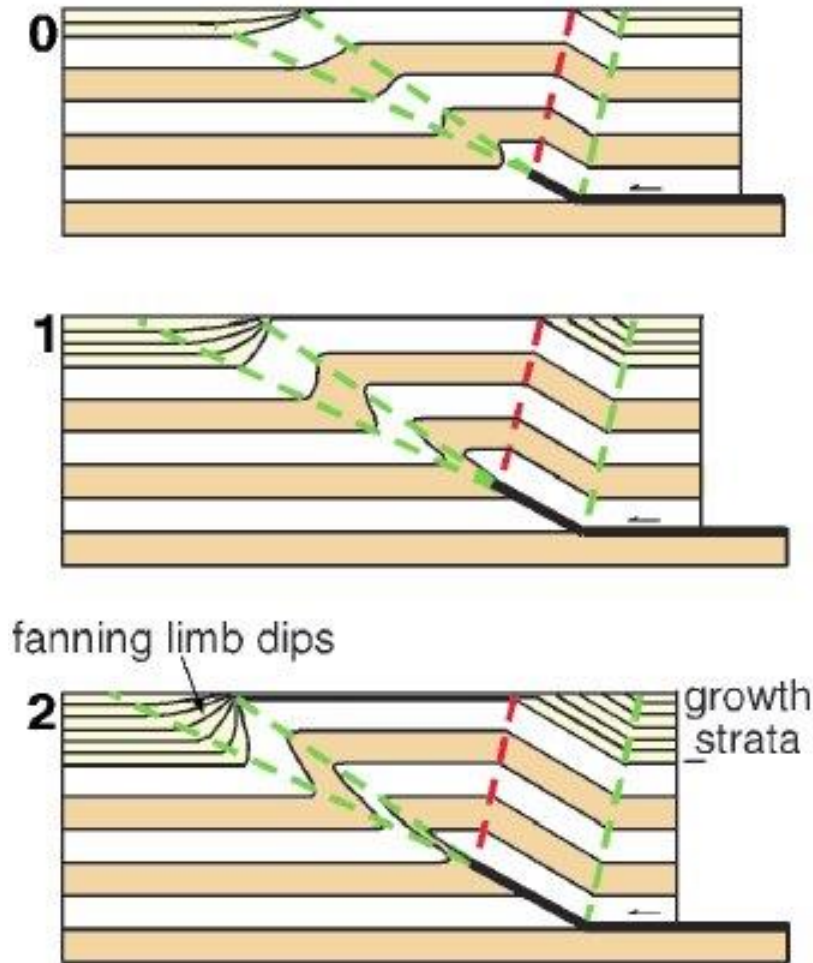


Fault-propagation fold. Growth geometries during fault-propagation folding when sedimentation rate is faster than uplift rate. The forelimb has one growth triangle and the backlimb has two. From Shaw et al. (2005), after Suppe et al. (1992).

Trishear складка пропагации разлома.
Trishear – треугольник деформаций

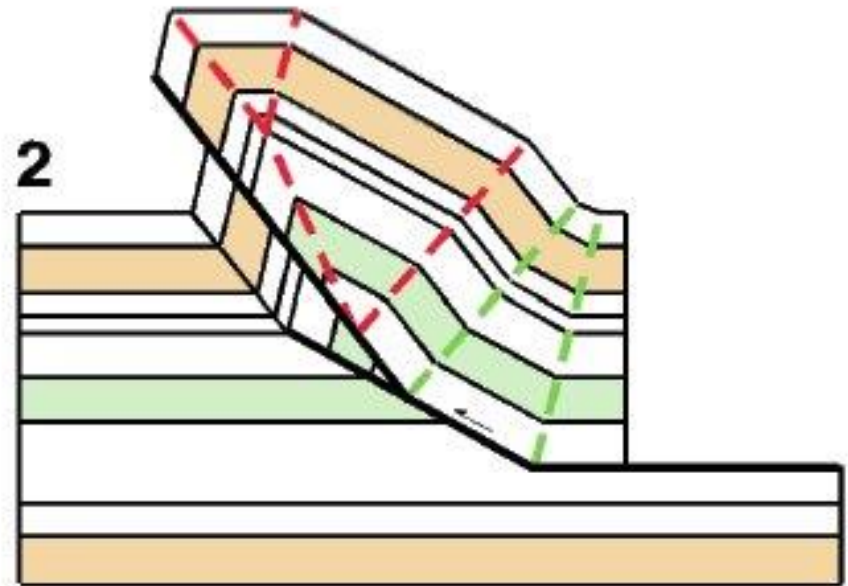
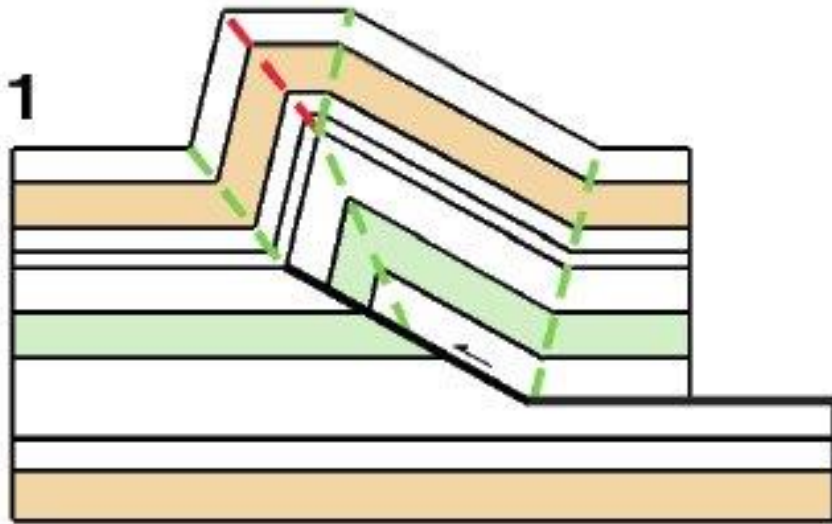


Trishear fault-propagation folds. Another variation of fault-propagation folds is produced when there is distributed shear within a triangular forelimb domain, resulting in fanning forelimb dips.
From Shaw et al. (2005), after Erslev (1991).

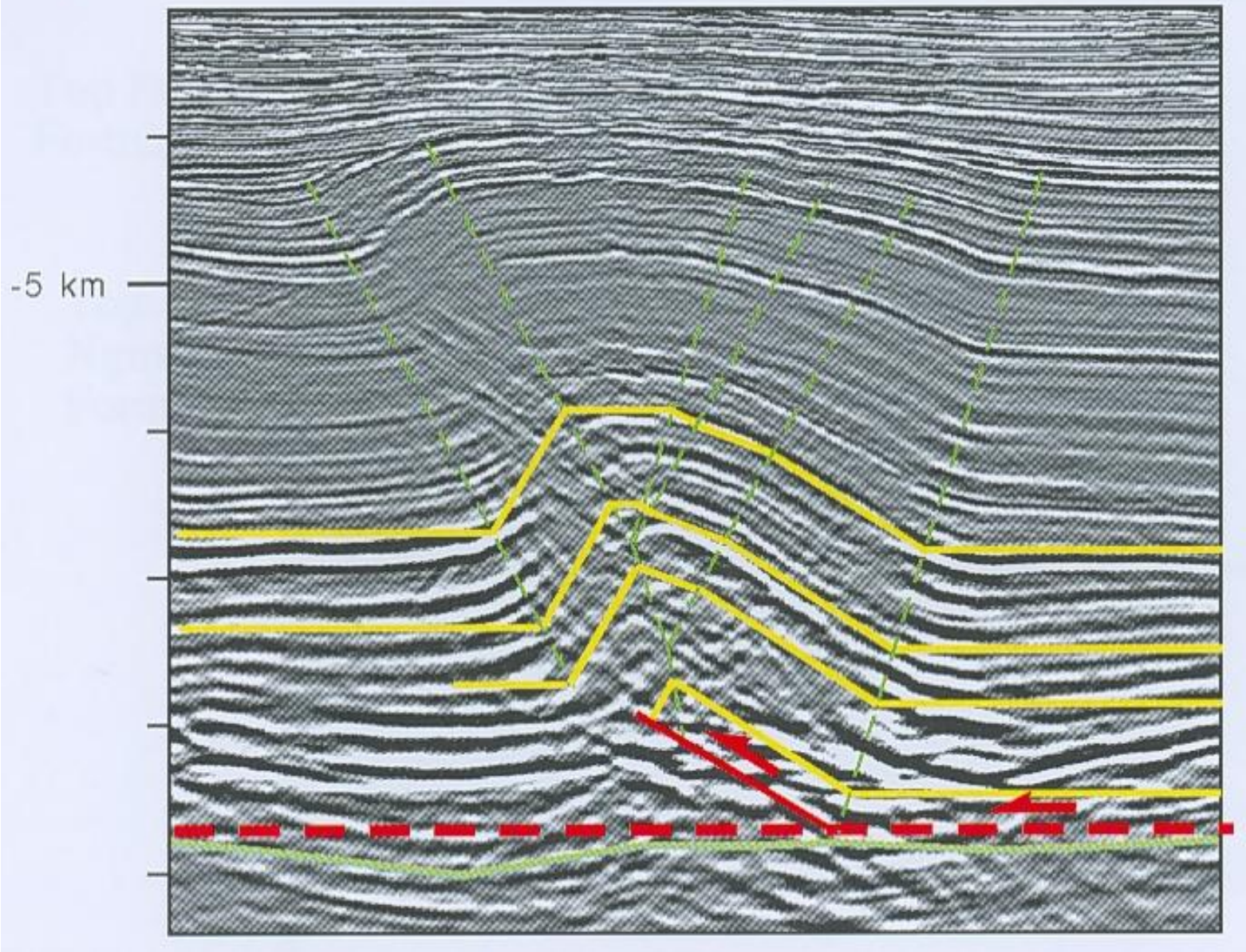


Trishear fault-propagation folds. Growth geometries produced during trishear fault-propagation folding. The forelimb has fanning geometries in both prekinematic and growth intervals, but the former have the same thickness in the fold crest as in front of the fold. From Shaw et al. (2005), after Hardy and Ford (1997).

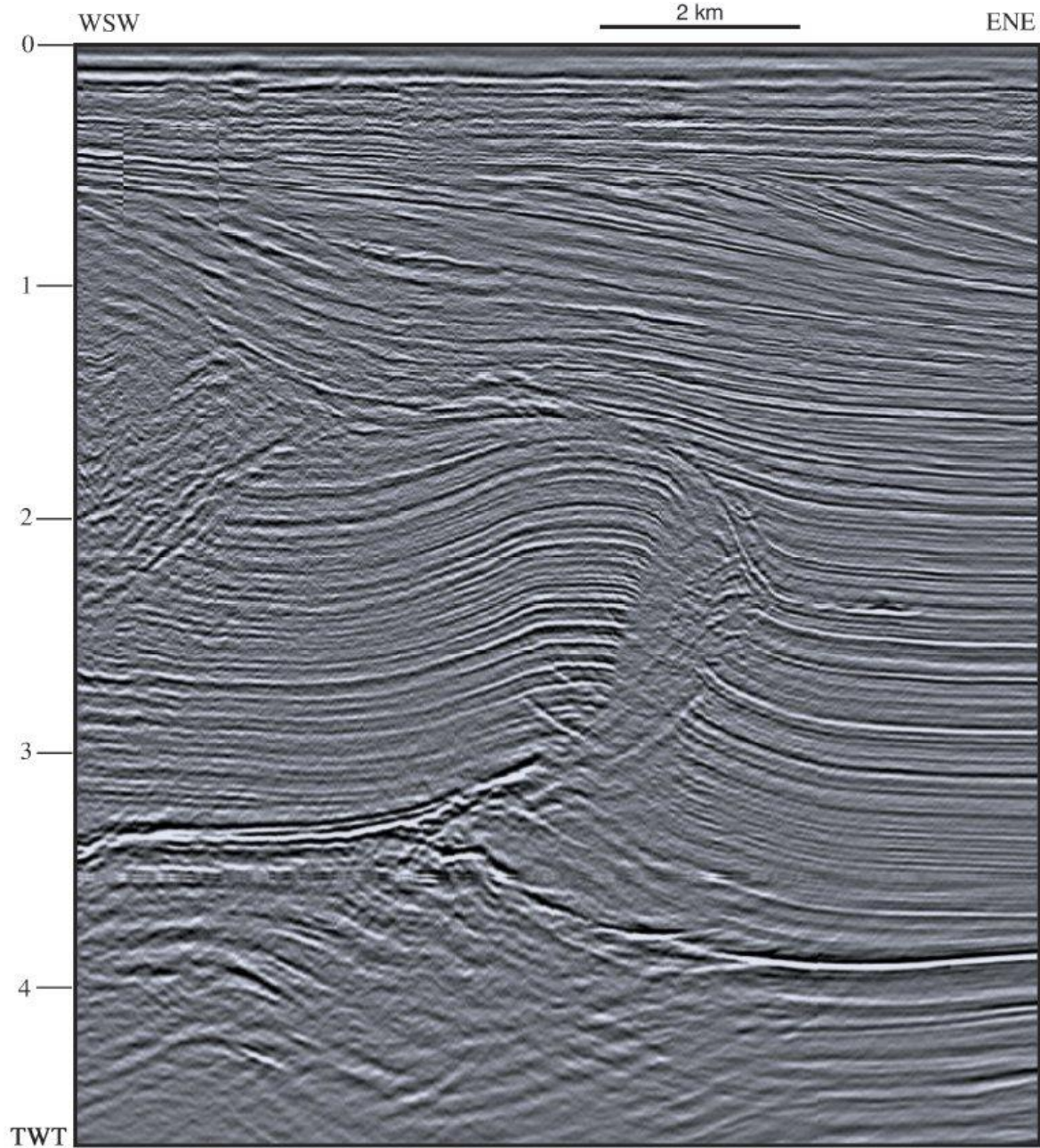
Forelimb breakthrough



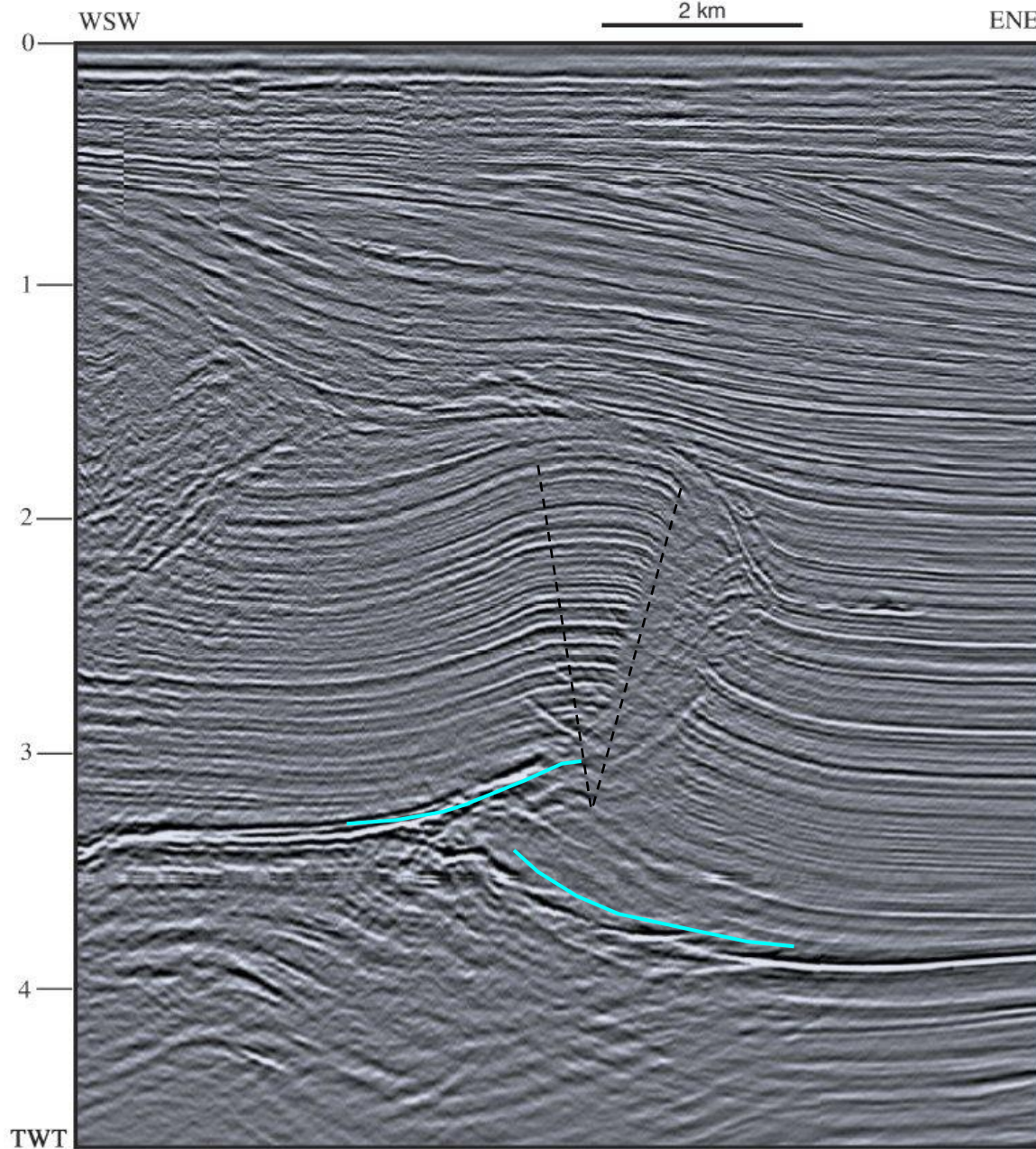
Breakthrough fault-propagation folds. It is not uncommon to find thrust fault breaking through a developing fault-propagation fold. Although the forelimb breakthrough is the most common, other geometries are possible. From Shaw et al. (2005), after Suppe and Medwedeff (1990).



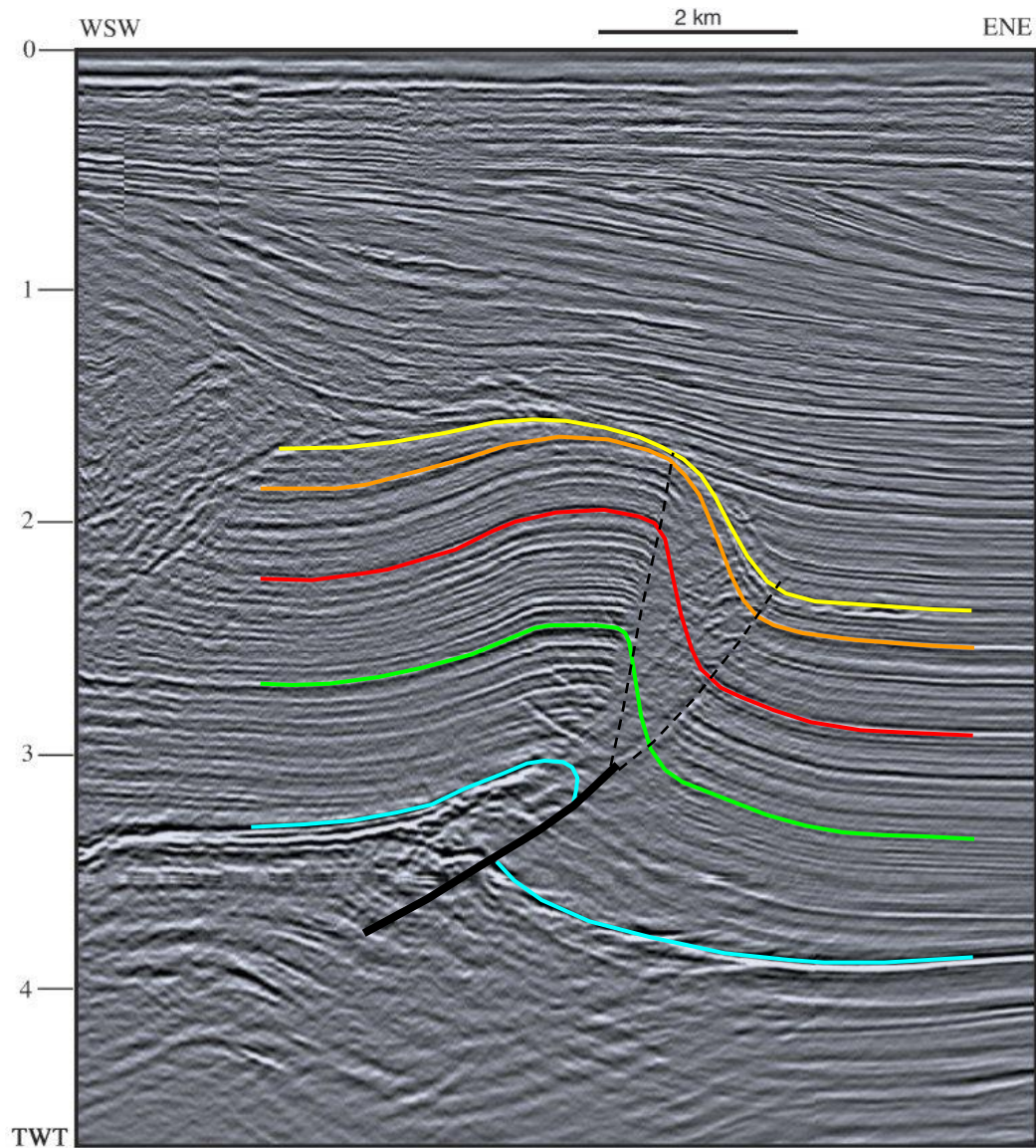
Possible fault-propagation fold. Model fit to data using constant-thickness fault-propagation fold theory. From Bilotti et al. (2005).



Exercise 3 - Fault-propagation fold. Interpret the fold, fault, and axial-trace geometries on this structure from the Adriatic Sea, offshore Italy. From Storti et al. (2005).



Exercise 3 - Fault-propagation fold. The crestal axial traces intersect below a level (blue) that is clearly faulted, suggesting that this structure does not fit simple fault-propagation fold theory.



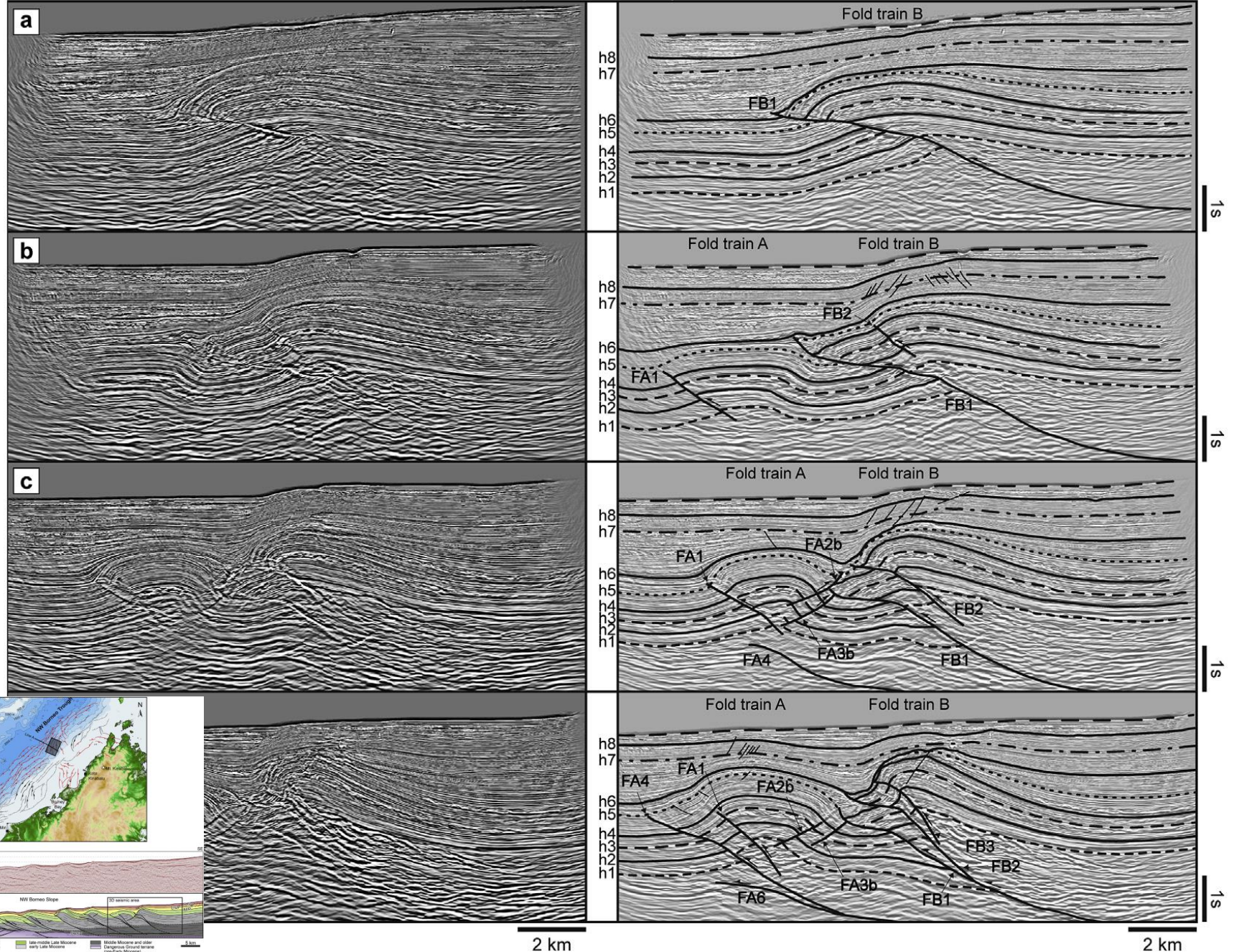
Exercise 3 - Fault-propagation fold. A better interpretation is that of trishear fault-bend folding. However, we are dealing with time, not depth data, so geometric relationships can be misleading.

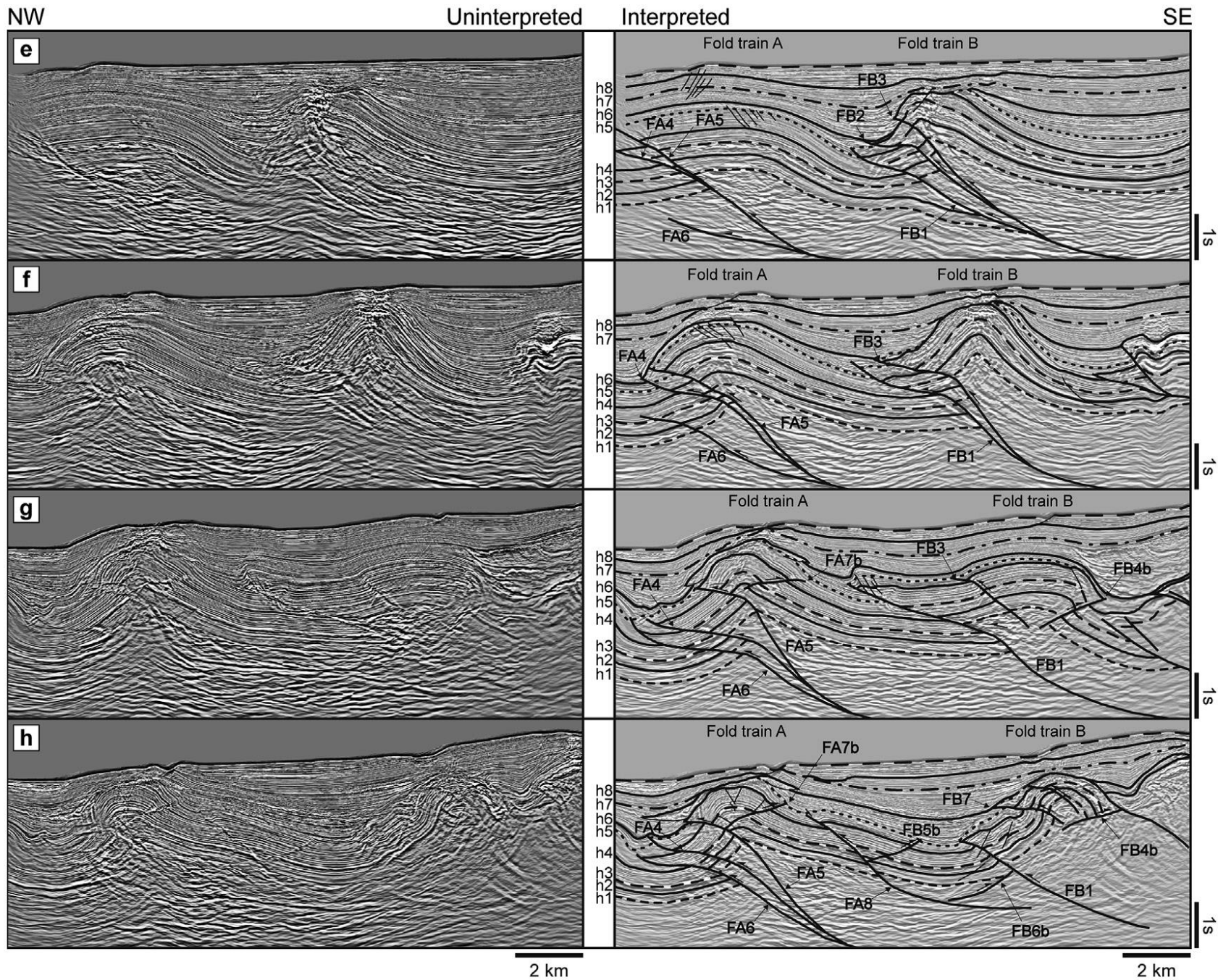
W or NW

Uninterpreted

Interpreted

E or SE

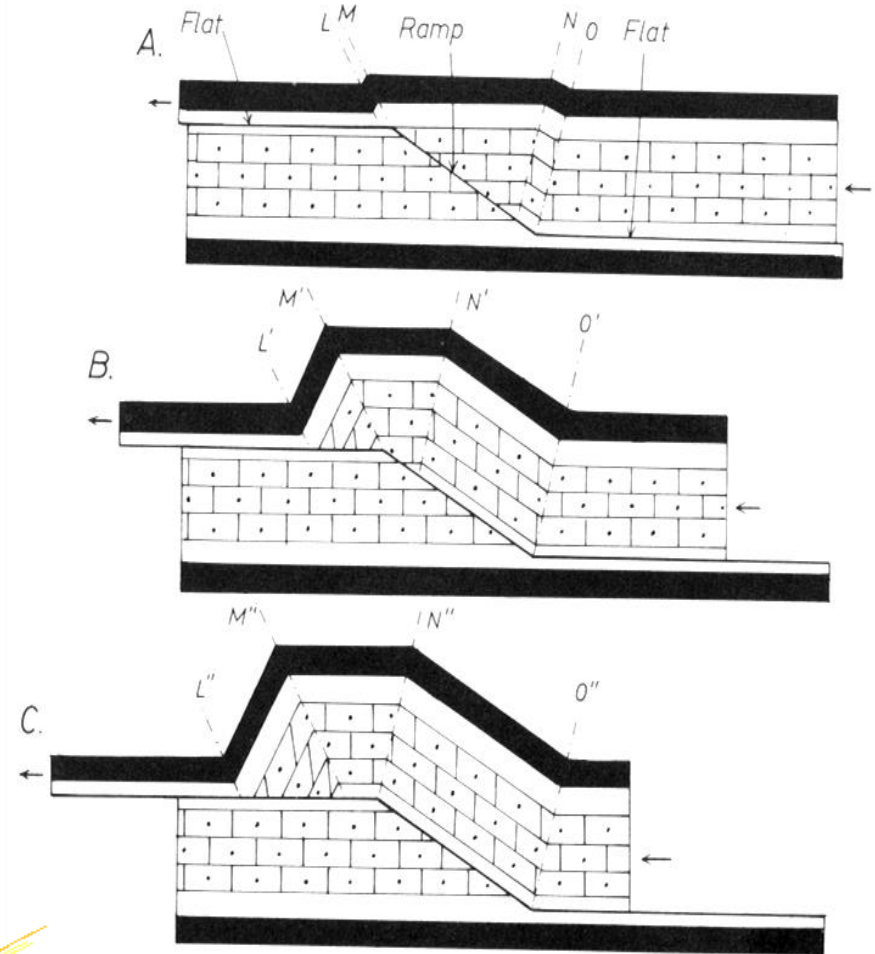
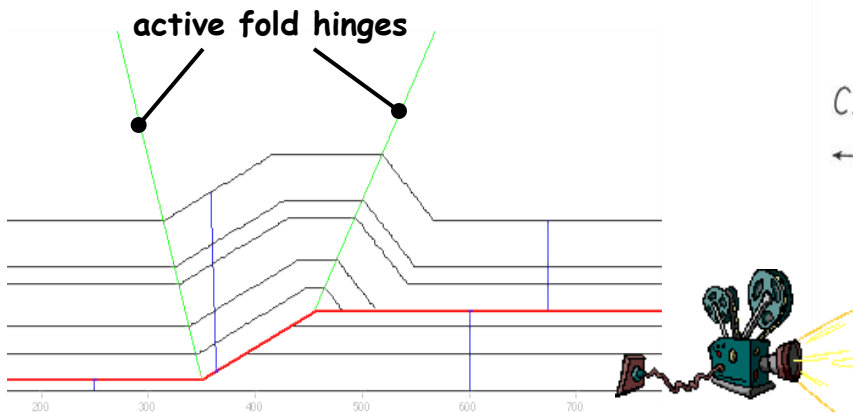


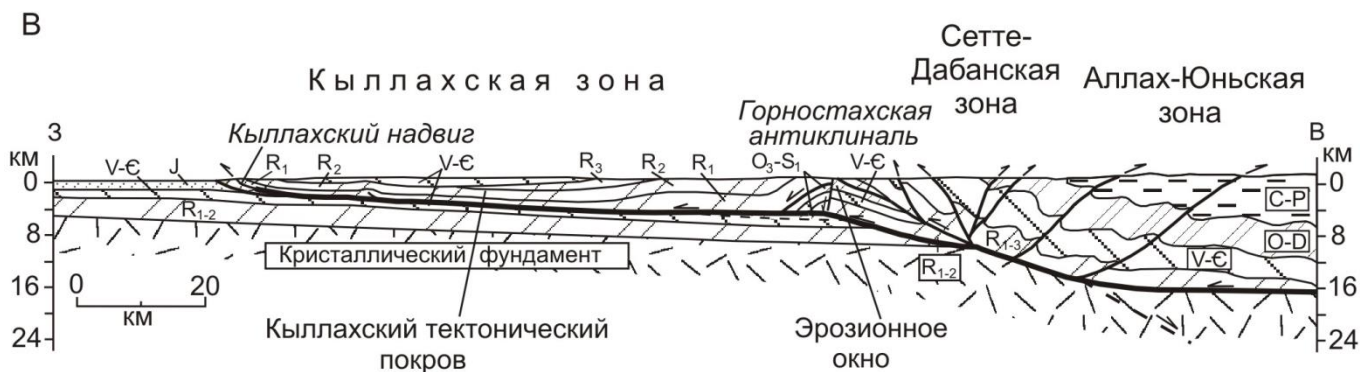
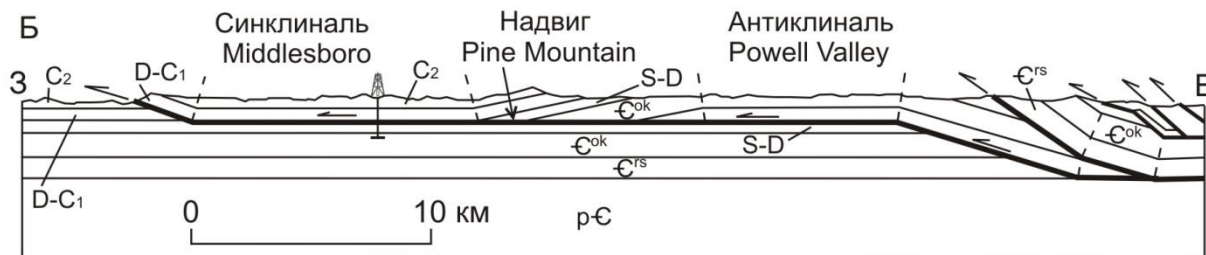
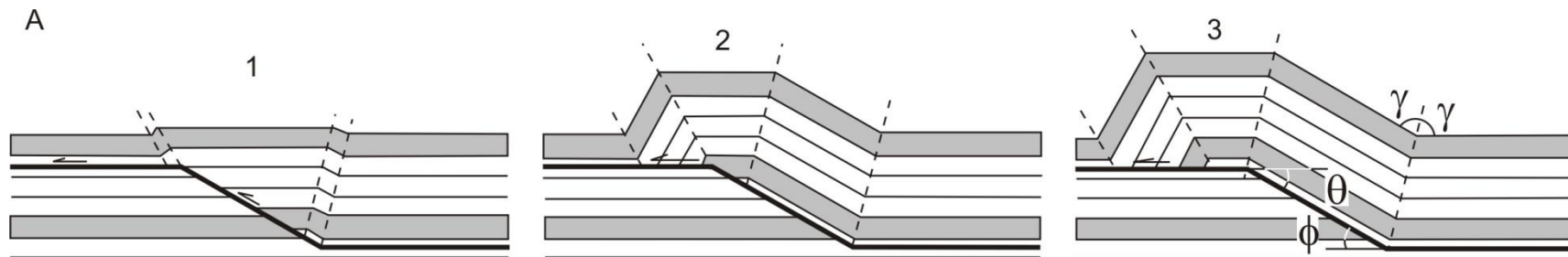


Fault Bend Folding

Складки изгиба надвига (рамповые складки)

- Деформации в висячем крыле происходят из-за прохождения над разломом с измененными наклонами
- Изломы разлома образуют складки в перемещающемся висячем крыле
Bends in fault induce folding of the translating hanging-wall
 - Классический пример описан в (Rich, 1934) в Аппалачах

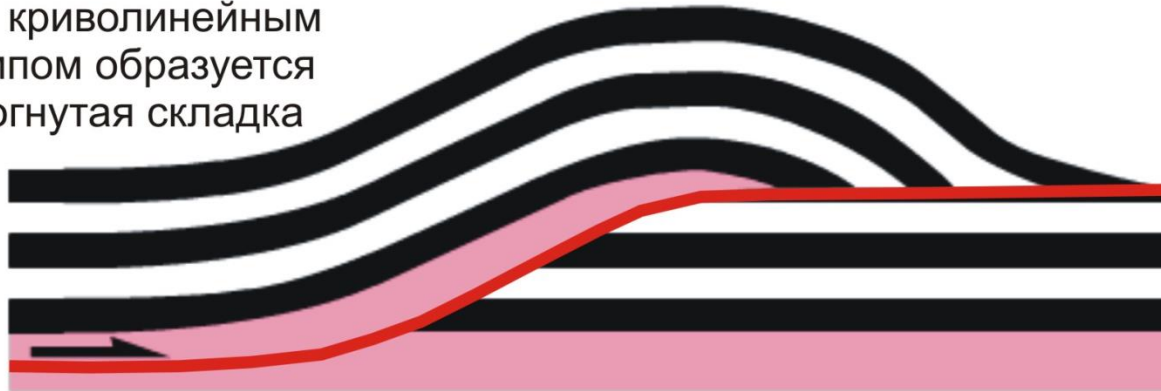




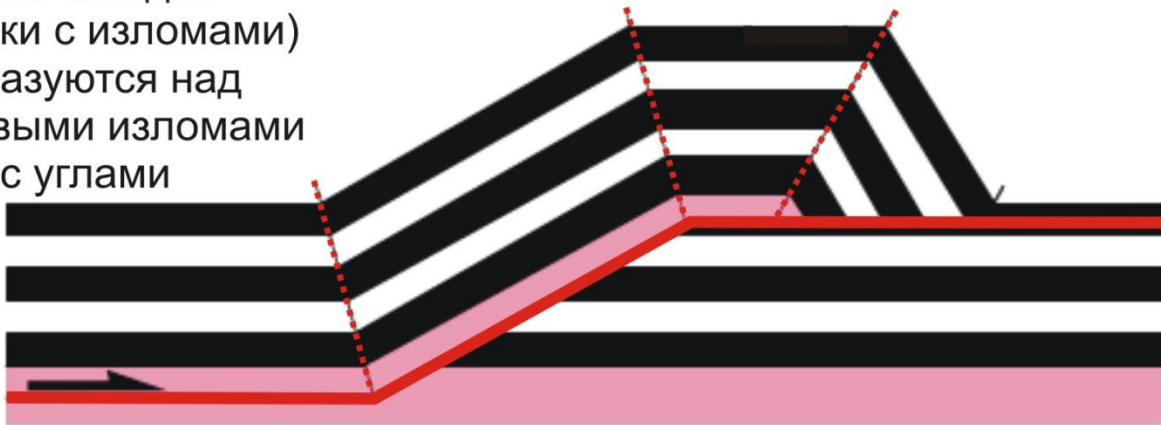
А - стадии формирования рамповой антиклинали (Suppe, 1983). Б - рамповая антиклиналь Powell Valley (Аппалачи), связанная с перескоком detachment Pine Mountain с кровли фундамента в девонские отложения. С этой антиклиналью связано нефтяное месторождение Rose Hill (Аппалачи, штат Вирджиния, США) (Hatcher, 1990). В - Горностахская рамповая антиклиналь, возникшая в результате перескока detachment с кровли фундамента в палеозойские отложения (Южное Верхоянье, Восточная Якутия) (Парфенов и др., 1998).

Примеры рамповых складок в зависимости от геометрии надвига

над криволинейным
рампом образуется
изогнутая складка



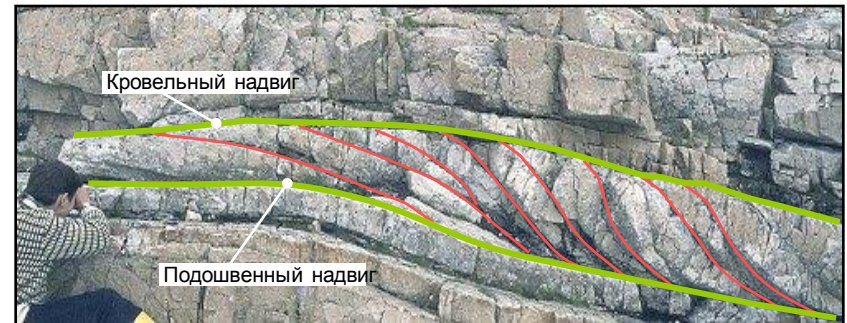
кинк-складки
(складки с изломами)
образуются над
рамповыми изломами
с углами



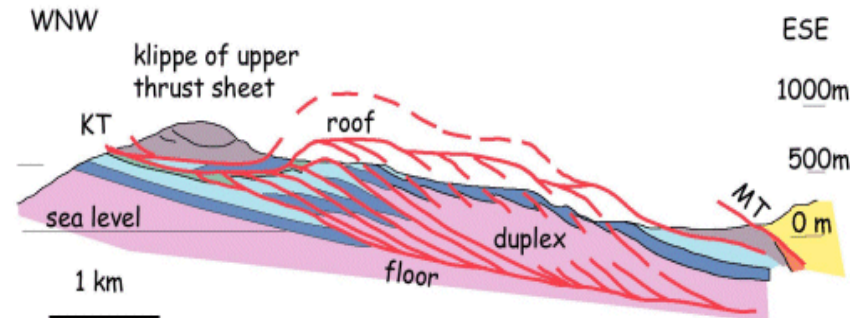
Дуплексы

- Дуплекс
 - Система надвигов, связанных подошвенным и кровельным надвигами в единую конструкцию
 - Кровельный надвиг
 - Подошвенный (базальный) надвиг
 - Суммарное смещение по кровельному и подошвенному надвигам распределено по многочисленным «хорсам» - блокам внутри дуплекса
 - Более высокие «хорсы» деформированы в складки и приподняты подстилающими «хорсами» при нормальной последовательности надвигания

Обнажение в Альпах



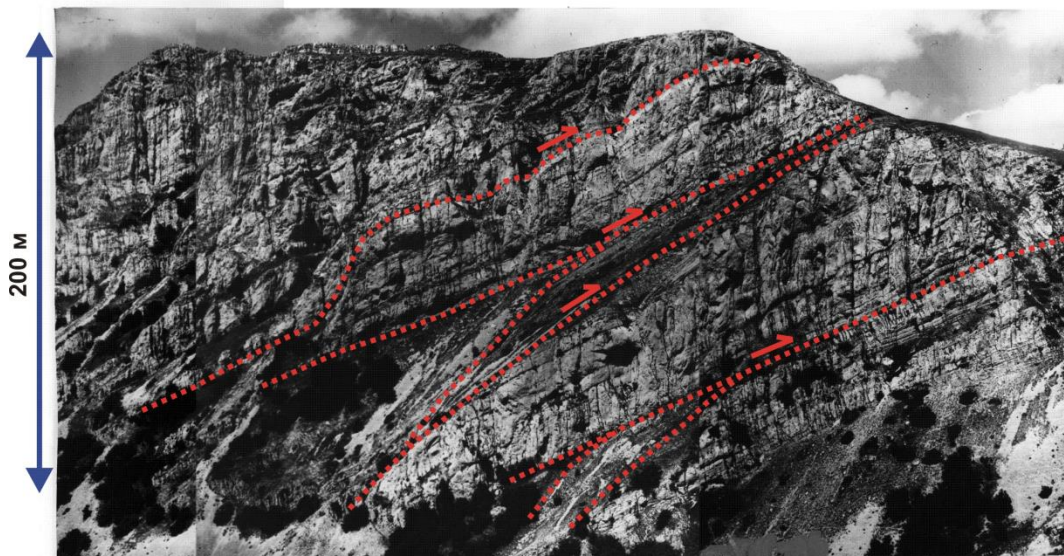
3-С Шотландия



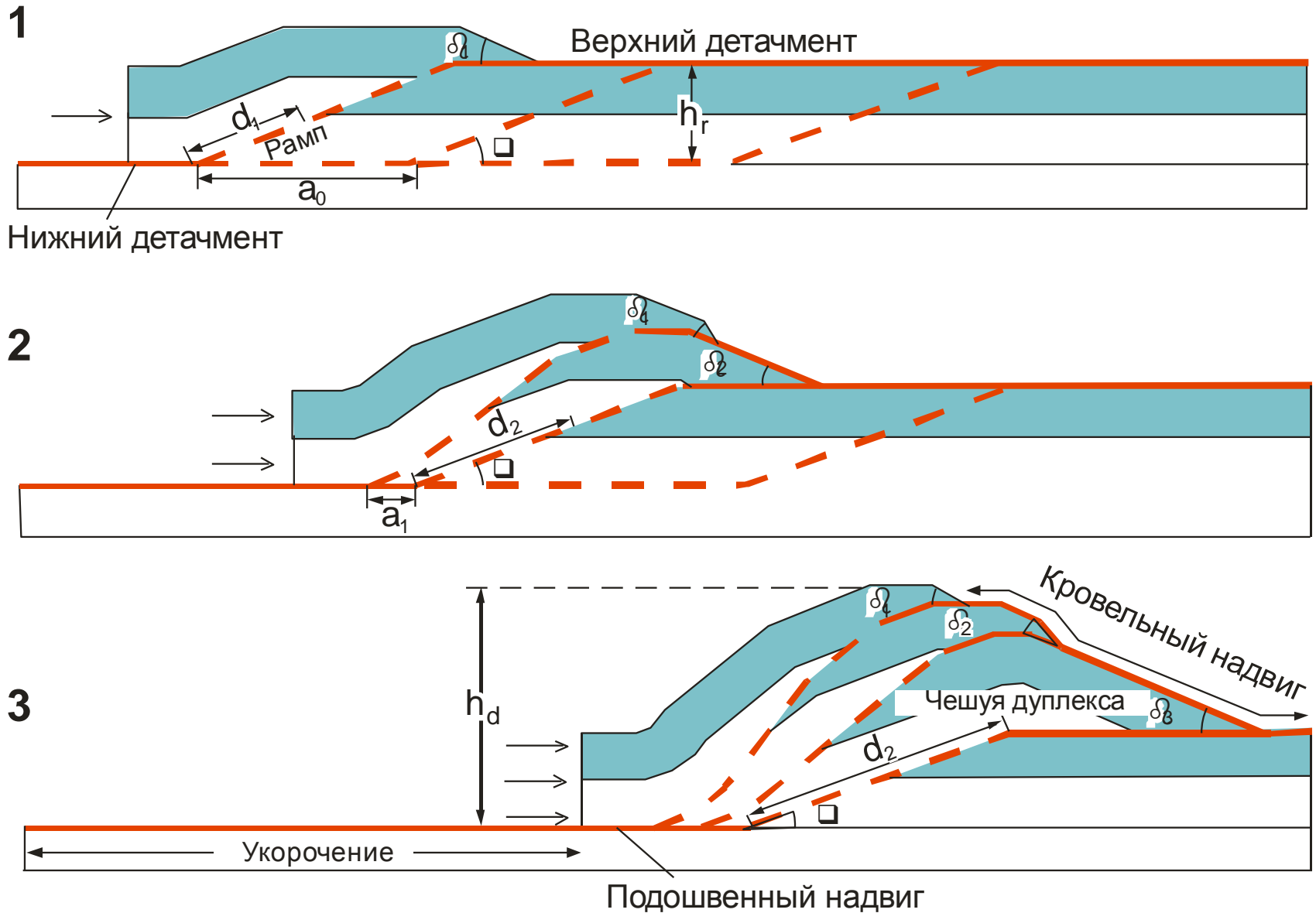
Крым. Южный склон плато Чатыр-Даг.
Дуплексы в отложениях верхнеюрской карбонатной платформы

ЮВ

СЗ

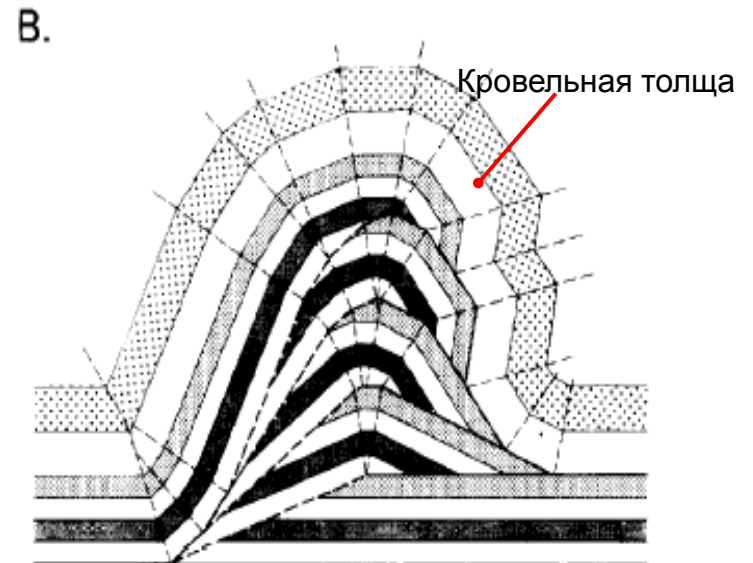
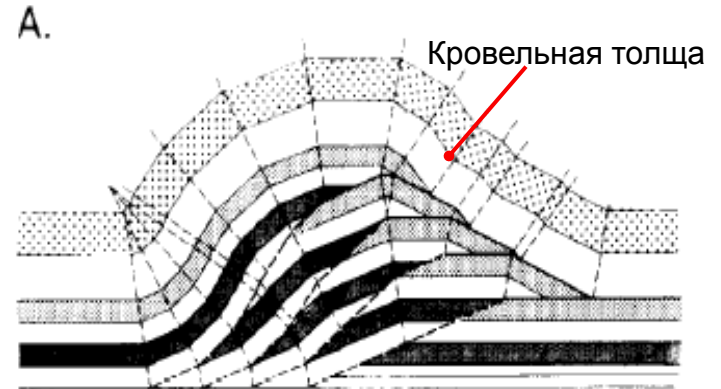


Модель формирования дуплекса антиформного скупивания (Mitra, 1986). 1-3 стадии формирования дуплекса.



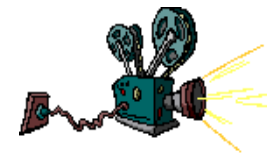
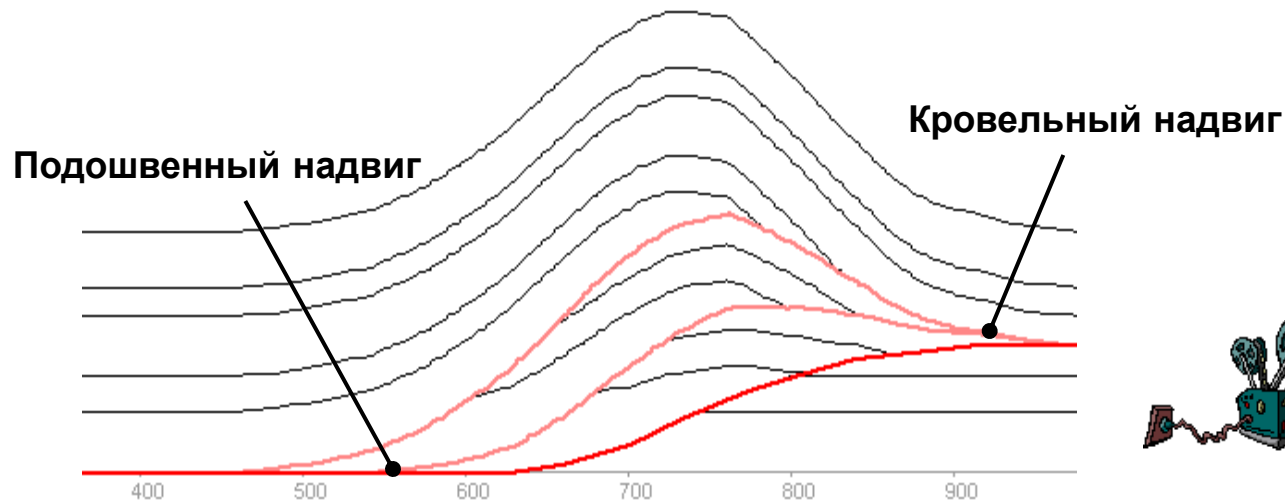
Дуплексы

- Антиформное сучивание
 - При сильной величине сокращения индивидуальные ограниченные разломами «хорсы» могут быть сучены субвертикально
 - Может формироваться крупное антиформное образование из надвиговых «хорсов» (блоков, чешуй)
 - Такое сучивание может приводить к значительному складкообразованию в перекрывающей толще и образованию регионального поднятия в складчатом поясе



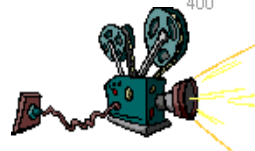
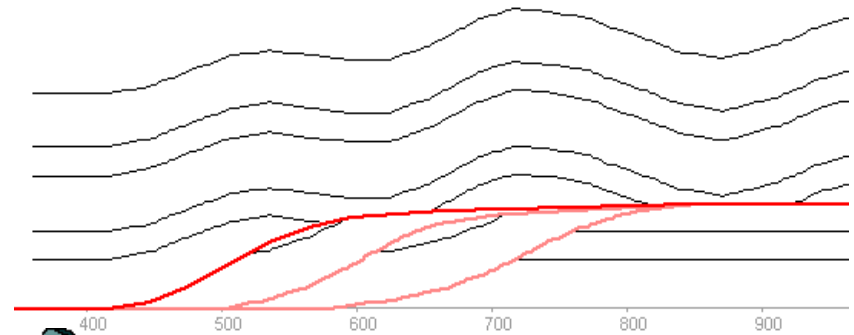
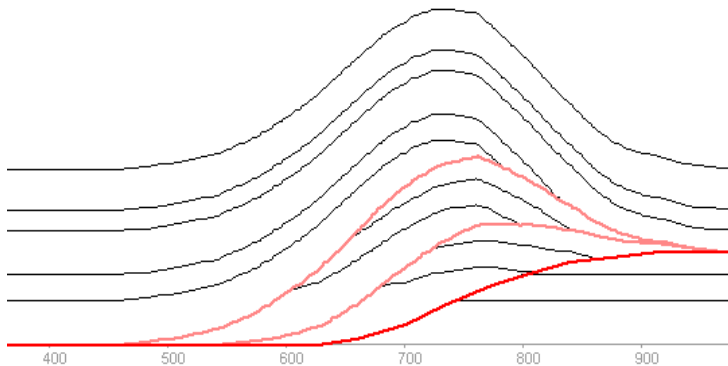
Складки изгиба надвига (рамповые складки) и дуплексы

- При формировании дуплексов происходит:
 - Серии кинематически связанных «складок изгиба надвигов» ограничиваются подошвенным и кровельным надвигами
 - Смещение передается от одного детачмента к другому
 - Более молодые «хорсы» повторно деформируют перекрывающие их надвиговые пластины
 - Комплексная структурная история у более высоких надвиговых пластин

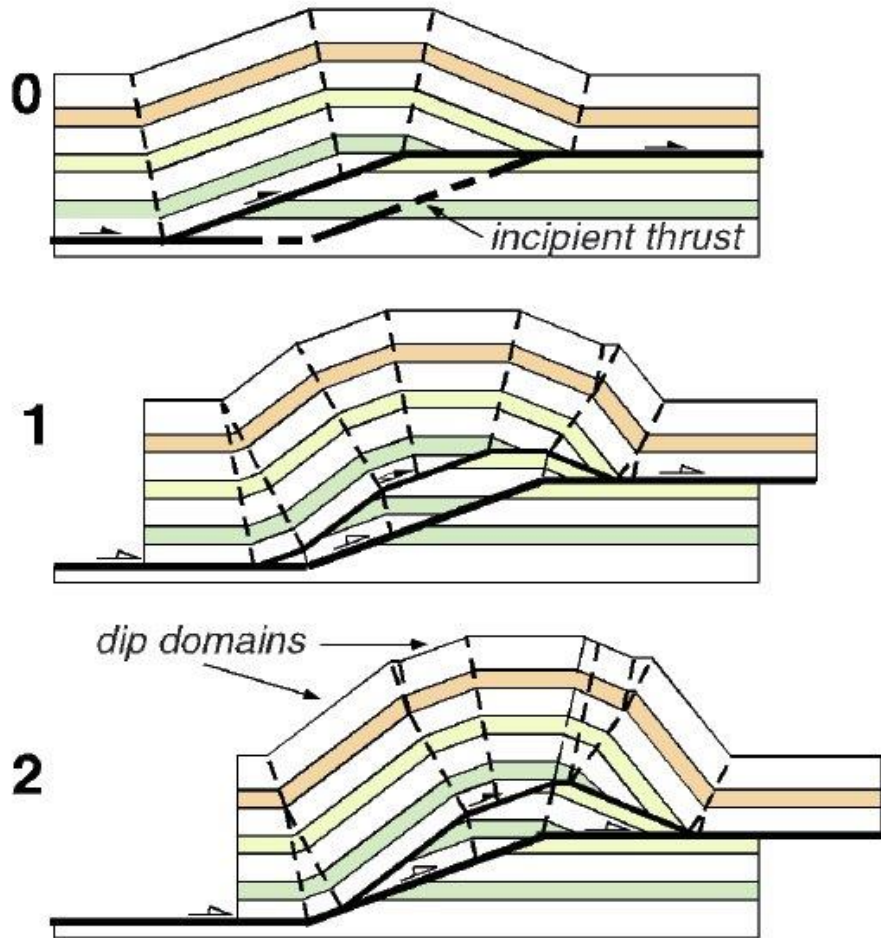


Последовательность формирования надвигов

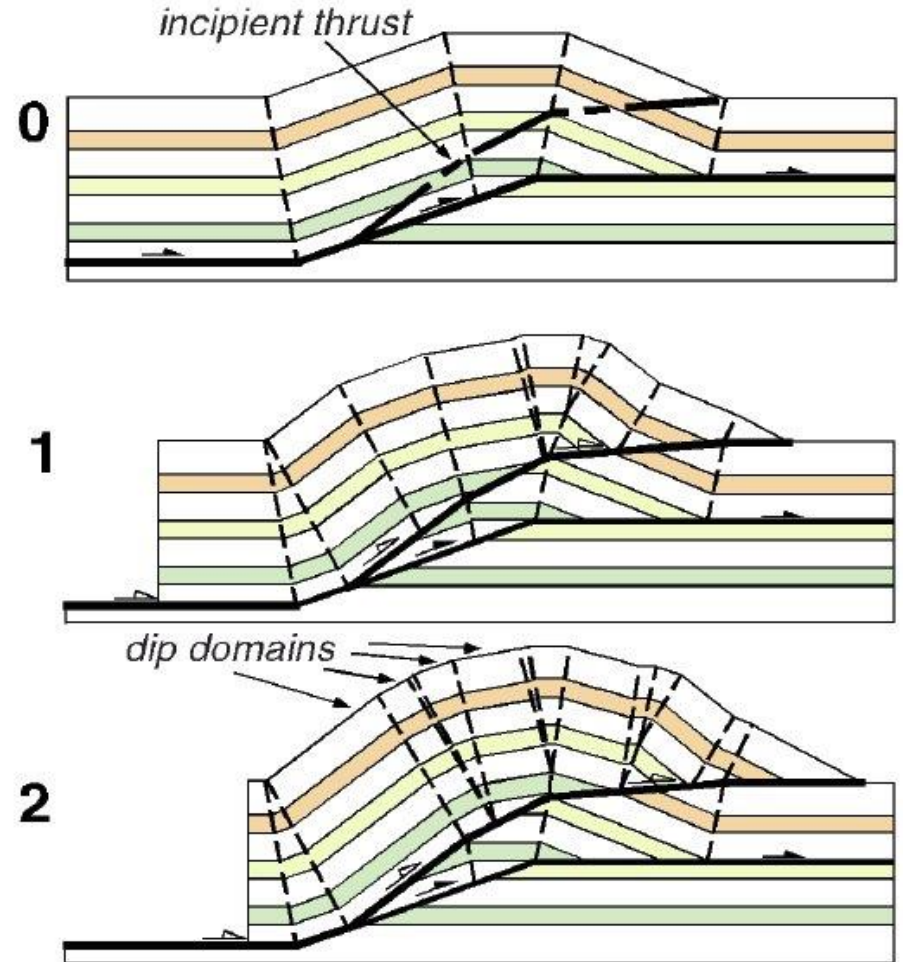
- Дуплексы нормальной последовательности
 - Более ранние складки/разломы испытывают повторную складчатость и вращаются назад
 - Высокий угол падения у более ранних структур
 - Много фаз деформаций накладываются друг на друга
- Дуплексы обратной последовательности
 - Молодые структуры срезаются более поздними надвигами
 - Отсутствует вращение назад и подъем более ранних структур
 - Одна фаза деформаций в надвиговых пластинах



Break-forward imbricate



Break-backward imbricate



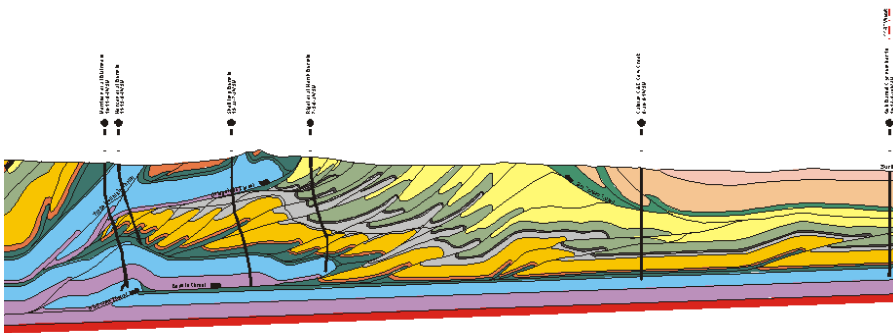
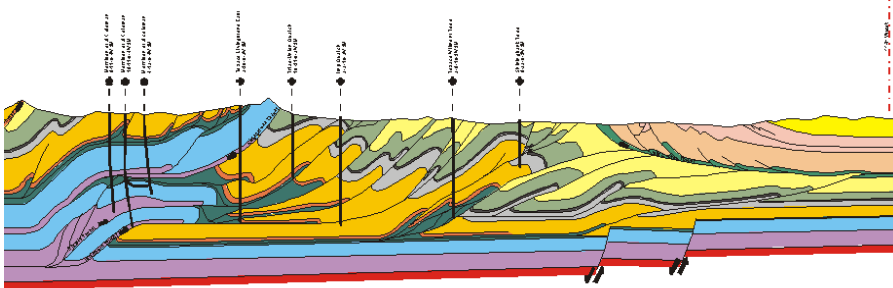
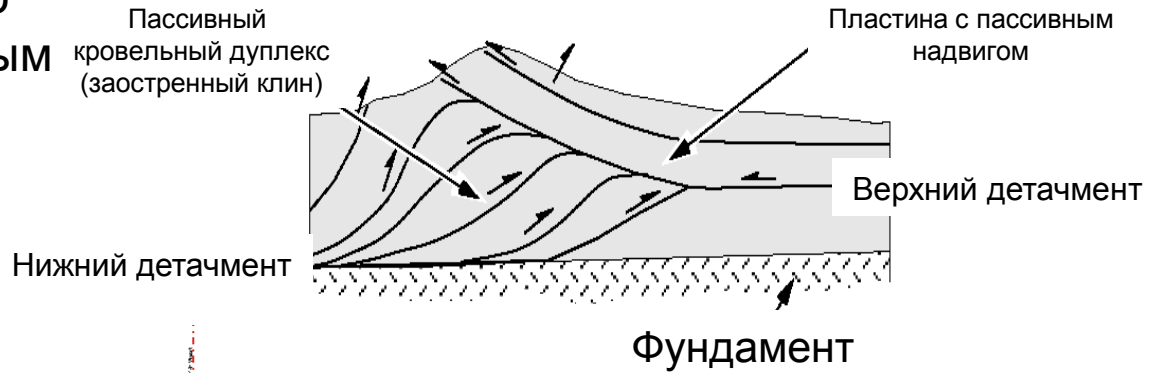
Imbricate fault-bend folds. The sequence of deformation may be either break-forward, in which case the earlier thrust sheet is folded by the new one, or break-backward, in which case the initial hanging wall is cut by a newer thrust. From Shaw et al. (2005).

Треугольные зоны

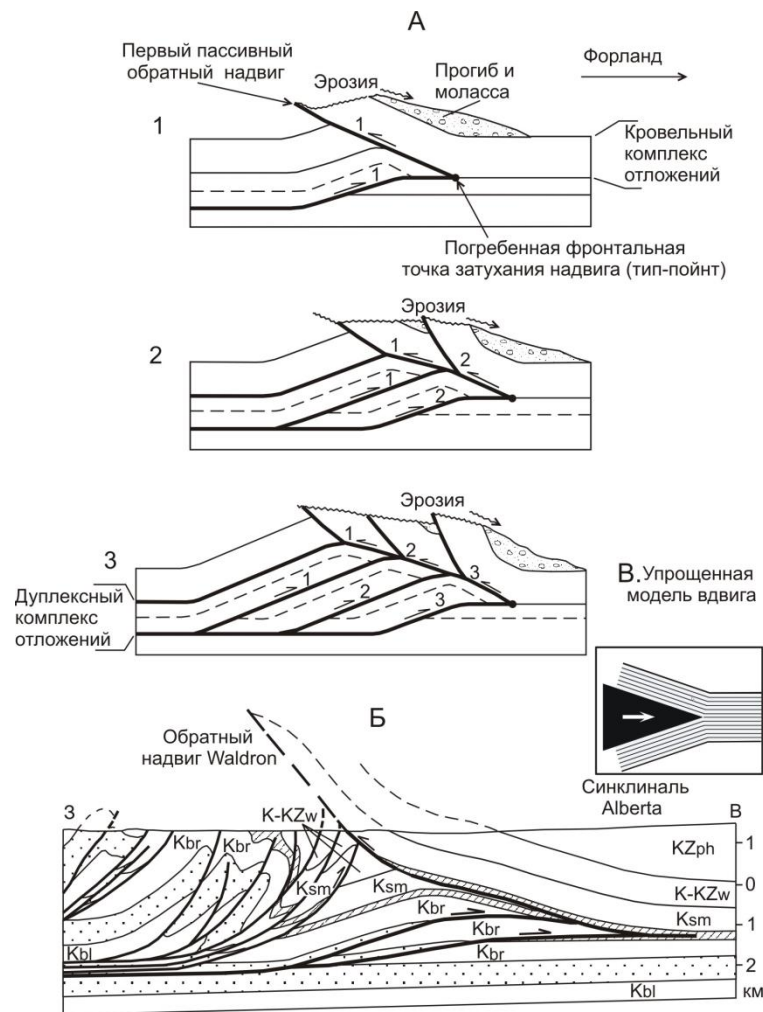
Треугольные зоны

- Треугольные зоны образуются в краевой зоне надвигового фронта, где уровень верхнего detachment является обратным надвигом

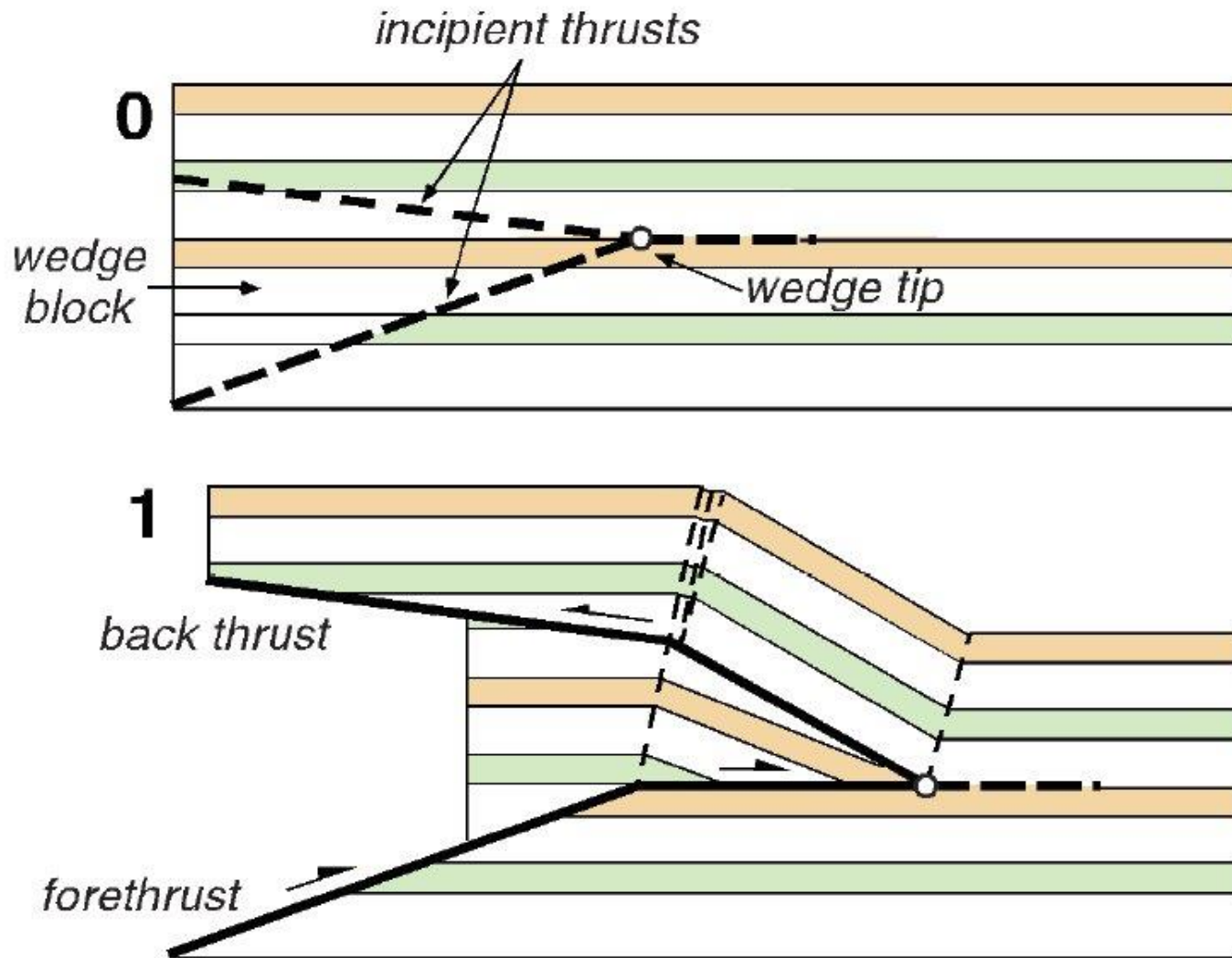
Классическая треугольная зона



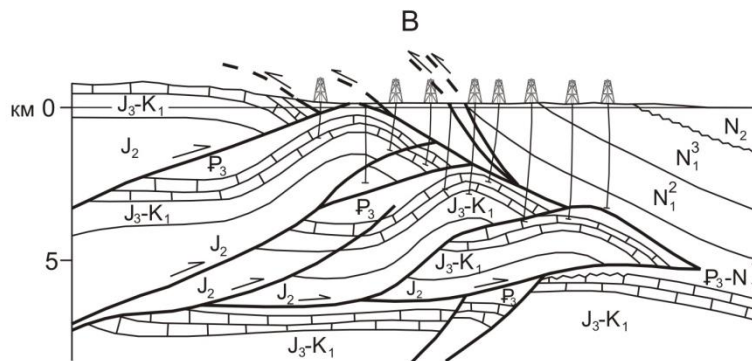
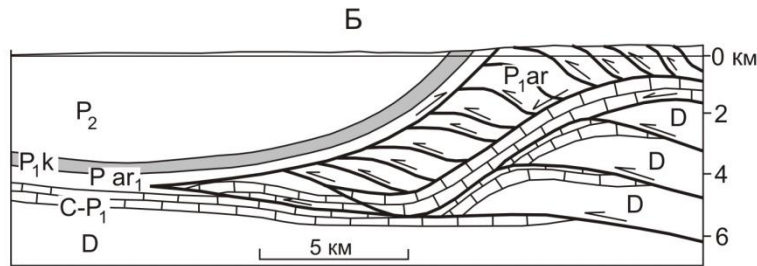
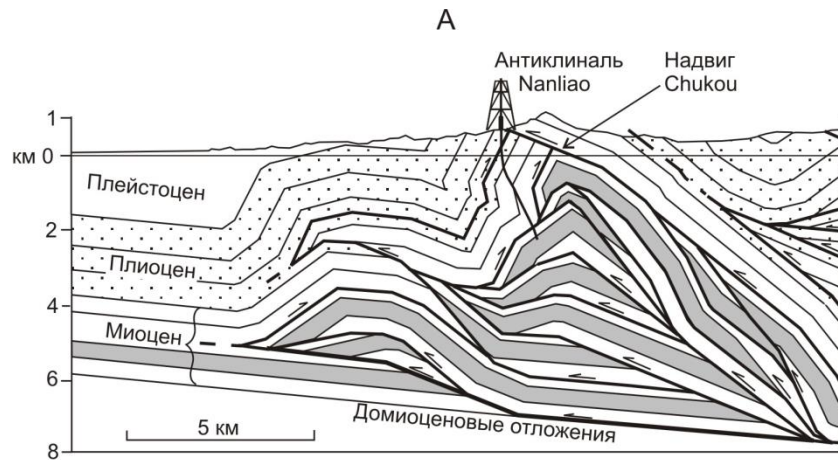
- Формируются важные ловушки в краевой части надвигового пояса



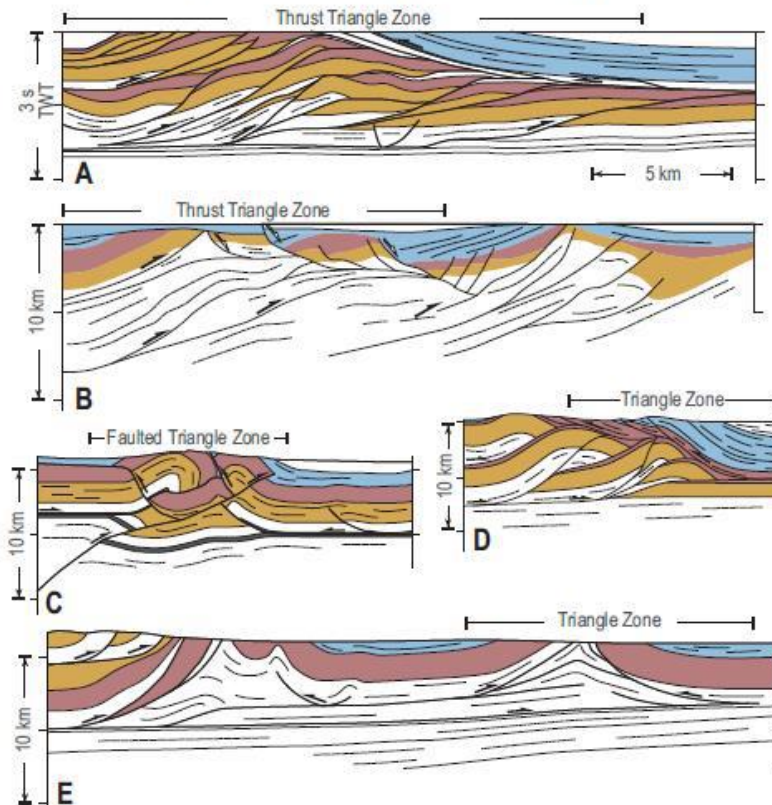
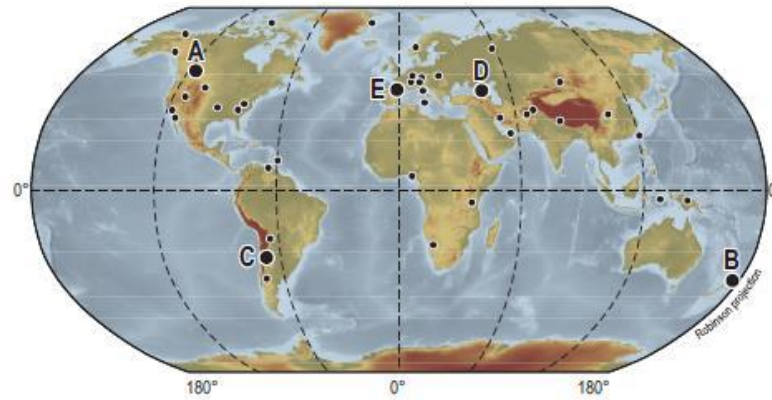
А - модель формирования клиновидного вдвига с обратным надвигом во фронте рамповой антиклинали. Обратный надвиг бывает приурочен к тому же стратиграфическому горизонту скольжения, что и висячее крыло детачмента (Banks, Warburton, 1986). Б - природный пример такой структуры, Предгорья Скалистых гор, Альберта, Канада (Price, 1986). В – упрощенная модель вдвига.



Thrust wedge. Type of fault-bend fold with a lower forethrust and an upper backthrust bounding a wedge of strata that moves into and delaminates the section. From Shaw et al. (2005), after Medwedeff (1989).

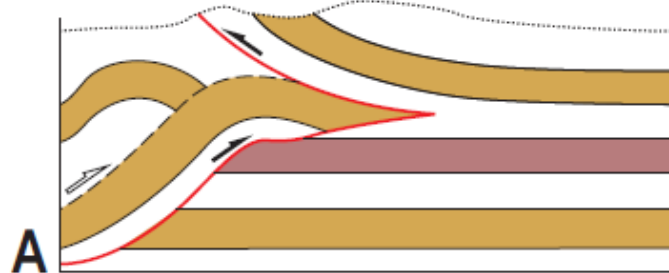


Клиновидные вдвижки во
фронте дуплексных систем.
А - Тайвань (Suppe, 1983). Б -
Северный Урал (Соборнов,
Бушуев, 1990). В - Северный
Кавказ (Соборнов, 1990).

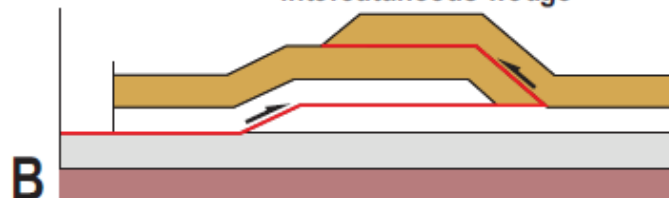


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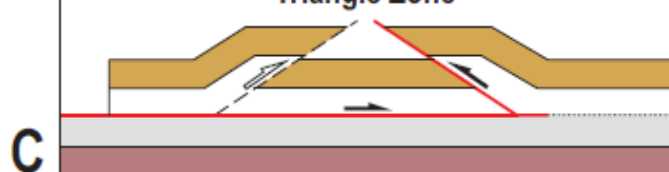
Tectonic Wedge



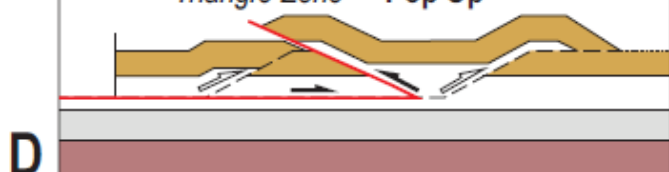
intercutaneous wedge



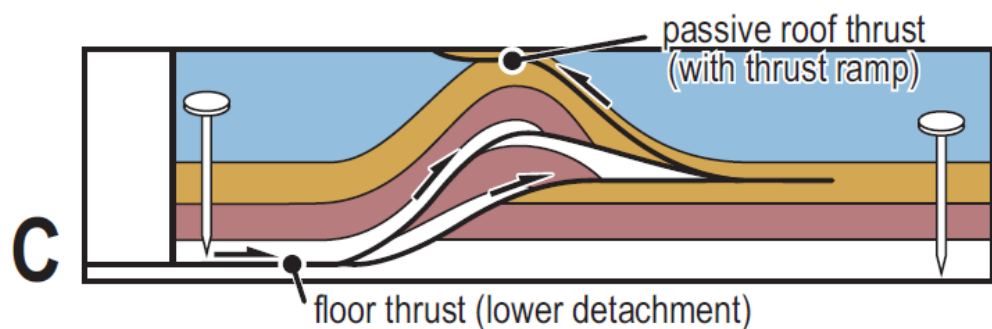
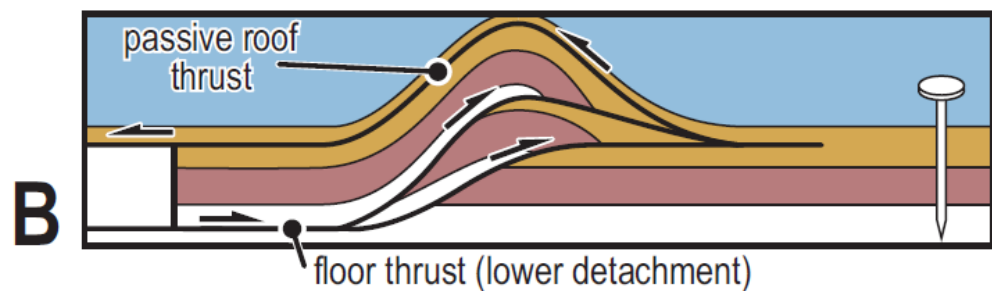
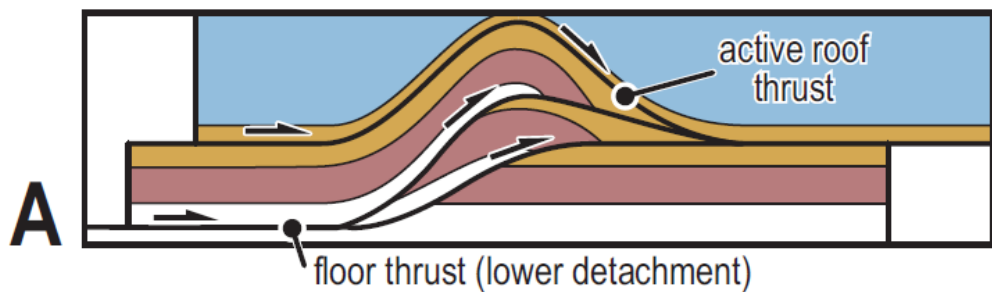
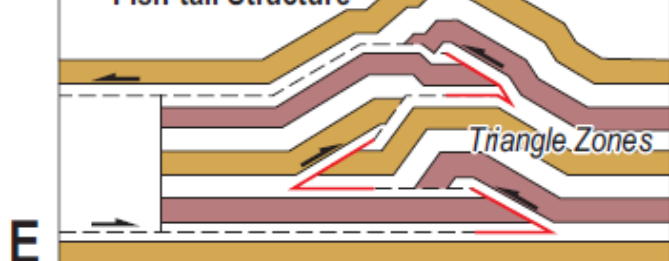
Triangle Zone



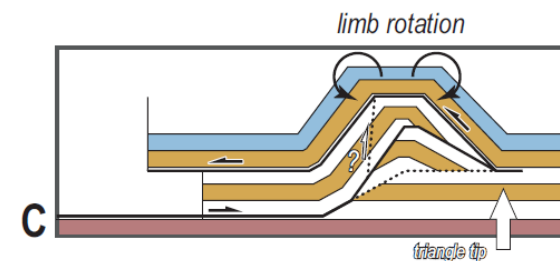
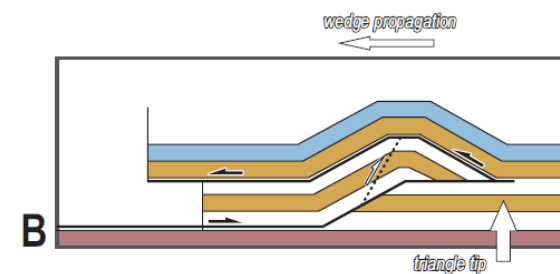
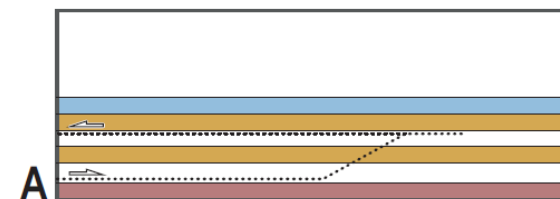
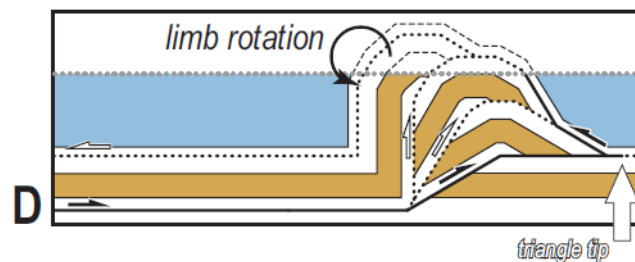
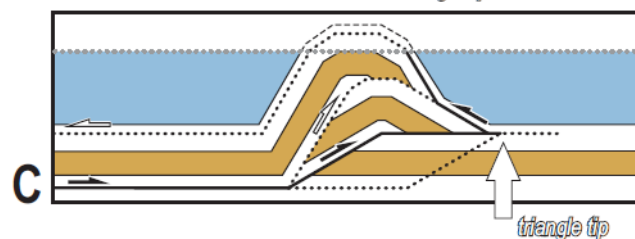
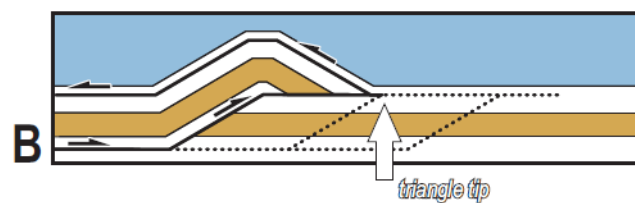
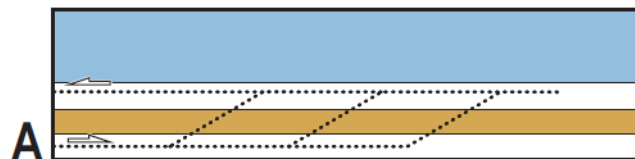
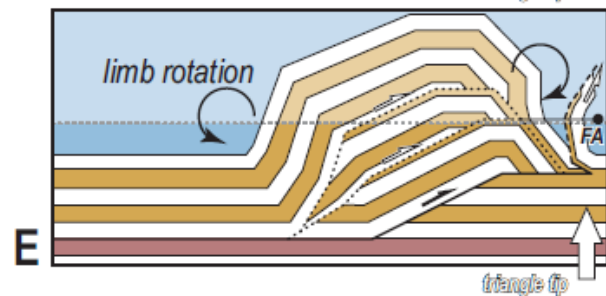
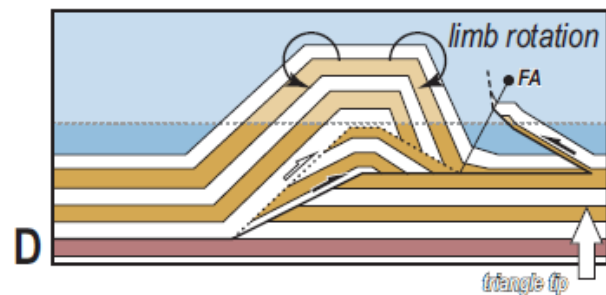
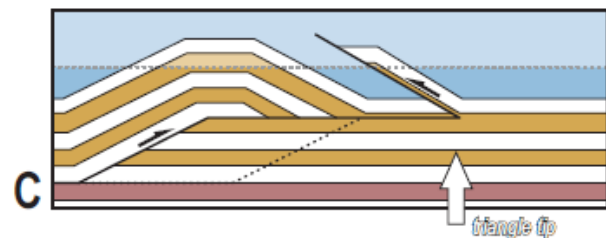
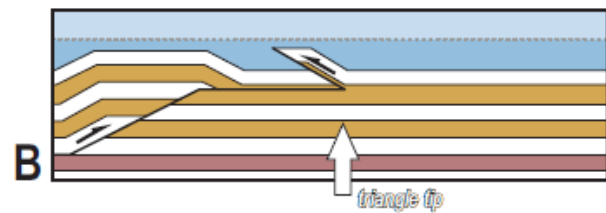
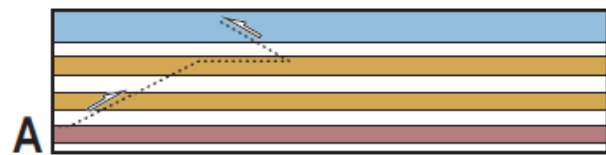
Triangle Zone Pop-Up



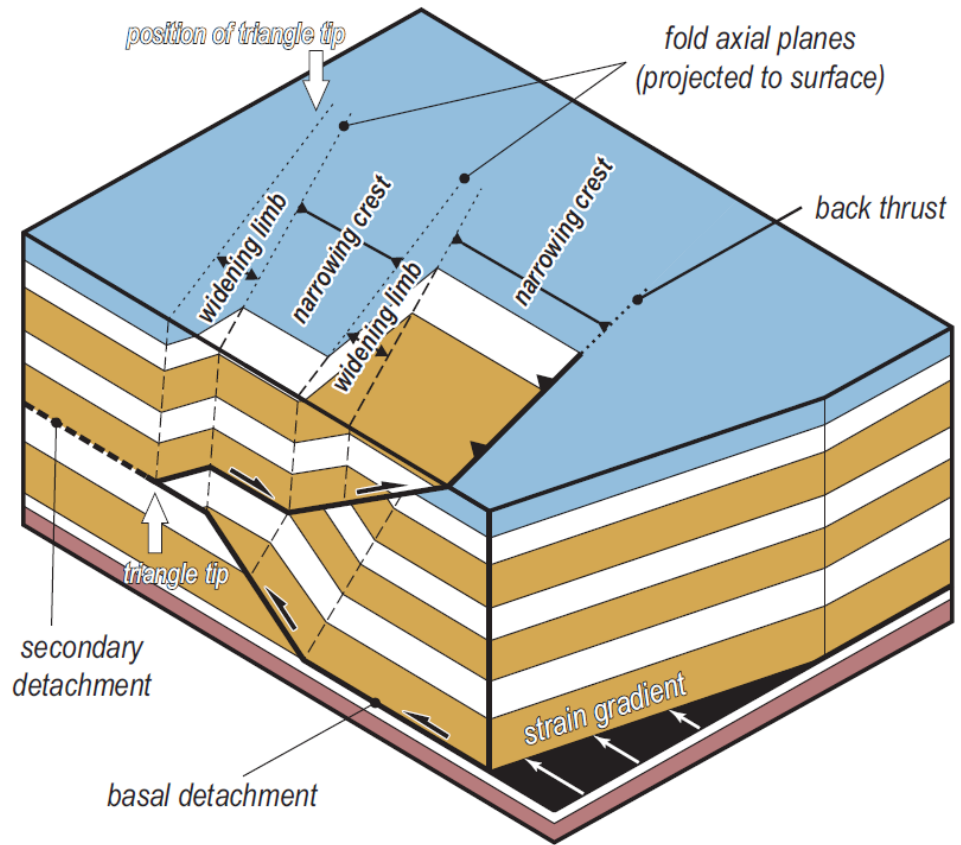
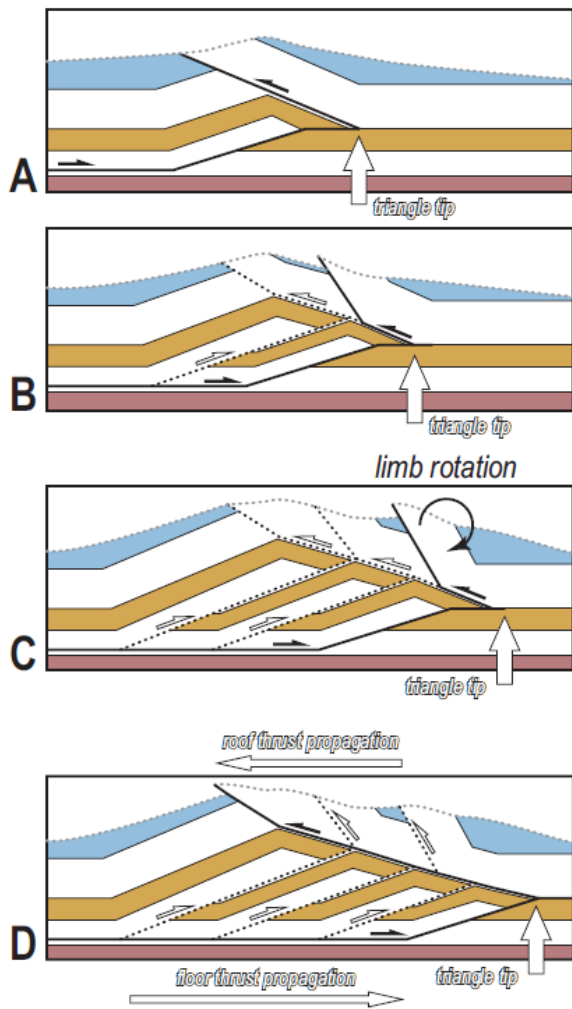
Fish-tail Structure



Please cite this article as: Christoph von Hagke, Alexander Malz, Triangle zones – Geometry, kinematics, mechanics, and the need for appreciation of uncertainties. The address for the corresponding author was captured as affiliation for all authors. Please check if appropriate. Earth(2017), doi:[10.1016/j.earscirev.2017.11.003](https://doi.org/10.1016/j.earscirev.2017.11.003)



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Некоторые примеры

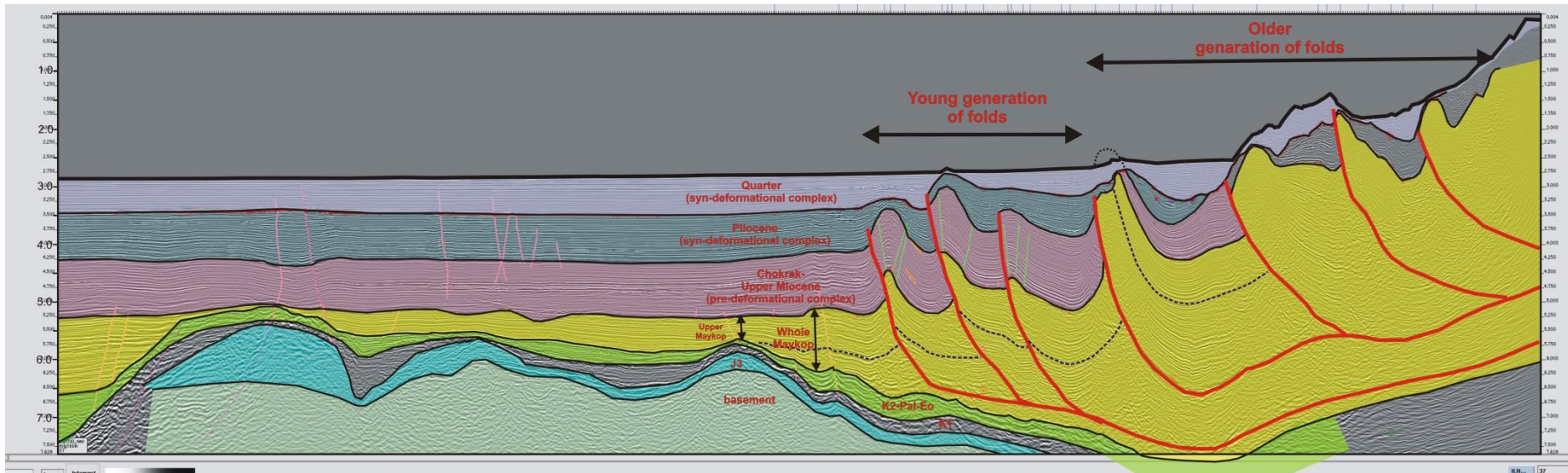
Туапсинский прогиб и вал Шатского, Черное море, данные Роснефти

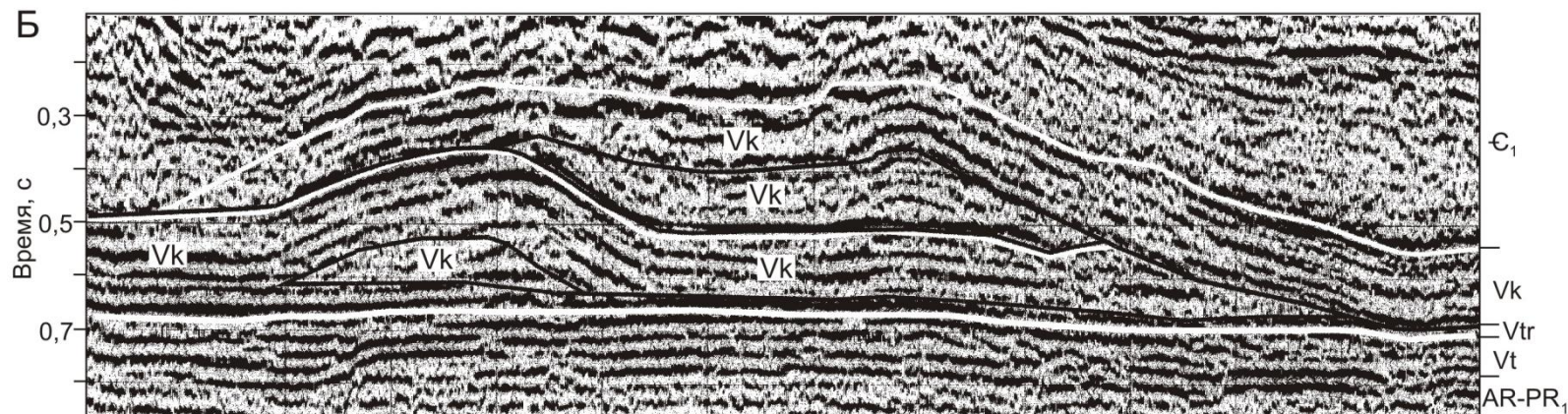
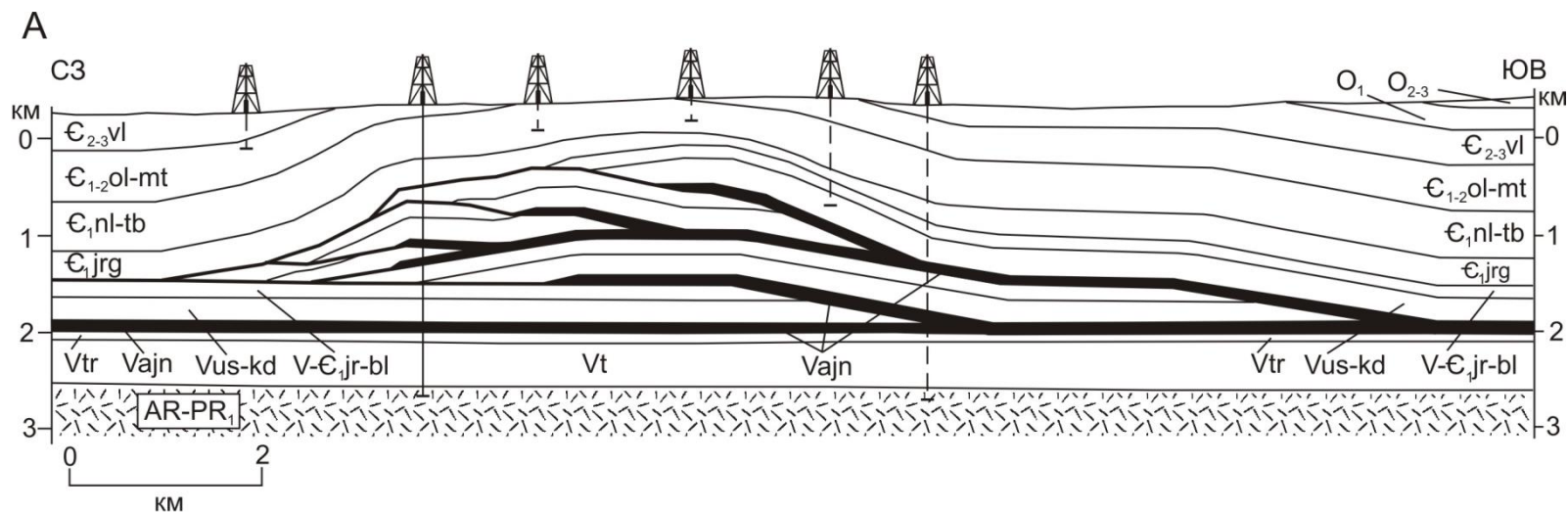
В-Черноморский бассейн

Вал Шатского

Туапсинский бассейн

Туапсинская Складчатая зона





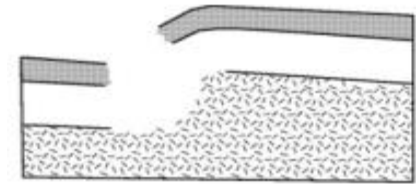
Примеры дуплексов антиформного скупивания Ньюско-Джербинской впадины Предпатомского прогиба (Прокопьев и др., 2004): А - Отраднинский дуплекс, реконструированный по буровым и сейсморазведочным данным (залежи газа установлены в верхних чешуях и в автохтоне); Б - дуплекс, реконструированный по сейсморазведочным данным (материалы АО "Якутскгеофизика").

Толстокожая тектоника

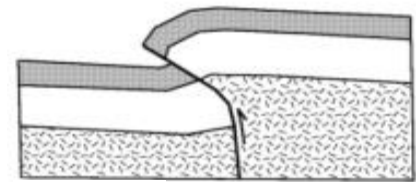
Толстокожая тектоника

(стиль единой тектоники без срывов-детачментов)

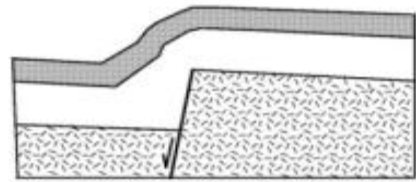
- Различные интерпретации используются для объяснения границ поднятий фундамента
 - **Взброс**
 - Формирование крутого взброса
 - **Флексура облекания**
 - Формирование складки растяжения над сбросом в фундаменте
 - **Надвиг**
 - Формирование надвига в фундаменте



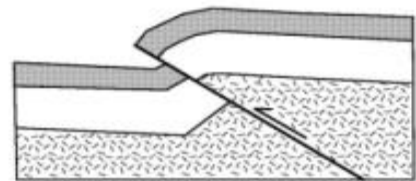
Нет данных



Взброс



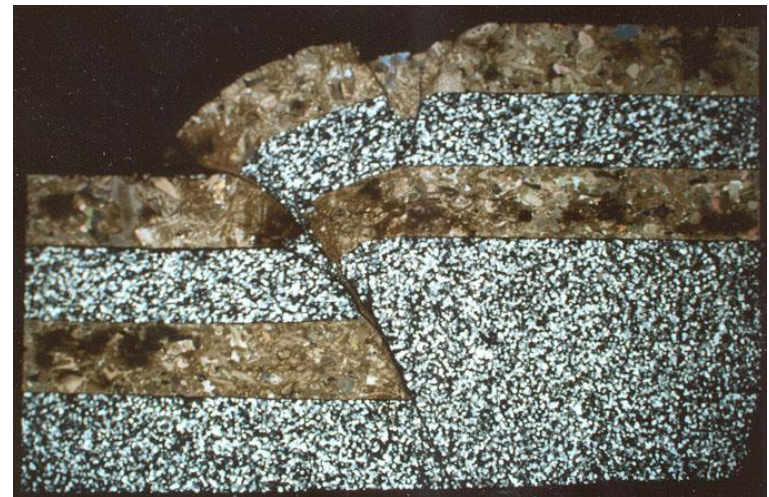
Флексура облекания



Надвиг

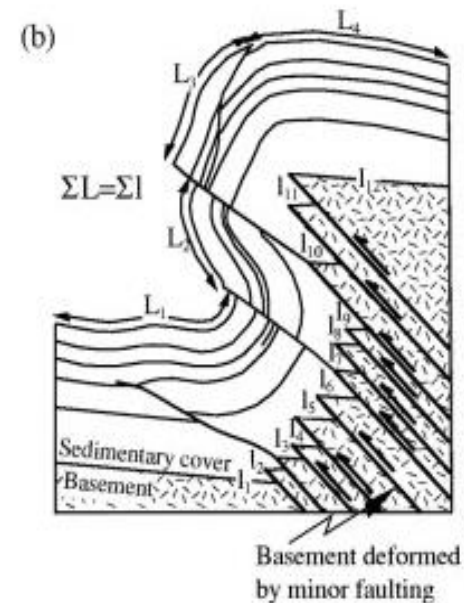
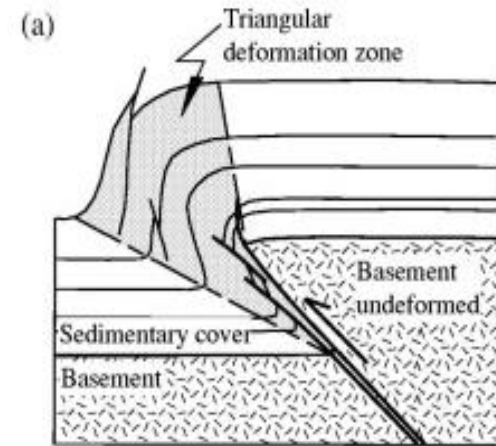
Толстокожая тектоника

- Отсутствие детачмента между фундаментом и чехлом
 - ‘Фундамент вовлечен’
- Возможна связь с реактивацией структур в фундаменте
- Обычна связь со значительными напряжениями сжатия



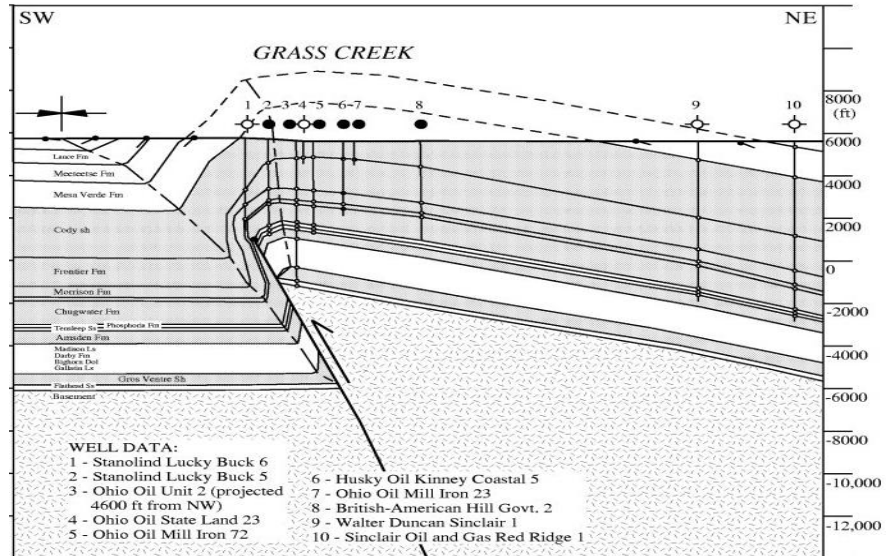
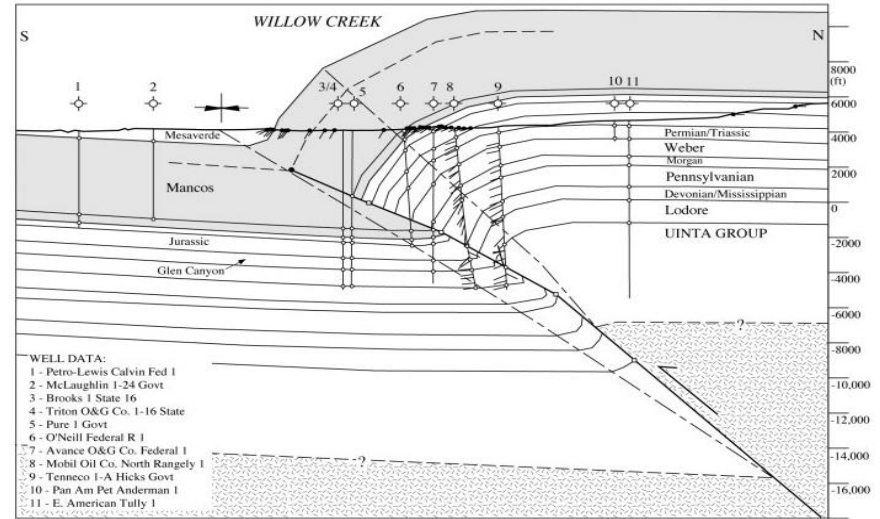
Толстокожая тектоника

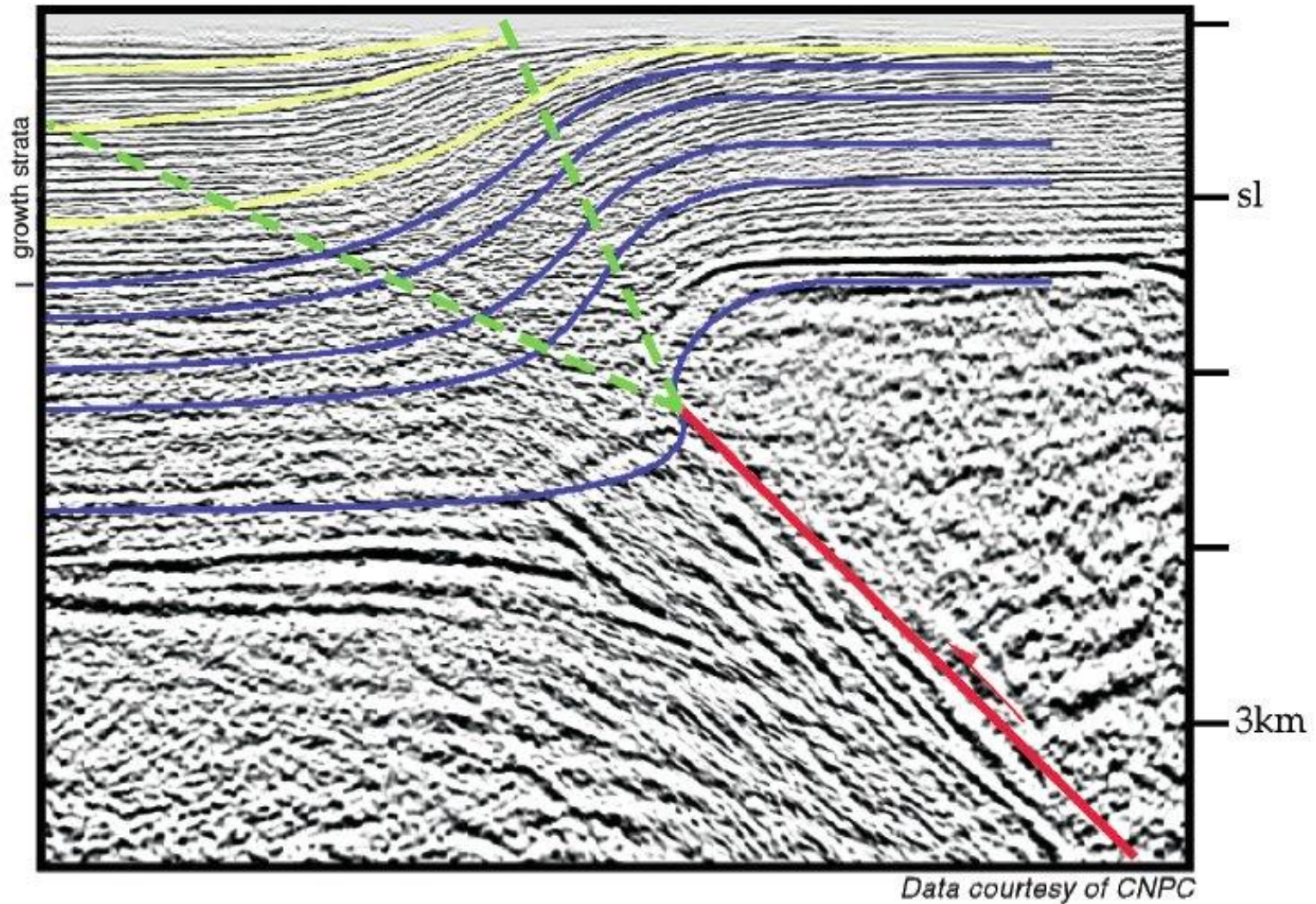
- Complex deformation associated with the 'overhang' developed at the uplifted corner of the underlying basement block
 - Triangular area undergoing a complex interplay of both folding and thrusting
- Basement reverse faulting is often localized on favorably oriented, pre-existing features
 - Earlier basement fault trends
 - Basin margin normal faults (structural inversion)



Examples – Western United States

- The Laramide orogeny occurred in Cretaceous-Tertiary time in response to plate convergence along the west coast of the North American plate
- Laramide contractional structures may reflect the trends of Proterozoic extensional faults
 - Regional variation in forced-fold vergence reflects the control of antecedent fault dips on fault-propagation fold geometry during reactivation



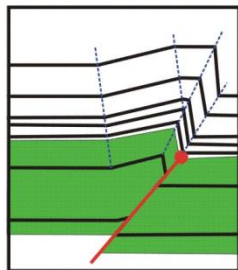
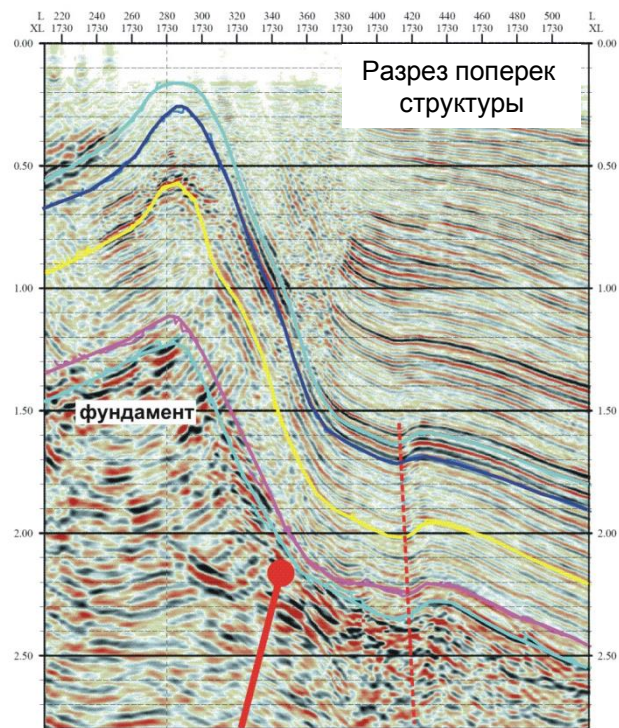
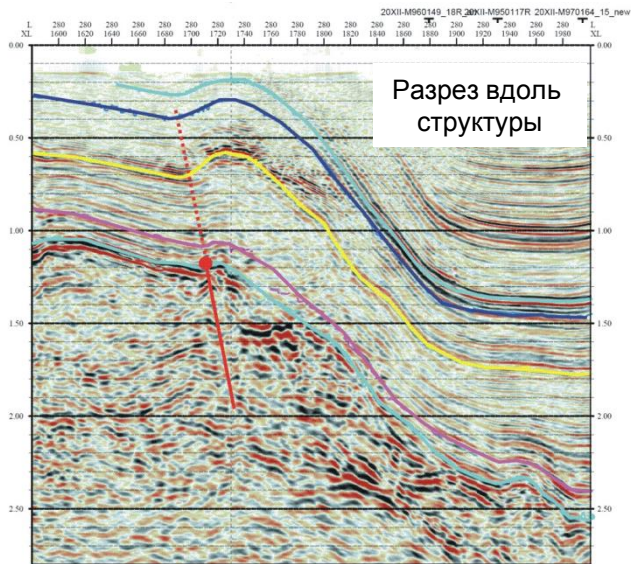


Trishear fault-propagation fold. Possible example from the Tarim Basin, China. From Shaw et al. (2005).

Большой Кавказ, Тамань, отложения меотиса



Интерпретация системы взброс-флексура. А. Никишин

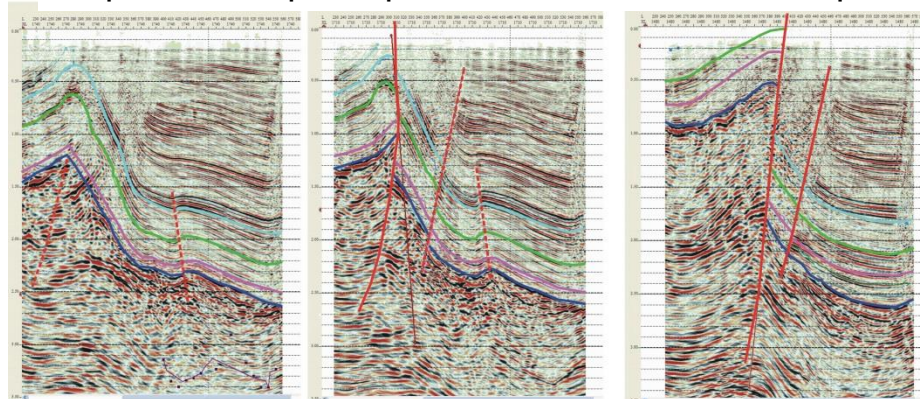


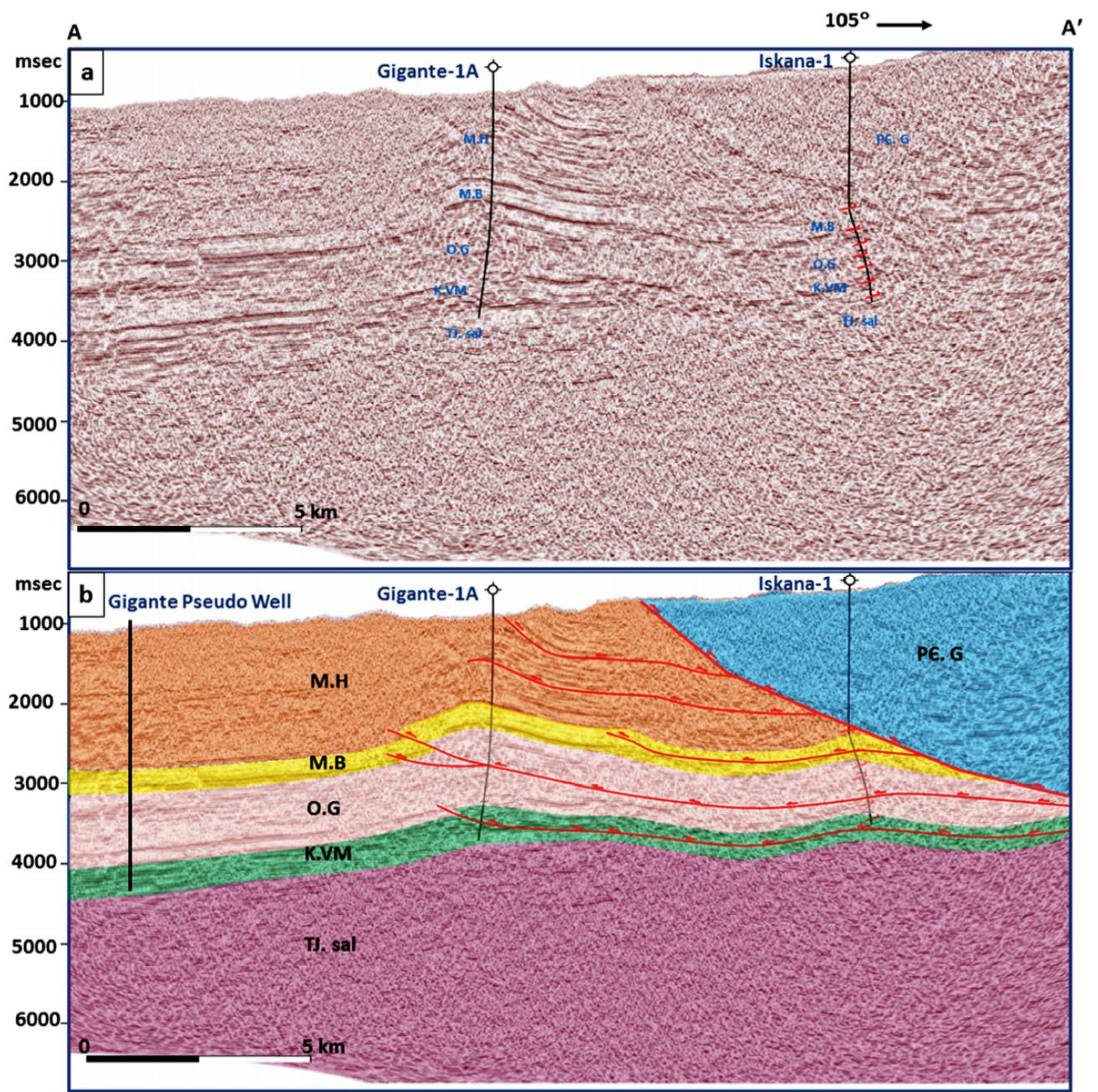
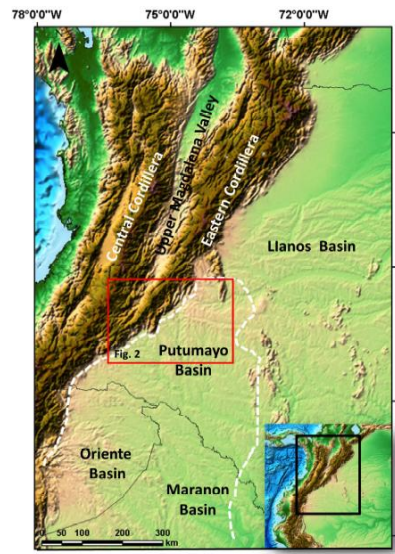
Модель складки:
складка пропагации
(прорастания)
разлома

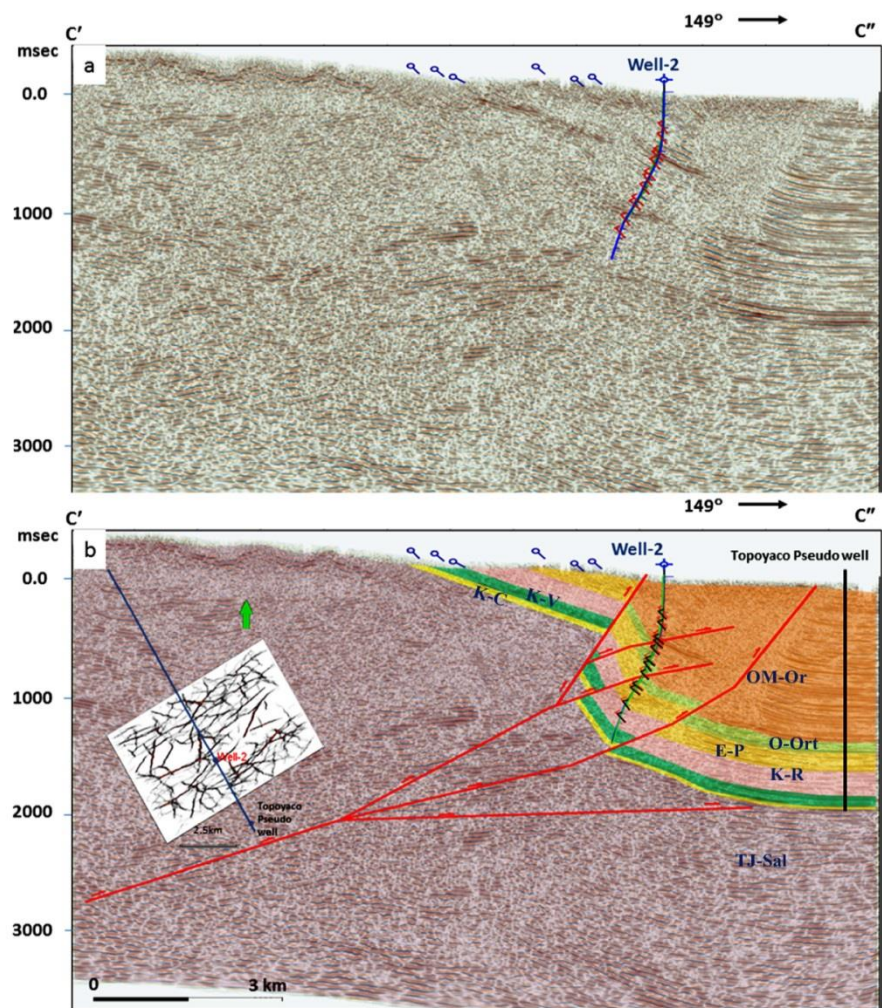
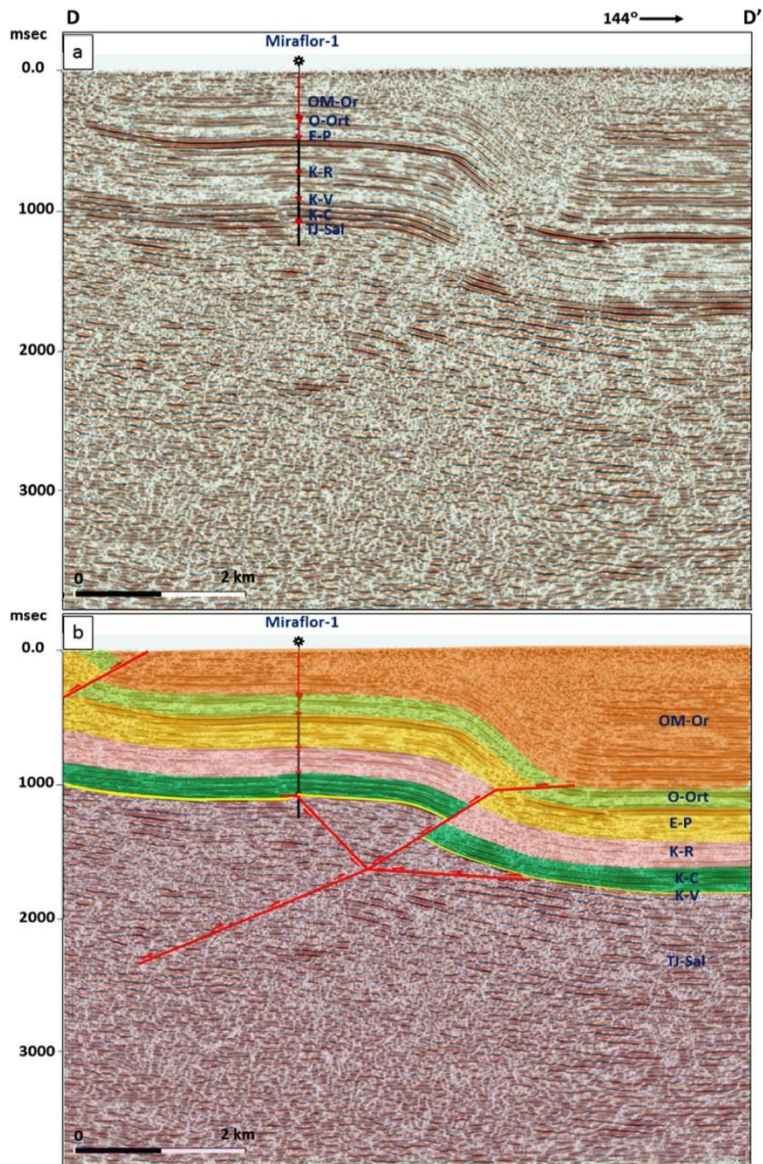
Район Сахалина

Толстокожая тектоника,
Фундамент вовлечен в
складкообразование.
Складка пропагации
разлома

Переход по простиранию складки в зоны взброса

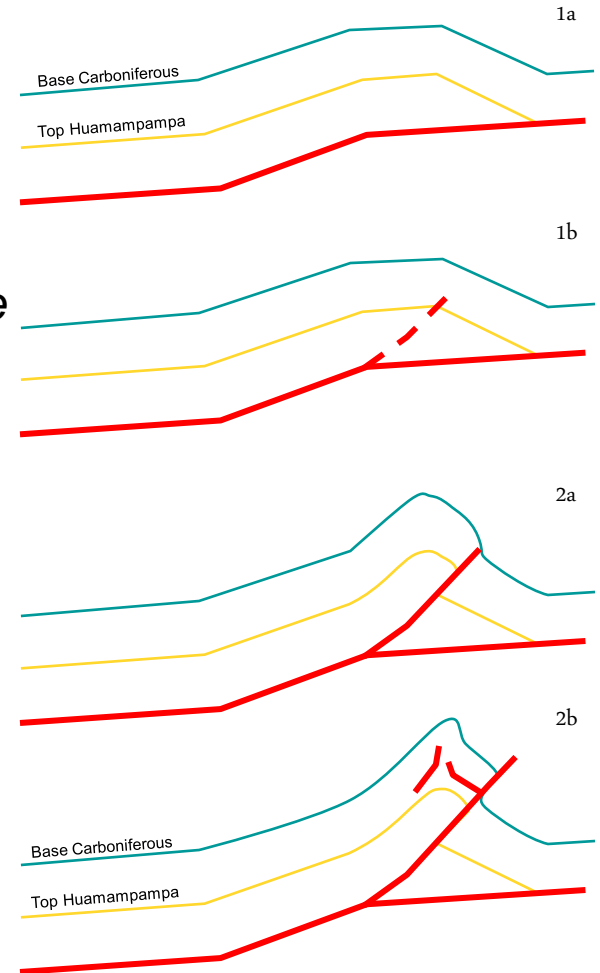
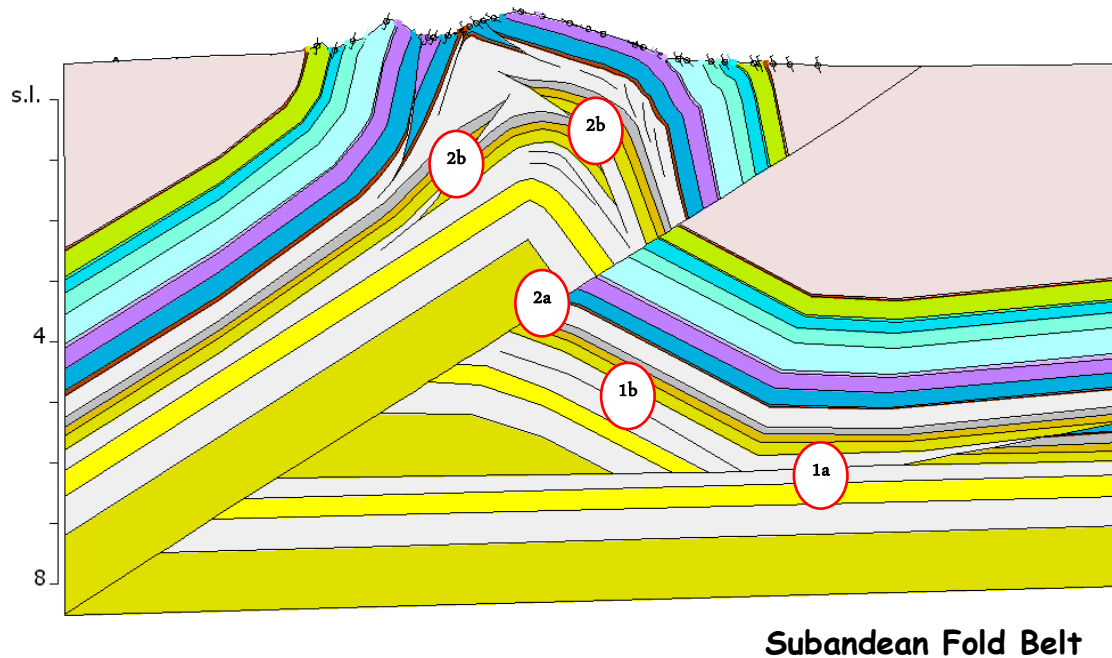






Sequence of Deformation

- *Ramp anticline emplaced prior to the development of the main HW closure*
- *Fault propagation folding on higher out-of-sequence ramp*
- *Thickening in the core of the translating anticline*

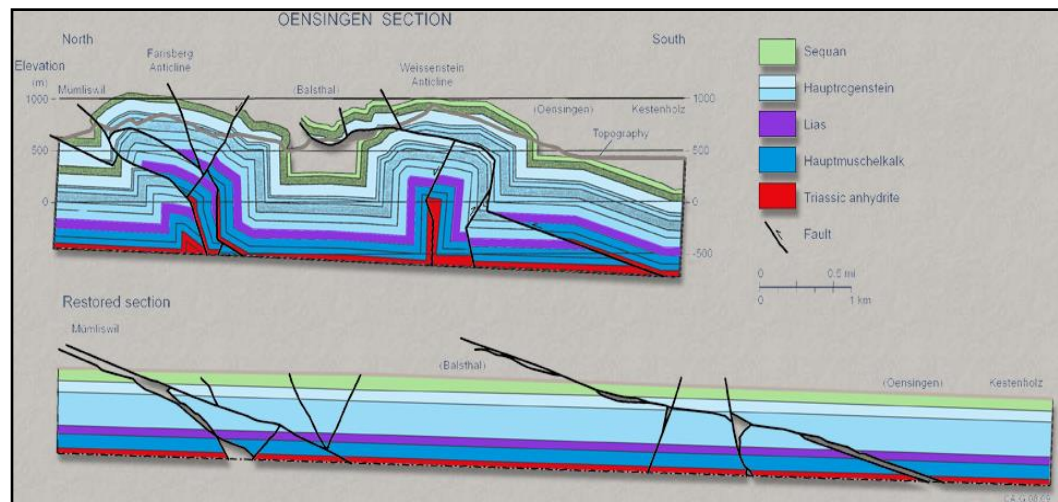


Механическая стратиграфия

Mechanical Stratigraphy

- Detachment Horizons
 - Layers of mechanical weakness relative to the enclosing stratigraphy
 - Typically shale or evaporite intervals, although coals locally can act as detachments
 - Zones of localized slip or distributed shear
 - Thin detachments typically localize thrust faults
 - Thicker detachments often underlie trains of 'detachment folds'

AGE	STRATIGRAPHIC UNIT	Formation top to CR-11 Elev. (m)	Internal velocity calculated from CR-92 well (m/s)	MECH- STRAT	
CENOZOIC	PLIOCENE	LA VILLA	1373	MODERATELY WEAK silt and sandstones	
	MIOCENE	LOS RANCHOS	2895		
	OLIGO- CENE	CARBONERA GROUP	1467		3424
		LA SIERRA	2219		3845
	EOCENE	MIRADOR	2893		4300
	PALEO- CENE	OROCUE GROUP	3542		2187
MESOZOIC	CRETACEOUS	COLON (shale)	4087	WEAK	
		SOCUY			
		LA LUNA		4812	
		COGOLLO GROUP			
		RIO NEGRO	4634		
JURASSIC	LA QUINTA		5445	STIFF-LAYER carbonates and clastics	
	?				



Mechanical Stratigraphy

- Detachment Strength
 - Weak vs. Strong
 - Variations in thrust belt structural style are strongly controlled by the mechanical properties of basal detachment unit
 - **Strong** – localization of thrust deformation on fault surfaces
 - **Weak** – general ‘flow’ of weak, ductile layers and shortening accommodated by folding processes

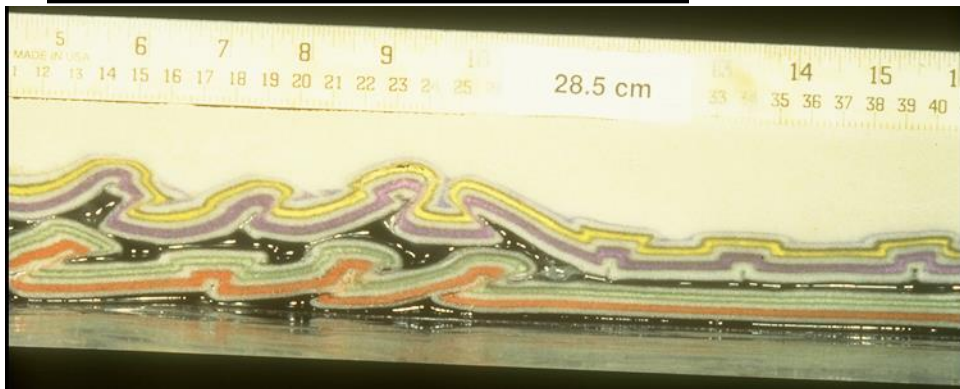
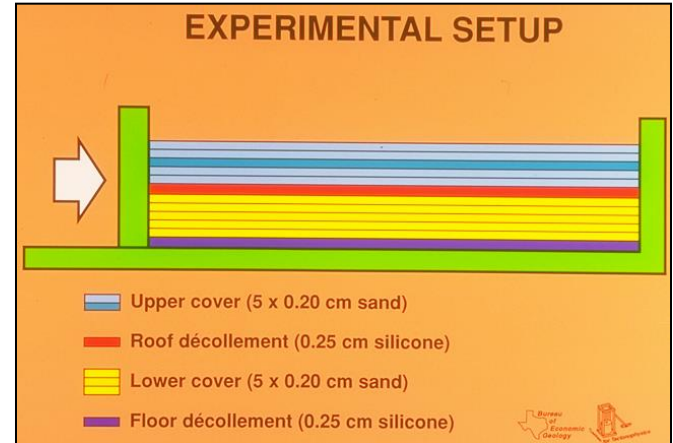
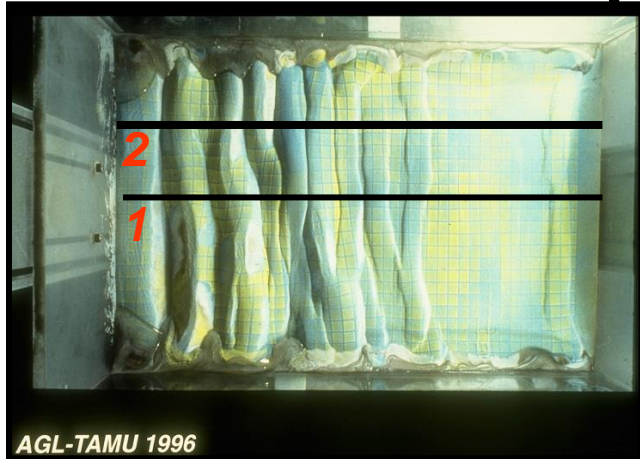


“STRONG” DETACHMENT

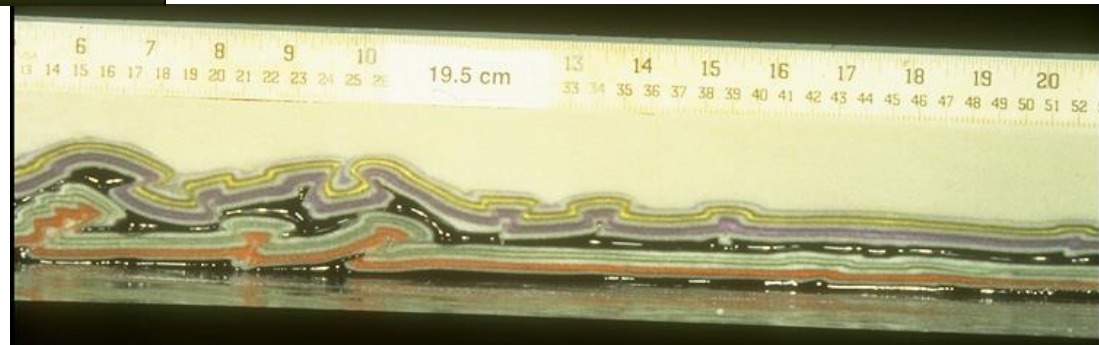


“WEAK” DETACHMENT

Multiple Detachments



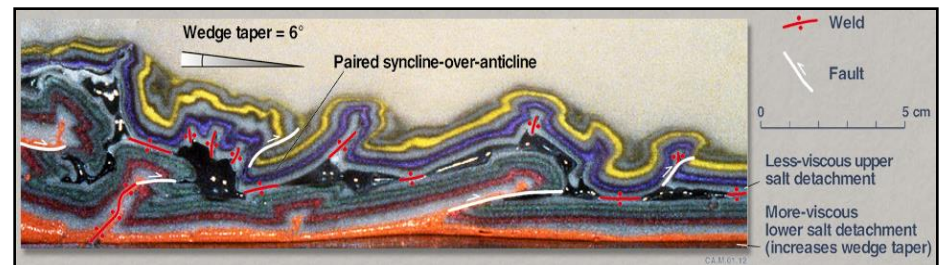
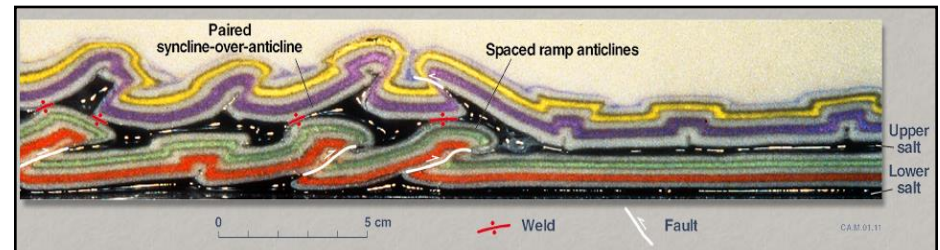
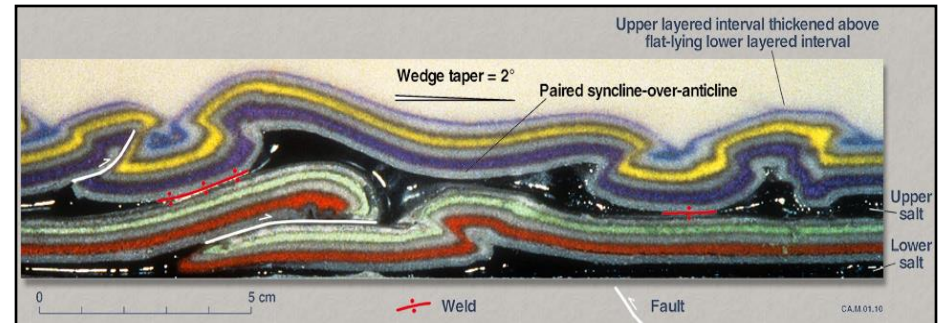
Compressional structures formed by uniform shortening of a layered section containing two detachment horizons



1

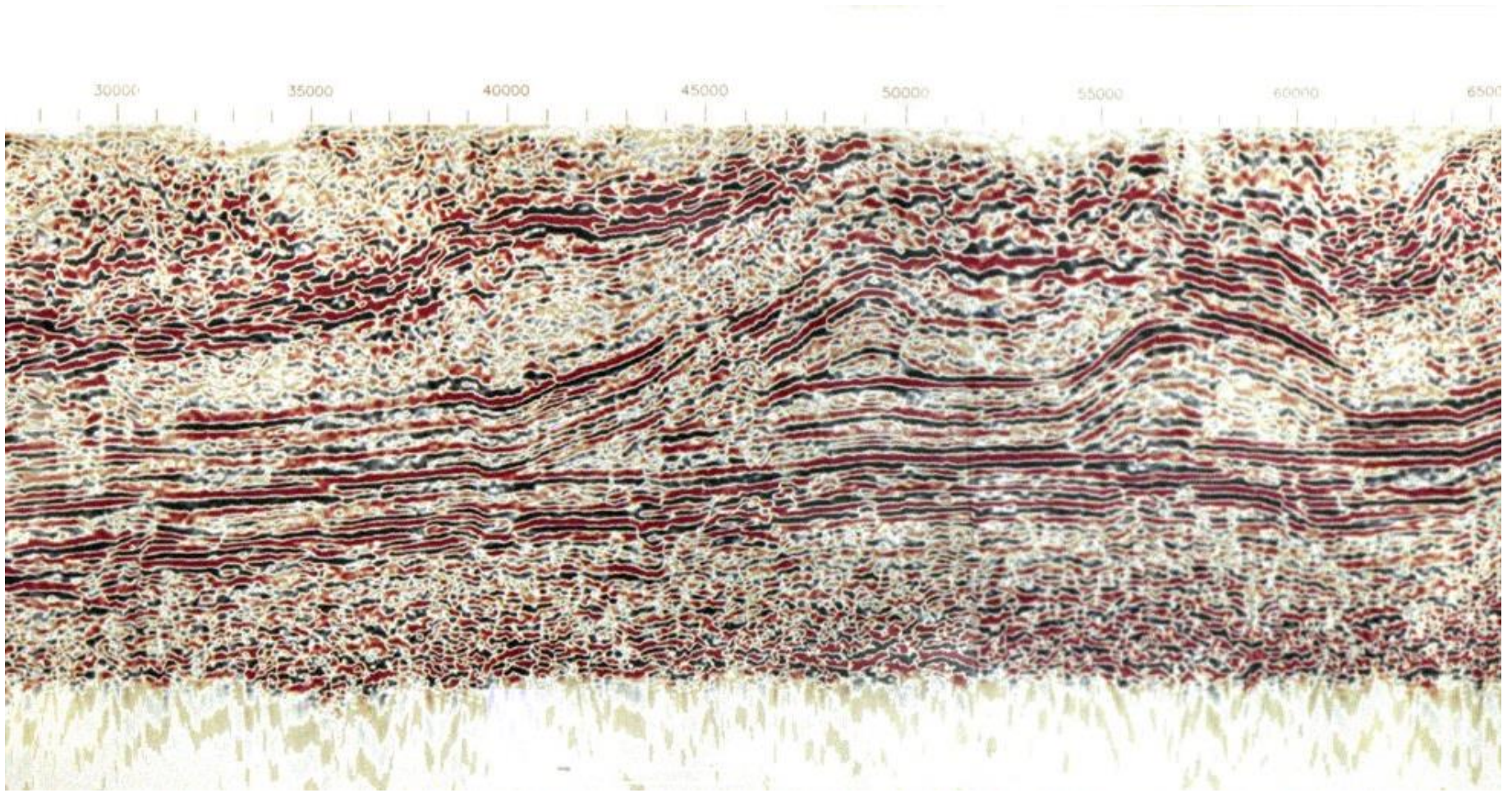
Mechanical Stratigraphy

- Multiple Detachments
 - Complex mixture of fold asymmetry, no consistent vergence (asymmetry) indicative of the tectonic transport direction
 - Lack of correspondence between structures at upper level and those beneath
 - Loose coupling between deep structures and shallow folds



Некоторые примеры

East Siberia

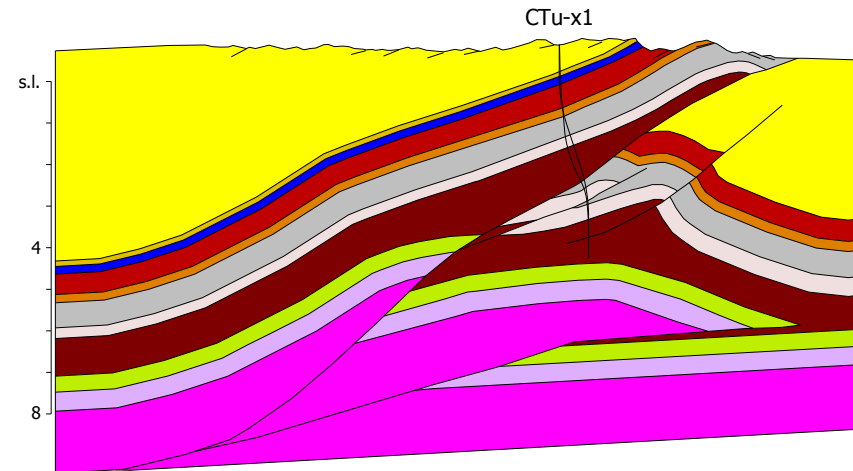


Сбалансированные разрезы

Construction of Balanced Cross-Sections

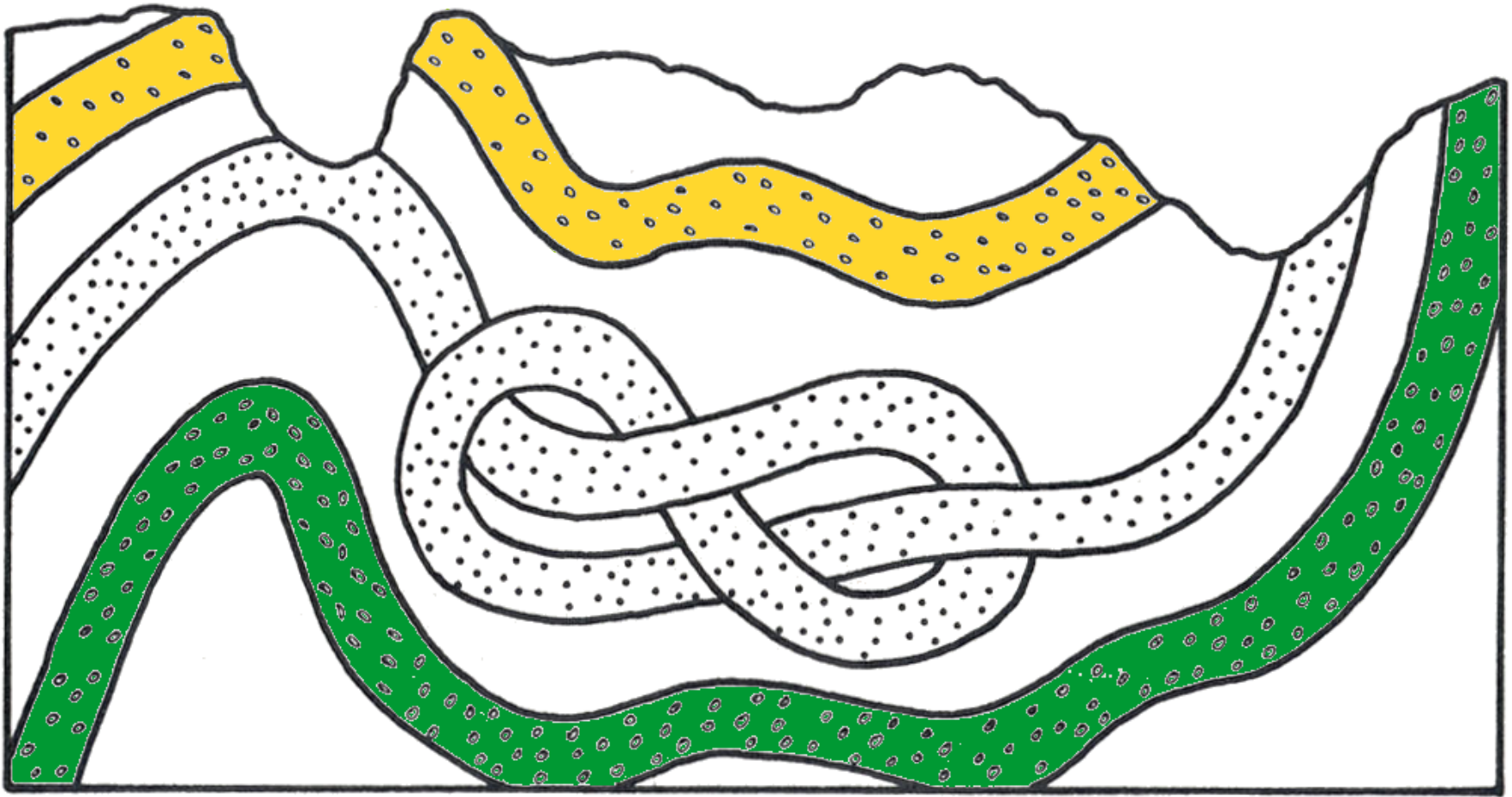
Key Concepts

- A geological cross-section should integrate all known geological and geophysical data
- Wherever possible, data from off the line of section should be projected down plunge onto the section plane
- The line of section should be chosen to lie parallel to the slip or movement direction, so that the cross-section can be balanced



- Following structural section integrates all of the available
 - Outcrop geology
 - Well-data
 - 2D & 3D seismic data
 - Regional structural style

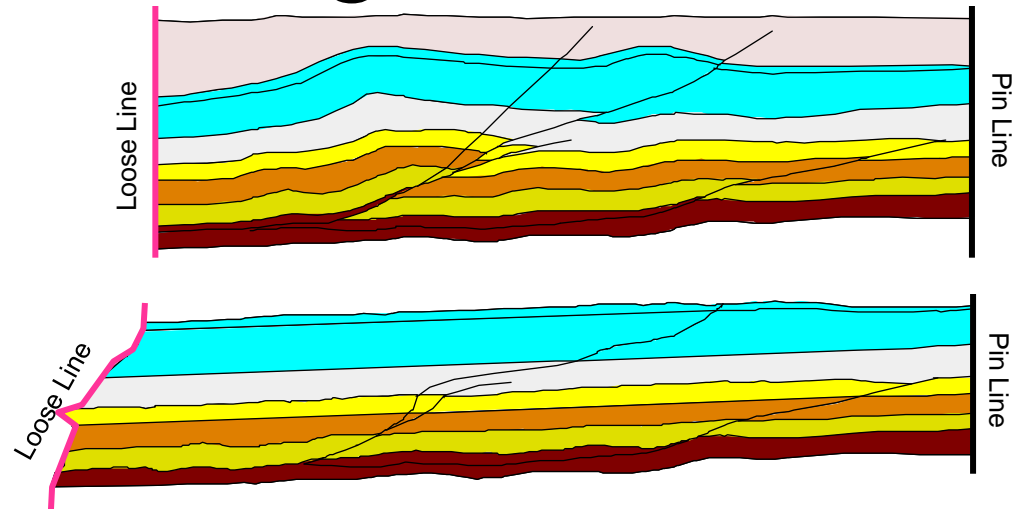
Some Problems Are Obvious



Structural Restoration & Balancing

Line Length Balancing

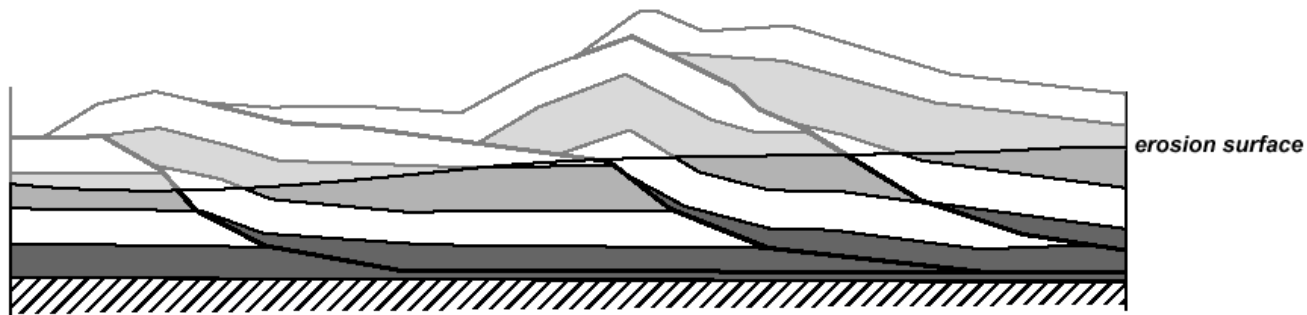
- Pin line
 - A line in the cross section that remained stationary and is therefore the same in both the deformed and restored cross sections
 - Usually selected to be
 - perpendicular to undeformed bedding
 - most undeformed portion of section
 - most complete stratigraphic section
 - Must not cross a fault



- Loose line
 - A line in a cross section that is distorted during deformation
 - Fault planes can be thought of as loose lines

Line-Length Restoration

- Restore the section below using a simple line length balance.
 - A footwall template has been provided for you to begin your



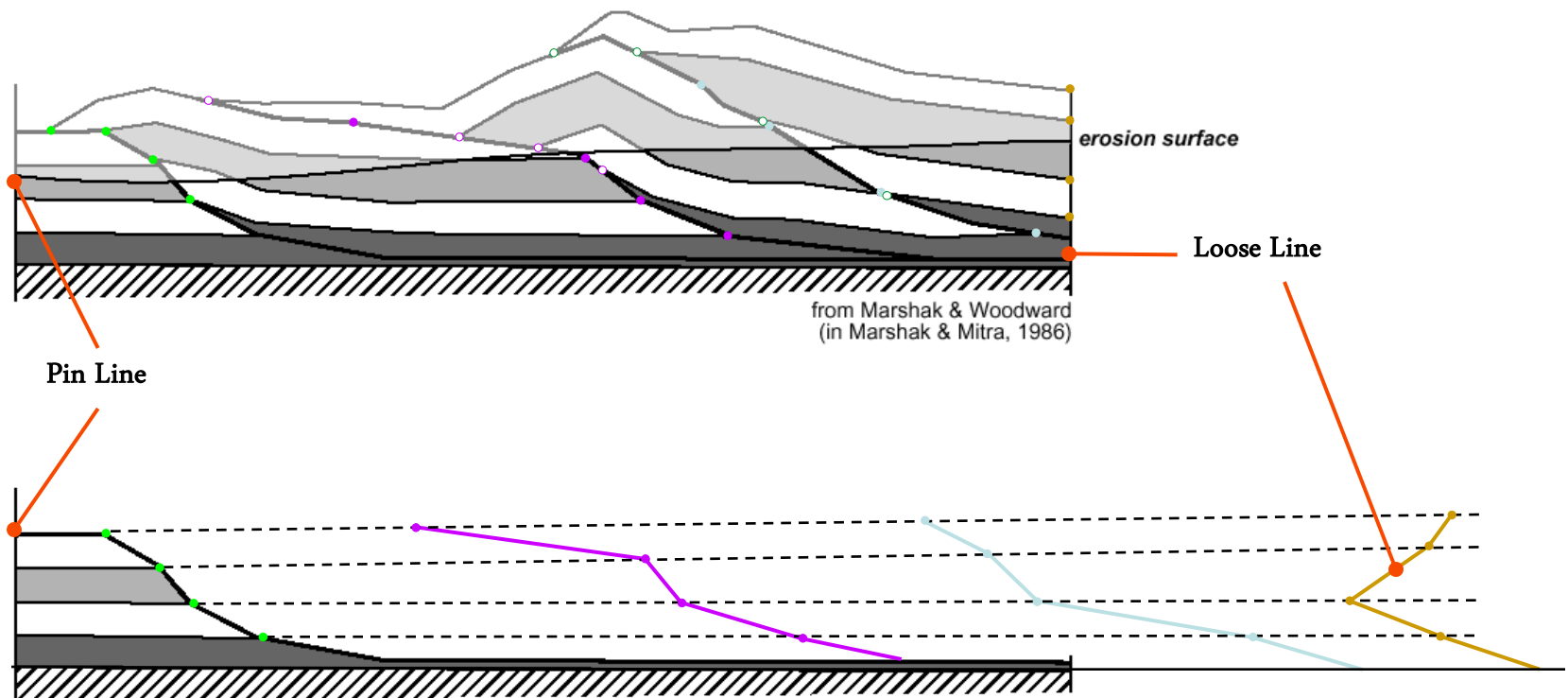
from Marshak & Woodward
(in Marshak & Mitra, 1986)

right so you
atum.



Line-Length Restoration: Solution

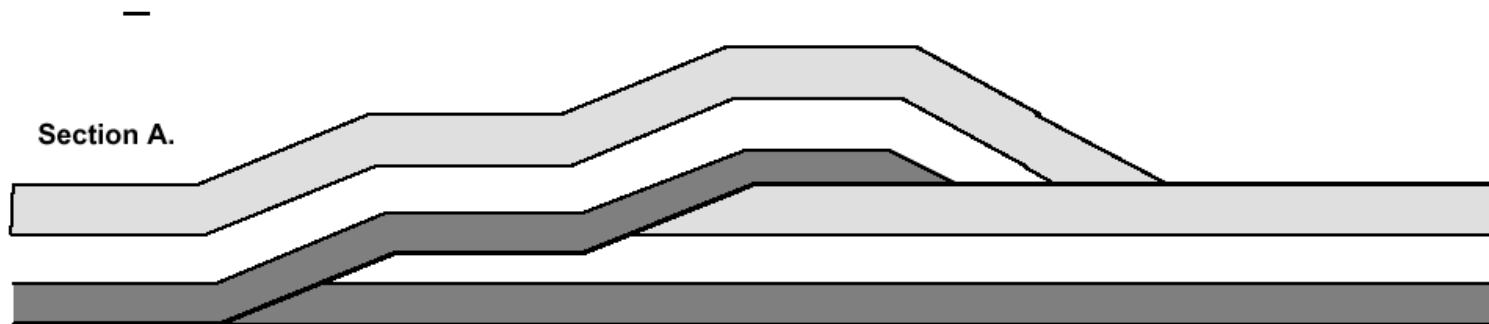
- HW & FW Cutoff points have been transferred from deformed to restored state, allowing construction of restored fault trajectories
- Trailing loose line has irregular geometry in restored state suggesting a line-length deficit exists at an intermediate stratigraphic level



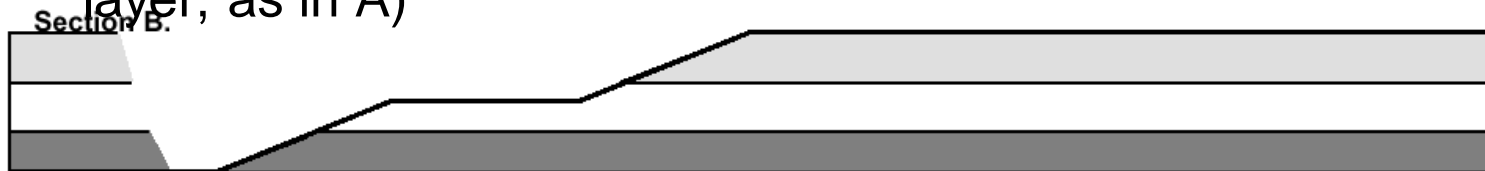
Quick-Look Analysis - Discussion

- **Cross-section A is incorrect.**

Identify what is wrong with the section in one or two sentences.



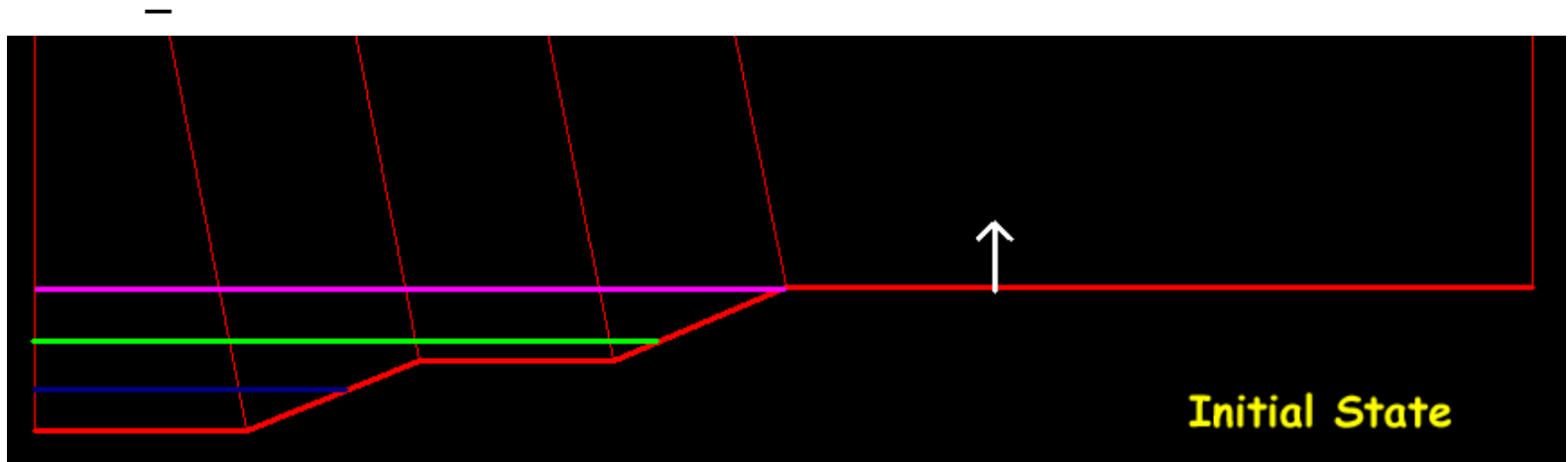
- Assuming the fault shape is correct, *sketch* the correct HW geometry below (Use the same displacement of the lowest layer, as in A)



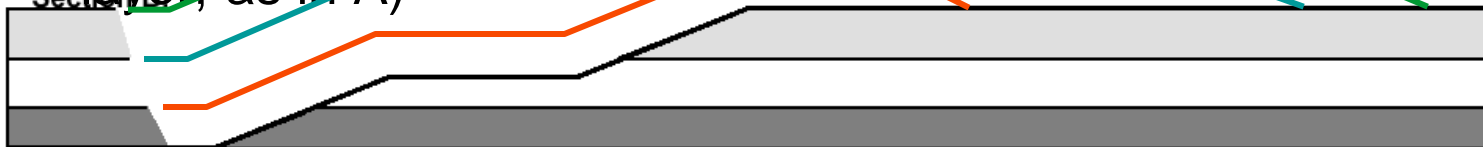
Quick-Look Analysis – *Solution*

- **Cross-section A is incorrect.**

Identify what is wrong with the section in one or two sentences.



- Assuming the fault shape is correct, *sketch* the correct HW geometry below (Use the same displacement of the lowest layer, as in A)



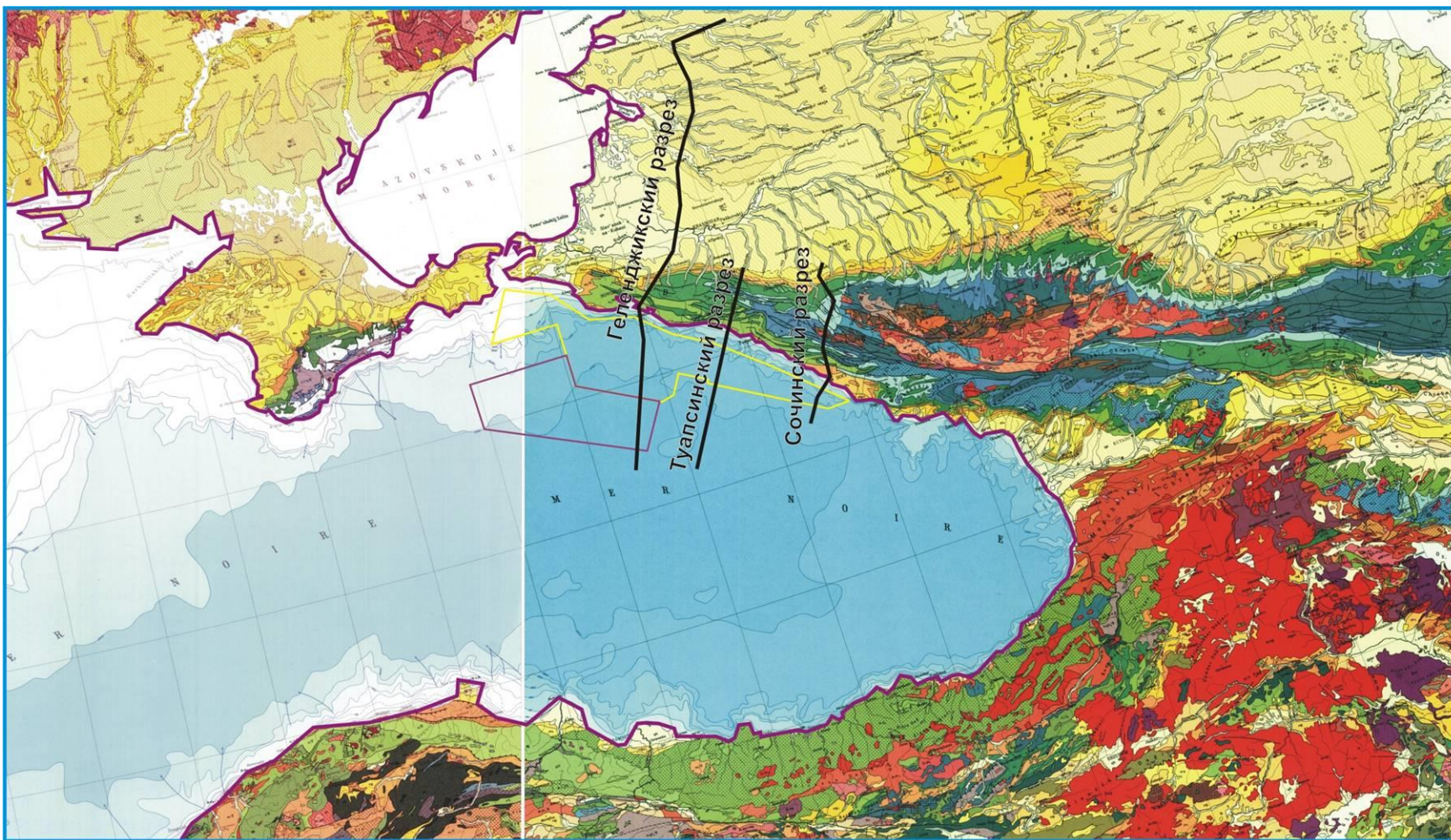
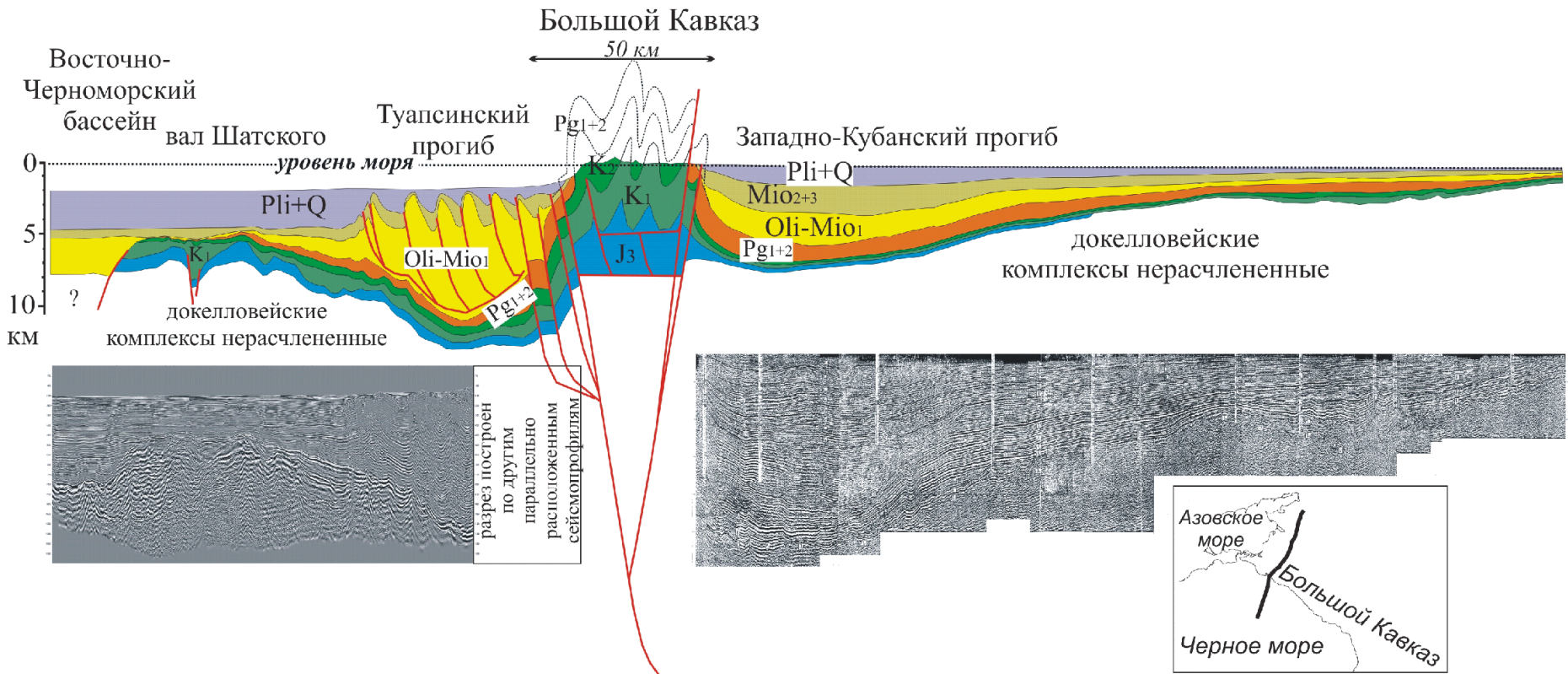


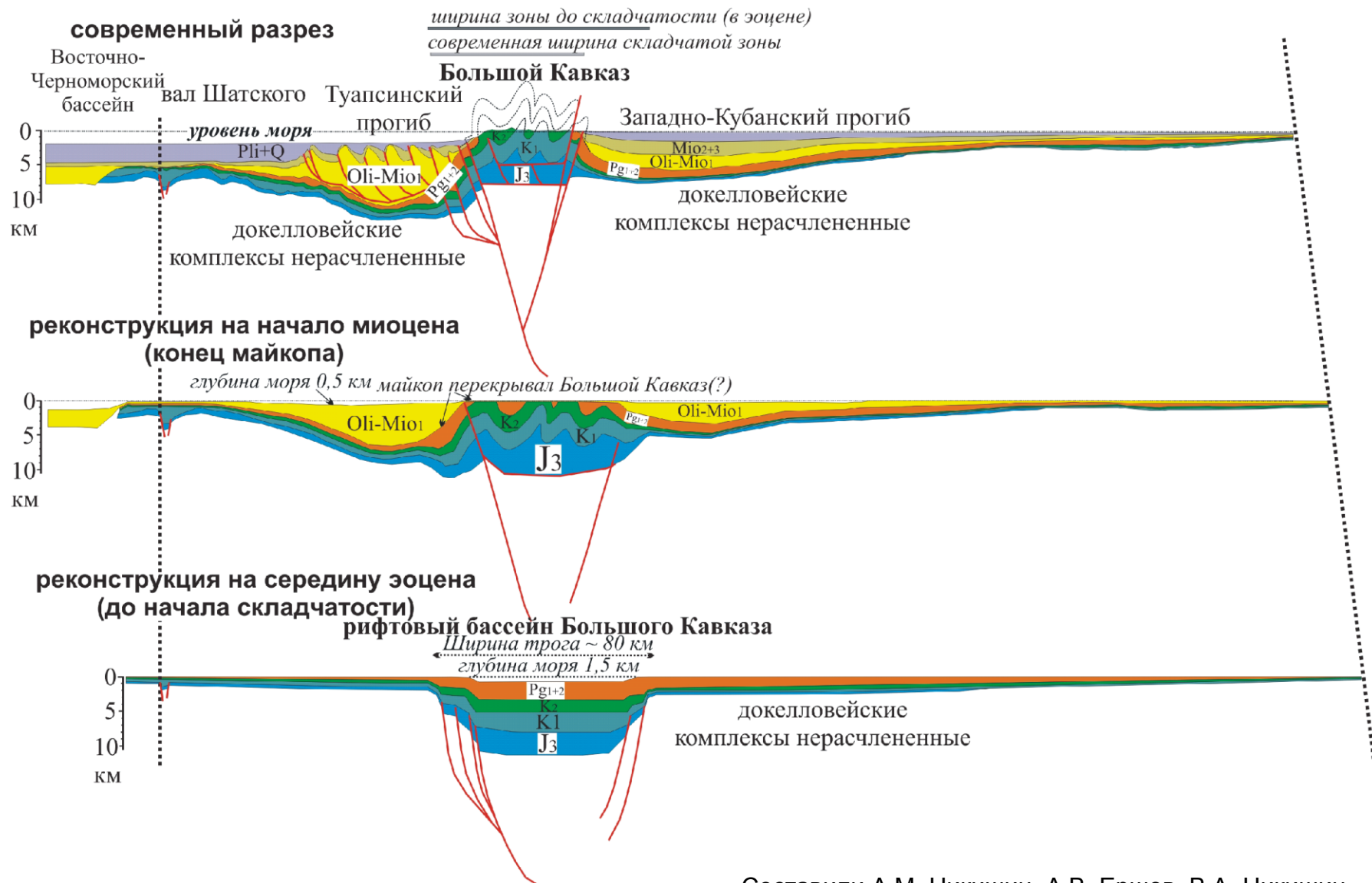
Схема расположения профилей, для которых были построены сбалансированные разрезы.

Геологический разрез через район Западного Кавказа



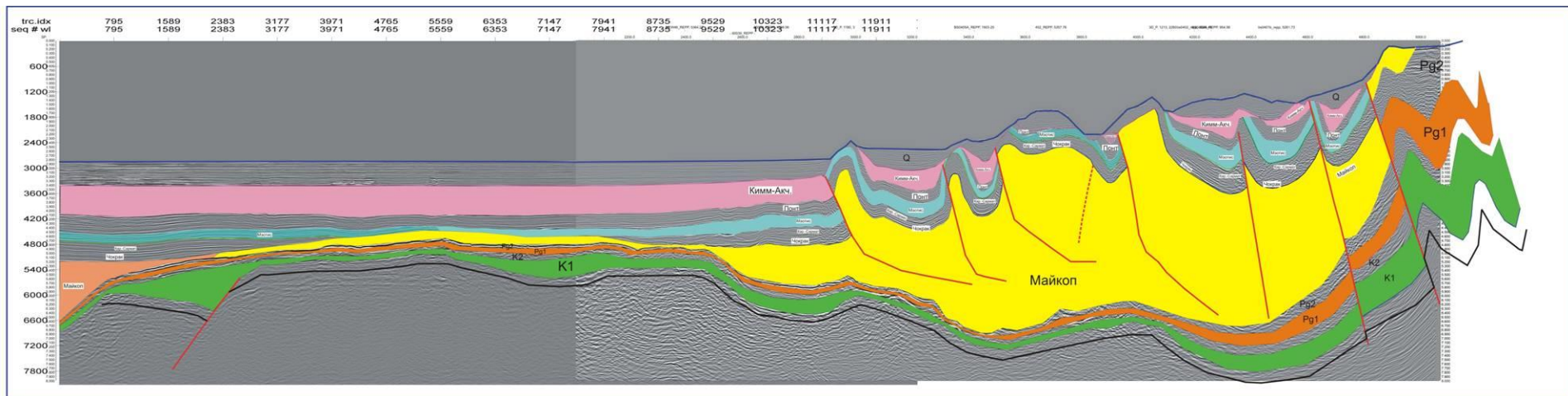
Составил А.М. Никишин

Геологическая история Западного Кавказа вдоль Геленджикского разреза



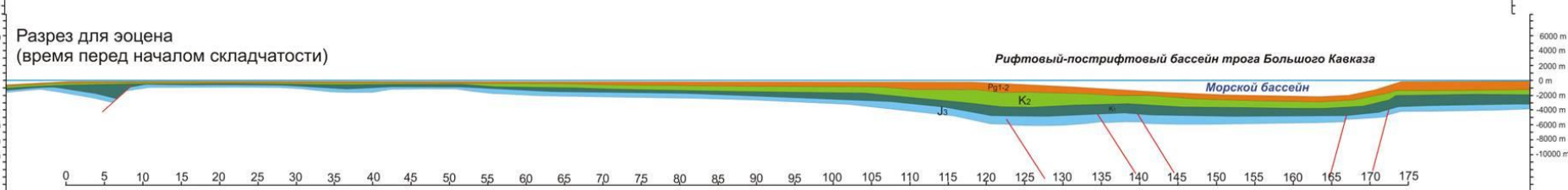
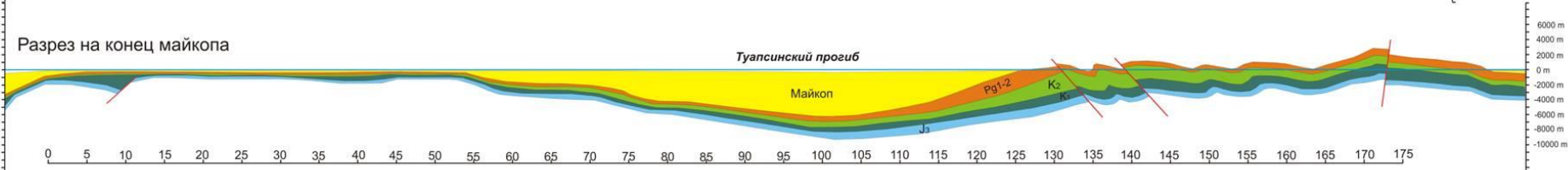
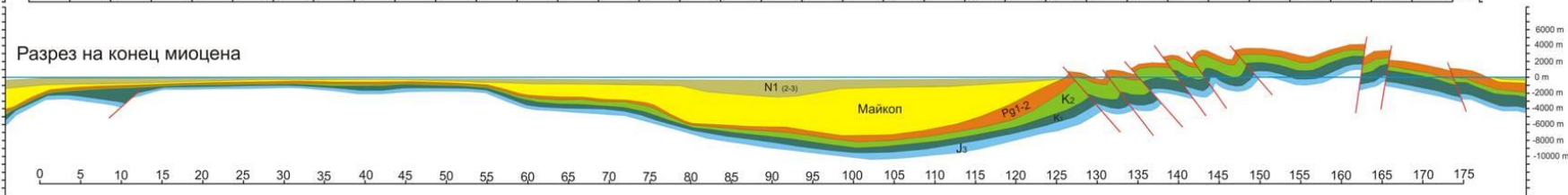
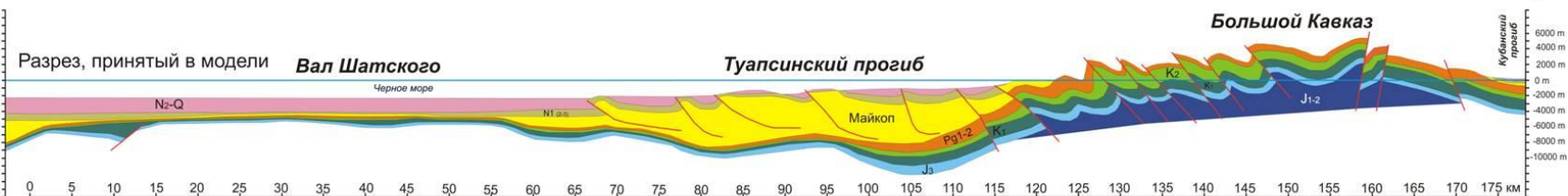
Составили А.М. Никишин, А.В. Ершов, В.А. Никишин

Геологический разрез по линии 39 сейсмического профиля

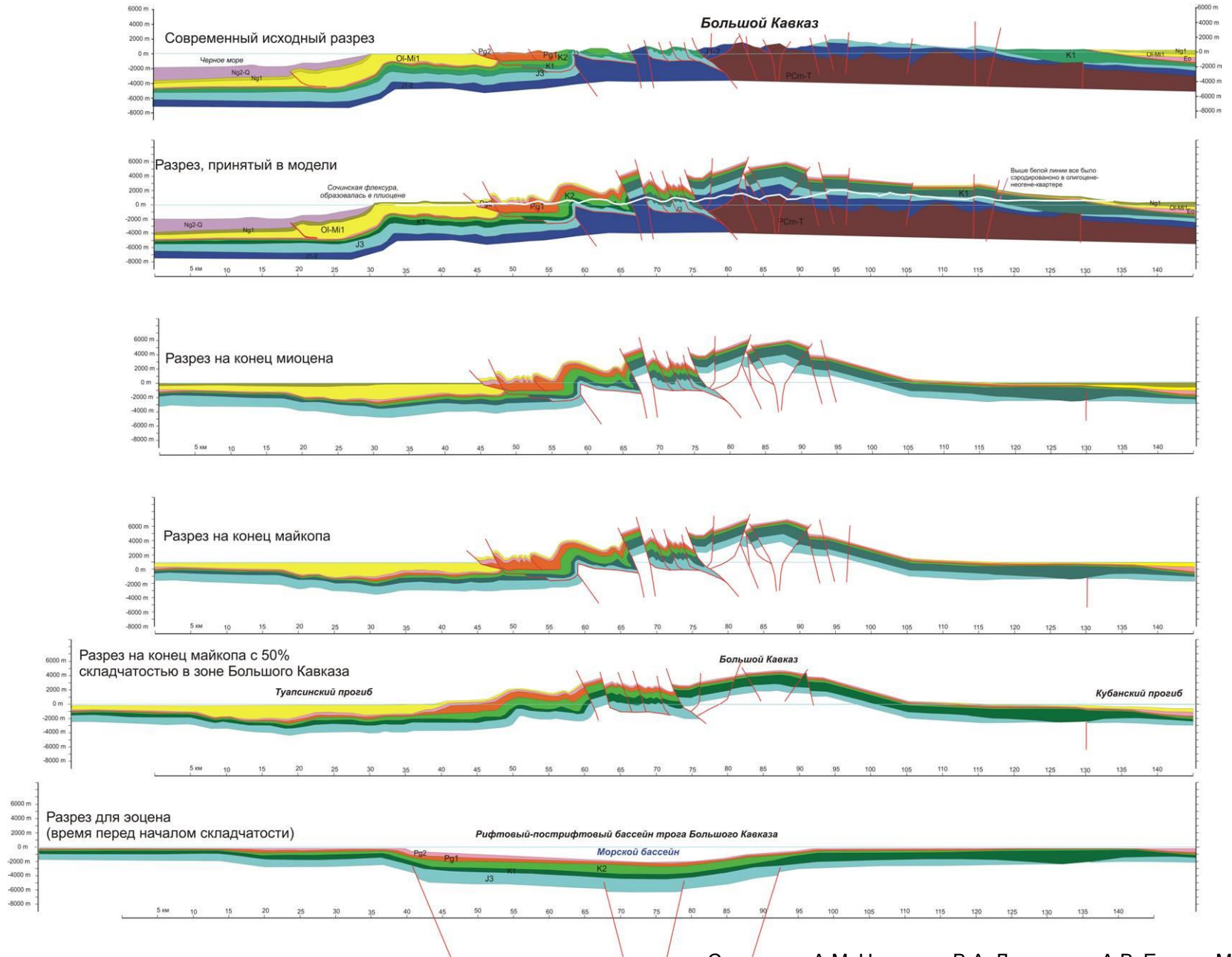


Геологическая история Западного Кавказа вдоль Туапсинского разреза

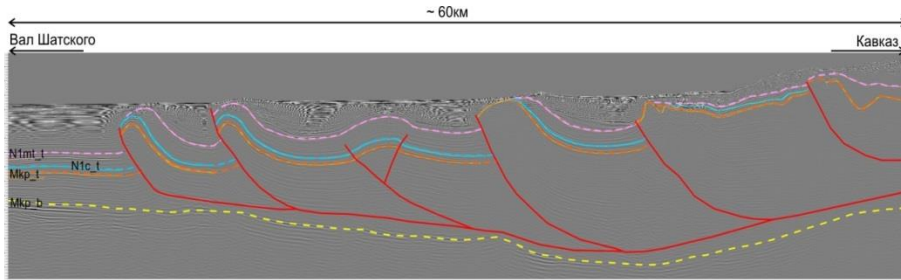
Современный исходный разрез



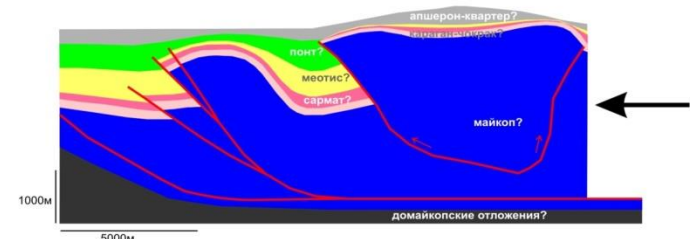
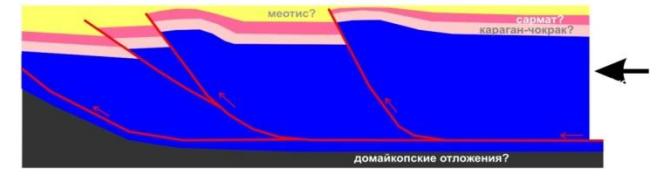
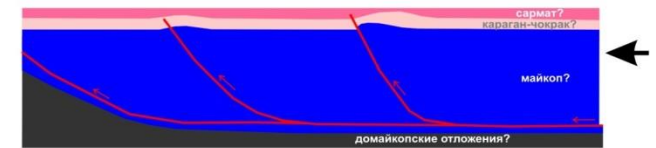
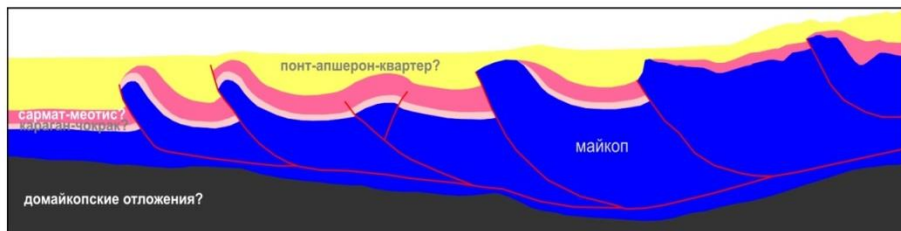
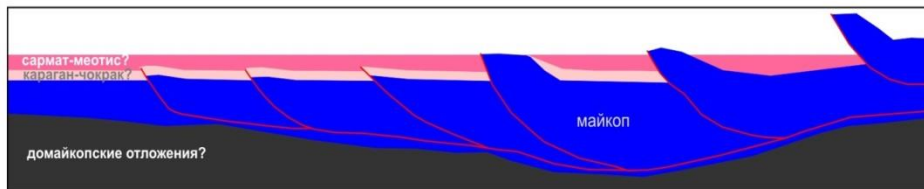
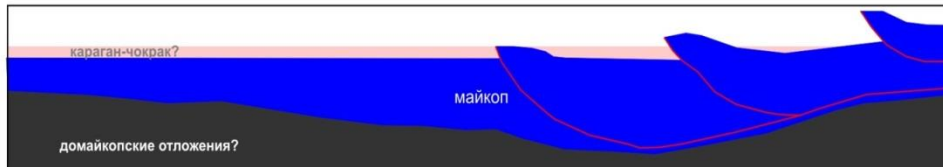
Геологическая история Западного Кавказа вдоль Сочинского разреза



профили через
 центральную часть Туапсинского
 прогиба и их реконструкция
 (Альмендингер, 2011).



Индексы отражающих горизонтов:
 Mкр_b - предполагаемая подошва майкопа
 Mкр_t - предполагаемая кровля майкопа
 N1c_t - предполагаемая кровля чокрака
 N1mt_t - предполагаемая кровля меотиса



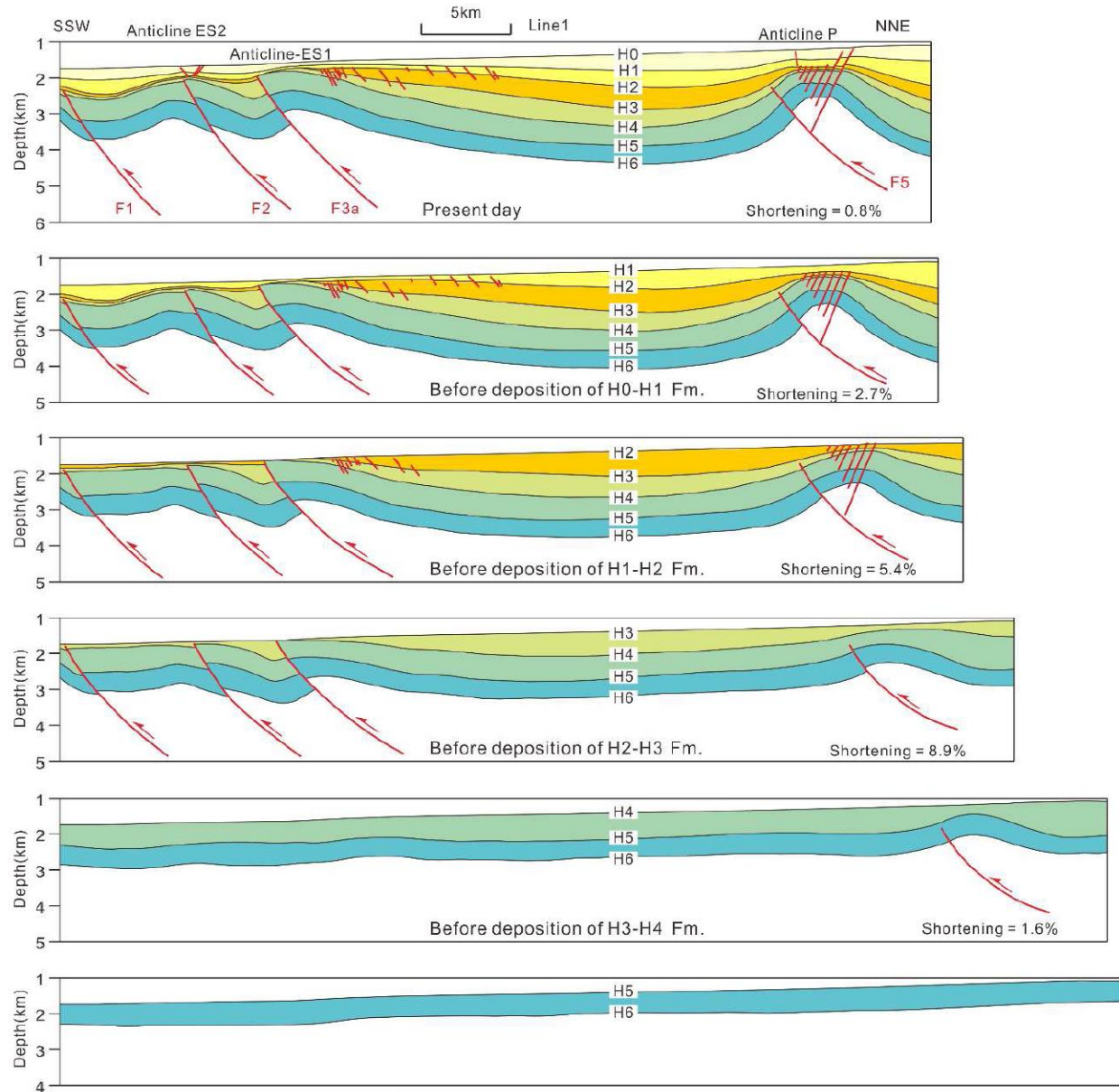
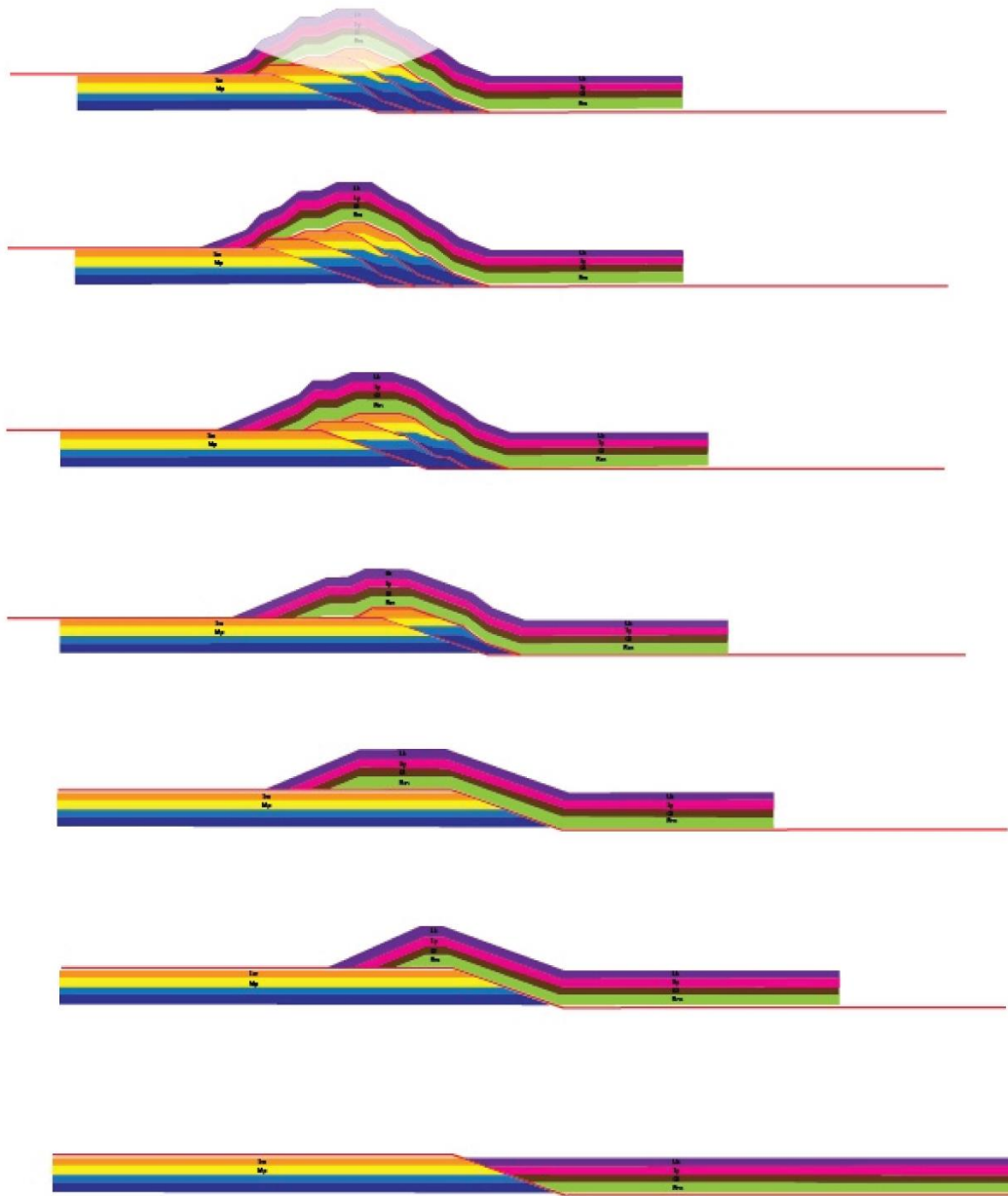


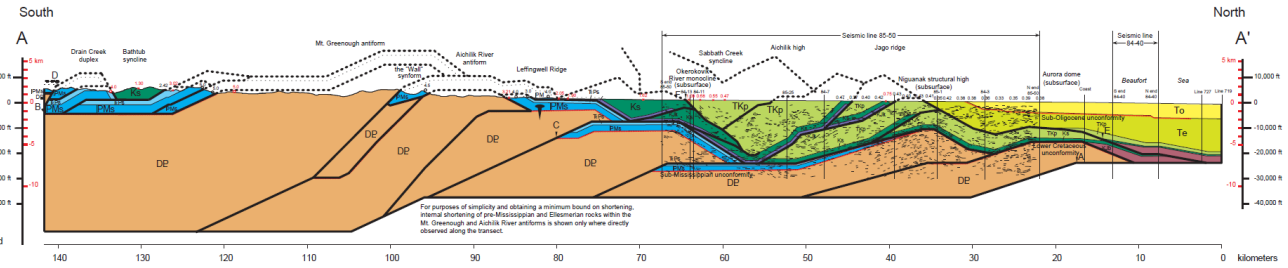
Fig. 14. Balanced cross-section of line 1 showing the structural evolution of the thrust-related folds and associated fault systems. For profile location, see Fig. 3.



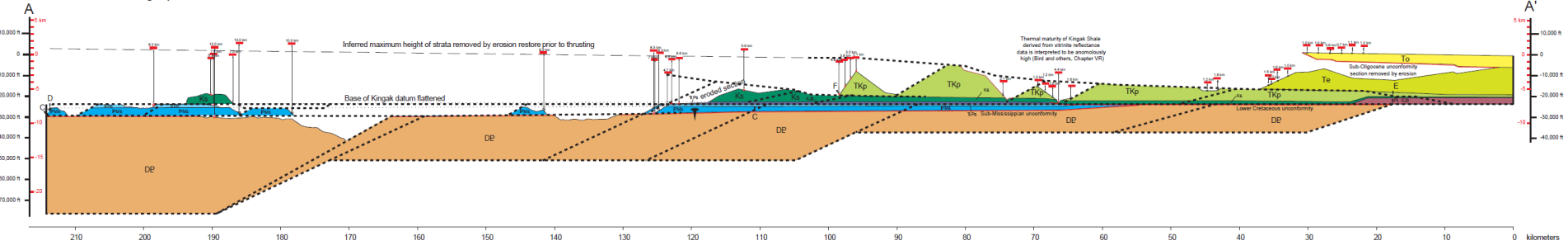
Explanation

- | | |
|--|---|
| Brookian Sequence | Pre-Mississippian rocks |
| To
Oligocene to Recent sedimentary rocks | DE
Proterozoic to Lower Devonian meta-sedimentary rocks; includes Kekikuk Conglomerate south of Leffingwell Ridge |
| Te
Eocene sedimentary rocks | Contacts and Symbols |
| TKp
Unconformity | Stratigraphic contact |
| Ks
Latest Cretaceous and Paleocene sedimentary rocks (includes Iago River Formation) | Fault |
| Cr
Cretaceous sedimentary rocks (includes Bathub, Graywacke, Arctic Creek unit, Hue Shale, and pebble shale units) | Unconformity |
| LCU
Lower Cretaceous unconformity (LCU), inferred to be locally present north of Sabbath syncline | Seismic reflections |
| Elsesmerian and Beaufortian Sequences | Pinpoint indicating unfaulted, depositional contact |
| KJK ? KJB
Jurassic to Lower Cretaceous sedimentary rocks KJK - Kingak Shale; KJB - Beaufortian sequence | Reference point. See text for explanation |
| TKPs
Permian to Upper Triassic sedimentary rocks (Sadleschit Group and Shublik Formation; includes Kingak Shale in Bathub Ridge area) | Location of conodont sample and conodont alteration index (CAI). Red symbols projected onto profile from outside of transect |
| PNs
Mississippian and Pennsylvanian sedimentary rocks (Kekikuk Conglomerate north of Leffingwell Ridge, if present, Kayak Shale, and Lisburne Group) | Location of vitinite sample and vitinite reflectance data. Locations of proprietary data not shown. Red symbols projected onto profile from outside of transect |
| Sub-Mississippian unconformity | Approximate depth of burial calculated from CAI and vitinite reflectance data assuming geothermal gradient of 30 km |

A. Balanced Cross Section, Bathub Ridge to Beaufort Sea, Arctic National Wildlife Refuge, Alaska



B. Structural-Stratigraphic Restoration of Cross Section



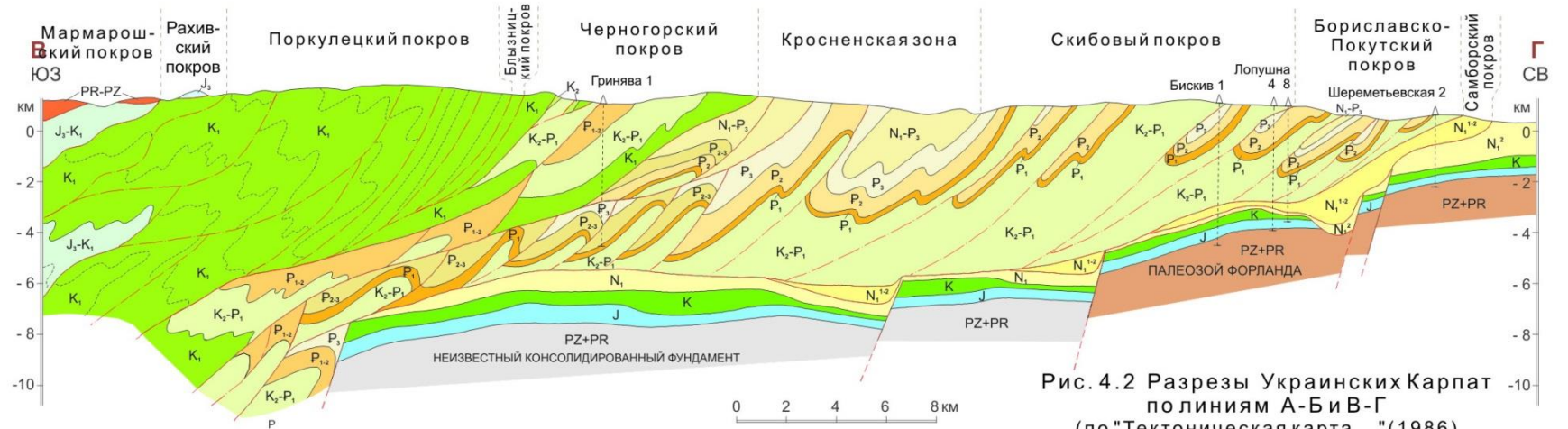
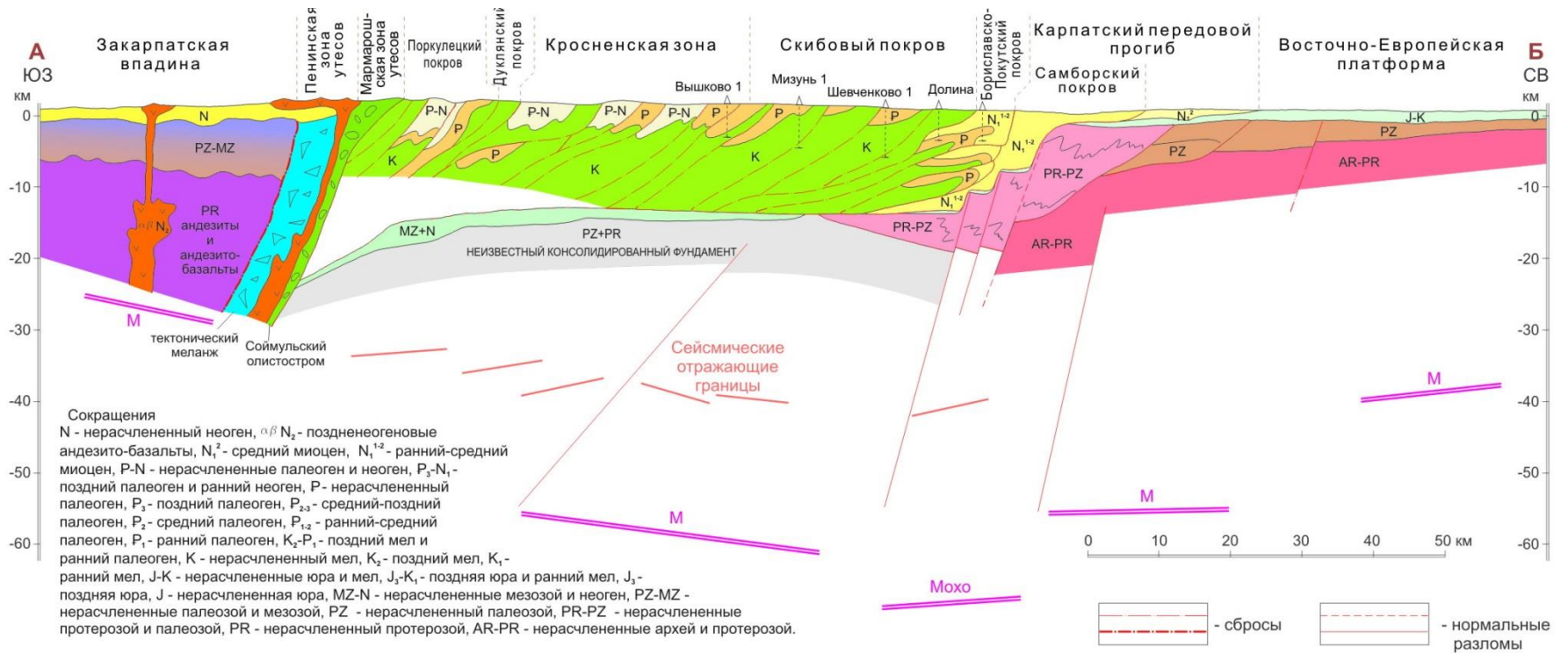


Рис. 4.2 Разрезы Украинских Карпат по линиям А-Б и В-Г (по "Тектоническая карта..." (1986) дополненный С. Кругловыми И. Попадюком) и (разрез основан на данных М. Вула, С. Круглова, В. Кузовенко, В. Шляпинского проинтерпретирован и дополнен С. Кругловыми и И. Попадюком)

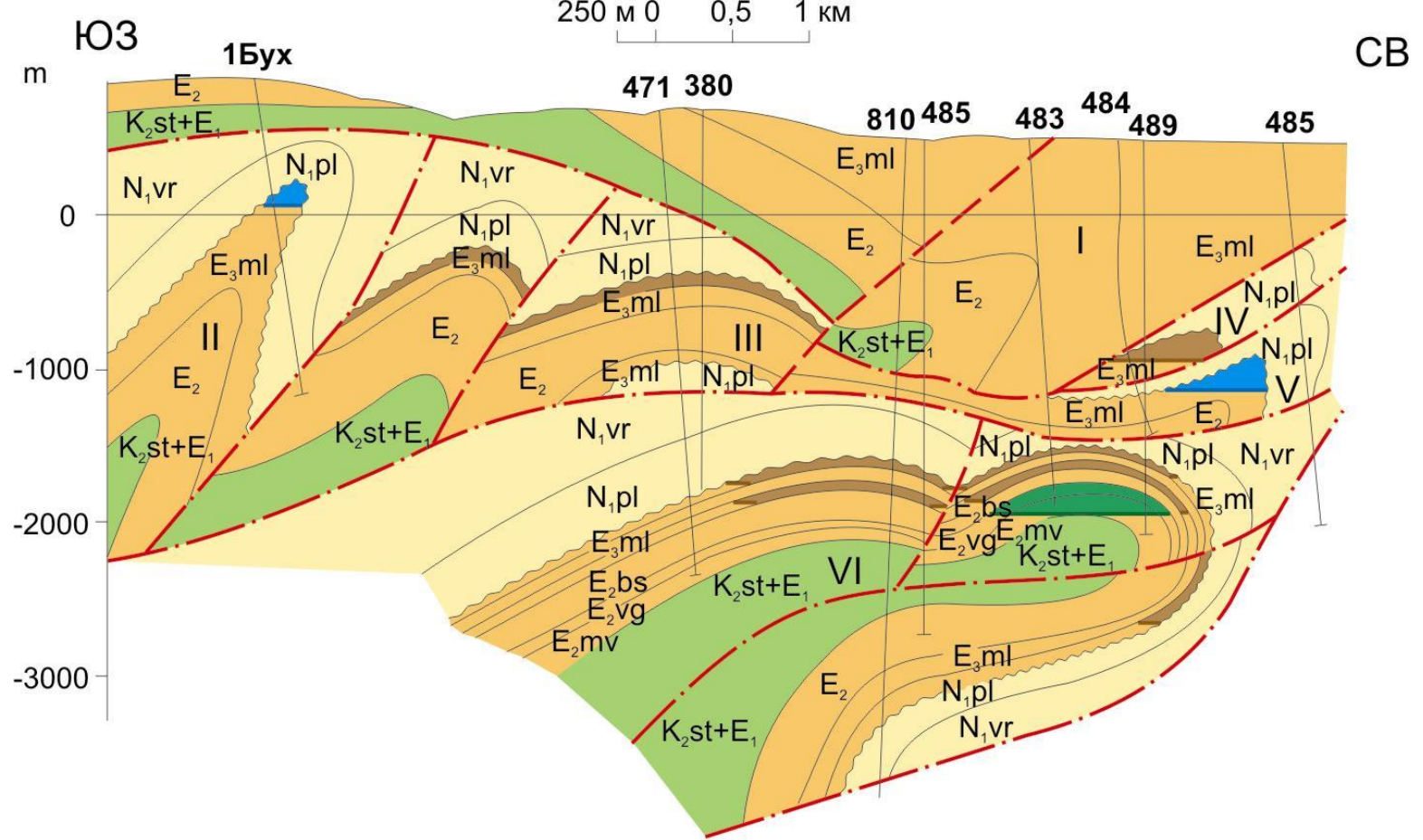
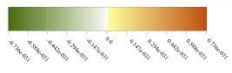
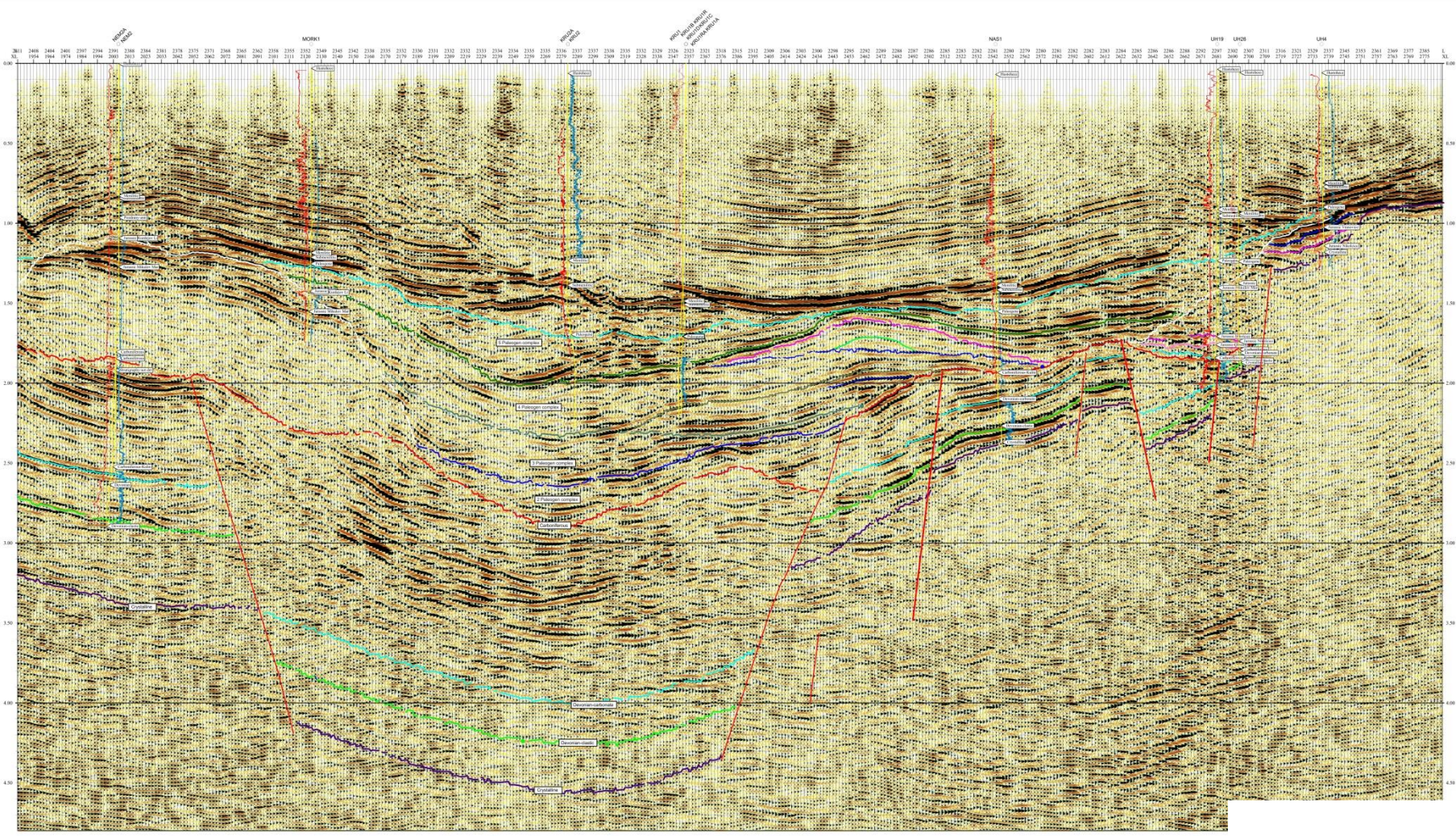


Рис. 4.12 Геологический разрез Бытків-Бабчинського нафтогазоконденсатного місцевості.

Умовні позначення: нафта; газ; конденсат; розломи;

Стратиграфічні символи: K_2st+E_1 - верхній мел - палеоцен, E_2mn - манявська свита (еоцен), E_2vg - вигодська свита (еоцен), E_2bs - быстрицька свита (еоцен), E_3ml - менилітова свита (олігоцен), N_1pl - поляницька свита (міоцен), N_1vr - Воротыщенська свита (міоцен). Складки: I - Скибовий покрив, II - Газова, III - Старая Копальня, IV - Молодків, V - Бабче, VI - Бытків Глыбынна.

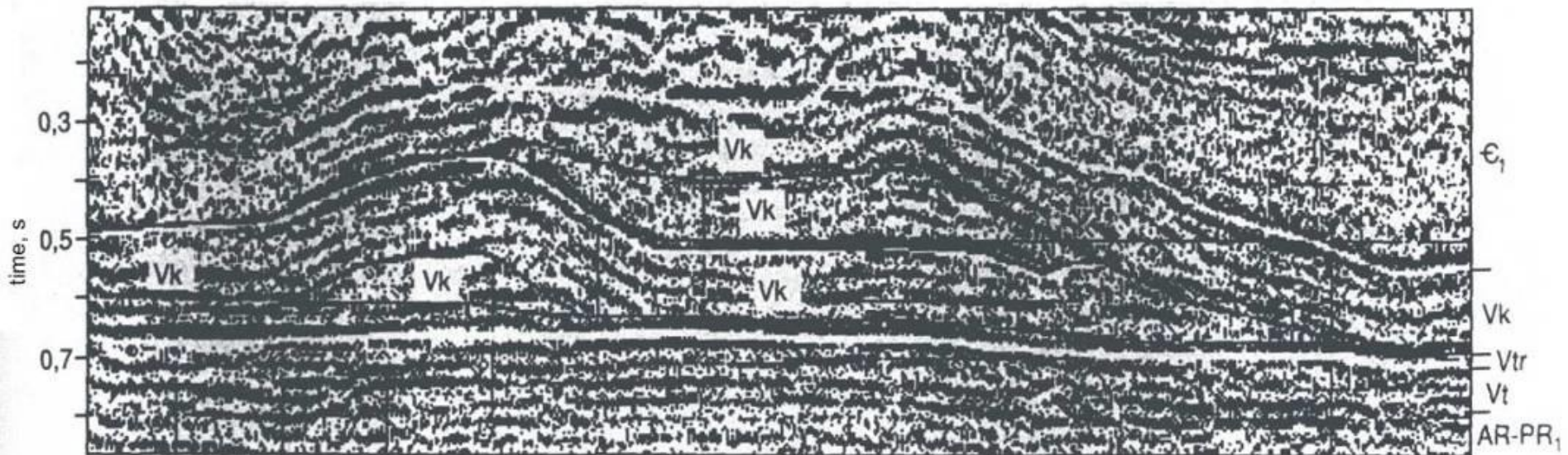
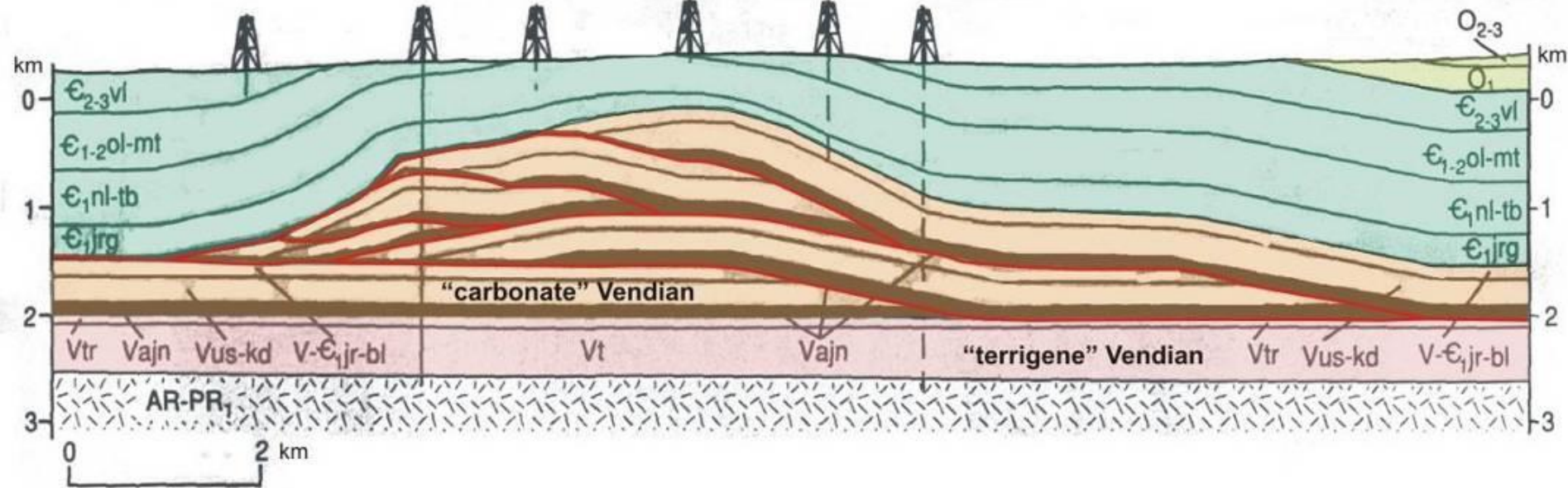
(Atlas... 1998, упрощений І. Попадюком)

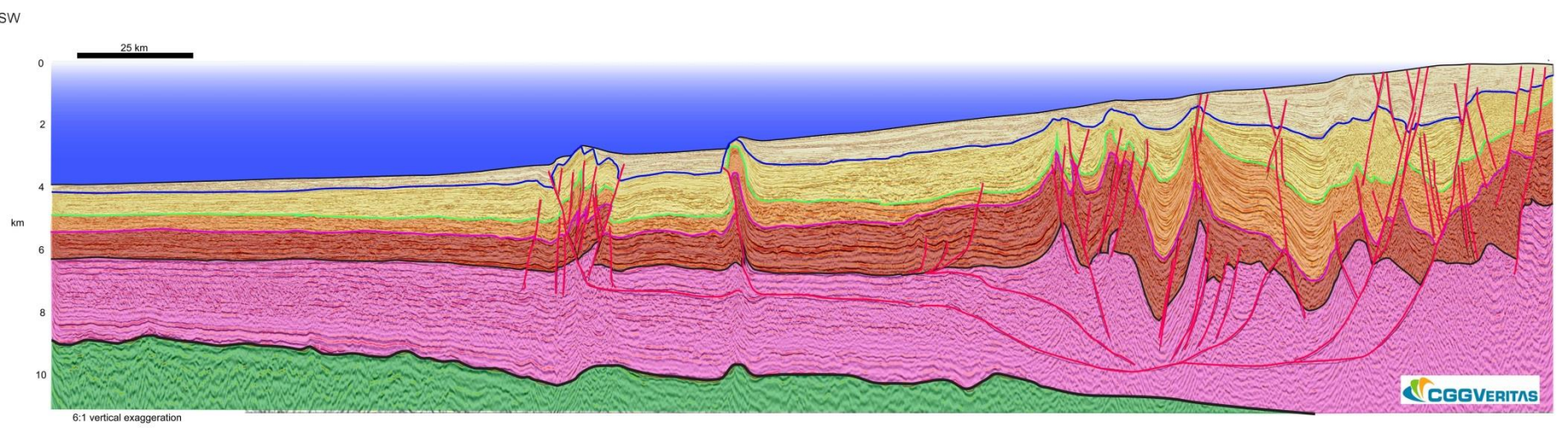
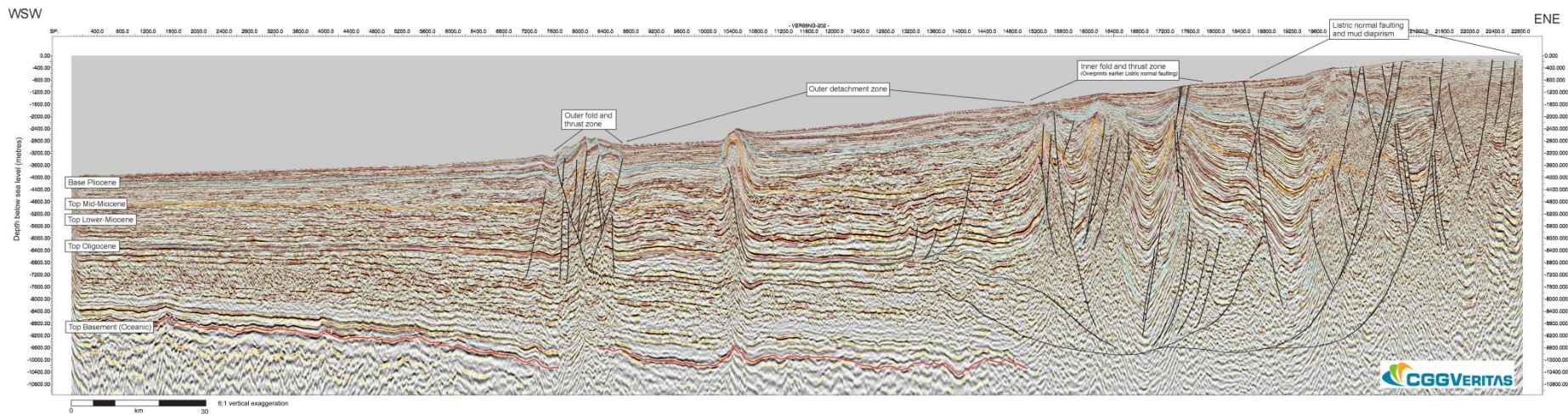


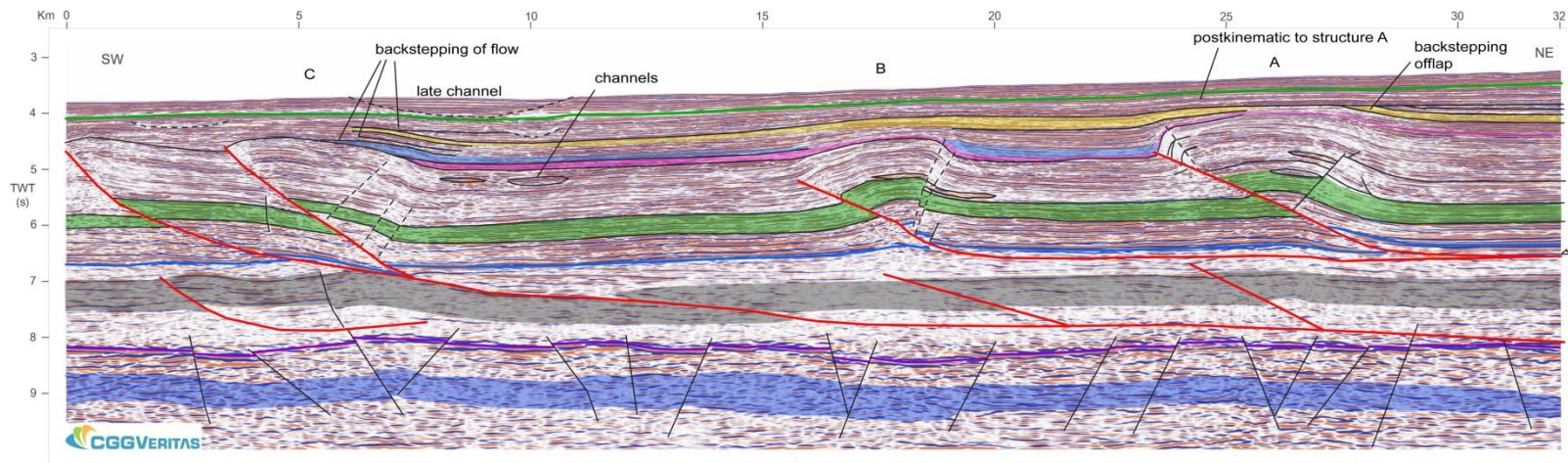
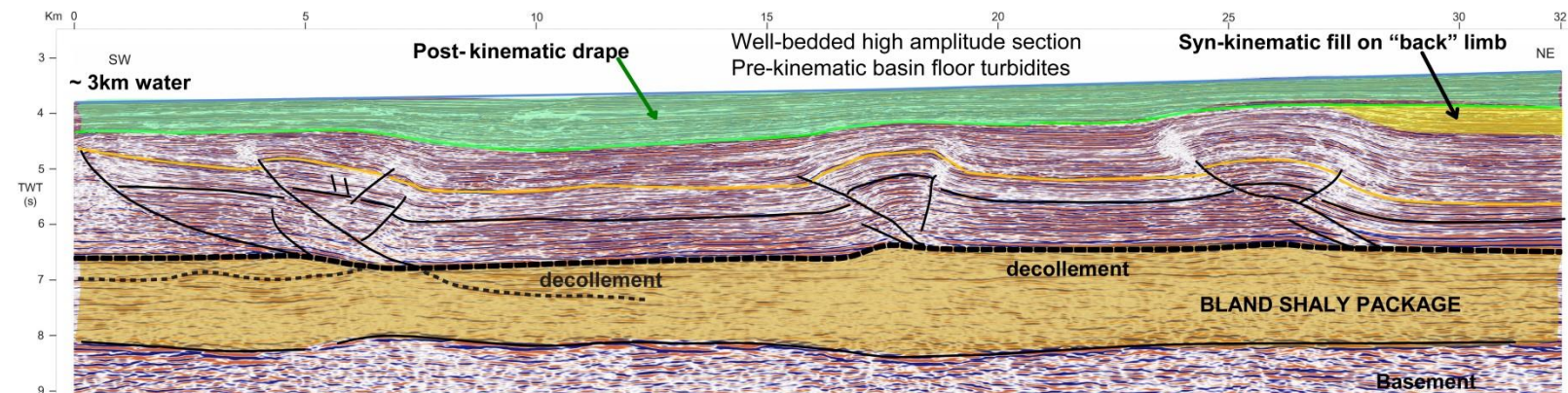
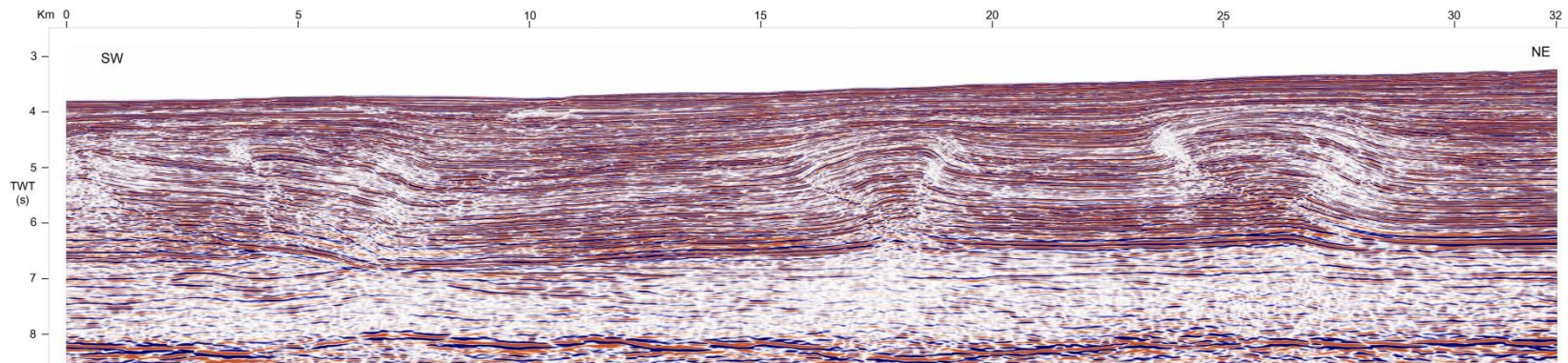
Некоторые примеры

Зоны надвигов

Otradninskoe gas field





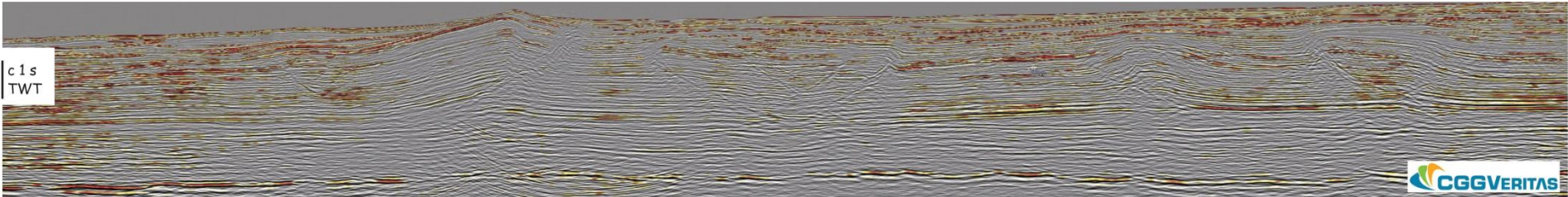


CGGVERITAS

Нигерия, дельта

SE

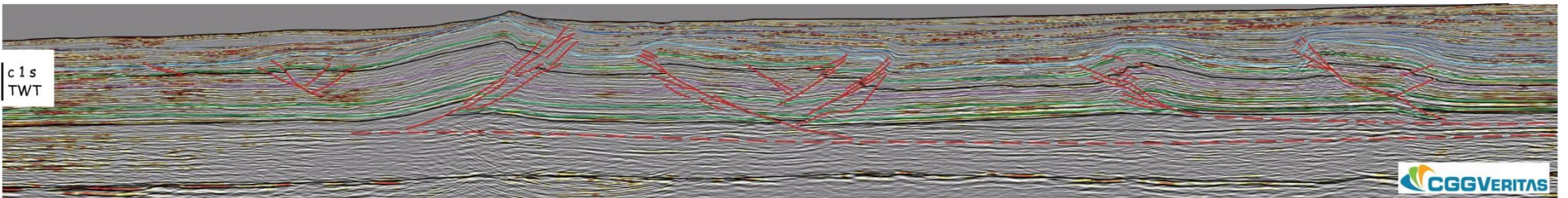
NW



10 km

SE

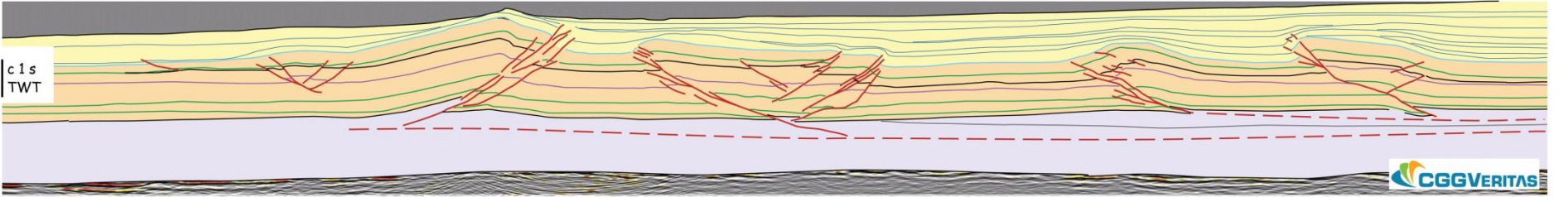
NW



10 km

SE

NW



10 km

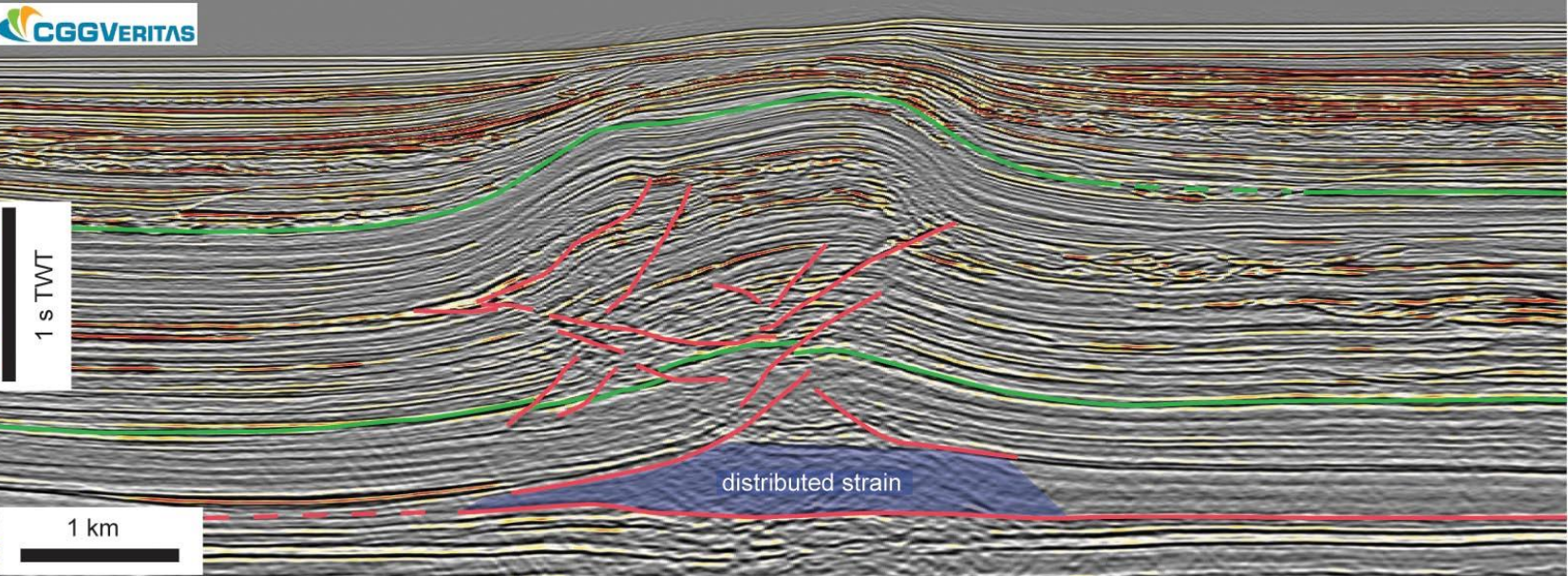
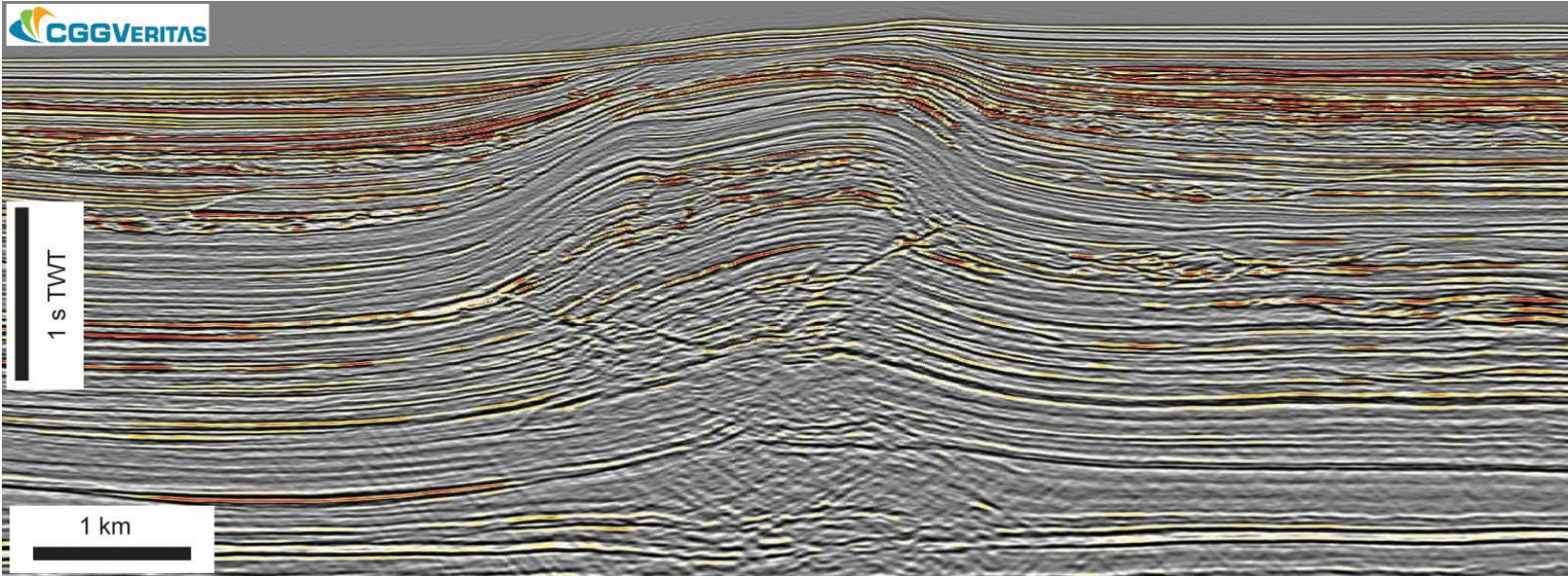
1 s TWT

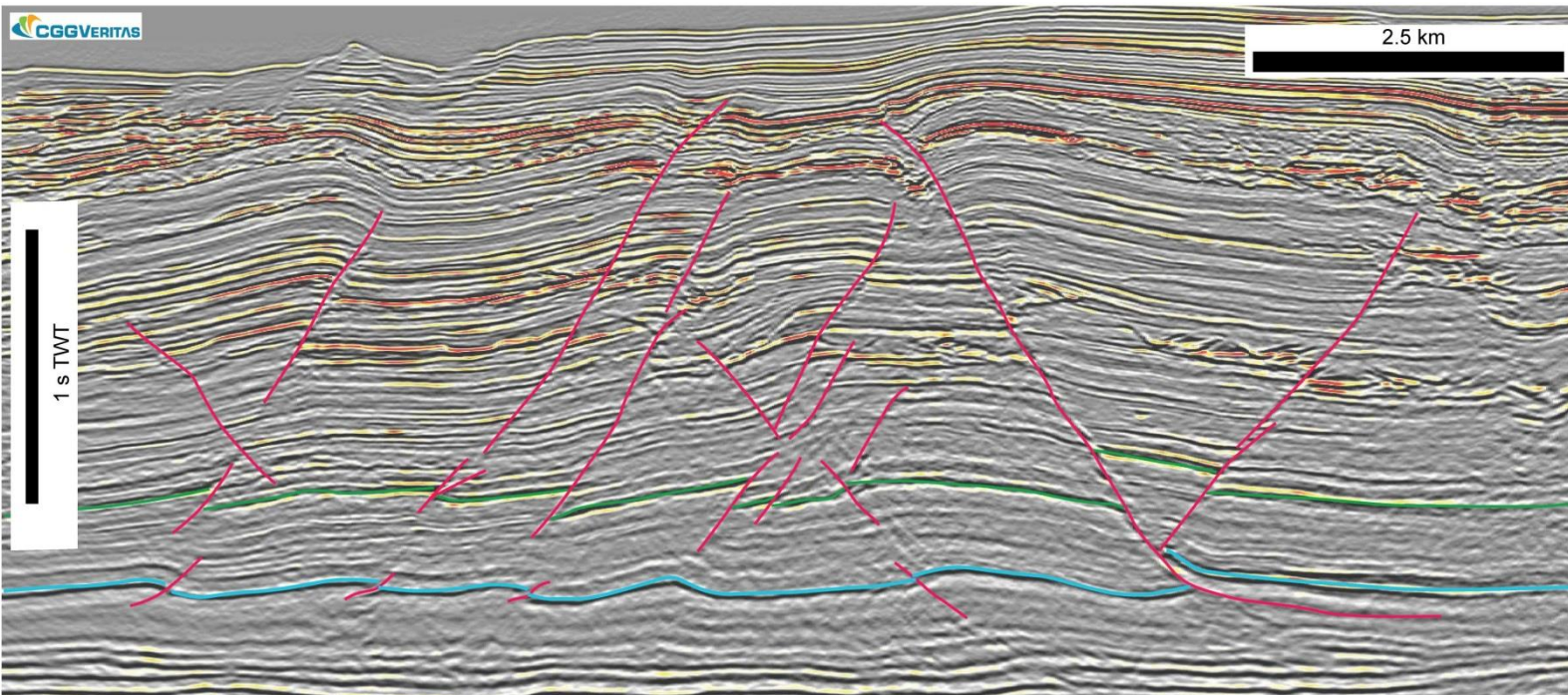
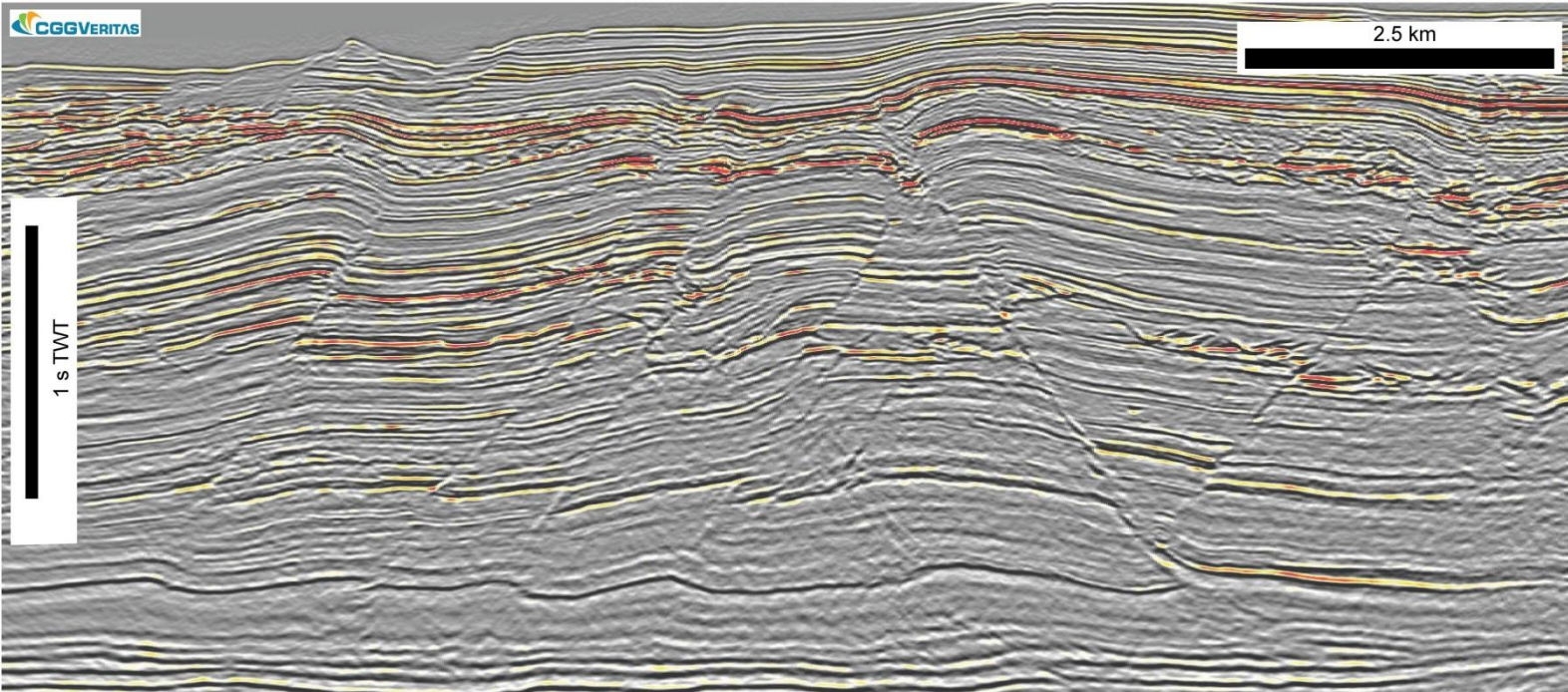
1 km

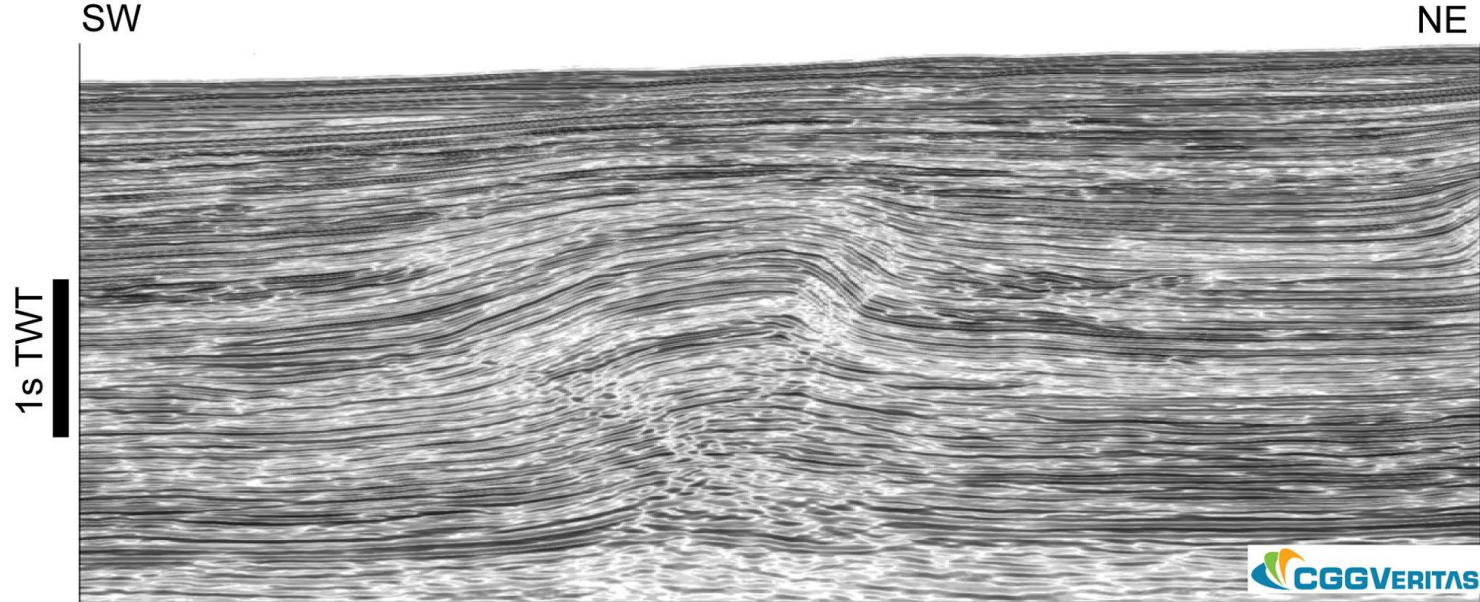
1 s TWT

1 km

distributed strain

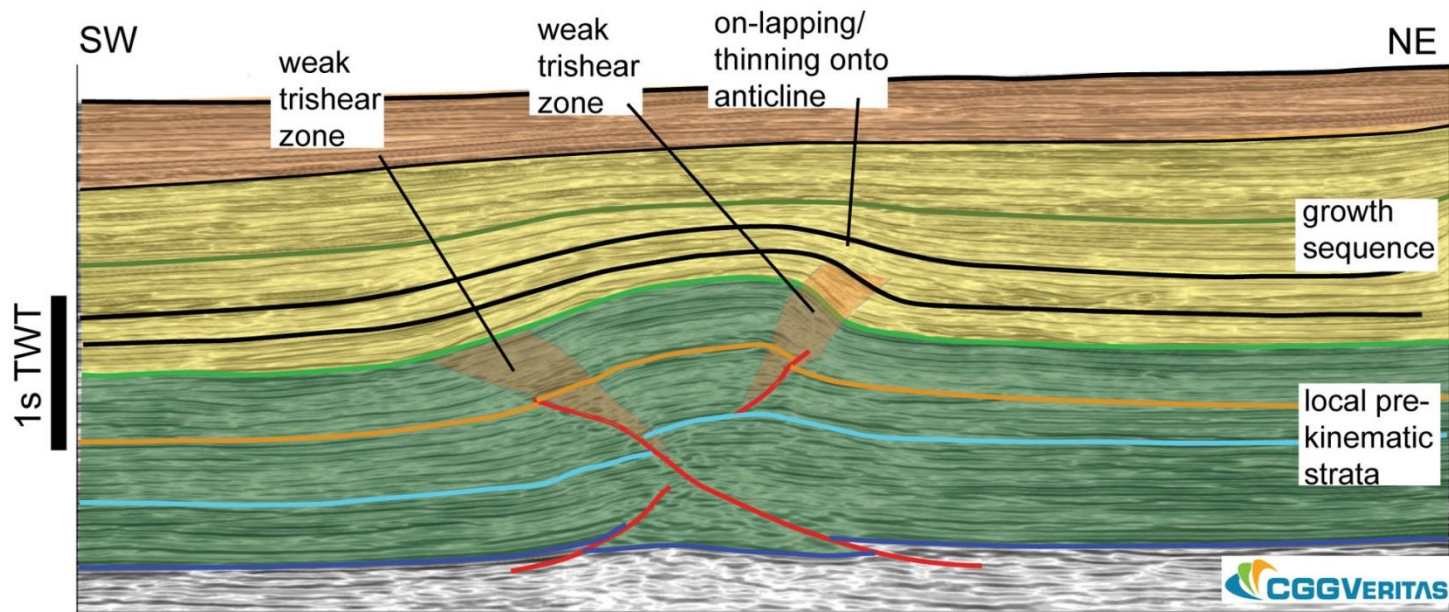






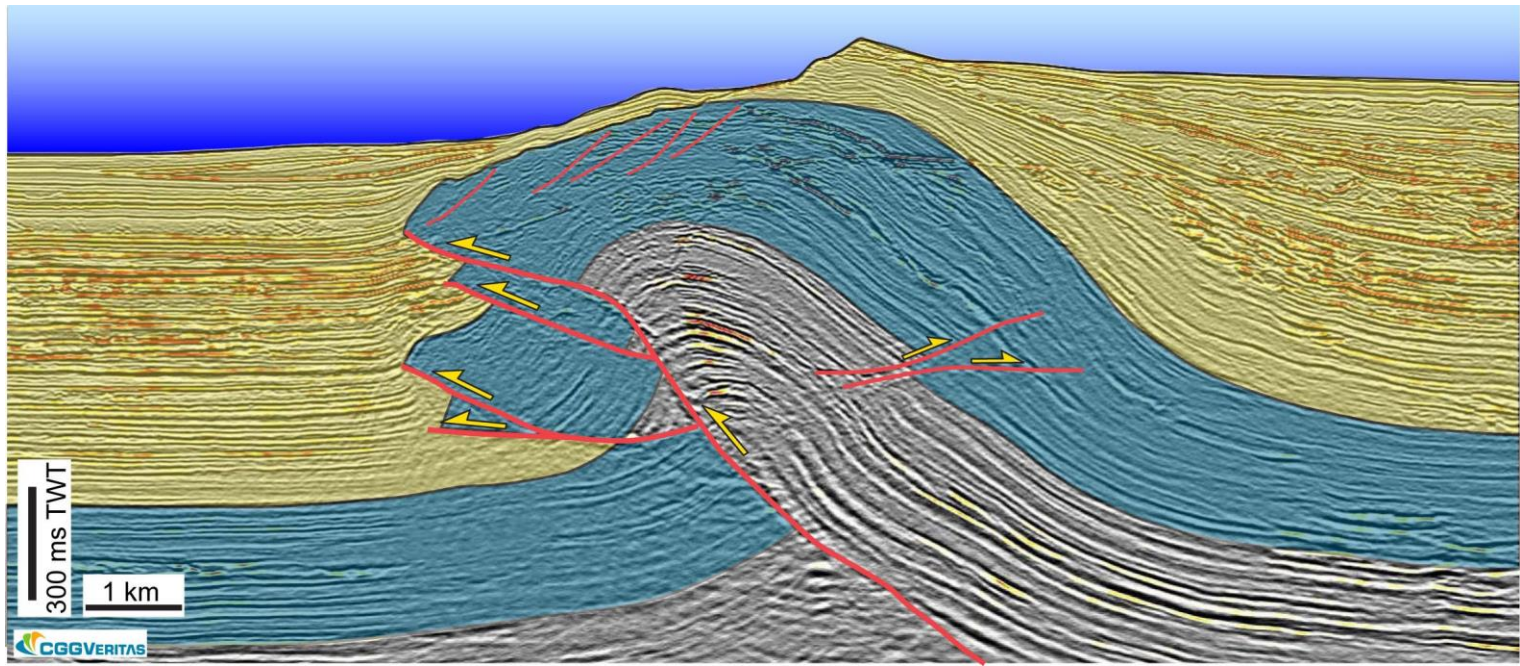
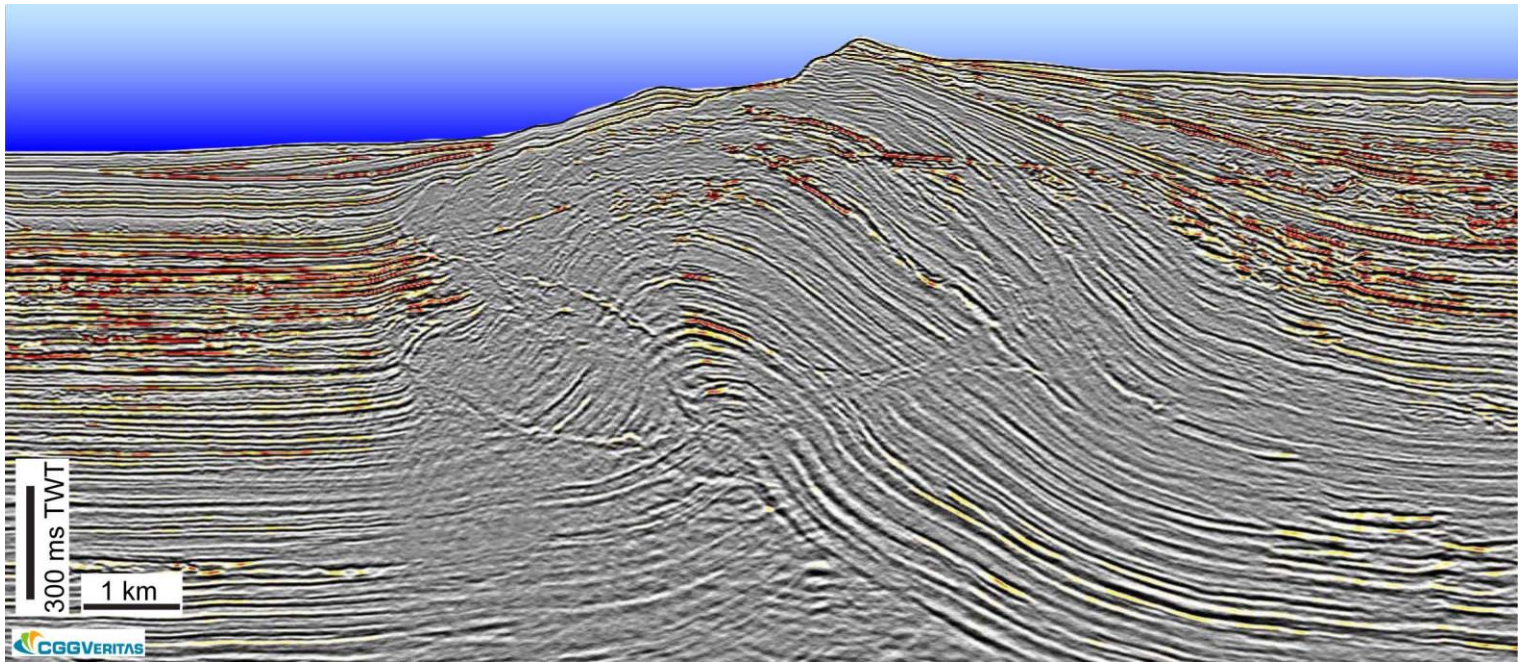
9.5 km

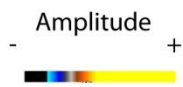
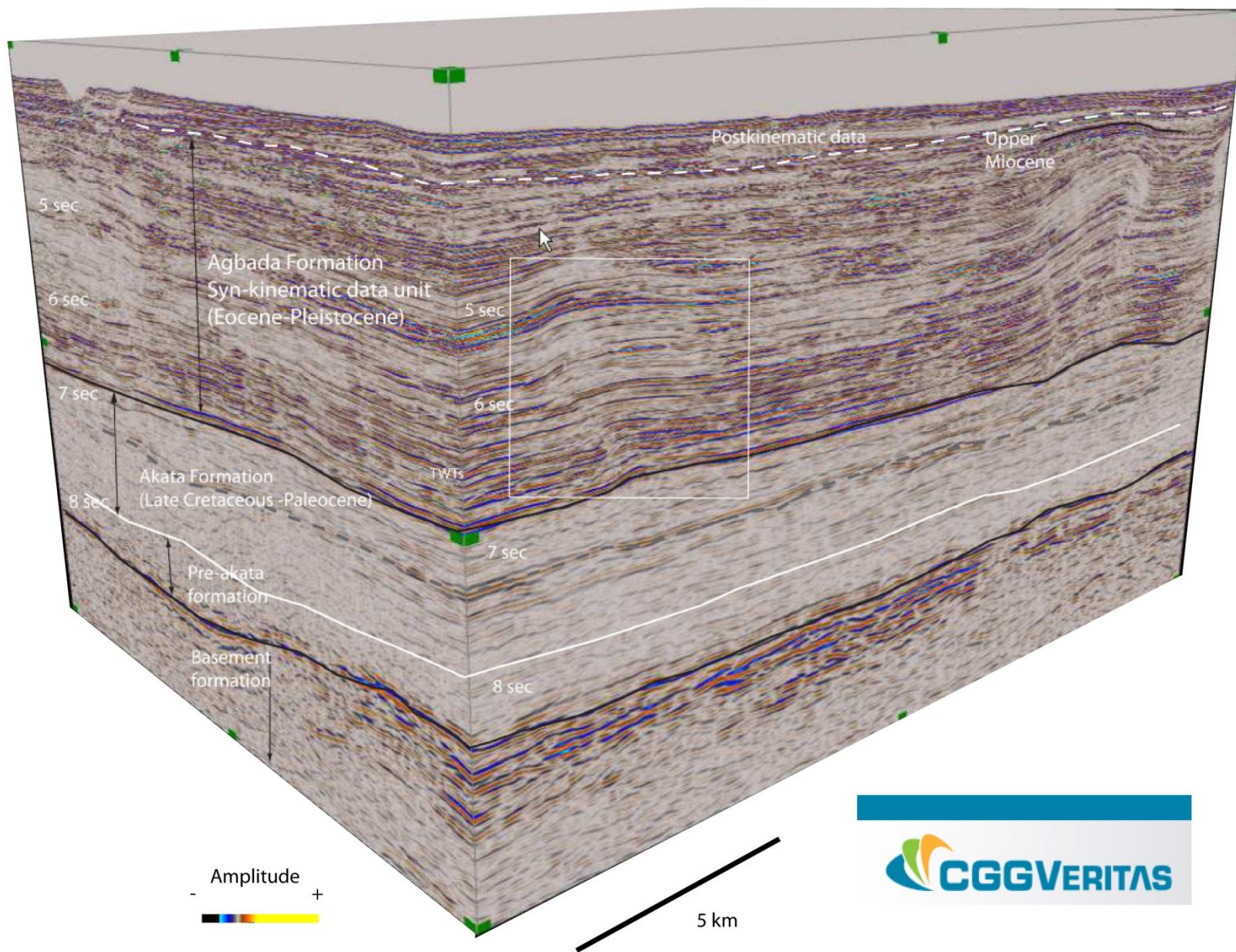
line 20



9.5 km

line 20 "backthrust" fold but cored by triangle zone

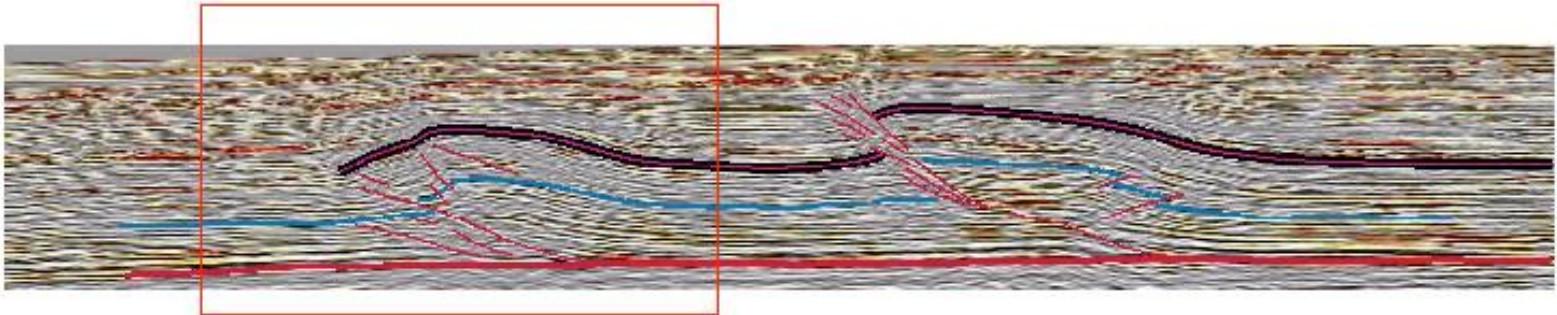






The Virtual Seismic Atlas

Lateral variation in structural style: deep water western Niger Delta.

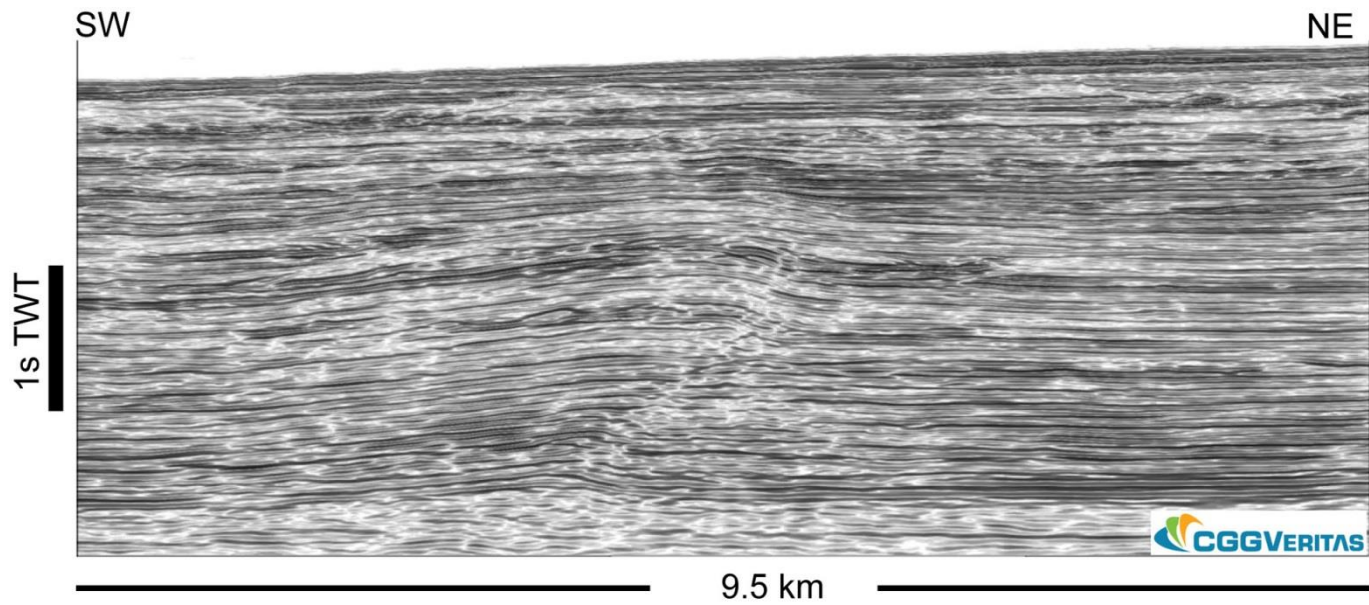


48 serial sections each 250m apart.

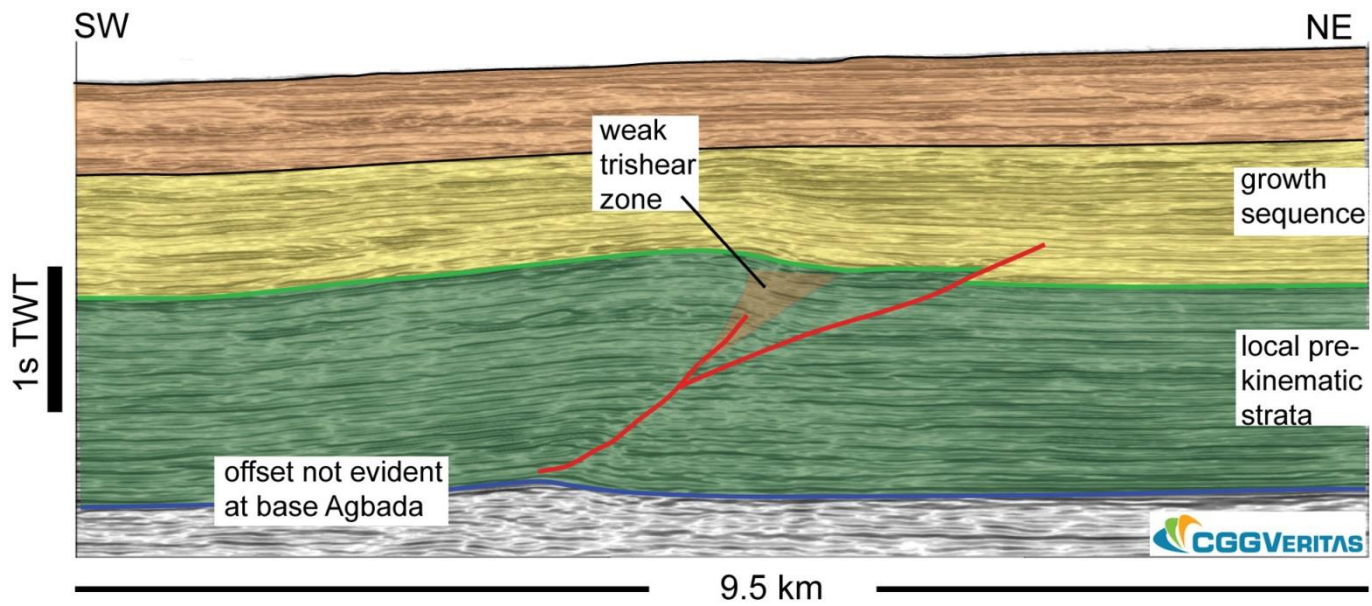
Data from 3D survey by:



Compiled by Estelle Mortimer and Rob Butler

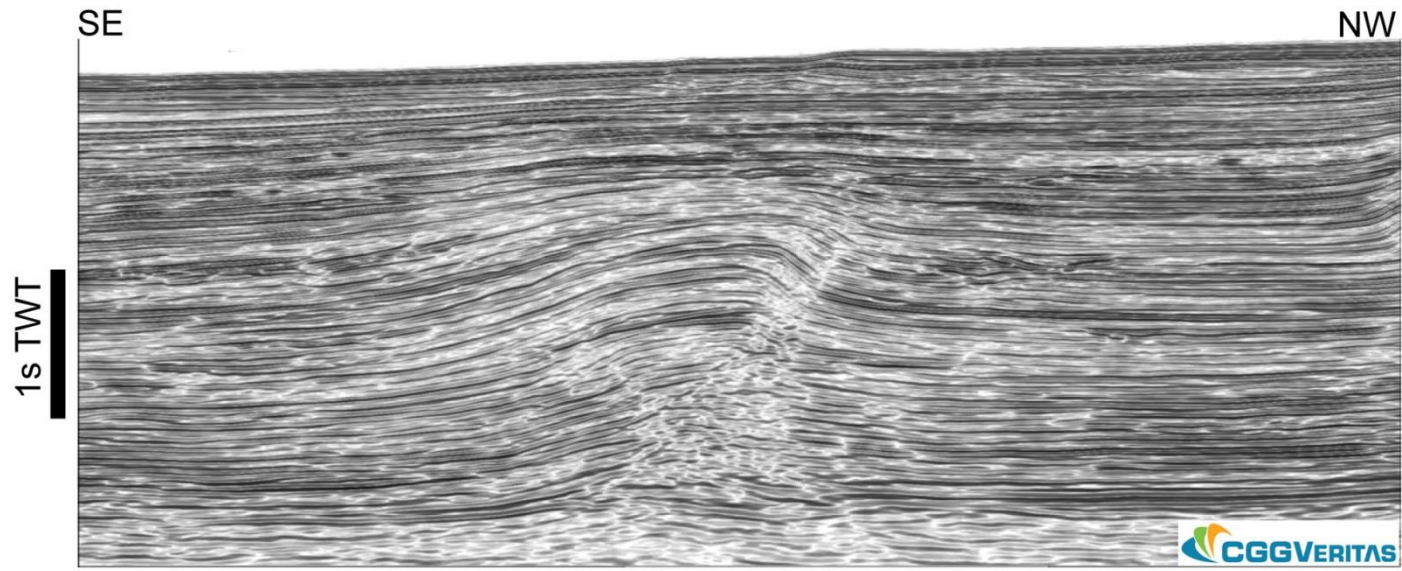


line 07



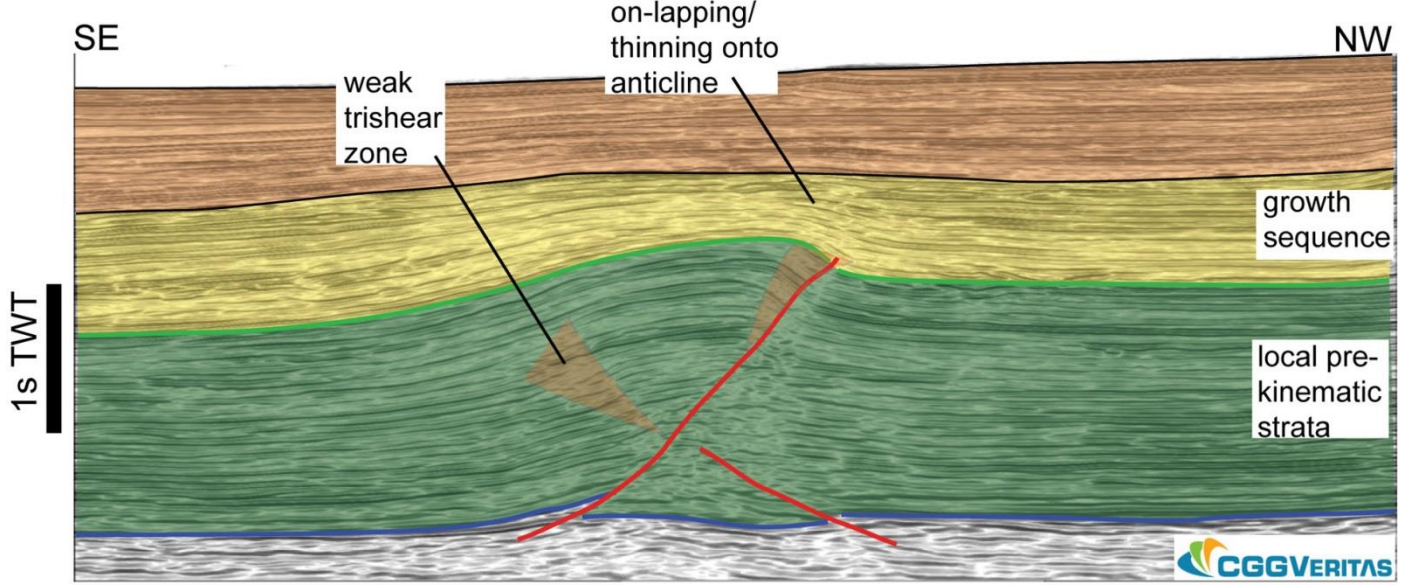
line 07

“backthrust” system



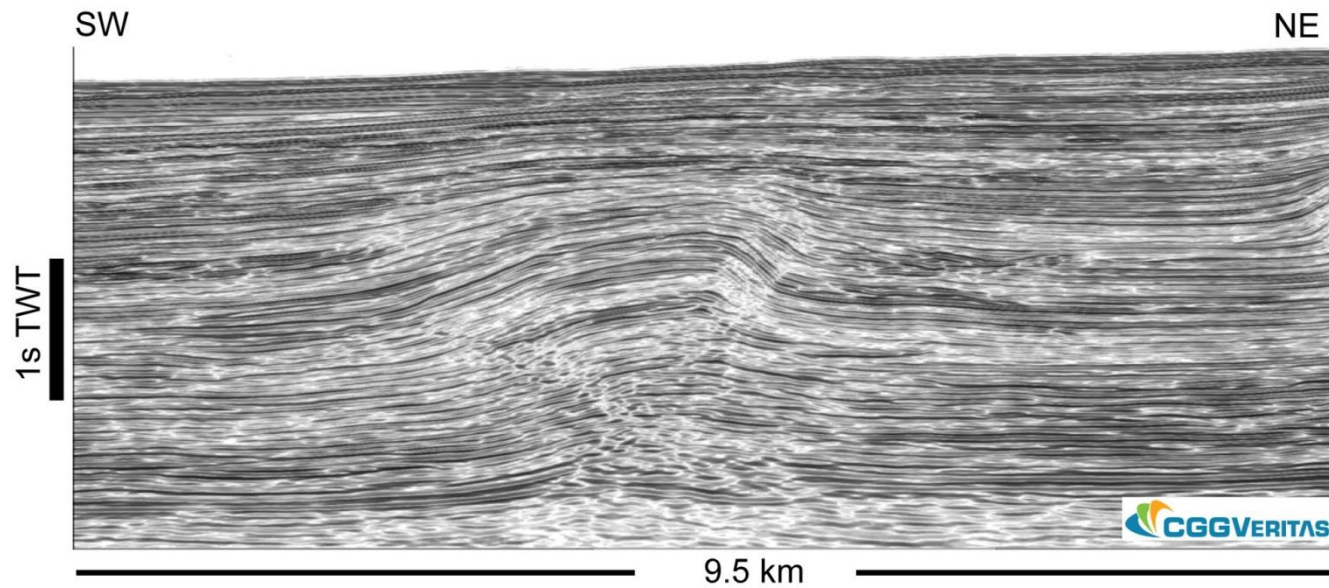
9.5 km

line 18

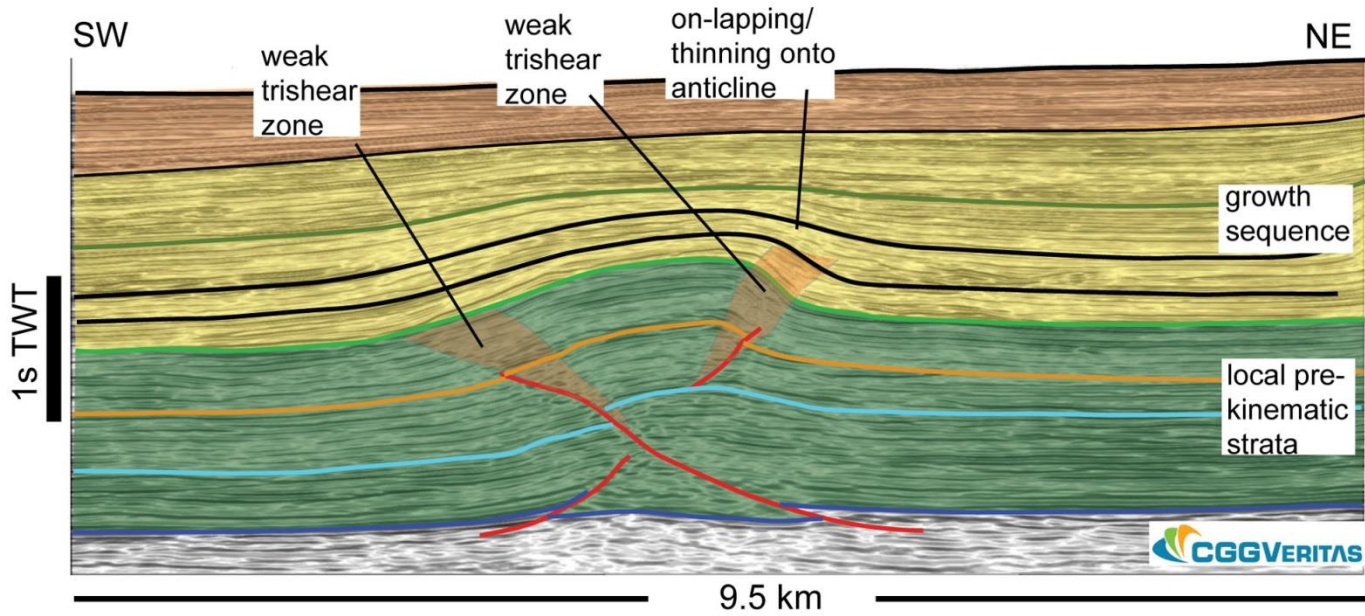


9.5 km

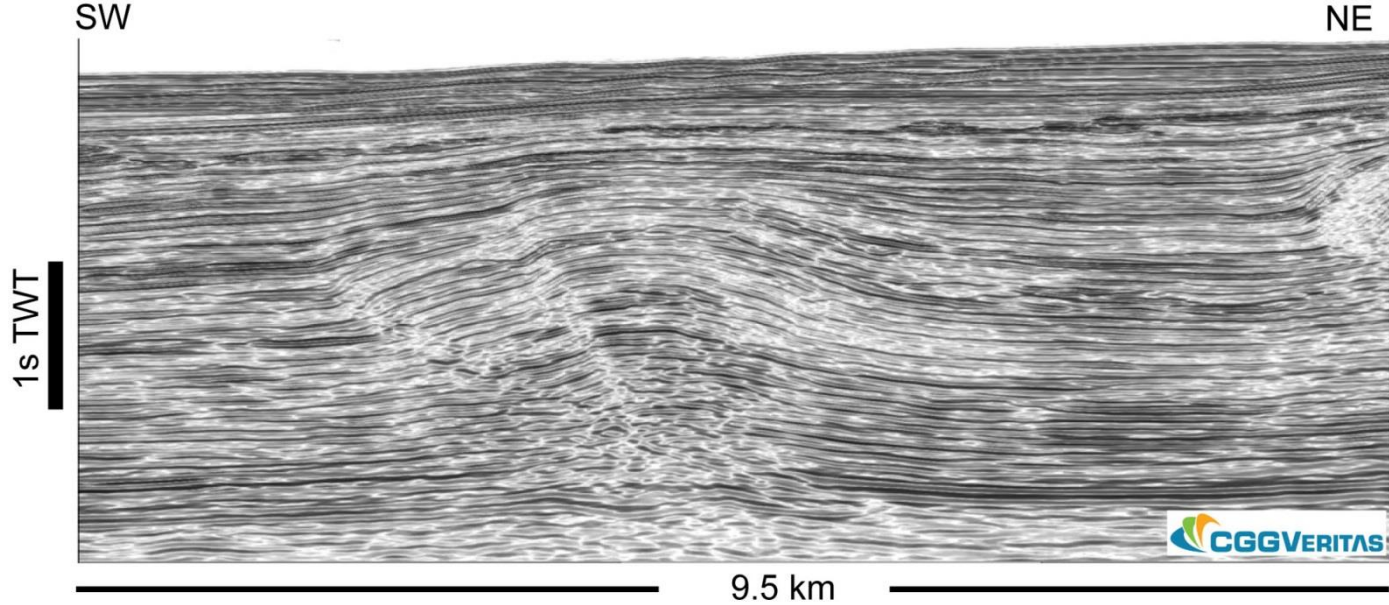
line 18 "backthrust" fold but cored by triangle zone



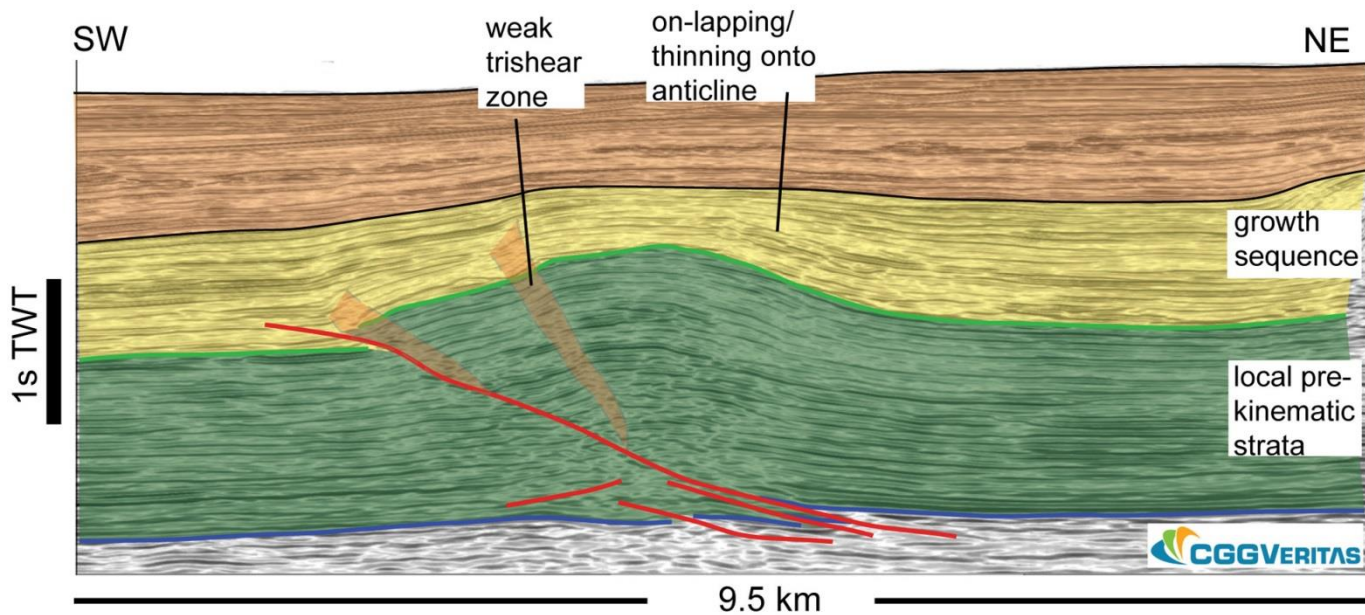
line 20



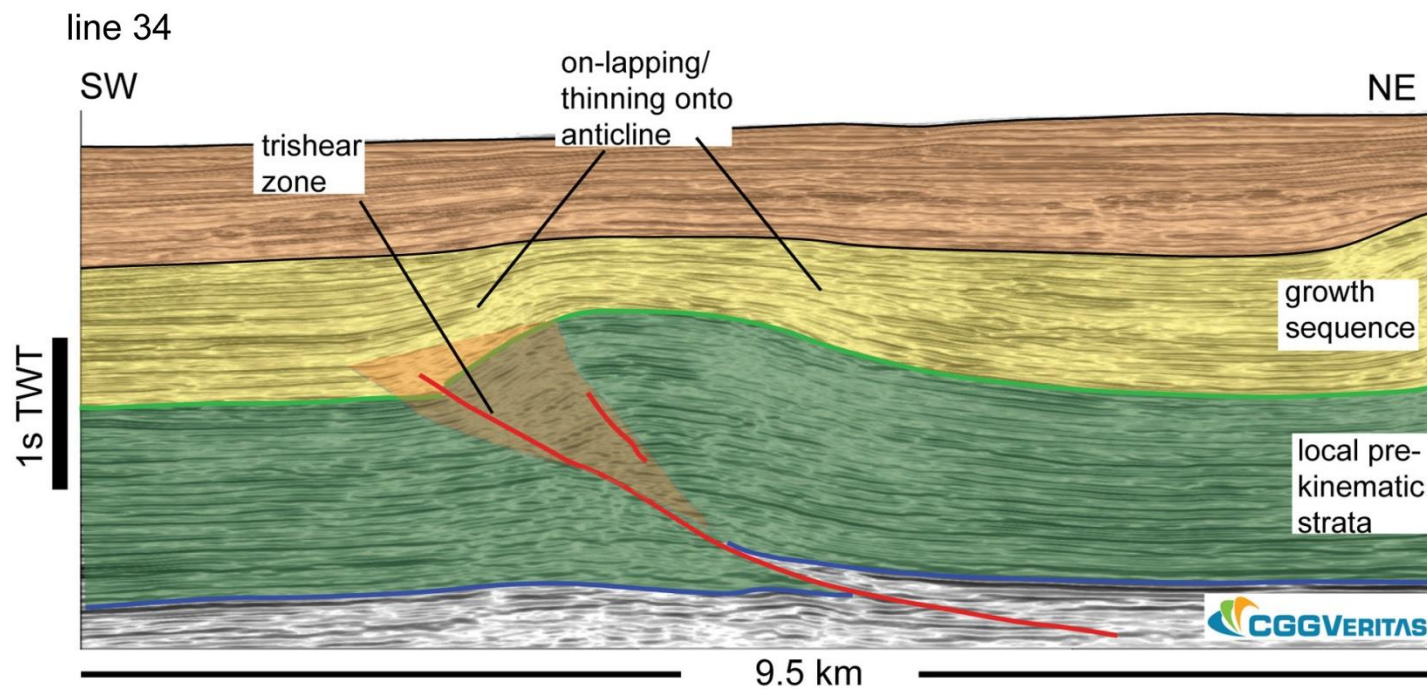
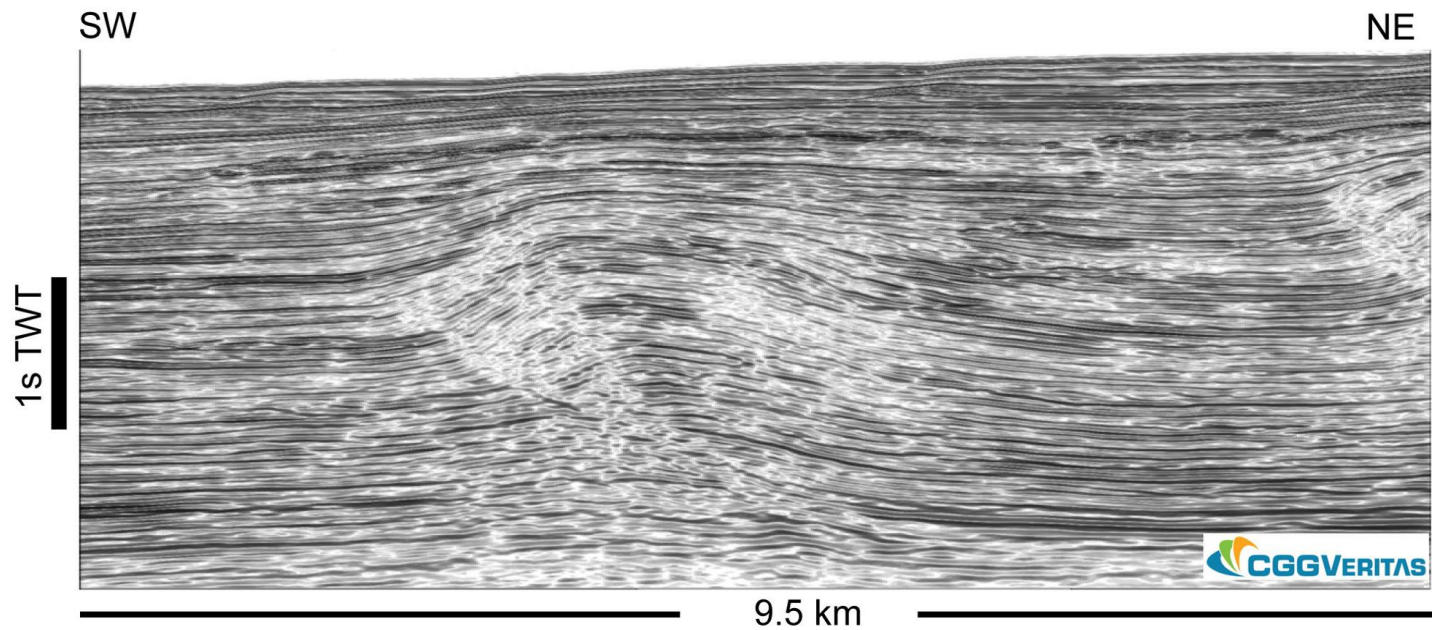
line 20 "backthrust" fold but cored by triangle zone



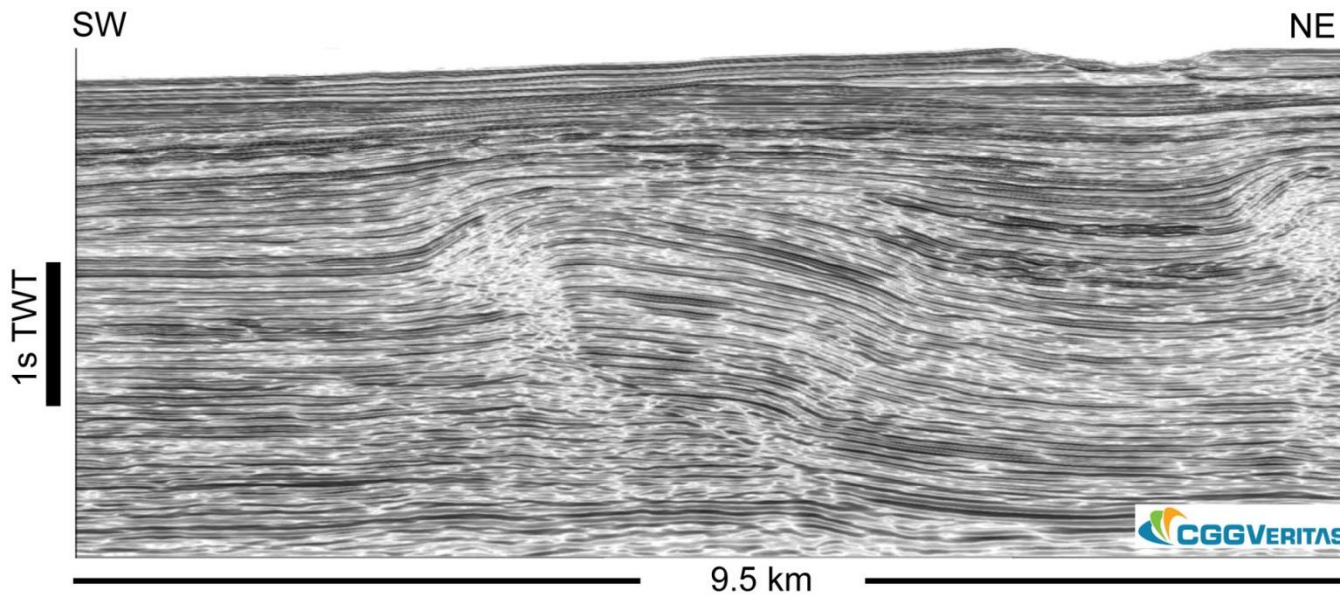
line 29



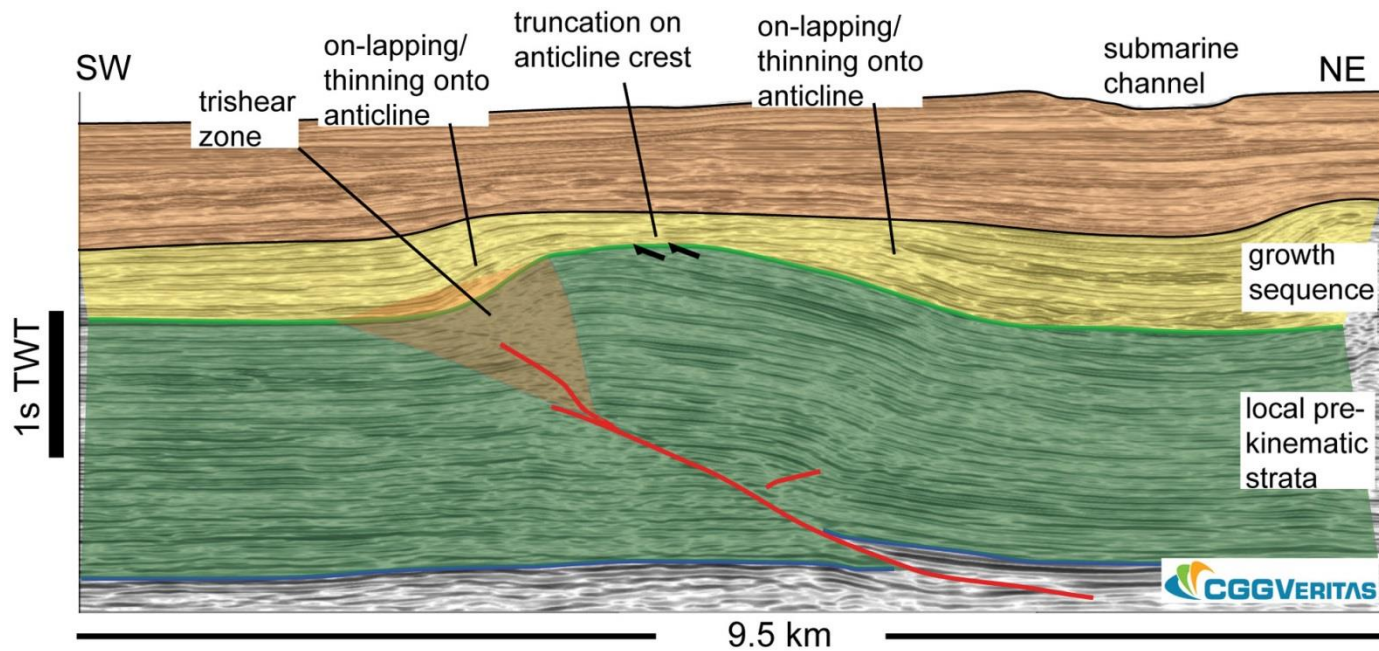
line 29 complex forethrust zone at depth, incipient backthrusting. Main forethrust breaks out ahead of the main anticline.



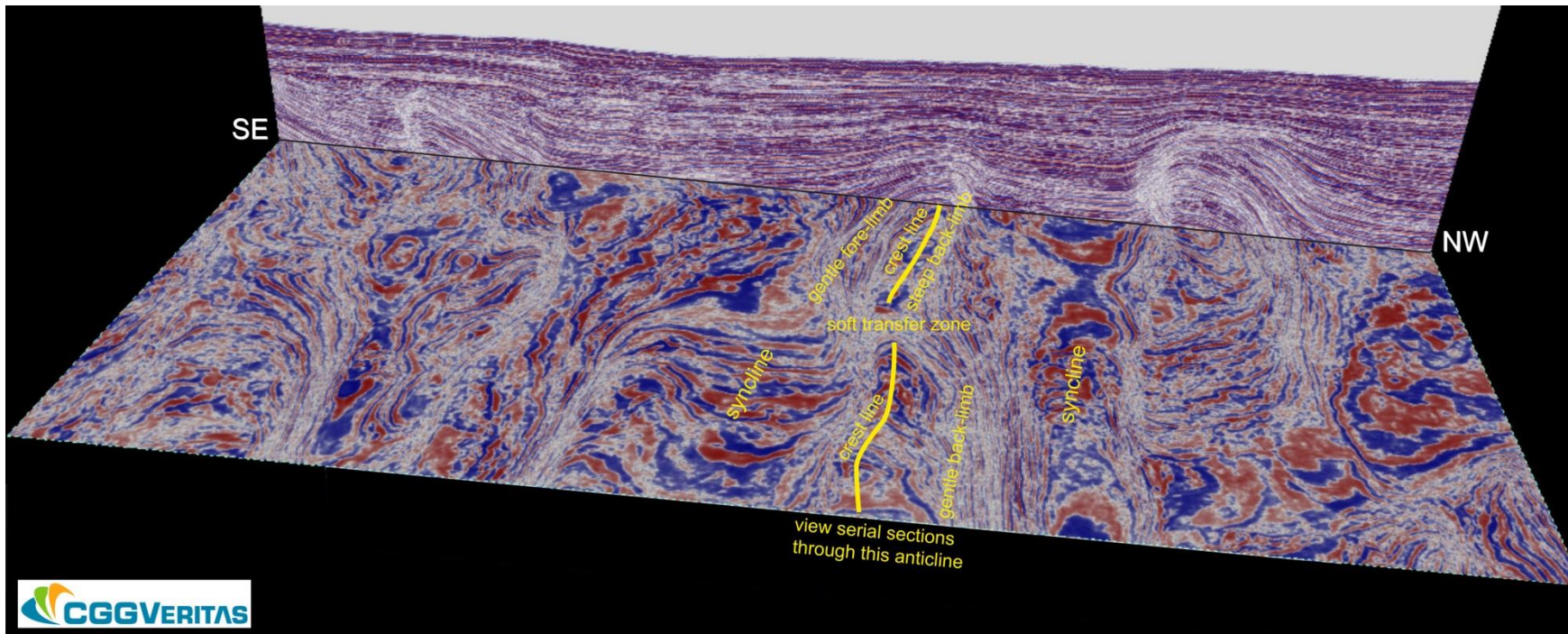
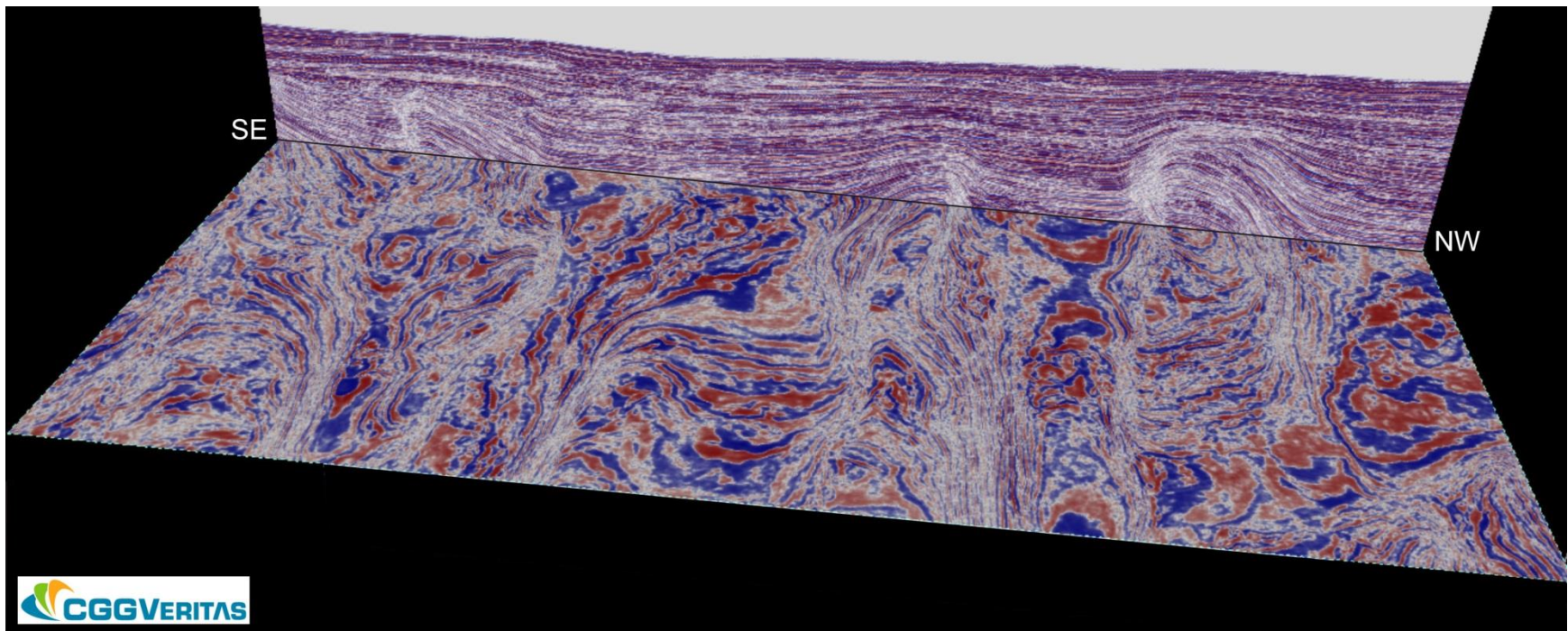
line 34 forethrust with ramp at depth, diverging up-dip into a trishear zone.

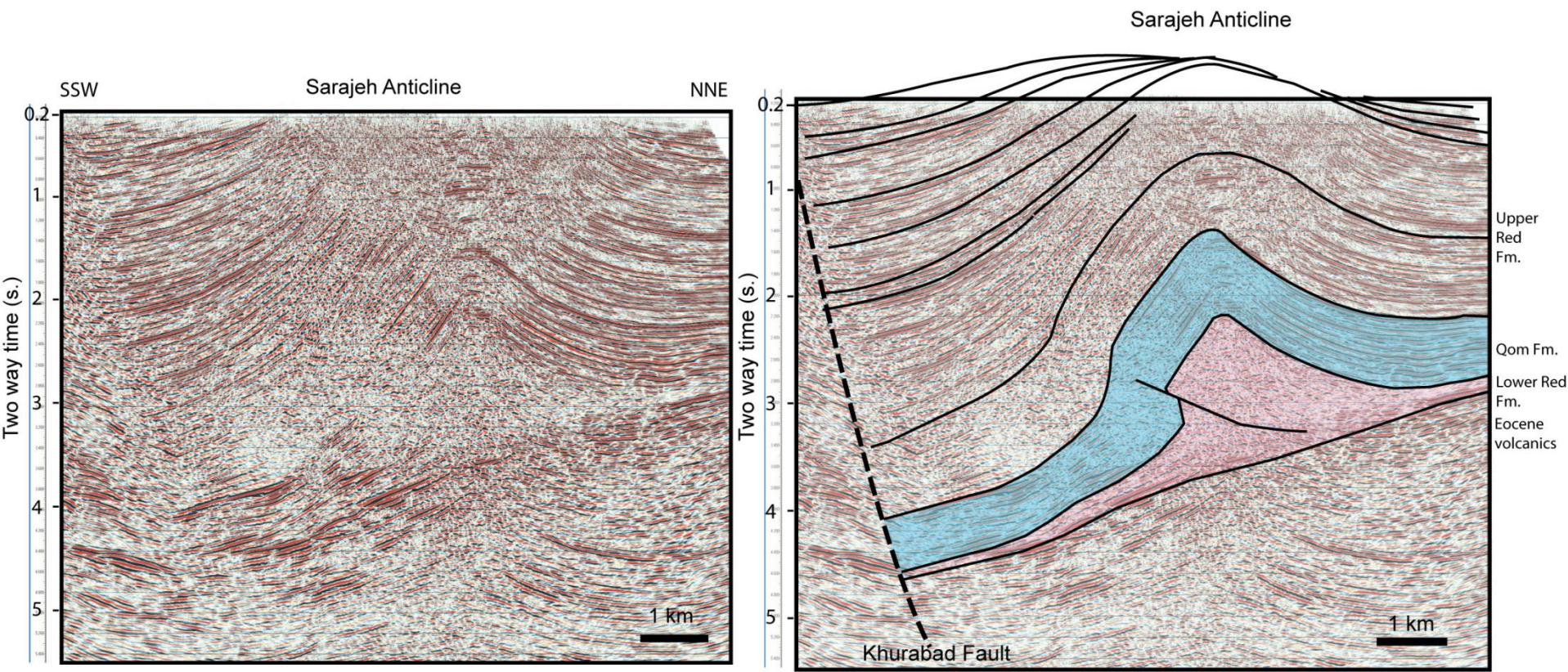


line 41

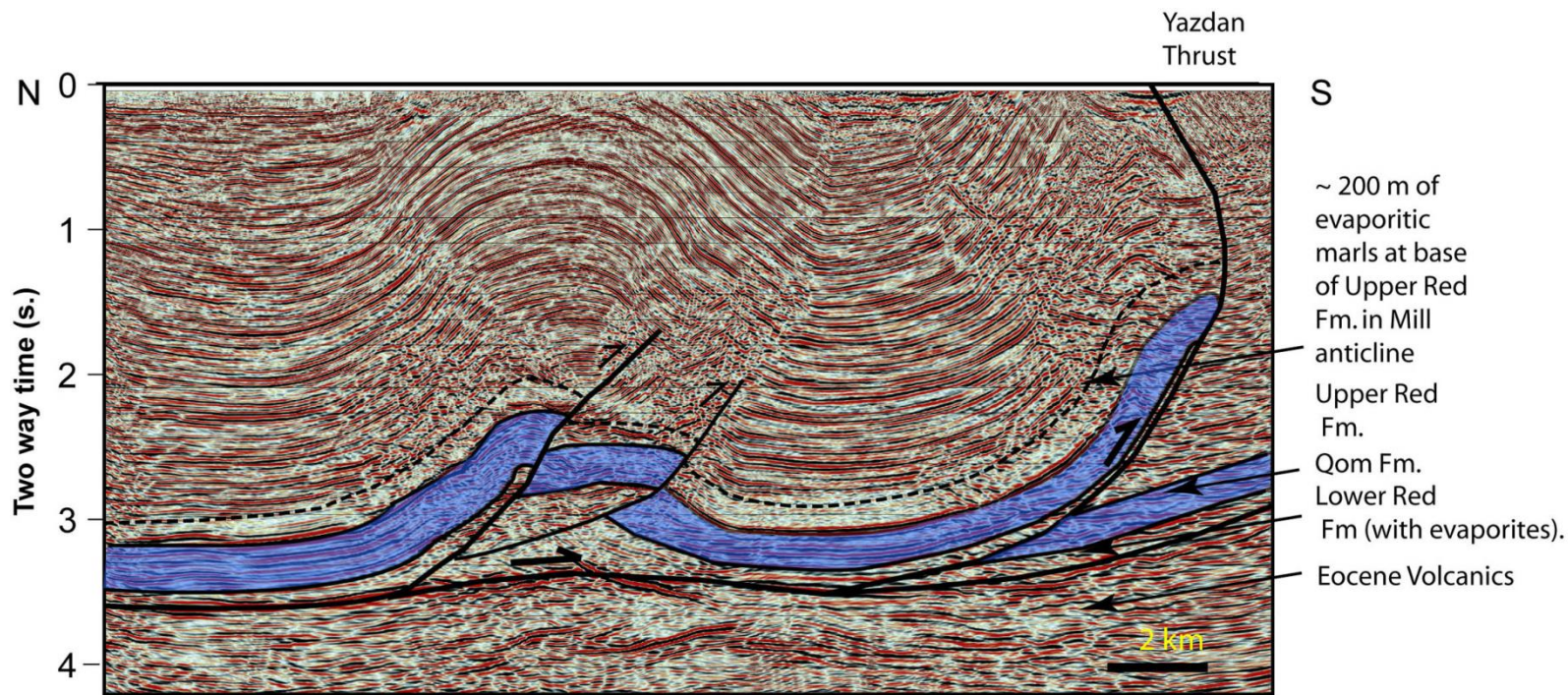
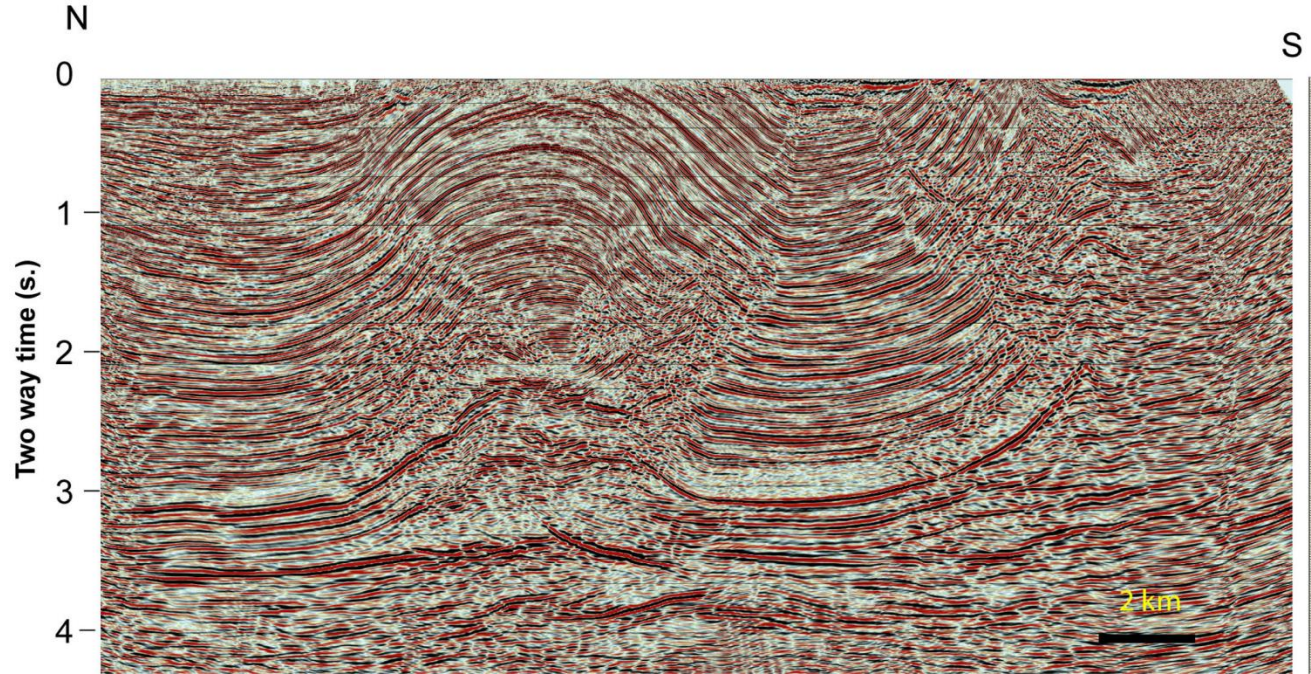


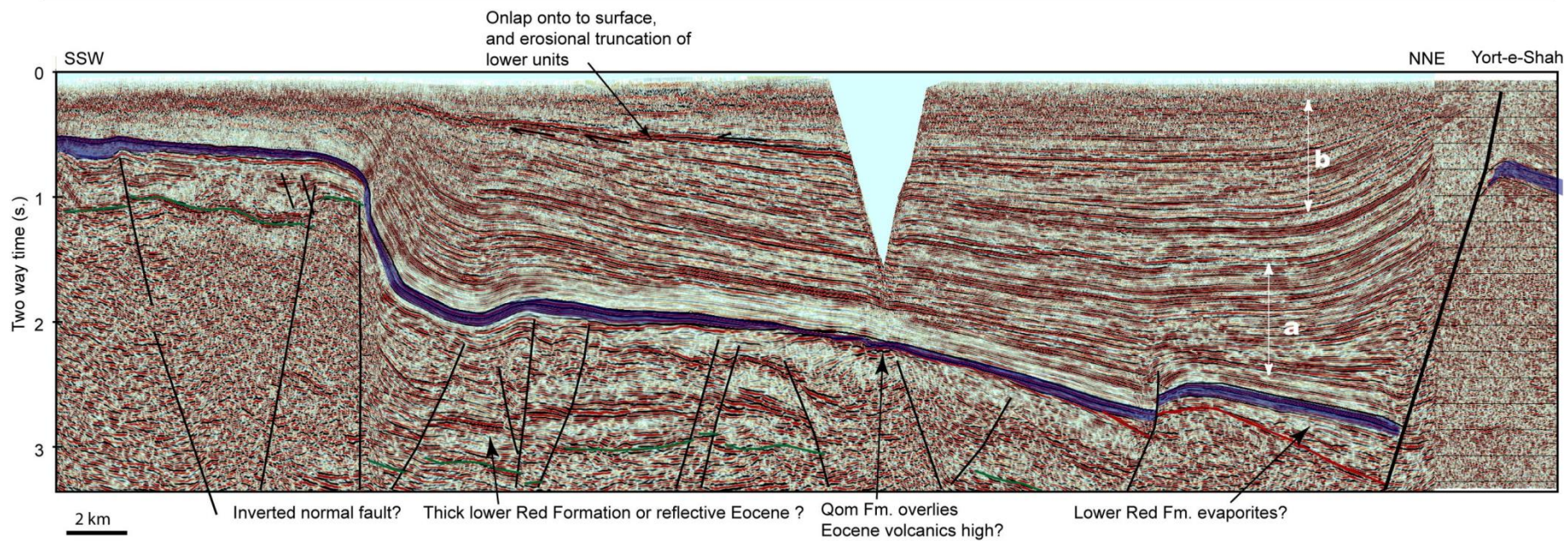
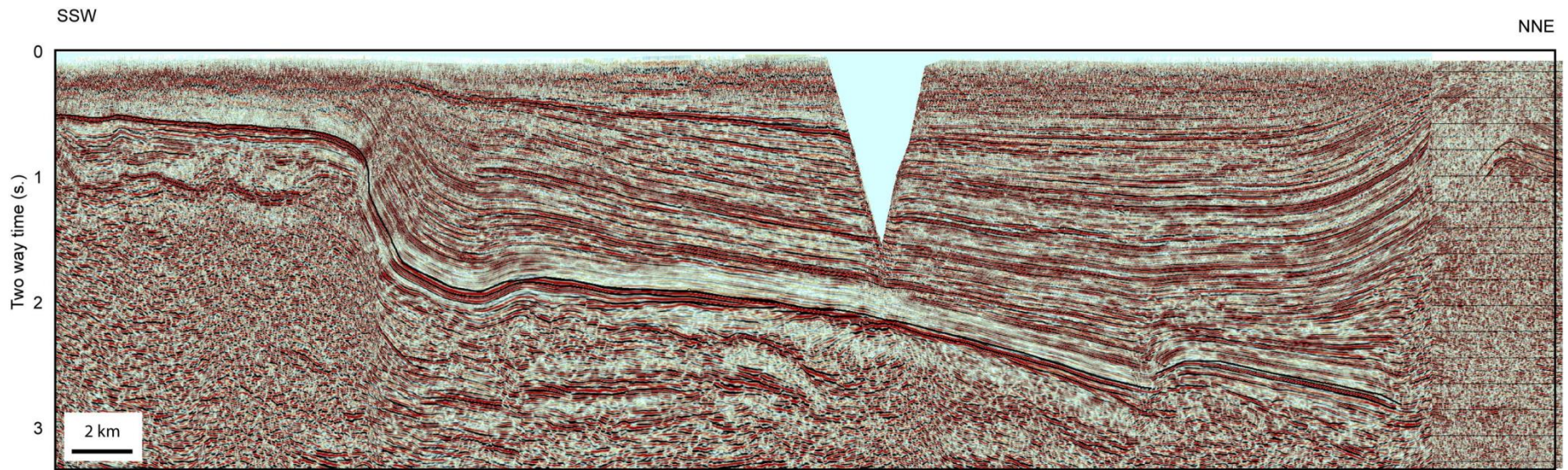
line 41 forethrust ramp diverges up-dip into trishear zone



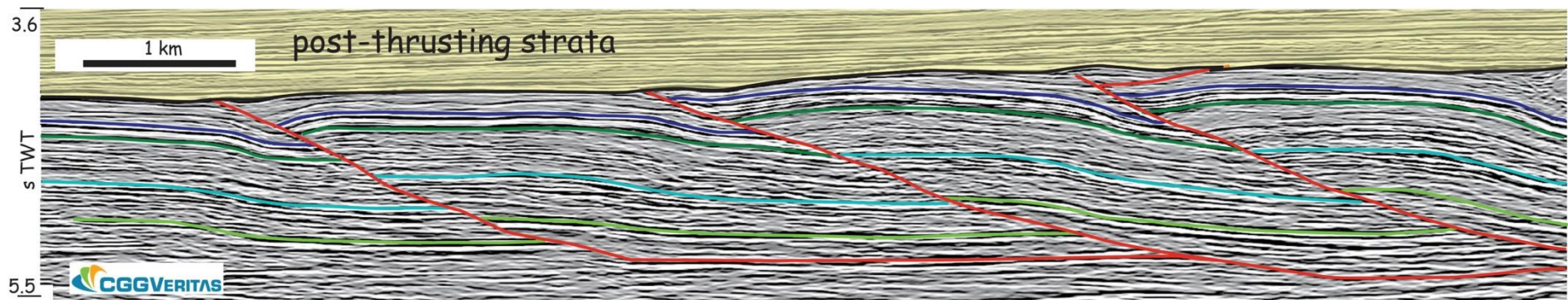
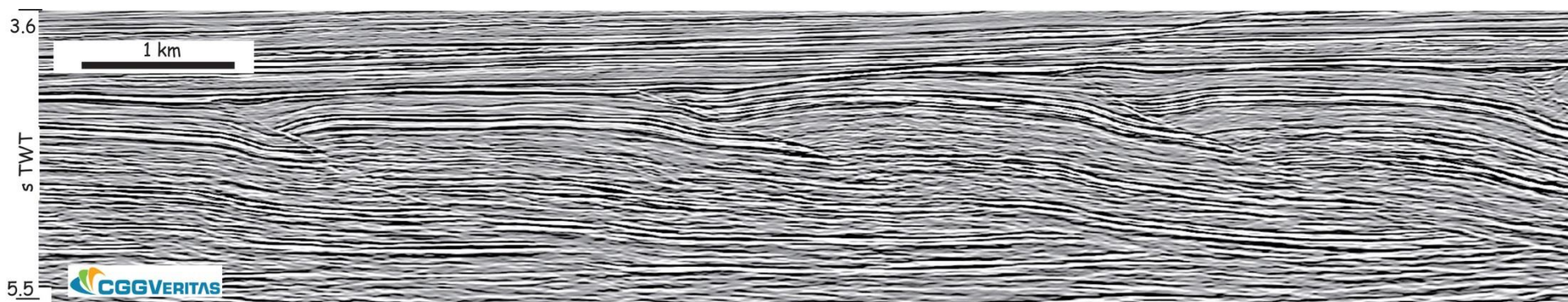


Seismic profiles across part of the Central Basin, Iran. Scene
 VSA Author: Chris Morley Organization: N/A Date Created: 2009-06-03





a = expansion of lower Upper Red Formation into boundary fault, b = thinning of upper Upper Red Formation towards boundary fault (inversion)

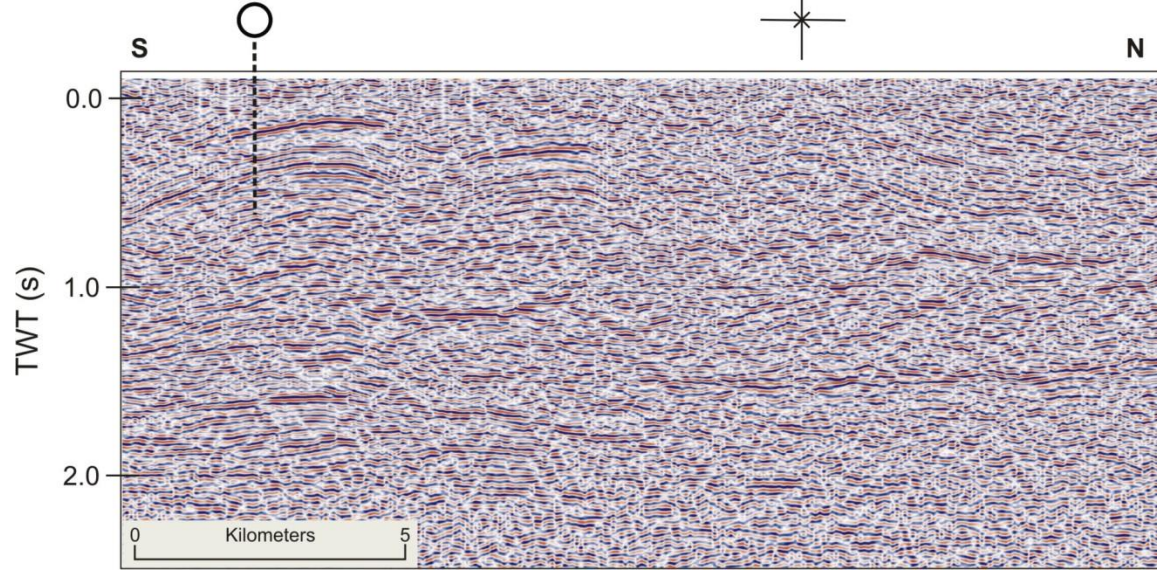


Намибия

Amoco PCP A-1
Cranswick A-22

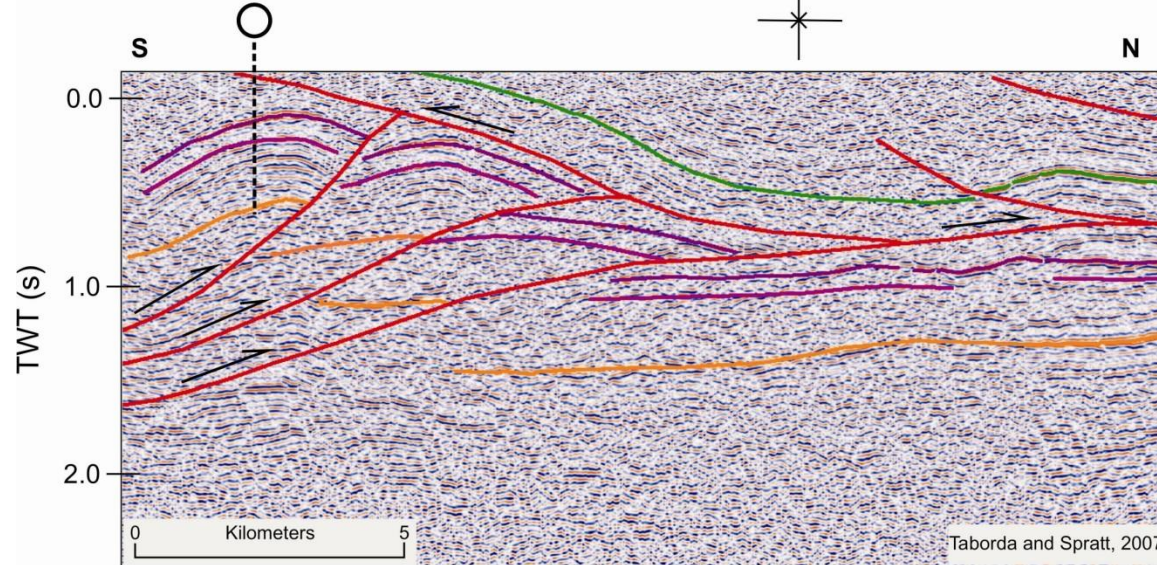
Lichen Syncline

Канадские Кордильеры

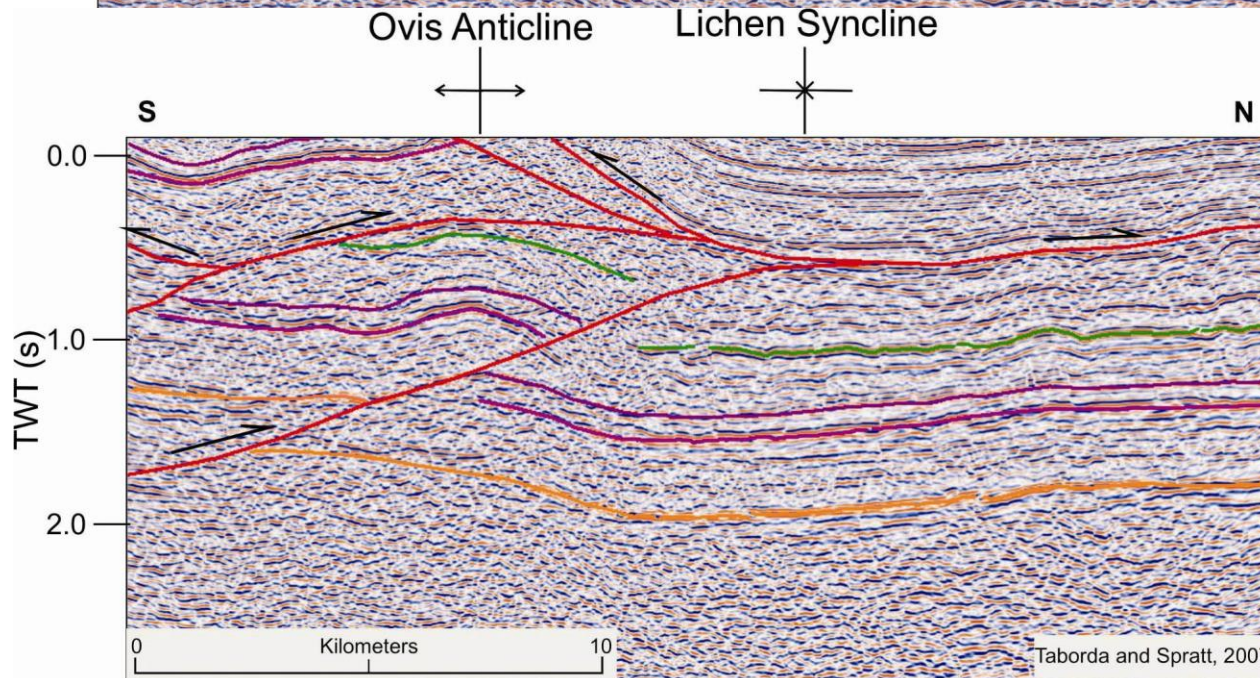
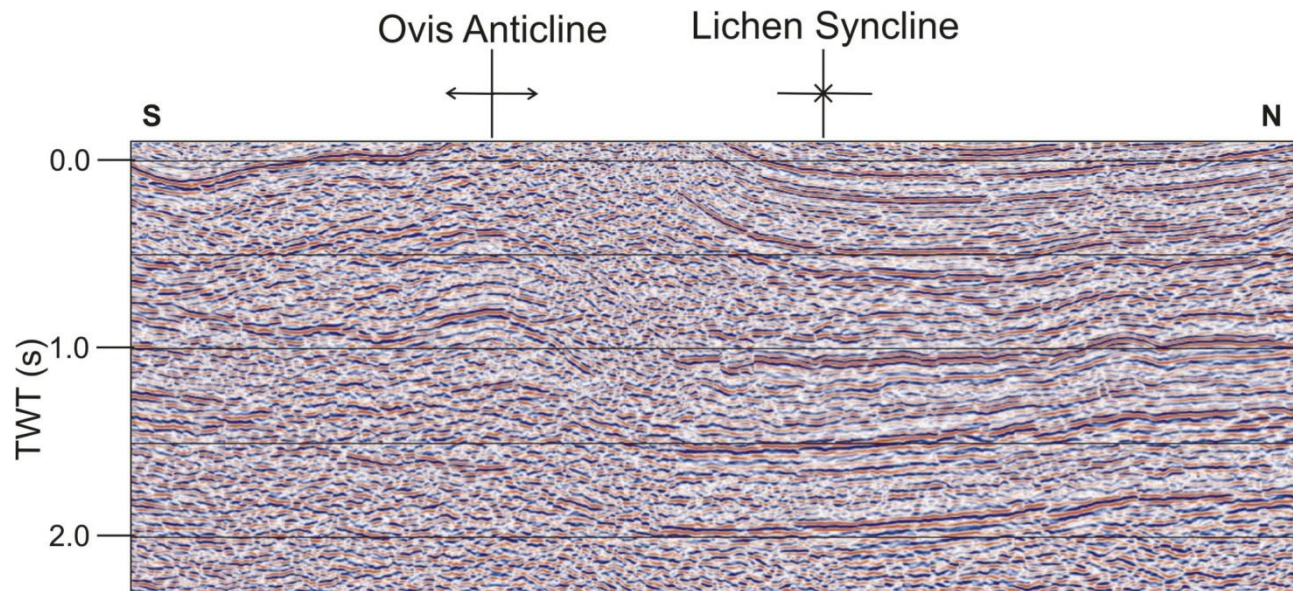


Amoco PCP A-1
Cranswick A-22

Lichen Syncline

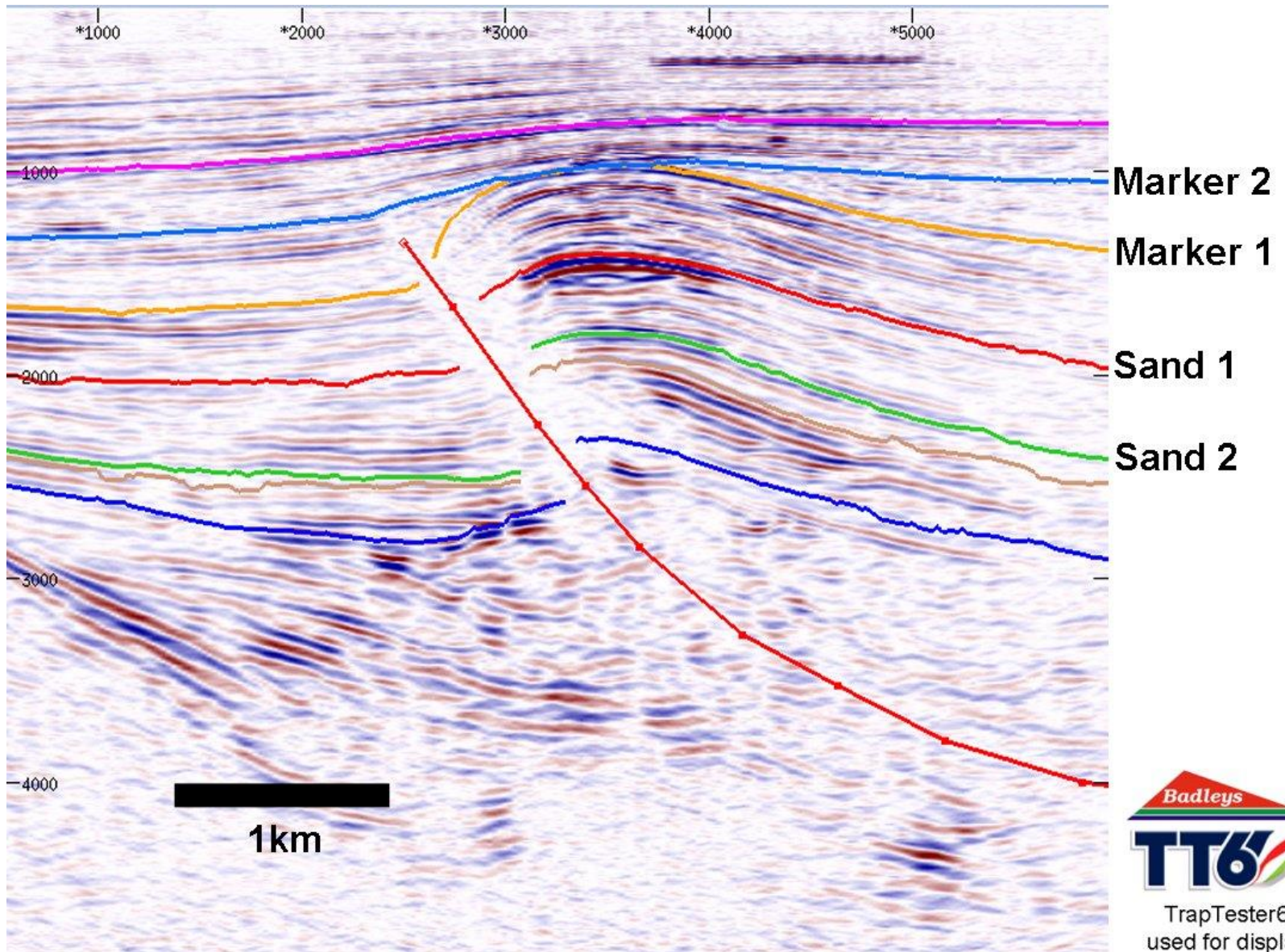


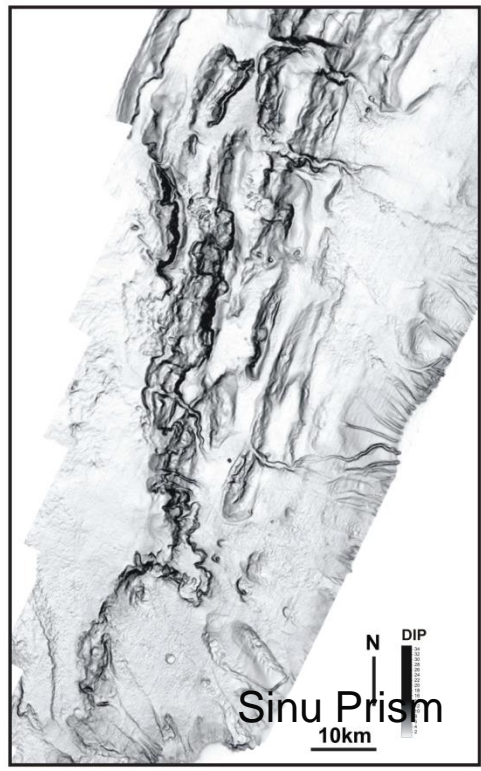
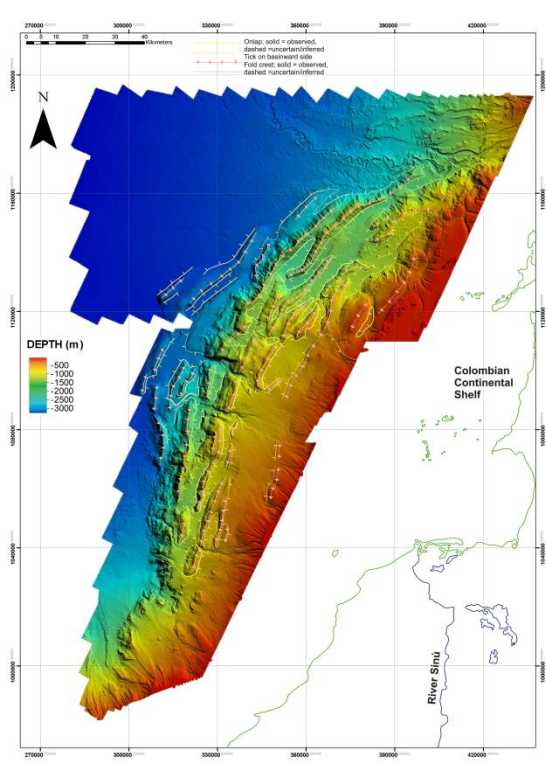
Base Cretaceous — green
Base Imperial Fm — purple
Top Hume Fm — pink
Top Cambrian — yellow
Top Proterozoic — orange



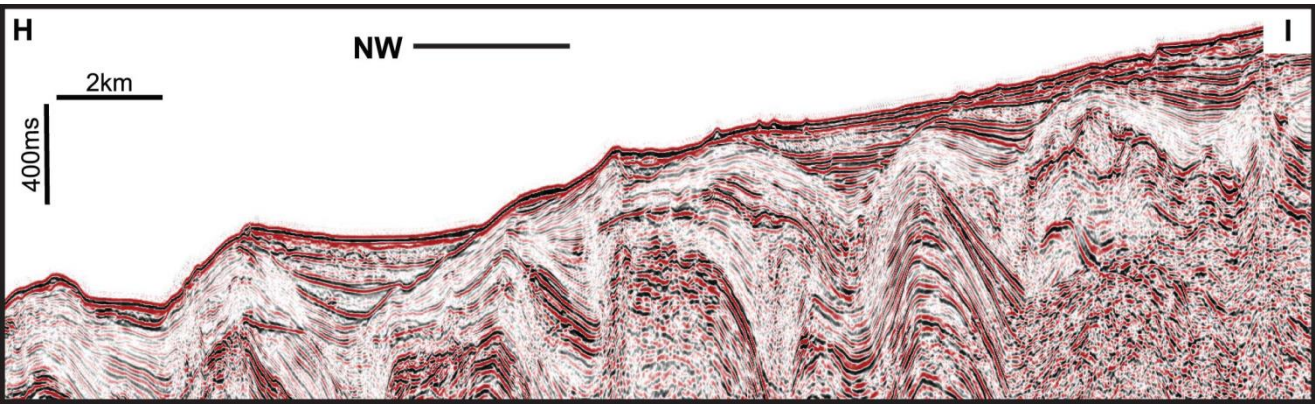
- Base Cretaceous ———
- Base Imperial Fm ———
- Top Hume Fm ———
- Top Cambrian ———
- Top Proterozoic ———

Венесуэлла

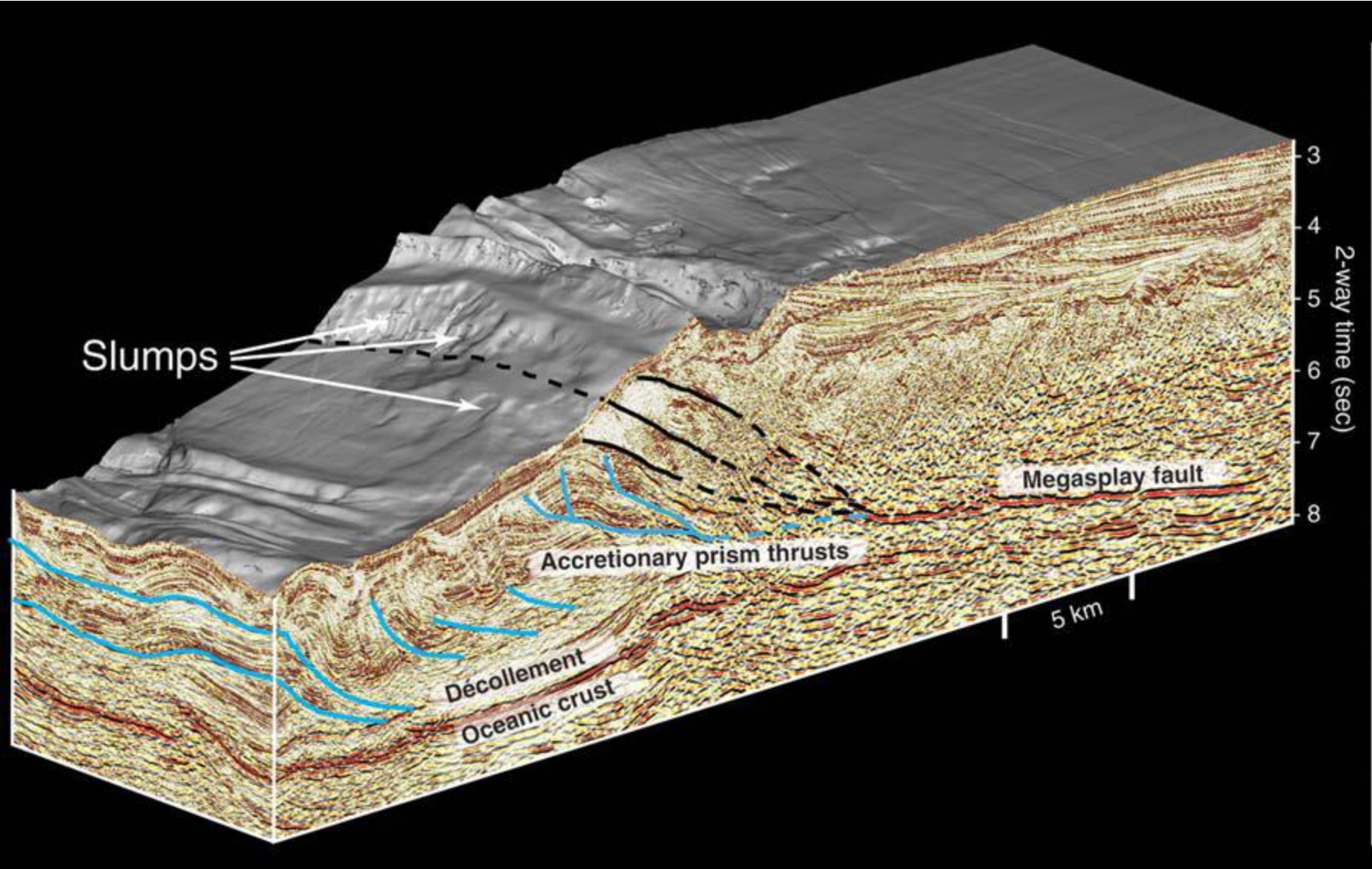


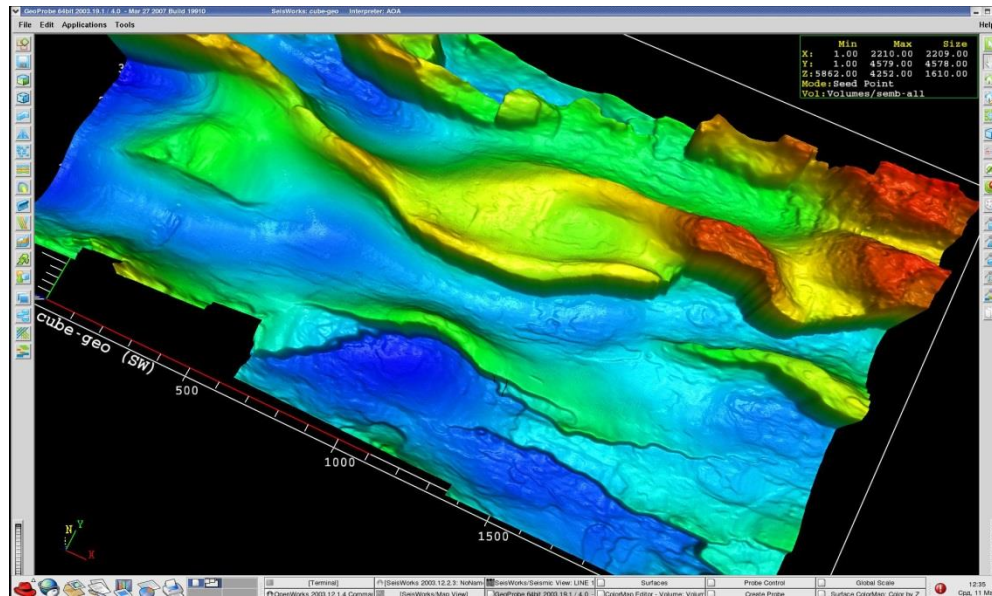
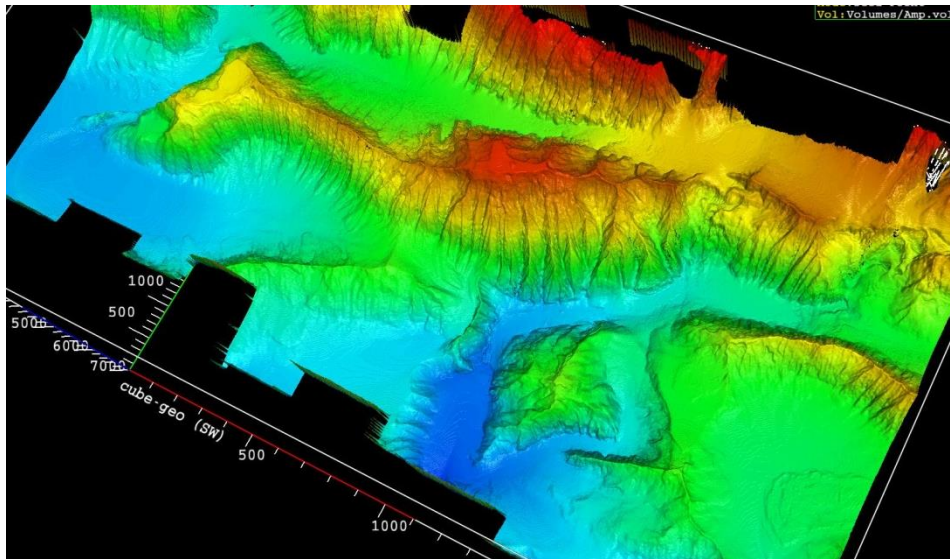


Sinu Prism



Sinu Accretionary prism





Сопоставление карт топографии дна моря (а) и кровли майкопской серии (б) в трехмерном виде. (Альмендингер, 2011)

Взбросы, надвиги и синтектоническая седиментация

Messinian evaporites across the Anaximander Mountains, Sırrı Erinç Plateau and the Rhodes and Finike basins, eastern Mediterranean Sea

A.E. Aksu*, J. Hall, T.J. Calon, M.C. Barnes, P. Güneş, J.C. Cranshaw

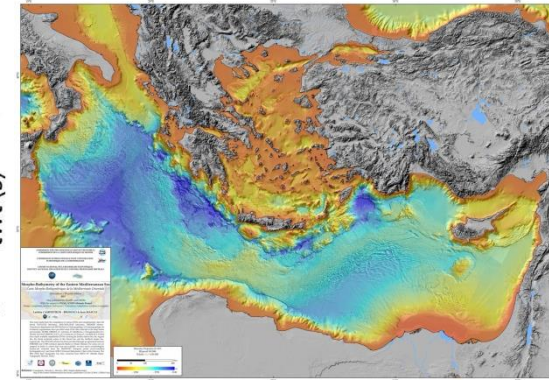
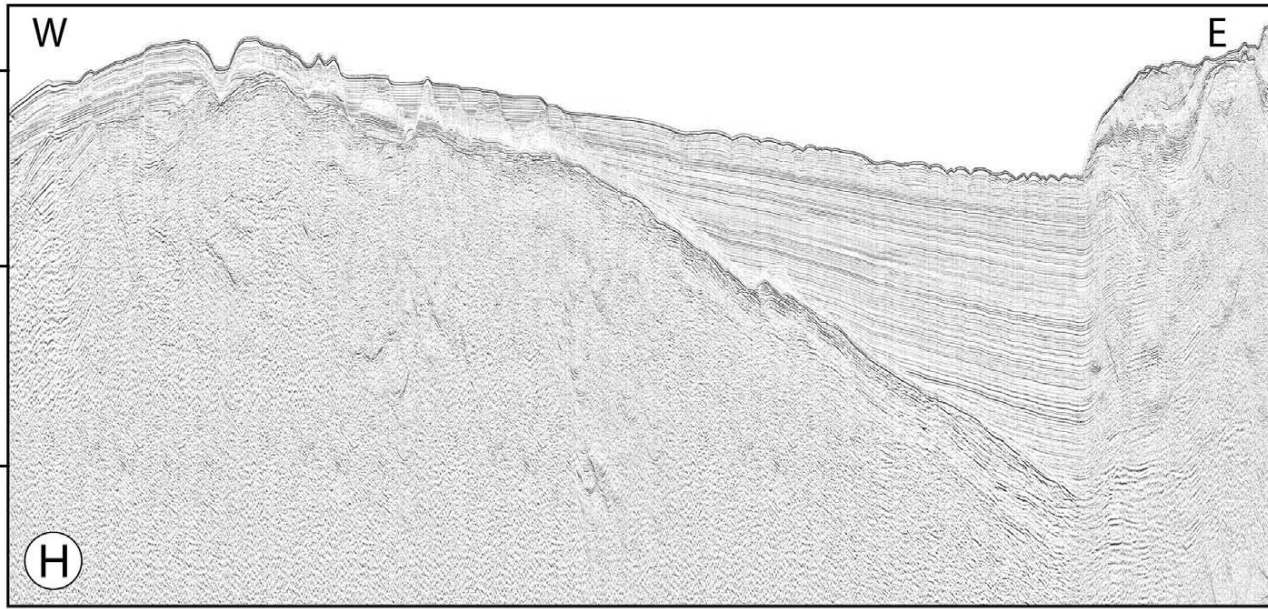
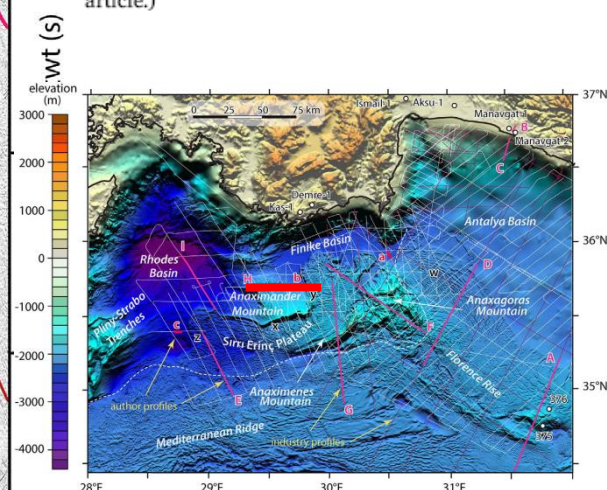
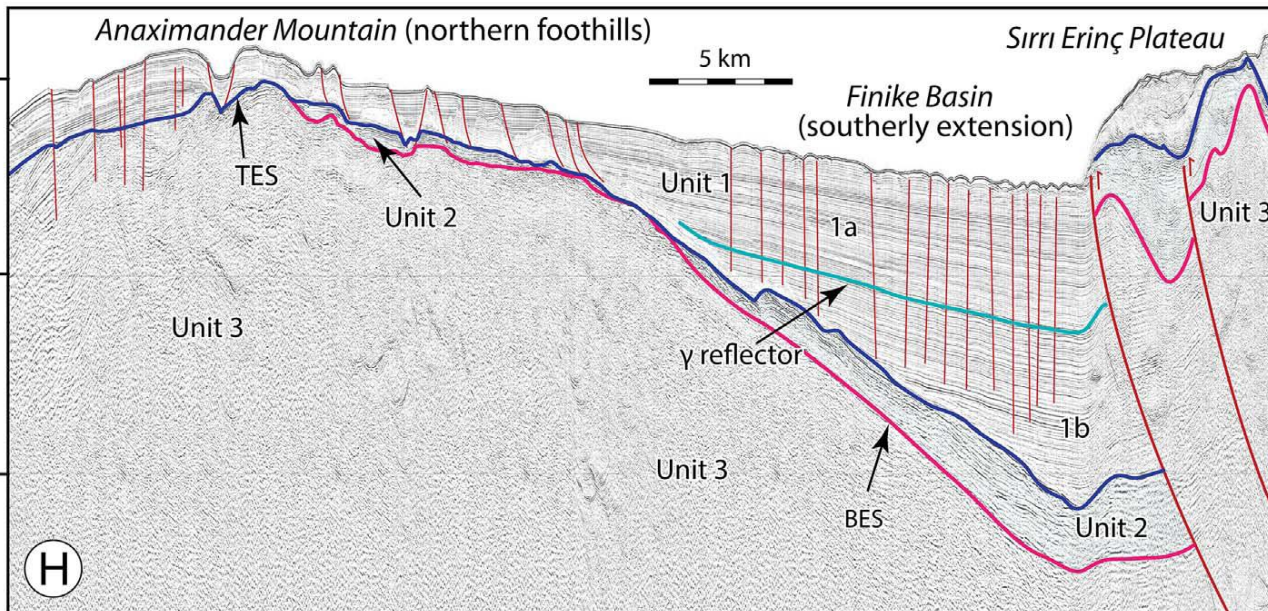


Fig. 17. Multichannel seismic reflection profile H extending from the Sırrı Erinç Plateau into the northern foothills of the Anaximander Mountain, showing the distribution of Unit 2. Reflectors defining TS/TES and BS/BES are discussed in text. The γ -reflector is a prominent marker that separates the isopachous lower sub-unit 1b from the upper sub-unit 1a which shows dramatic growth strata wedges that are shingled one on top of the other (also see Hall et al., 2009; Aksu et al., 2009). Location is shown in Fig. 2. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)



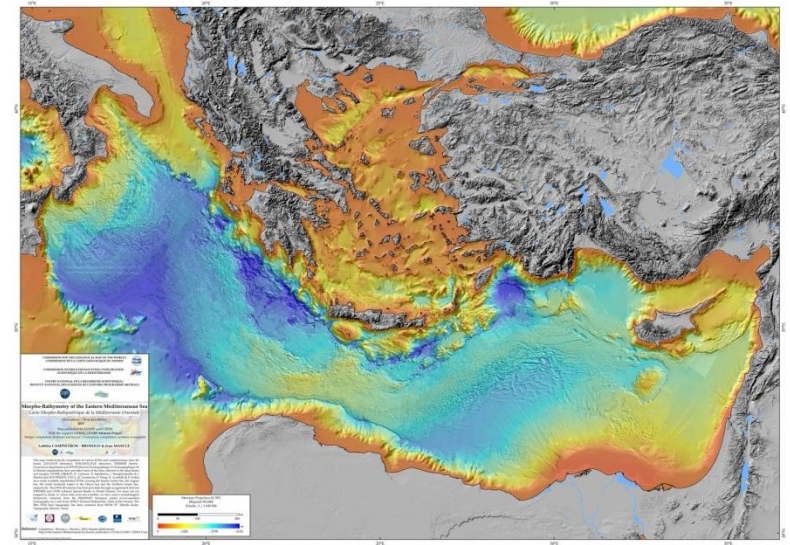
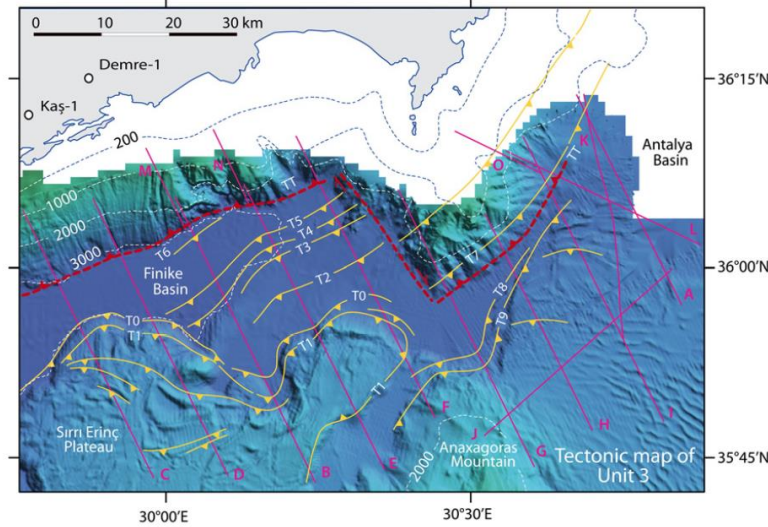
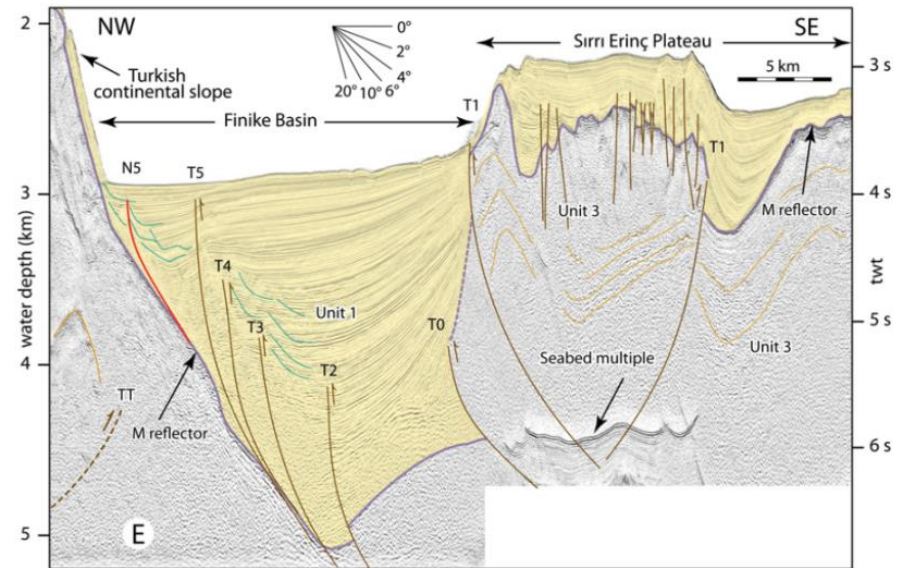
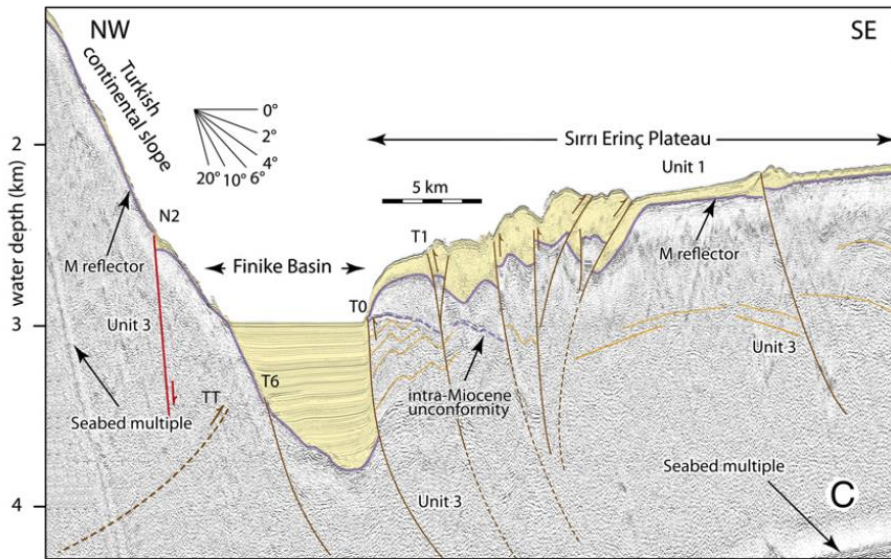


Fig. 10. Pre-Messinian tectonic map of the Finike Basin and environs showing major thrust faults (dark yellow lines with filled triangular ticks on the hanging walls). TT shown with dashed lines is the prominent thrust extrapolated using the thrust surfaces which are cut in the Demre-1 and Kaş-1 exploration wells drilled onland Kasaba Basin (also see Aksu et al., 2009). Letter with numbers are fault labels discussed in text. Isobaths contours (blue and white dashed lines) are in meters, calculated using the ANAXIPROBE 95 multibeam data and CARIS Bathy DataBase 4.0. Also shown are the locations of seismic reflection profiles illustrated in figures.



Некоторые примеры надвиговых систем

Предальпийский краевой прогиб

130

A. Malz et al. / Tectonophysics 670 (2016) 127–143

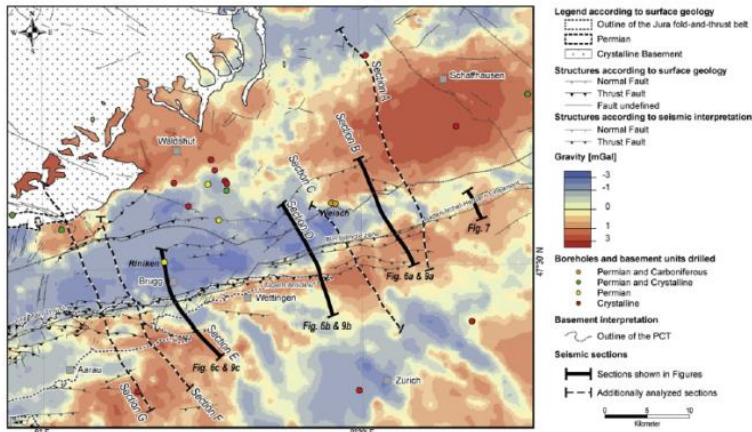


Fig. 3. Bouguer gravity anomaly map of the research area (residual field upward-continued 5000 m; Green et al., 2013) with deep boreholes reaching the basement. The negative gravity anomaly indicates the location of the Permo-Carboniferous Trough (PCT) of Northern Switzerland (dotted outline illustrates the deep central trough). Note that the trace of the BH-Lineament appears to correlate with the southern boundary of the central trough.

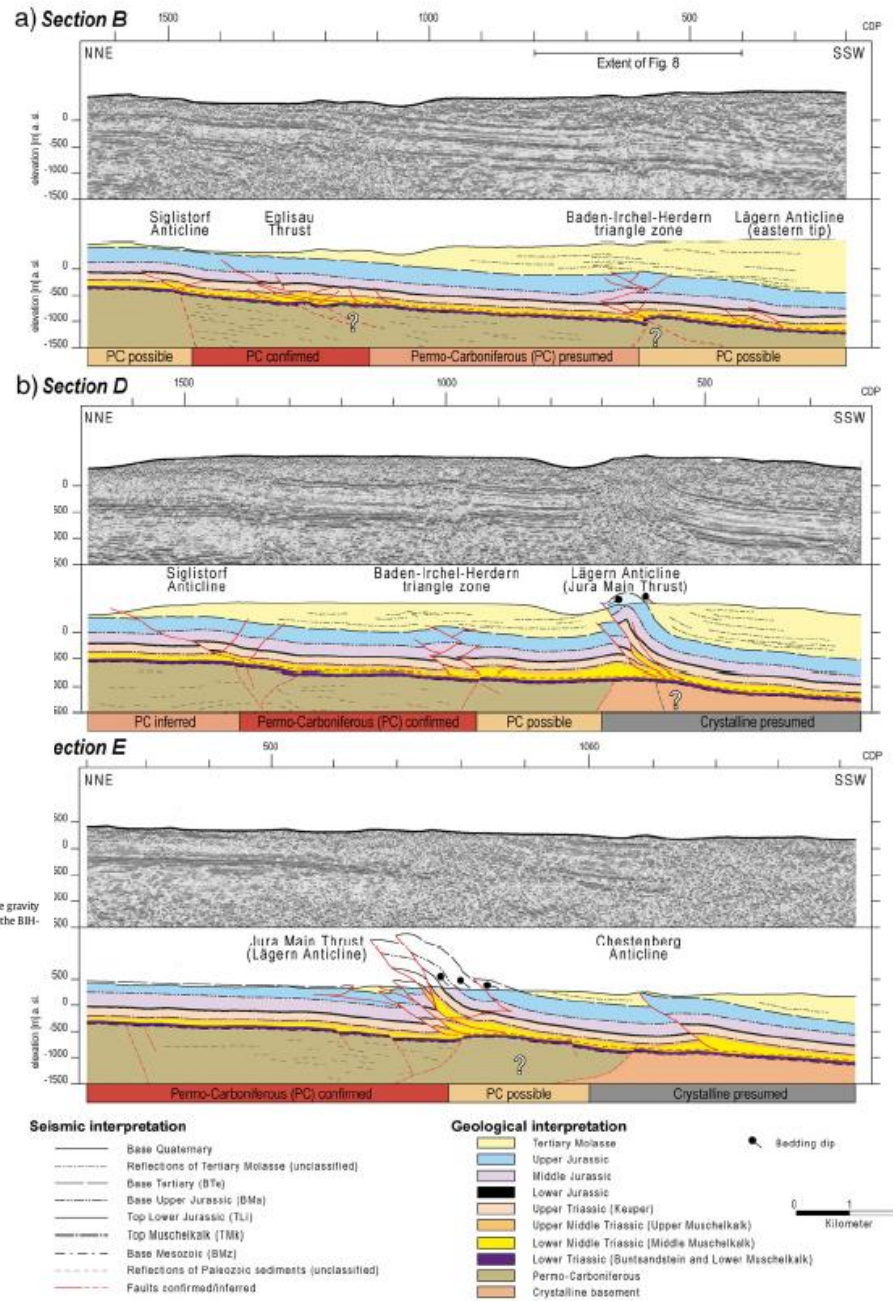
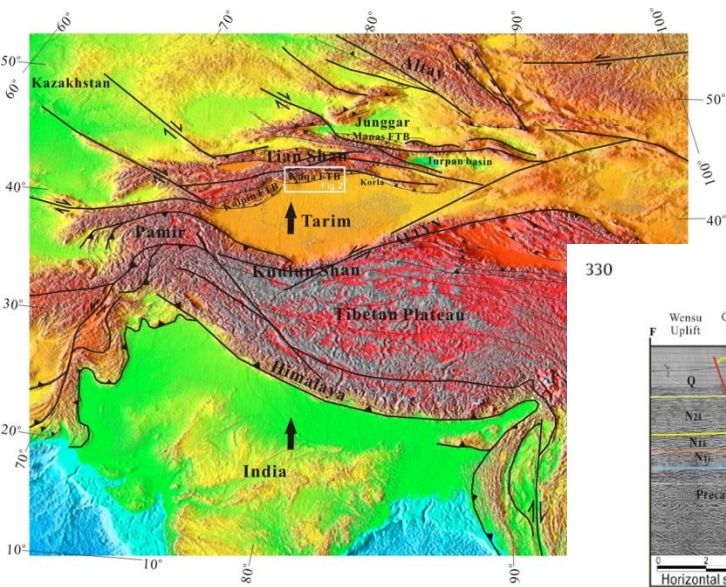


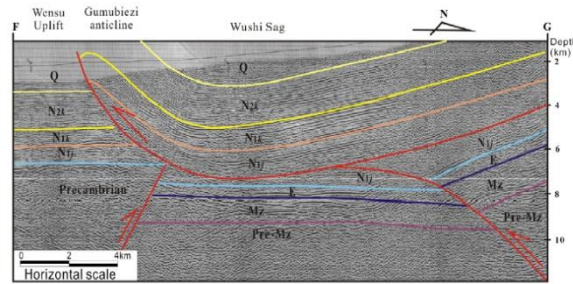
Fig. 6. Reflection seismic sections (B, D and E; cf. Fig. 2) with interpreted geological sections straddling the easternmost Jura fold-and-thrust belt and the contractionally overprinted Baden-Irchel-Herdern-Lineament (BIH triangle zone).

Надвиги на северном краю Таримский платформы



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Q: Quaternary;
 N2k: Pliocene Kuche Formation;
 N1k: Miocene Kangcun Formation;
 N1j: Miocene Jidike Formation;
 E: Paleogene;
 (E2-3)s: Paleogene Suweiyi Formation;
 (E1-2)k: Paleogene Kumugeliem Formation;
 K: Cretaceous;
 J: Jurassic;
 T: Triassic;
 Mz: Mesozoic.

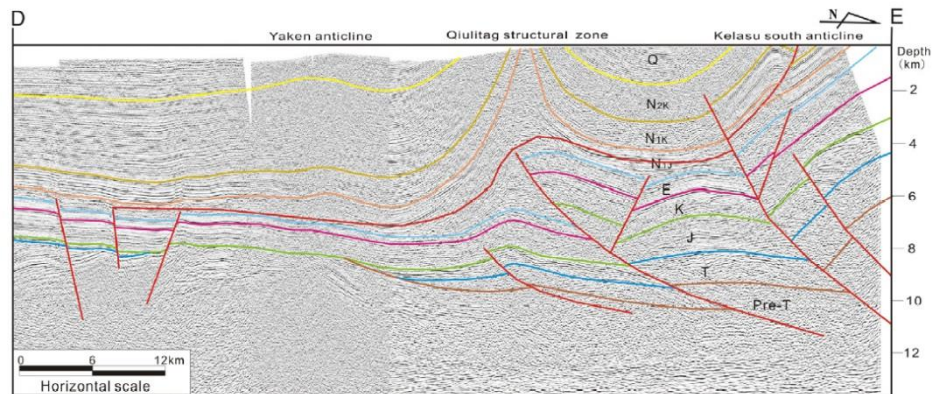
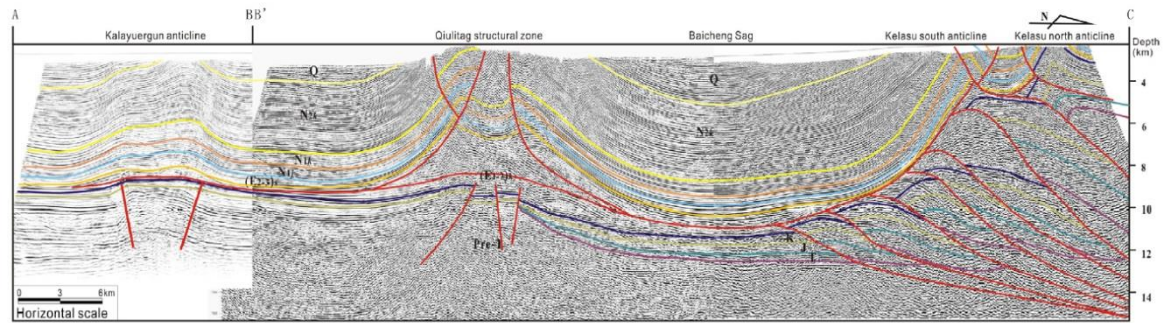


Fig. 3. Three representative seismic profiles across the west, middle and east segment of the Kuqa FFB respectively (profile location shown in Fig. 2).

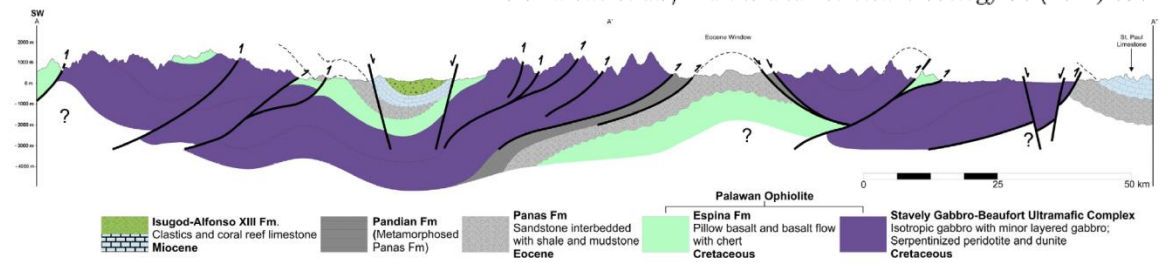
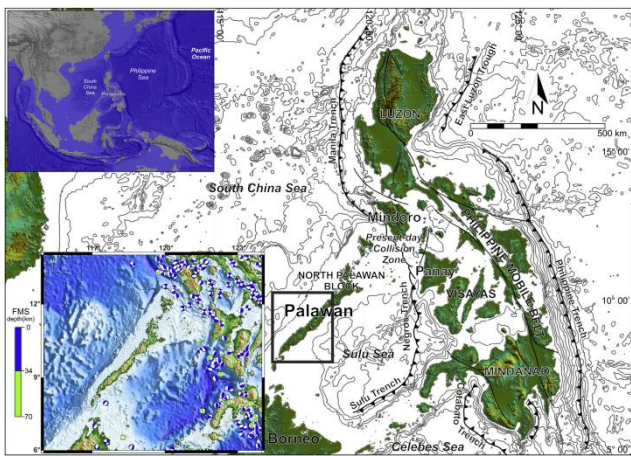
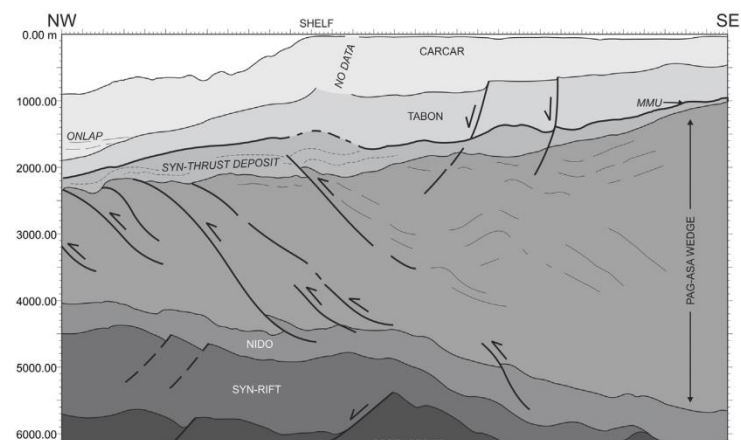
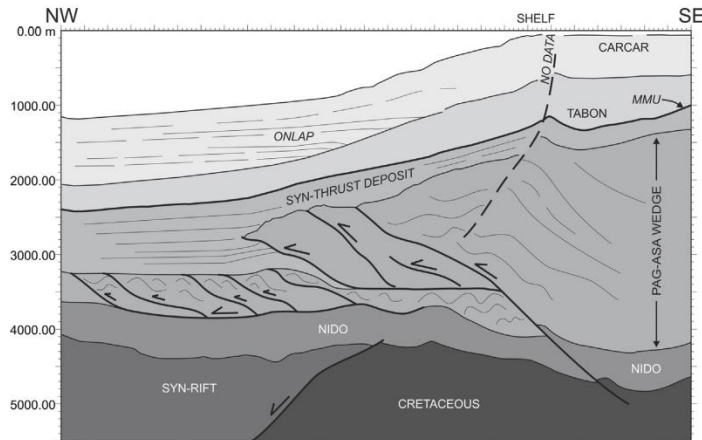
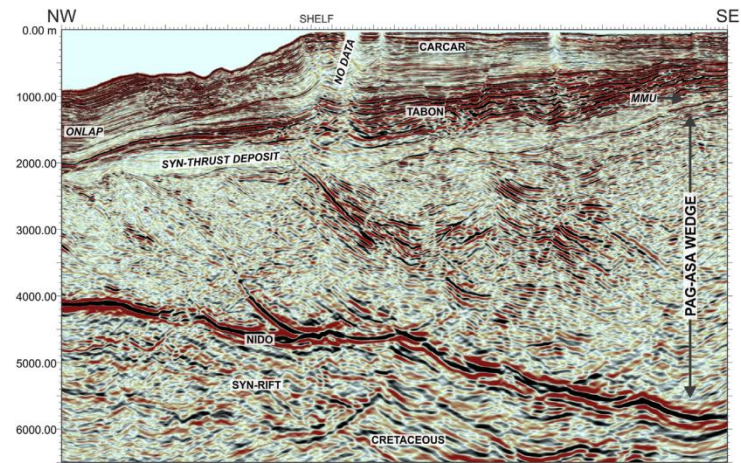
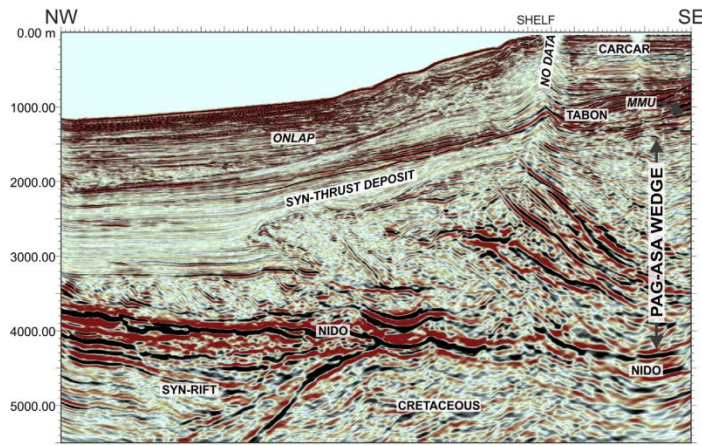
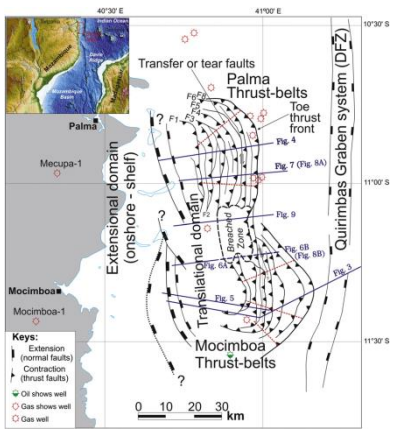


Figure 4. Longitudinal Structural Transect of Central and South Palawan. Structural features include: thrust-faulted Mesozoic ophiolites emplaced over Eocene turbidites (tectonic window). Early Miocene sedimentary sequences sealing thrusting, post-ophiolite emplacement normal faults affecting flanks of Early Miocene – Pliocene sedimentary Basin. Transect location is shown in Figure 2 as Line A-A'. See text for discussion.

Разрез на островах

Сейсмические профили в море с надвигами (надвиговыми клиньями)





Гравитационная тектоника на континентальном склоне

E.S. Mahanjane, D. Franke / Tectonophysics 614 (2014) 91–99

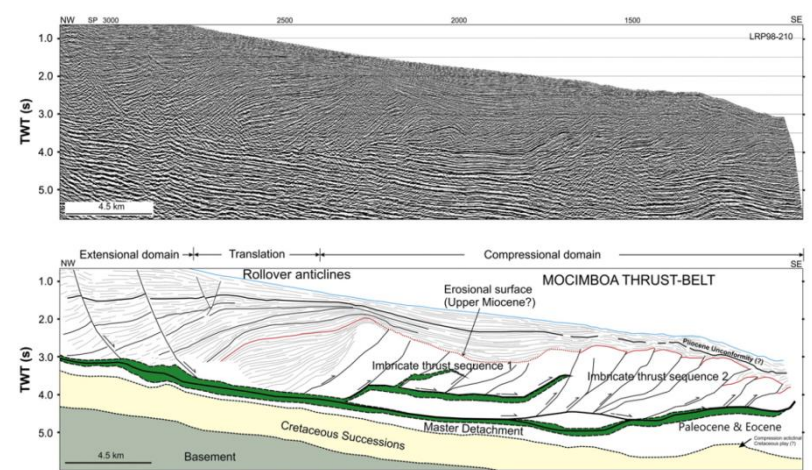


Fig. 5. Top: Reflection seismic lines showing the general architecture of the southern Rovuma deltaic system from the translation to the contractional domains of the Mocimboa Arcuate Complex. Bottom: Structural and stratigraphic interpretation showing basinward-dipping listric extensional faults with rollover anticlines in the translational zone. The contractional region is dominated by DWTFBs with partly dual detachment surfaces resulting in thrust duplexes.

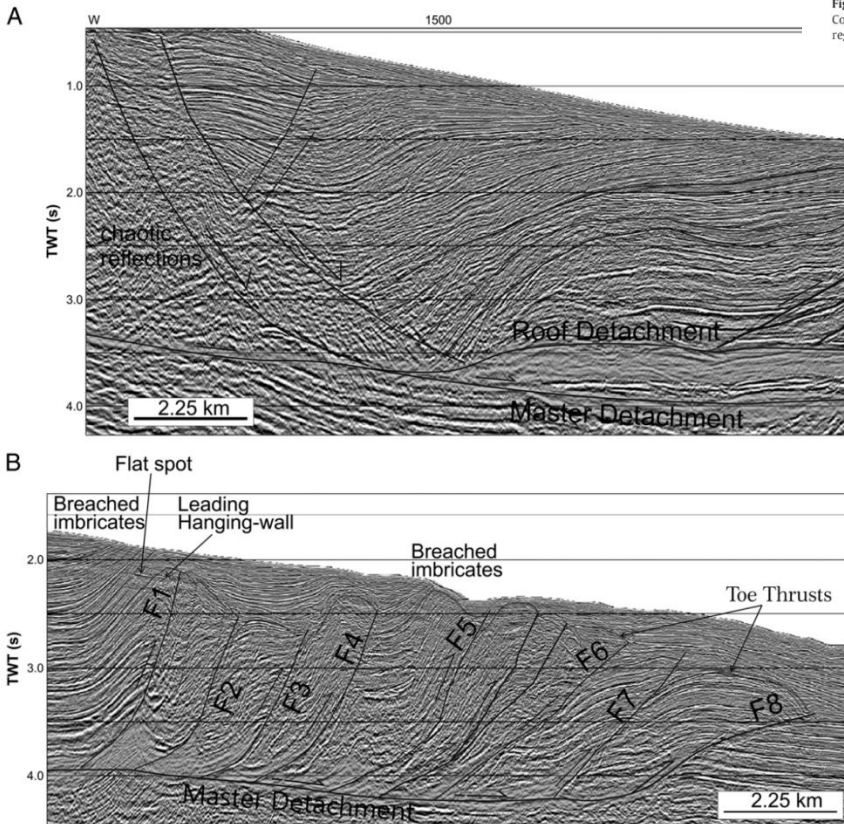


Fig. 6. Example seismic section (Profile LRP98-212) showing regional listric normal faults (A), that sole out at a major detachment fault in the southern (Mocimboa) extensional domain. The deformation resulted in the formation of rollover structures in the translational zone and two detachments in the east. (B) Shows the corresponding compressional structures that developed above a single master detachment. The grey area indicates mobile strata.

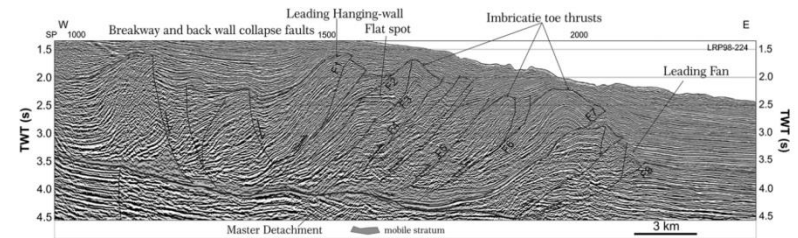


Fig. 7. Dip-line across the northern DWTFB complex of the Rovuma Delta. The eight major stacked imbricates are indicated as F1 to F8. See Fig. 1 for location. The extensional and contractional domains are located close together.

Глиняные диапиры и соляные тела в надвиговых системах⁴⁸

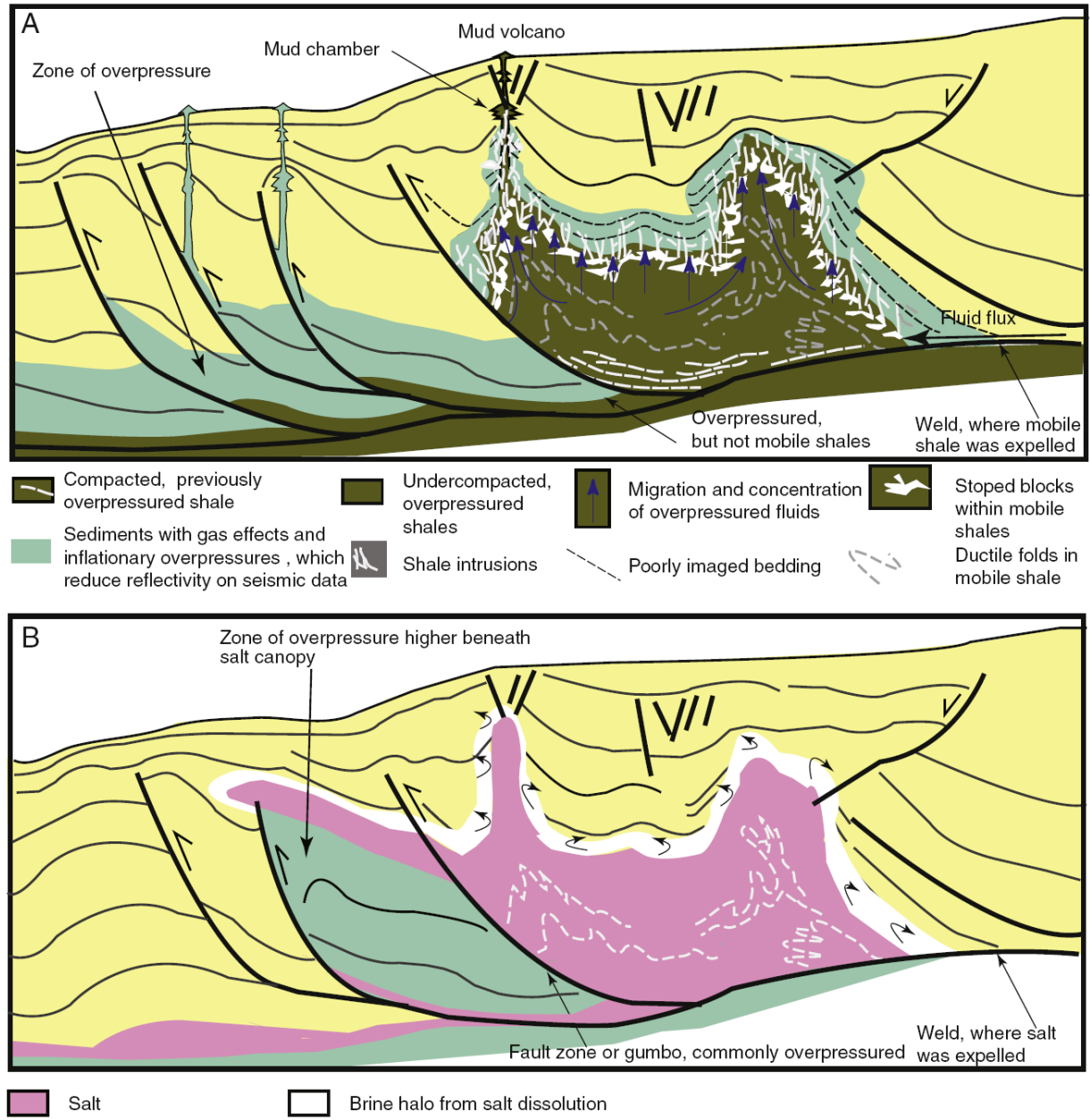


Fig. 7. Schematic comparison of structural style and overpressure distribution associated with thick mobile shale and mobile salt detachments. A) Mobile Shale, B) Salt. Partly based on Warren et al. (in press) and observations from the Niger Delta and Brunei Darussalam (Morley and Guerin, 1996; Van Rensbergen et al., 1999; Morley, 2003a,b).

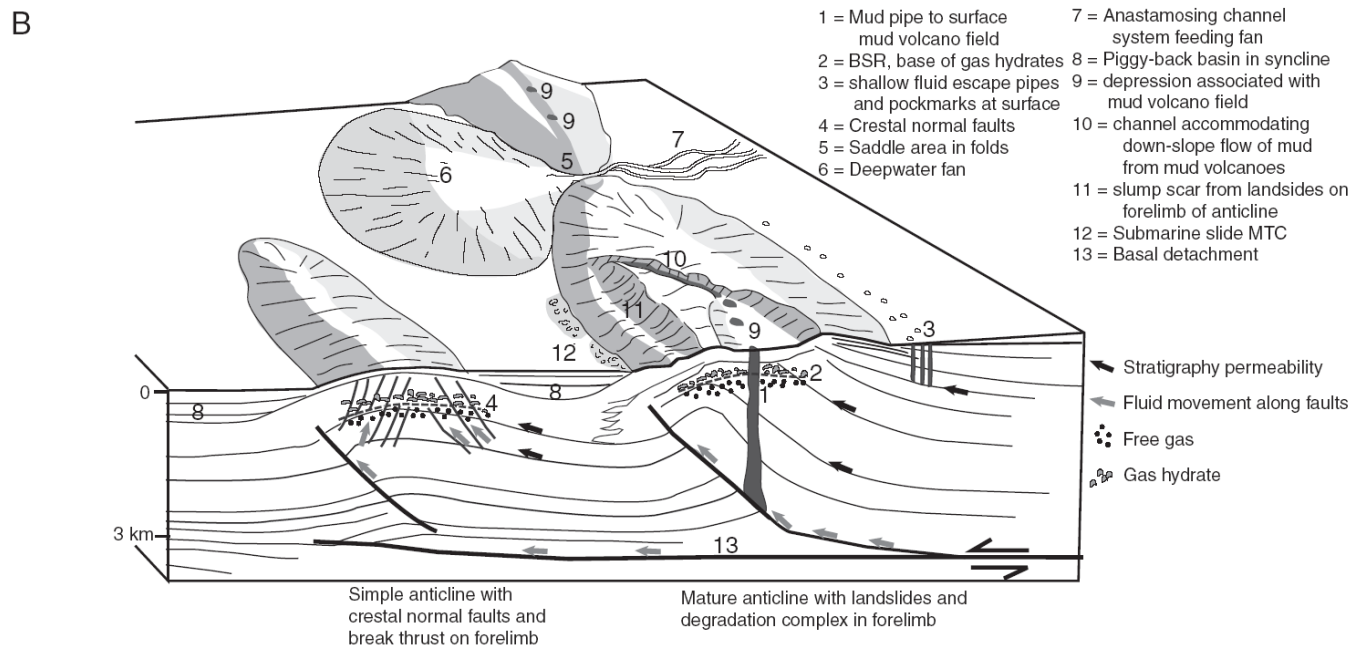
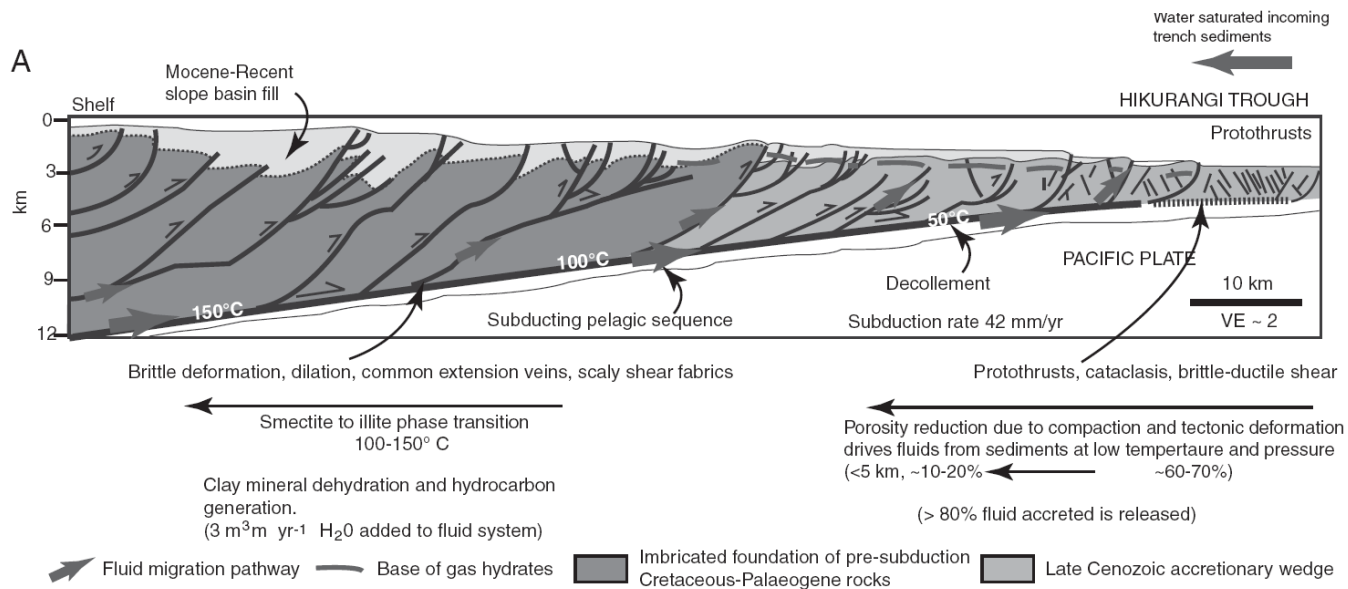


Fig. 8. Illustrations of fluid flow in deepwater fold and thrust belts associated with shale detachments. A) Cross section through the Hikurangi Subduction zone cross section (Barnes et al., 2010). B) Schematic 3D section showing typical features associated with growing deepwater folds (based on Morley, 2009a and Barnes et al. 2010).

Моделирование в коробках со слоистым песком

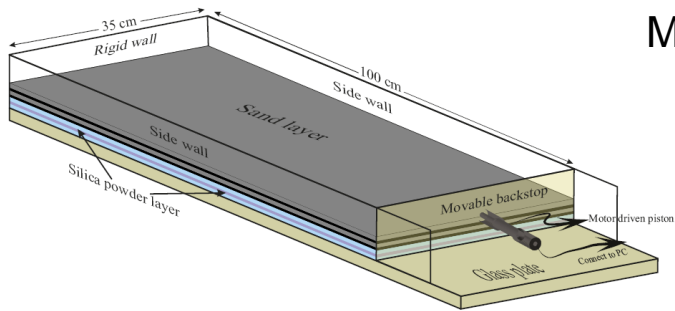
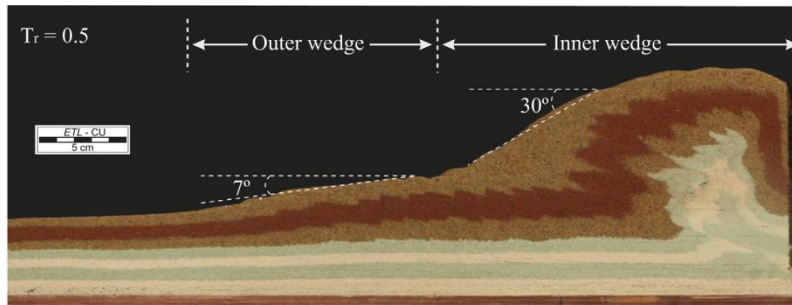
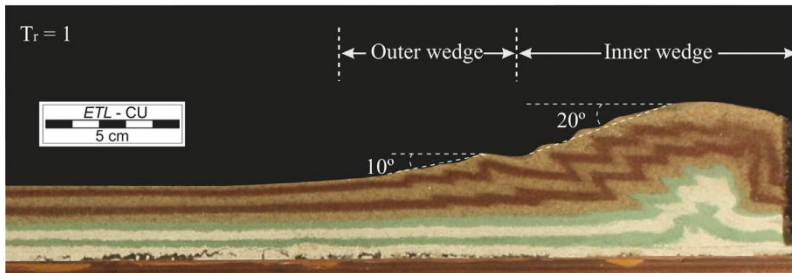


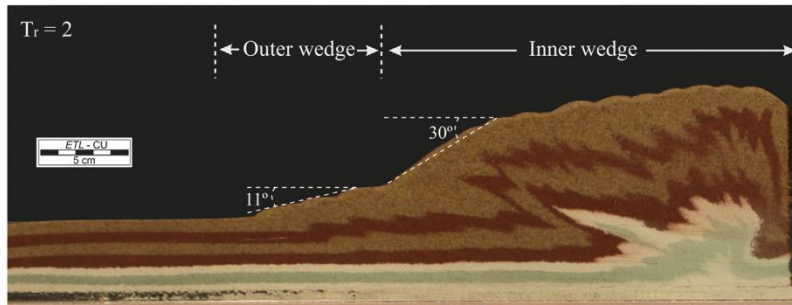
Fig. 2. A sketch of the experimental setup, giving a 3D view of the model.



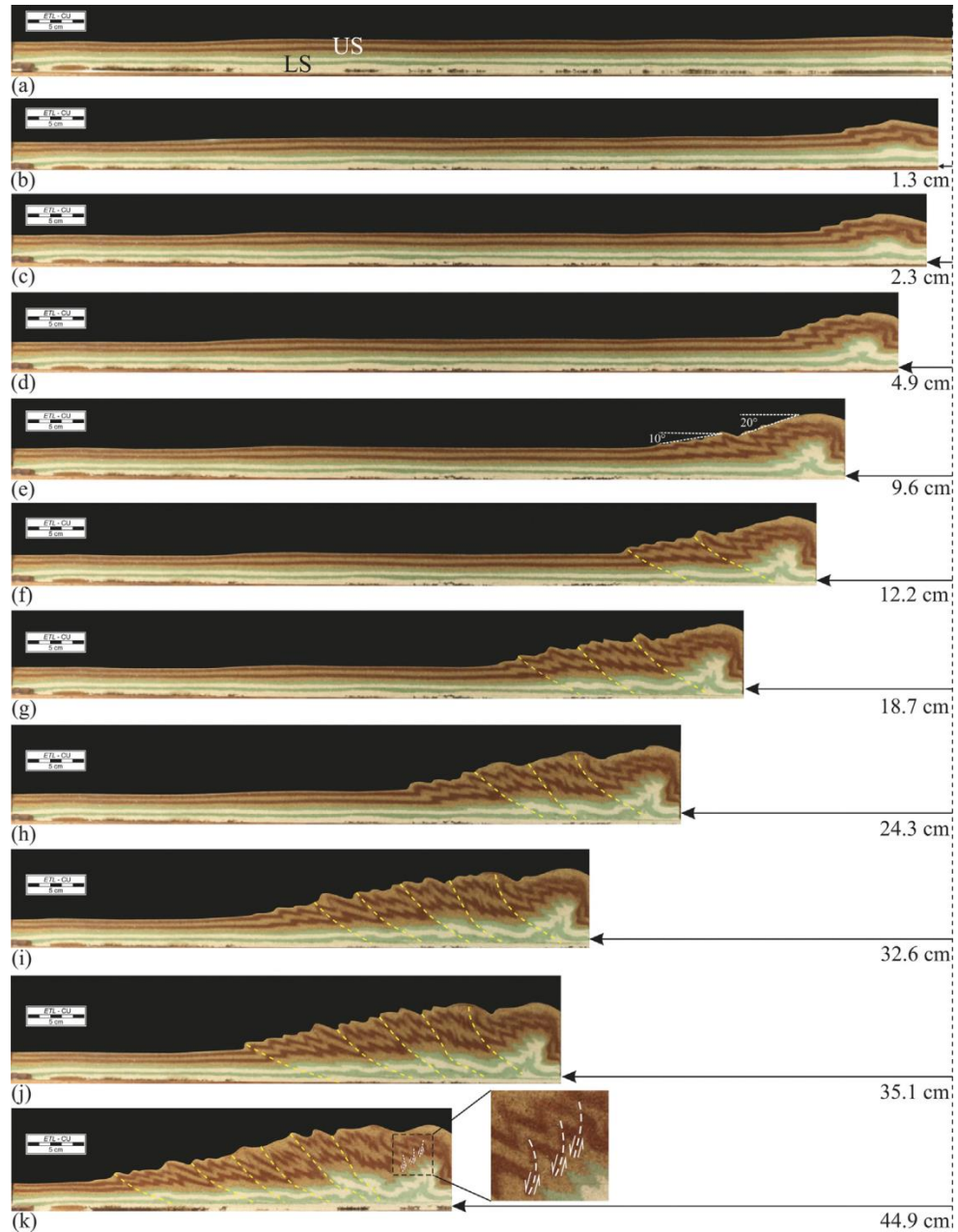
(a)



(b)



(c)



(k)

44.9 cm

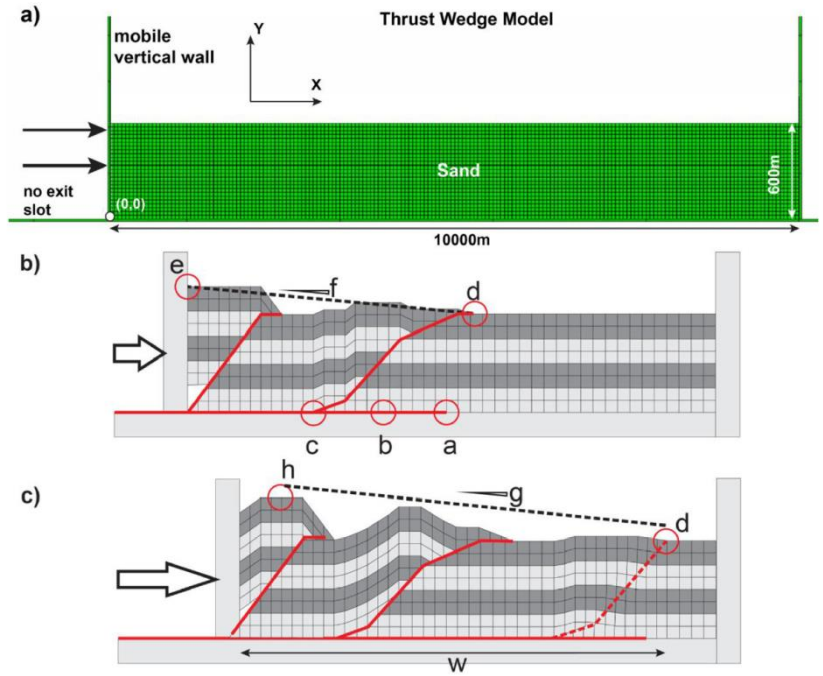


Fig. 2. Setup of the thrust wedge experiments and illustration of wedge parameters at different shortening periods. (a) Setup of thrust wedge model, a horizontal sand layer with thickness of 600 m and length of 10000 m is shortened by a mobile wall running from left to right, while the base and right wall remain fixed. (b) Schematic illustration of the process followed for measurements of wedge parameters. a = displacement front, defined as position of 0 m displacement along the detachment, b = 50 m displacement position along the detachment, c = failure front where the frontal thrust roots into the detachment, d = deformation front (in this case, the frontal thrust tip), e = inboard corner of the wedge, f = overall taper angle determined by the slope of straight line from e to d . (c) Schematic showing the measurements of additional wedge parameters. As further shortening added, a new fold is formed in front of the existing thrust. A new thrust is about to initiate to break the new fold with its fault tip reaching the wedge surface at the deformation front d . g = surface slope determined as the best fitting line enveloping the thrust wedge (Schreurs et al., 2006), h = height of the thrust wedge, w = wedge width determined by the stance from deformation front d to the moving left hand wall.

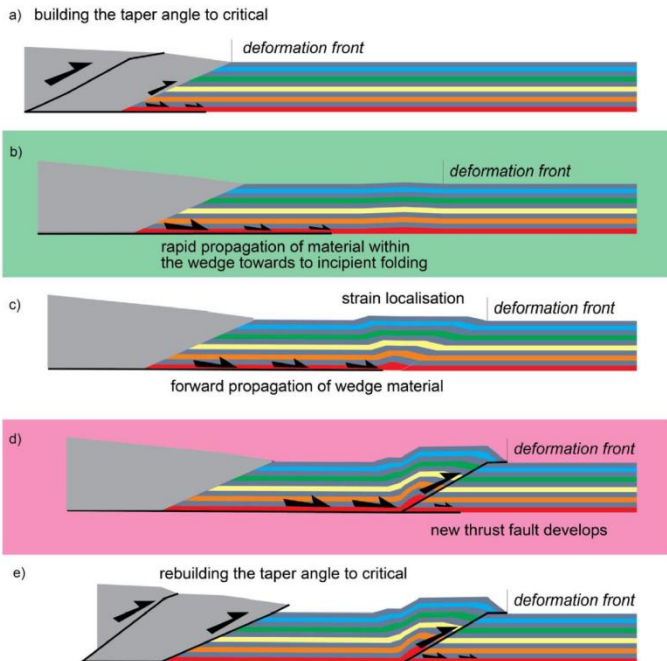


Fig. 15. Schematic sections showing how the observed cyclic behaviour in the numerical model relates to the cyclicity of tectonic processes in the thrust wedge. Pink (new fault initiation) and green background (wedge accretion) corresponds to the pink and green bars in Fig. 14. The size of black arrow represents the scale of displacement in the process of wedge growth. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

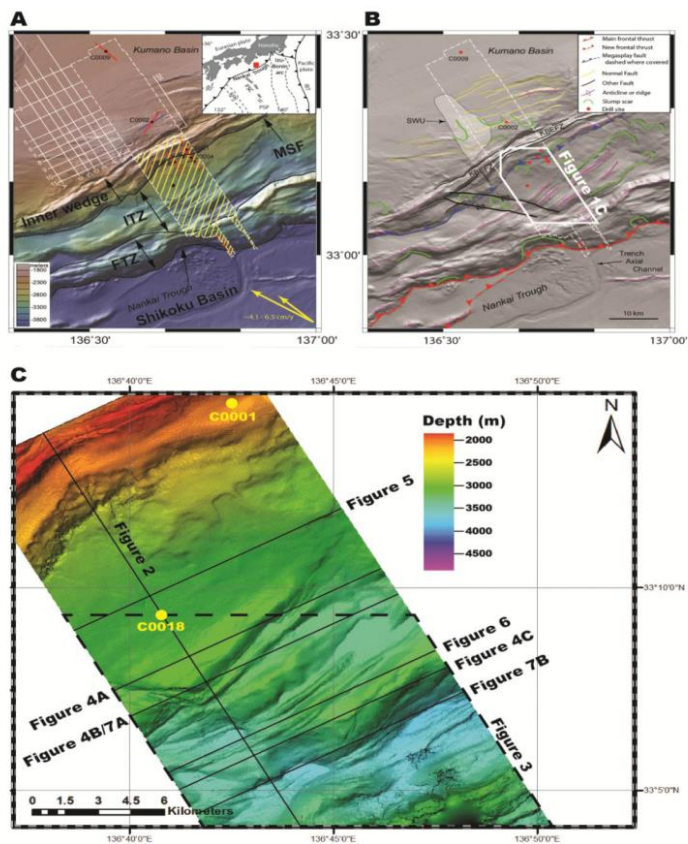


Figure 1. A) Relief map of the Kumano Basin Region of the Nankai Trough as modified from Moore et al. (2013). The figure shows the location of the 3D seismic volume (white dashed box), maximum horizontal stress directions (red lines and blue line), the location of JAMS-TEC 2-D seismic lines (white lines) and convergence vector between the Philippine Sea plate and Japan (yellow arrows). Also highlighted in the figure are also the study area (yellow lines) and the distinct tectonic regions of the NAP as shown in Kimura et al. (2011). Inset shows a regional tectonic map with the present day configuration of the Nankai Trough. MSF - Megasplay Fault; ITZ - Imbricated thrust zone; FTZ - Frontal thrust zone; KPR - Kyushu-Palau Ridge; FSC - fossil spreading center; PSP - Philippine Sea Plate; IBT - Izu-Bonin Trench. Red box shows the location of main map. B) Tectonic interpretation from Moore et al. (2013) with the area interpreted in Figure 1C. KBEFZ = Kumano Basin Edge Fault Zone; SWU = southwestern uplift. C) Bathymetric map derived from the Kumano 3D seismic volume showing the direction of seismic profiles in this paper and IODP Sites C0001 and C0018. The study area comprises the southern limit of the Kumano Transect, until the MSFZ.

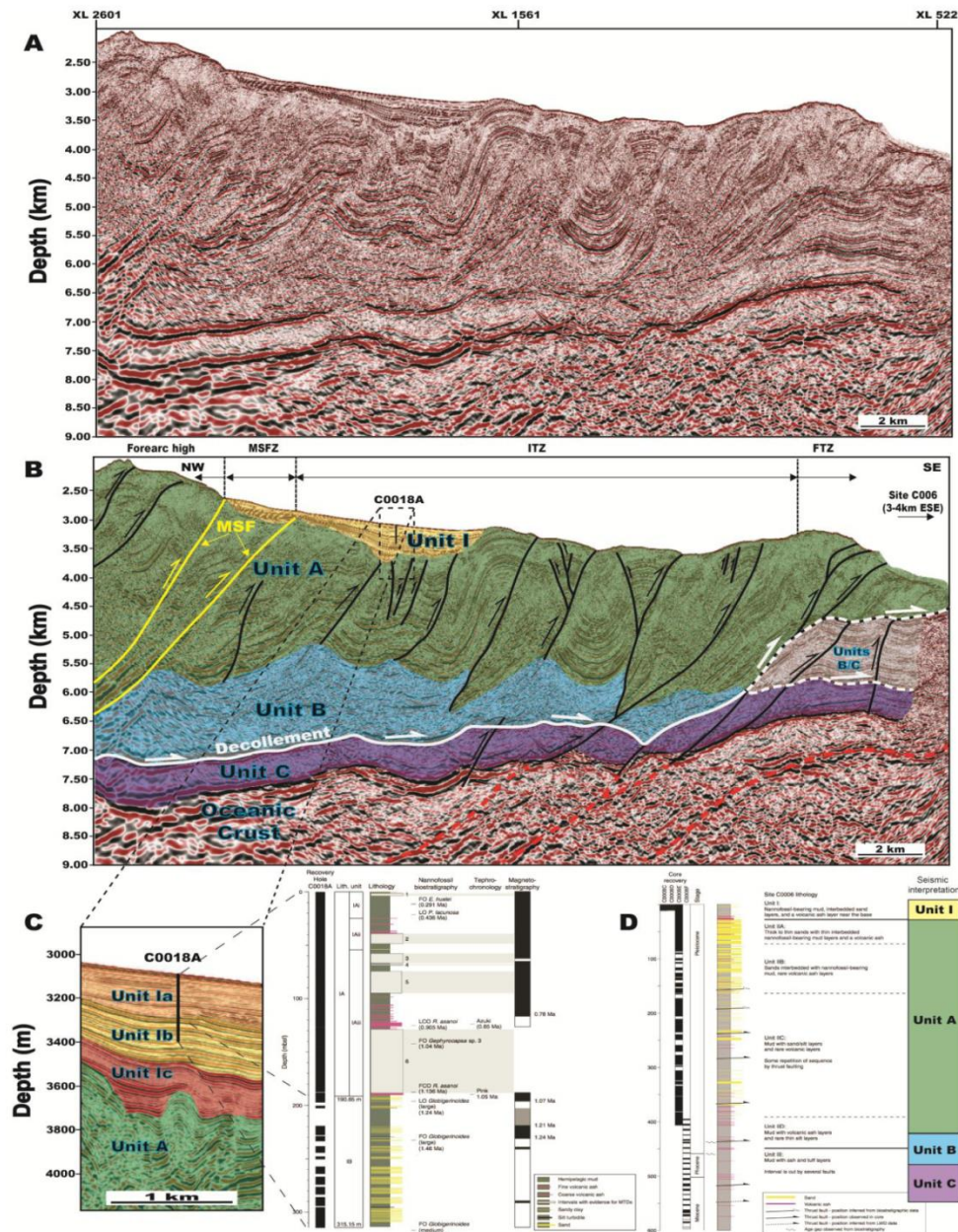


Figure 2. A & B) Depth-migrated seismic profile (Inline 2315) across thrust-and-fold structures of the NAP showing interpreted (coloured and shaded) tectono-stratigraphic units and the location of IODP Site C0018A. Unit I (yellow) is slope sediment cover (Expedition 315 Scientists 2009; Kimura et al., 2011; Alves et al., 2013; Strasser et al., 2014) and Units A (green), B (blue), C (purple) and oceanic crust (colorless) are adapted from the Park et al. (2010). (black lines – major thrust and back-thrust faults; arrows – vergence of anticlines and thrusts; white line – décollement fault; dashed lines – possible décollement paths; yellow lines – splays of the MSFZ; MSFZ – Megasplay Fault Zone; ITZ – Imbricated Thrust Zone; FTZ – Frontal Thrust zone). C) Close-up of IODP well C0018A highlighting the subdivision of Unit I in Units Ia, Ib and Ic based on Strasser et al. (2014). D) Compiled well log of IODP Site C0006 from Expedition 316 Scientists (2009) tied to interpreted units in this work. According to Expedition 316 Scientists (2009), Unit III is consistent with deposition in the Shikoku Basin.