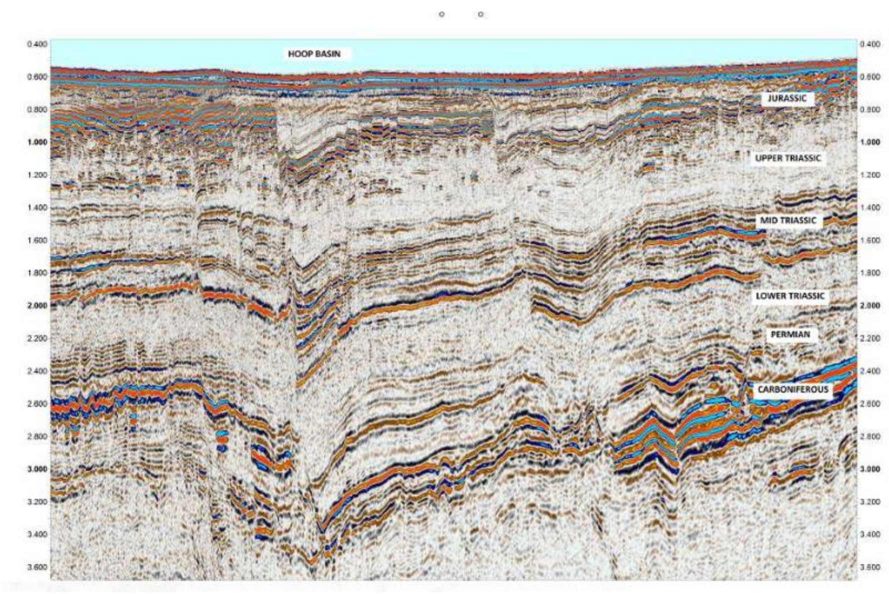
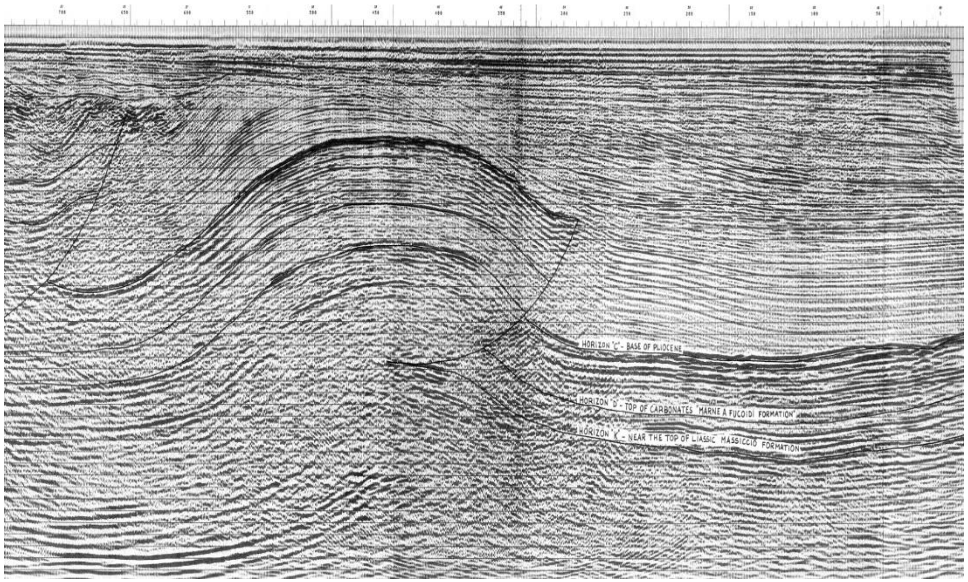
Seismic Evidence of faults (systems)

A tectonic regime is characterized by the presence of a more or less complex fracture system related to the brittle deformation of sedimentary sequences, Often with a ductile component.

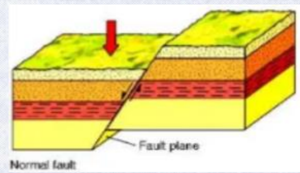
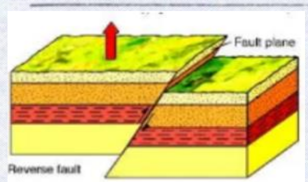
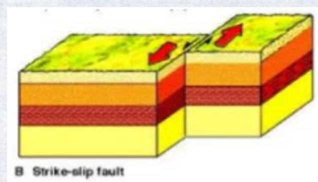
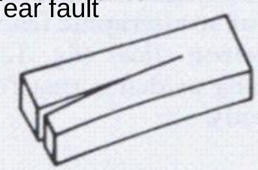
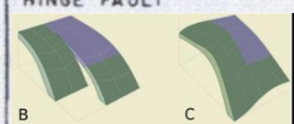
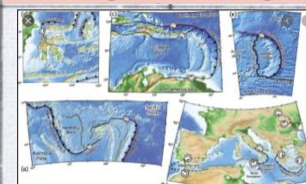
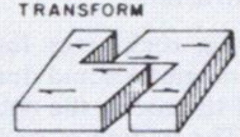


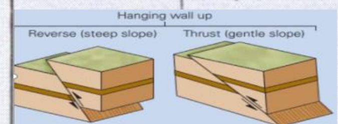


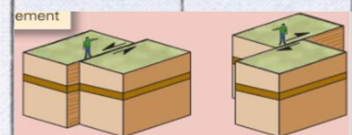
Different types of faults

Faults can show very variable aspects along the seismic profiles: they can be seen as a reflecting surface or as a fracture system that interrupts the continuity of reflectors.

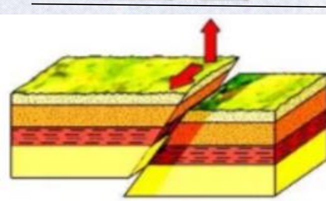
The inclination is apparent, as a function of the P velocity, of the scale adopted (vertical exaggeration), of the direction of the profile with respect to that of the fault.

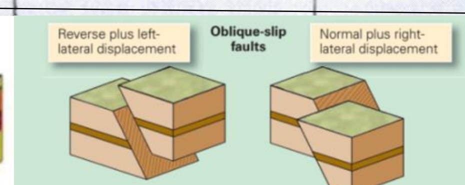
FAULT TYPE	RELATED TERMS	STRESS DIRECTION MINIMUM	STRESS DIRECTION MAXIMUM	CHARACTERISTICS
	TENSION FAULT GRAVITY FAULT SLIP FAULT LISTRIC FAULT (CURVED FAULT PLANE)	HORIZONTAL (Tension)	VERTICAL (Gravity)	Dip usually 75° to 40°
	THRUST FAULT LOW ANGLE (dip < 45°) HIGH ANGLE (dip > 45°)	VERTICAL	HORIZONTAL (Compression)	Fault plane may disappear along bedding → faglie listriche
	TRANSCURRENT FAULT TEAR FAULT WRENCH FAULT RIGHT LATERAL (Dextral) LEFT LATERAL (Sinistral)	HORIZONTAL	HORIZONTAL	Fault trace often 30° to maximum stress
ROTATIONAL Tear fault 	SCISSORS FAULT HINGE FAULT 			Throw varies along fault strike; may vary from normal throw to reverse.
TRANSFORM 	DEXTRAL SINISTRAL	HORIZONTAL		Associated with separation or collision of plates New material fills rifts between separating plates or one plate rides up on another if plates collide.





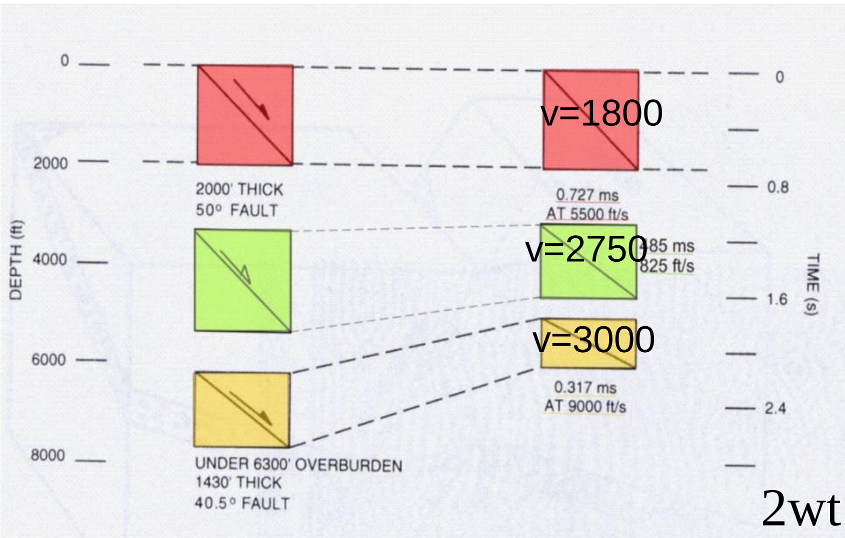
STEP: **S**ubduction-**T**ransform **E**dge **P**ropagator

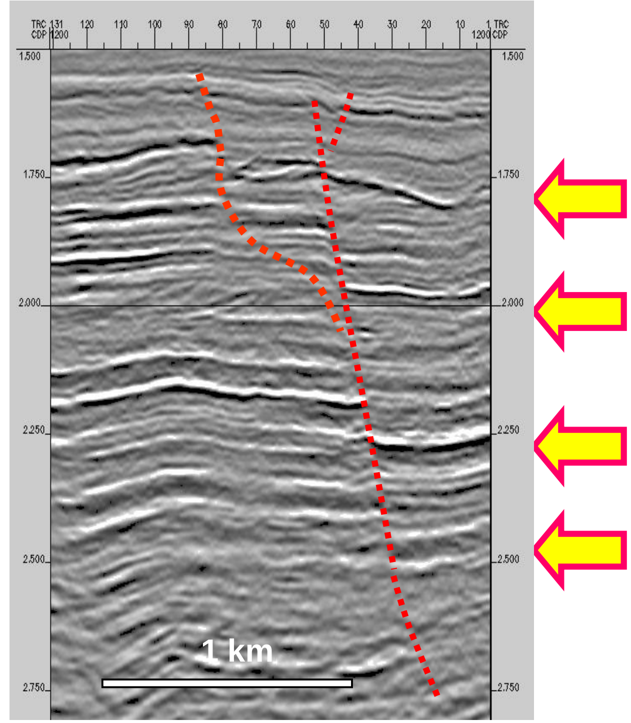




(c) Displacement on an oblique-slip fault combines dip-slip and strike-slip displacement. One block moves diagonally relative to the other.

Rate between the real slope of faults and their slope on the twt seismic profiles



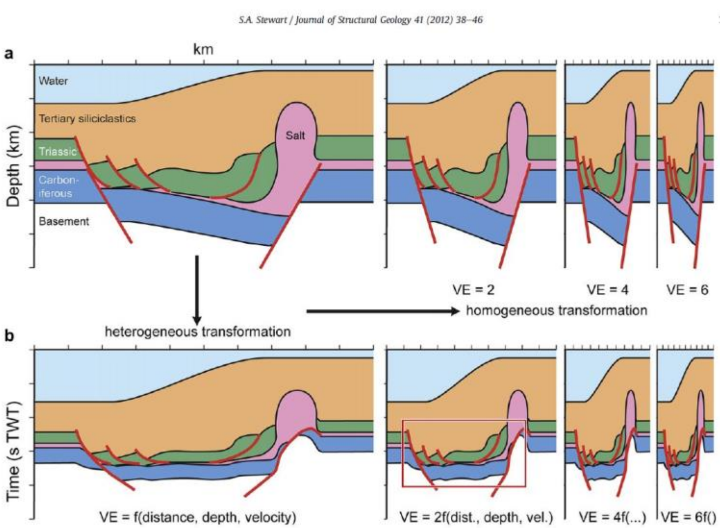


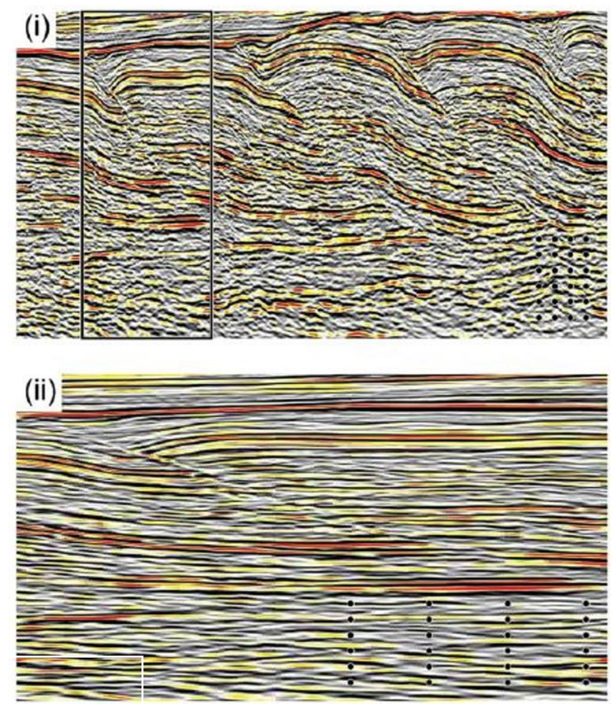
V:H is 1.3:1 at 1900 m/s

V:H is 1:1 at 2500 m/s

V:H is 0.9:1 at 3000 m/s

V:H is 0.8:1 at 3500 m/s

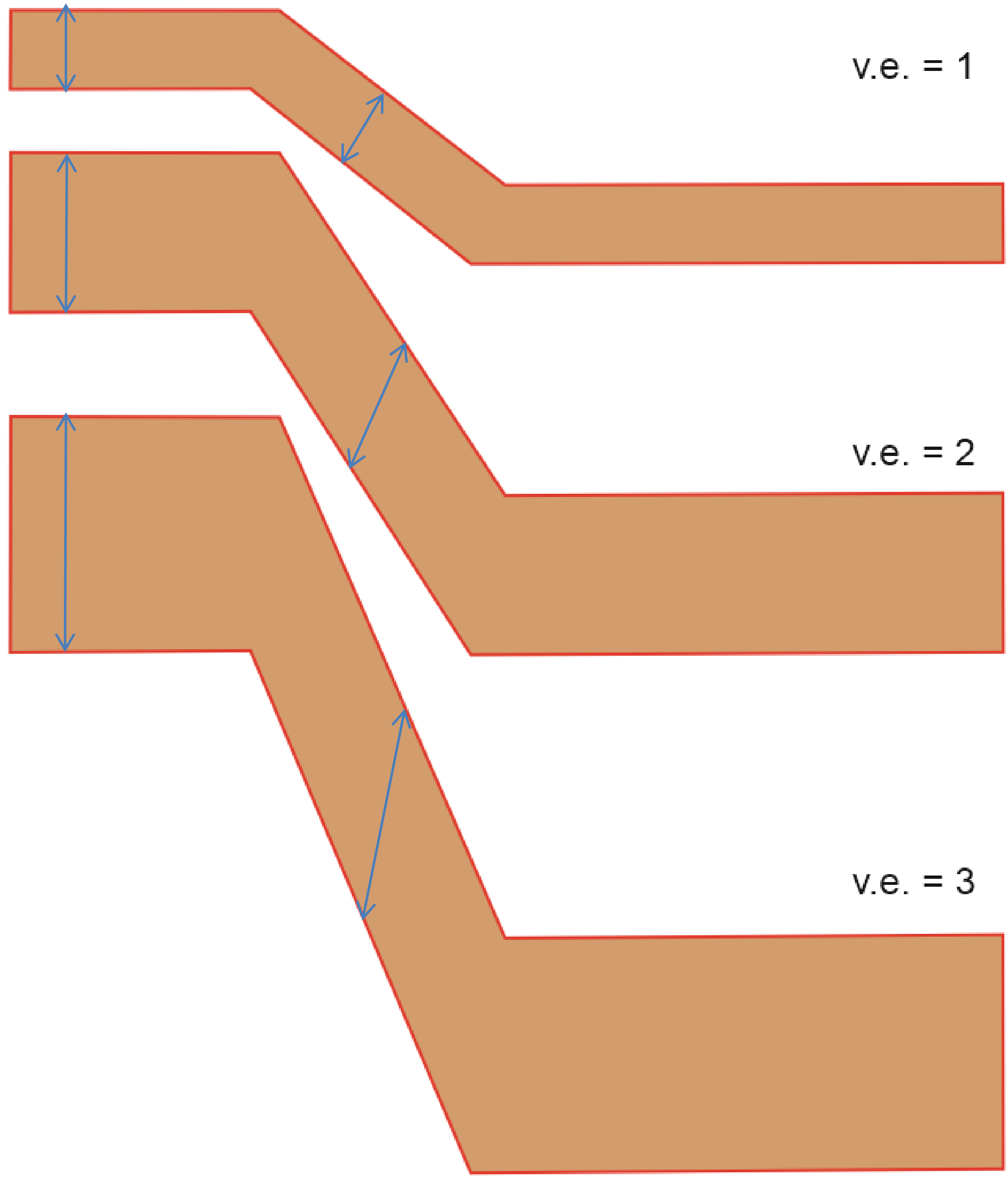




by Butler and Paton, 2010

About thicknesses…

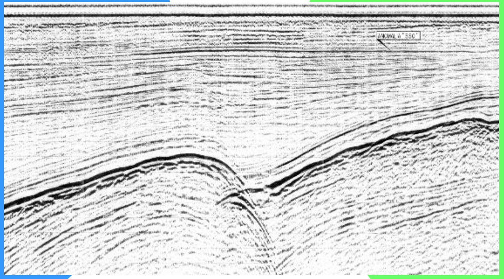
We must also consider the effect on the apparent thickness of layers when we adopt a vertical exaggeration: in sloping layers, the thicknesses must be measured not- orthogonally to the layers.



Interpreting Faults

Structural Observations

- Fault segments on seismic lines
- Fault plane orientation
- Sense of motion
- Magnitude of offset
- Range of depths
- Relative timing
  - when faults moved
  - when structures grew



Structural Concepts

- Tectonic Setting
  - Divergent zones
  - Convergent zones
  - Strike-slip zones
  - Mobile substrate
- How Structures Evolve
  - Fault-bend folds
  - Fault-propagation folds
  - Salt movement
  - etc.

Courtesy of ExxonMobil

Fault recognition

Faults are recognized along the seismic profiles on the base of:

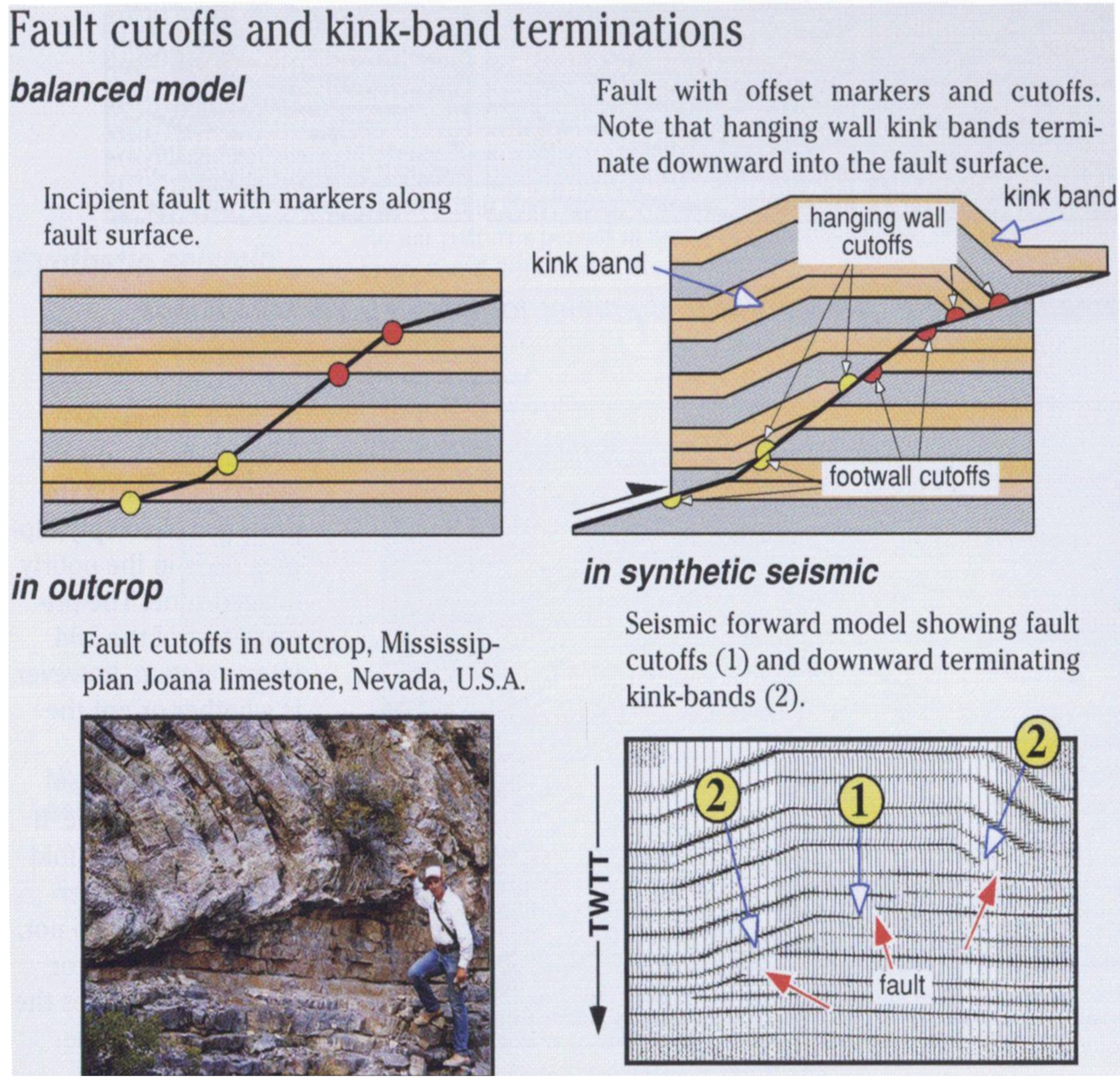
1 - *Fault cutoffs*: abrupt reflection terminaion or marked seismic attribute variation

2 – *Kink bands*: “piega a gomito” of strata

3 – Direct reflection from the fault plane.

The 1 and 3 criteria give us directly the fault position;

All the 3 criteria, if recognized, are useful to identify and correctly interprete a fault.



Example of seismic profiles where we can recognize:

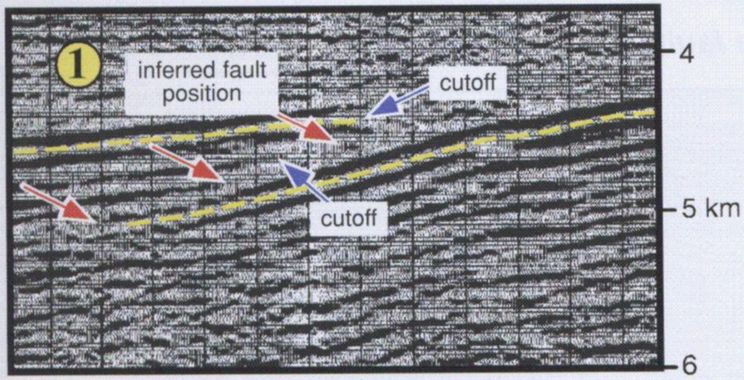
1 - *Fault cutoffs**:

2 – *Kink-bands*:

3 – Reflection from fault plane

remember the effect of diffracted signals in stack and 2D migrated profiles: fault cutoff is more difficult to recognize.

Recognizing and interpreting faults in seismic section



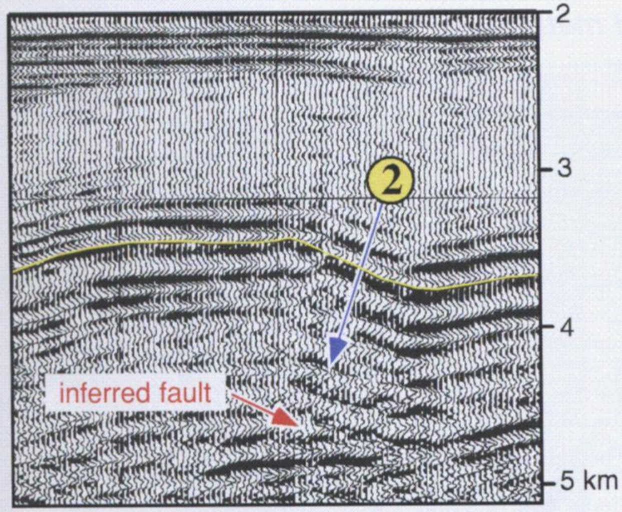
Data courtesy of Texaco, Inc.

fault cutoffs

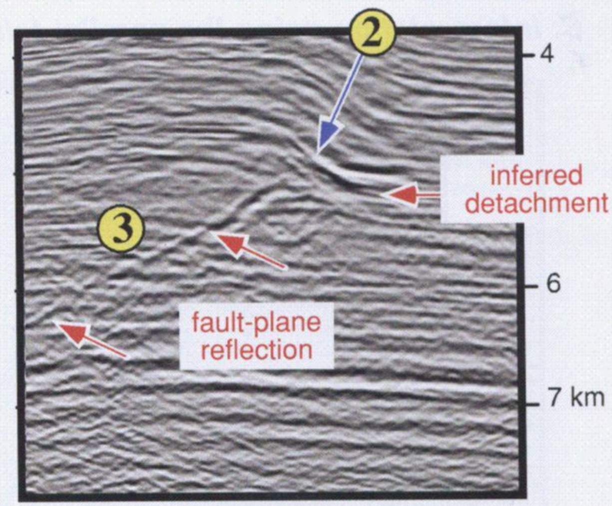
Abrupt terminations (cutoffs) and duplications of prominent reflections constrain the position of a gently dipping thrust fault. (2-D seismic data, Permian basin, Texas, U.S.A.)

kink-band terminations

Thrust faults and bed-parallel detachments can be identified by the abrupt, downward terminations of kink bands. Terminations are generally marked by regions of dipping reflections above horizontal or more gently dipping reflections, and may contain fault cutoffs. Dipping reflections in kink bands represent strata folded in the hanging wall of a thrust/reverse fault or detachment; whereas, horizontal or more gently dipping reflections represent footwall strata below the fault or detachment. Thus faults and/or detachments should be interpreted at the transition between these two dip domains.



Data courtesy of Texaco, Inc.



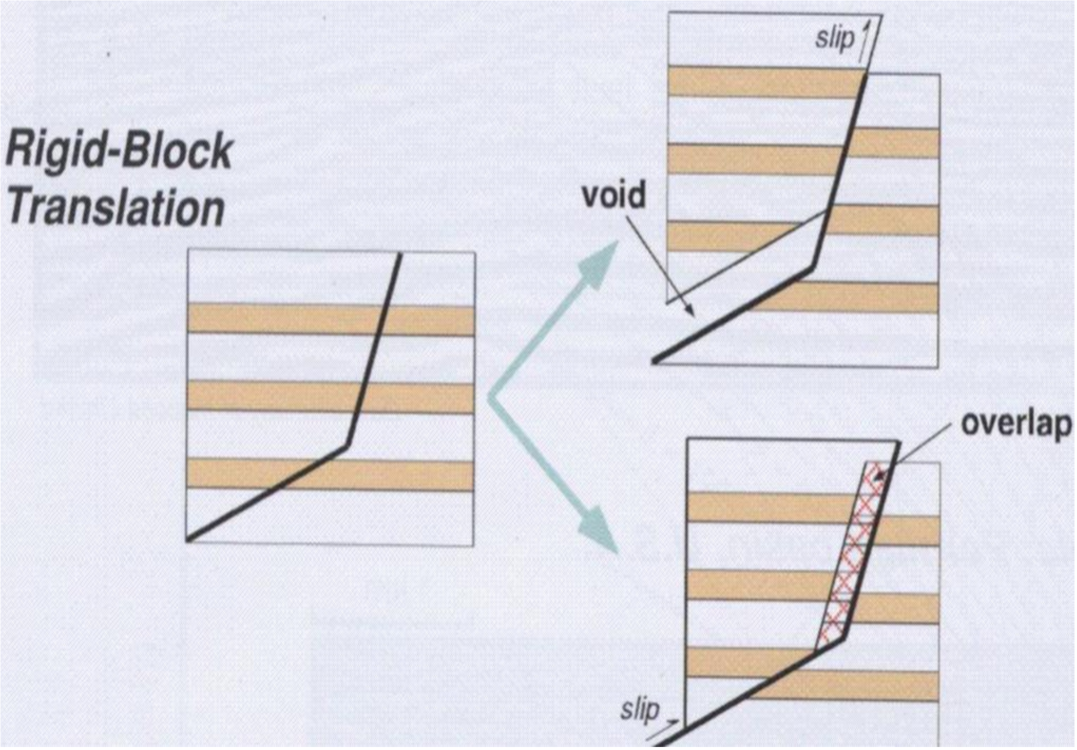
Data courtesy of Mabone, Ltd.

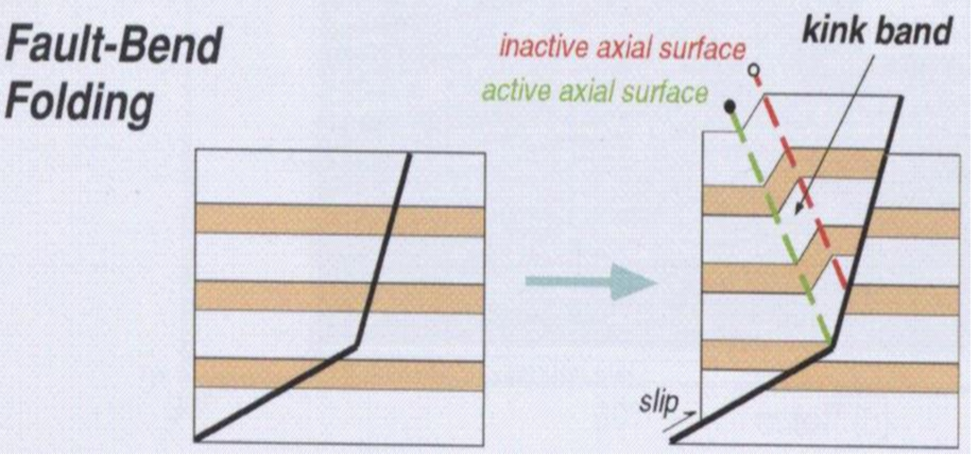
Fault-bend folds

(bending of fault blocks as they ride over non planar fault surfaces)

These folds origin when the *hanging wall* moves above a *fault kink*.

Sliding along different segments of fault, the translation of a rigid block would produce a gap or an overlap between the two blocks separated by the fault. Both of these situations are not feasible in reality.

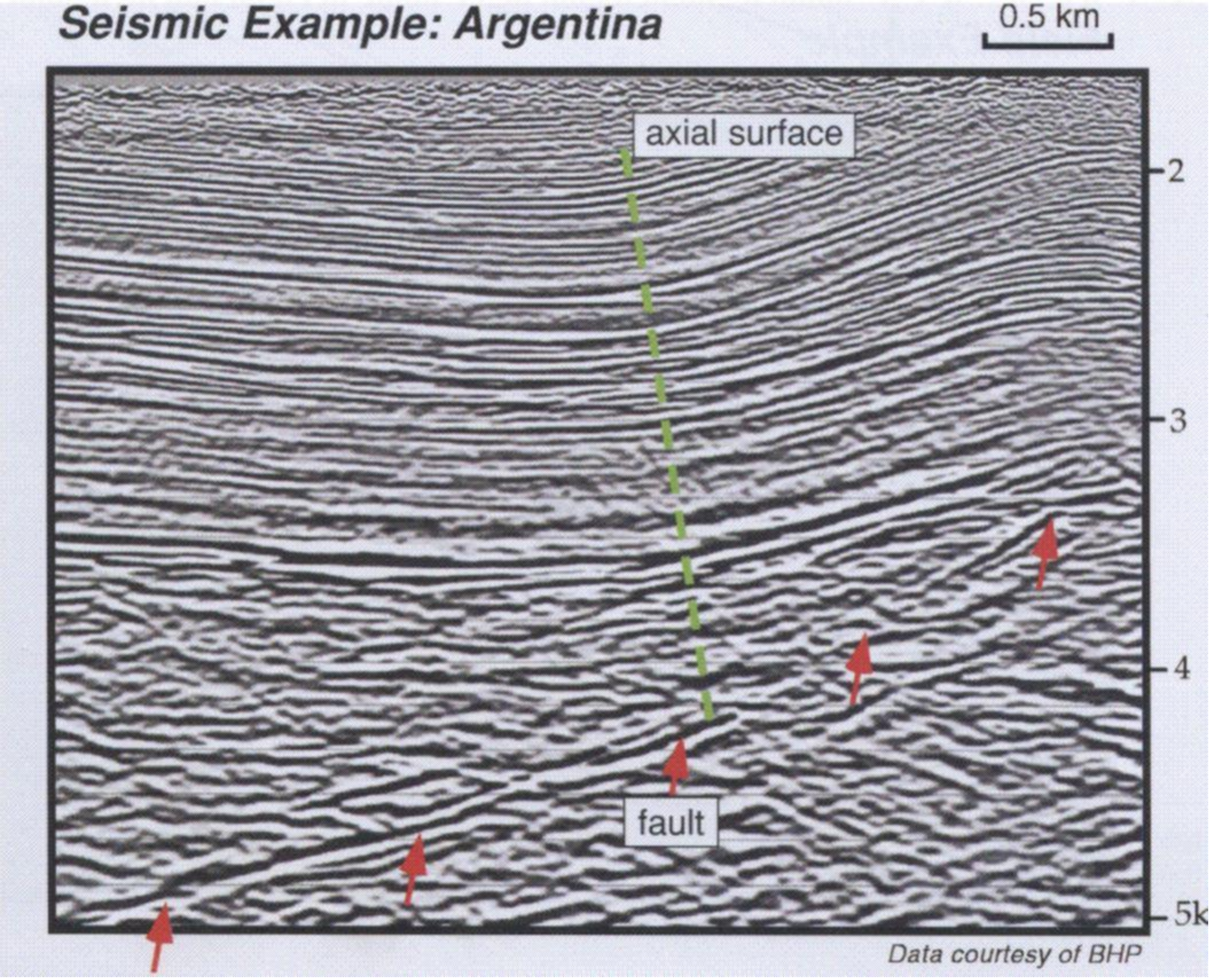




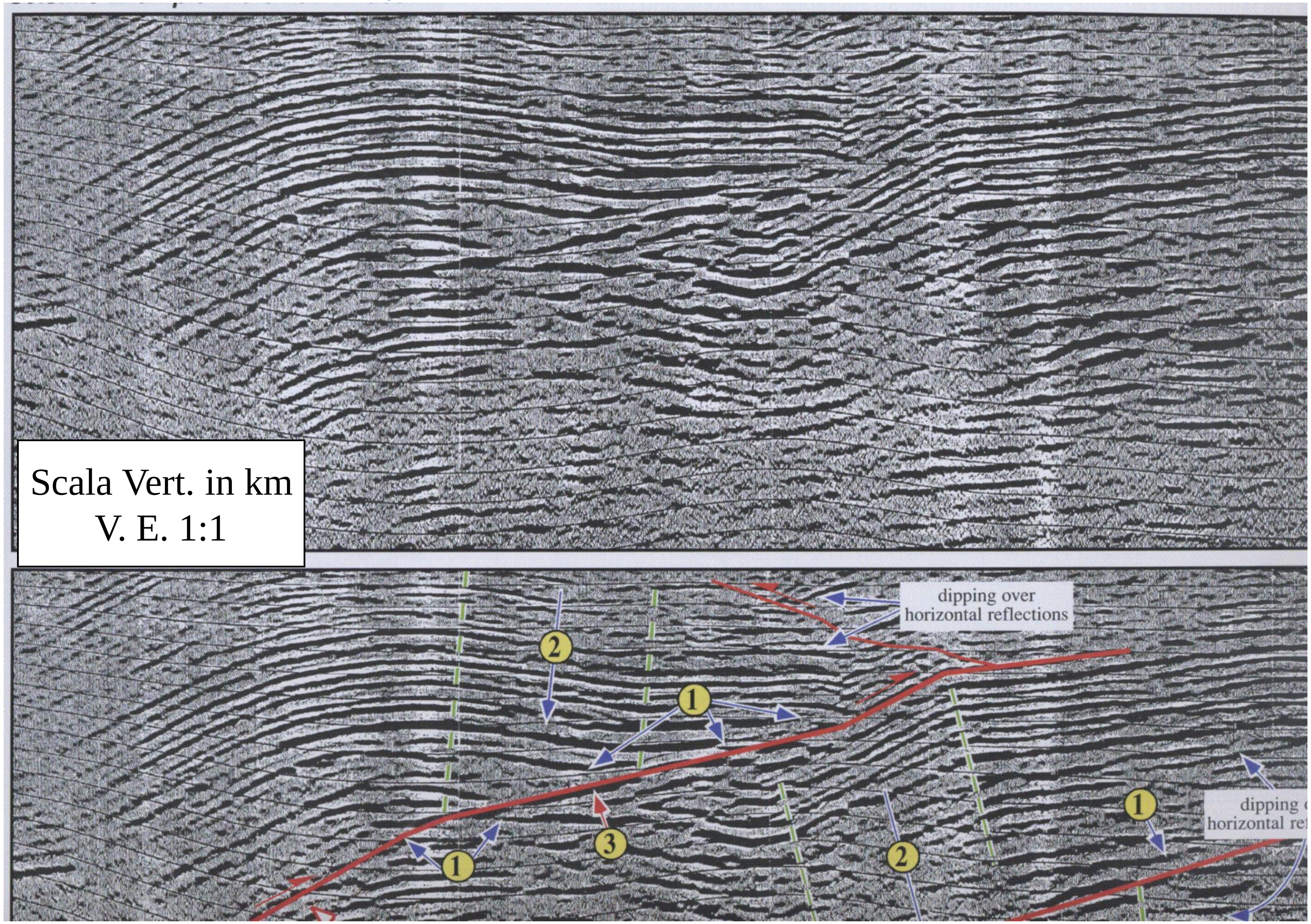
Accomodation is achieved by forming a fold in the *hanging wall block*, located along an active axial surface, while the inactive axial surface identifies the active surface of the first phase.

https://www.researchgate.net/profile/John_Suppe/publication/237044249_Geometrv_and_Kinematics_of_Fault-bend_Folding/links/0c960522d463fbbfe6000000/Geometrv-and-Kinematics-of-Fault-bend-Folding.pdf

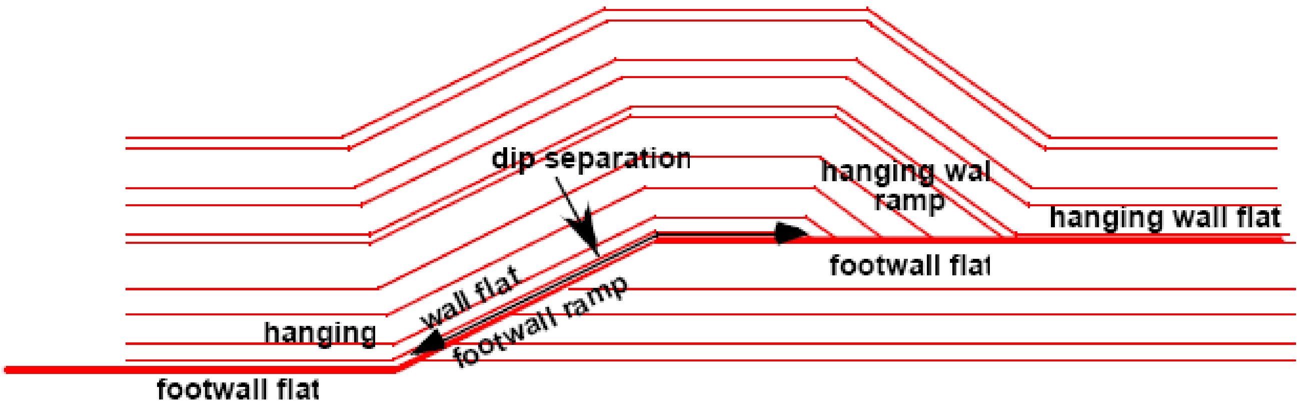
Fault-bend folds – example



Example of interpretation of an inverse fault, based on recognition of:
1 - *Fault cutoffs*
2 – *Kink bands*
3 – Reflection from the fault plane



"*flat & ramp*" geometry



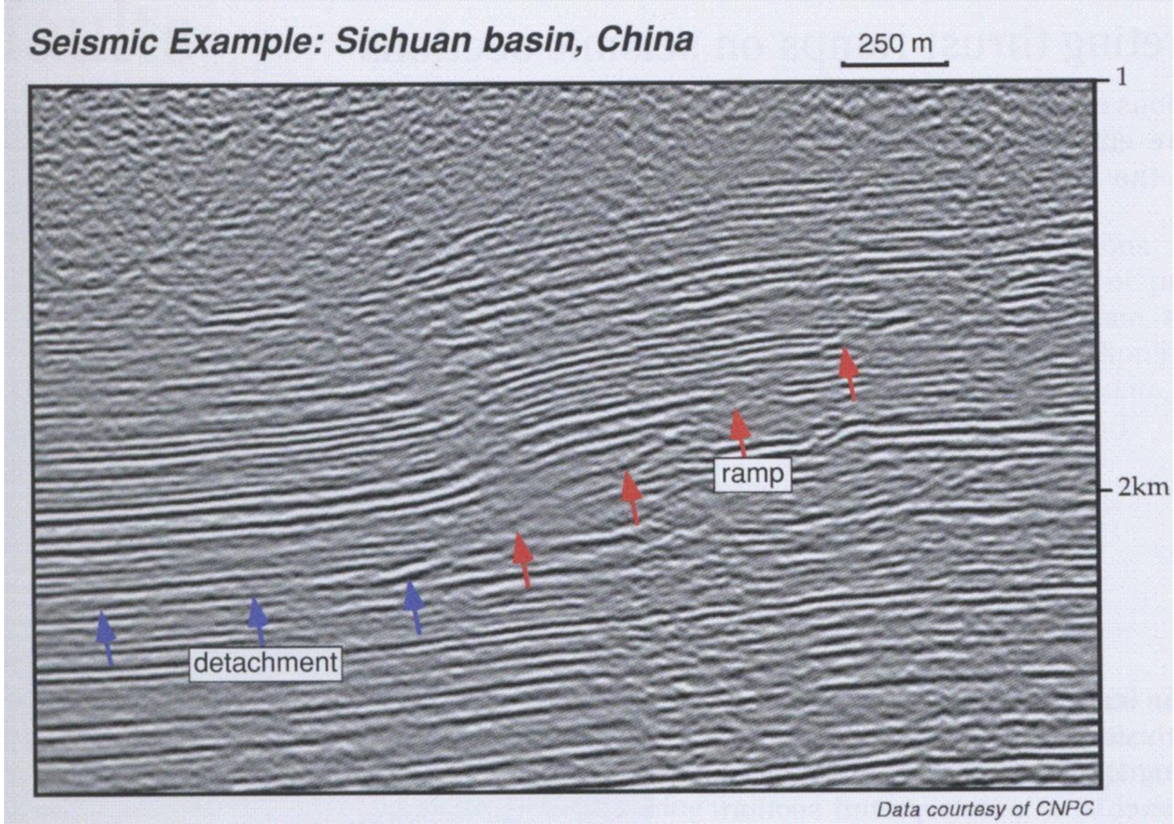
The thrust planes generally tend to be arranged:

-parallel to stratification (flat) in less resistant sediments, such as evaporites or clays

-cutting the stratification (ramp) in the most resistant sediments, such as limestone, sandstone, etc.

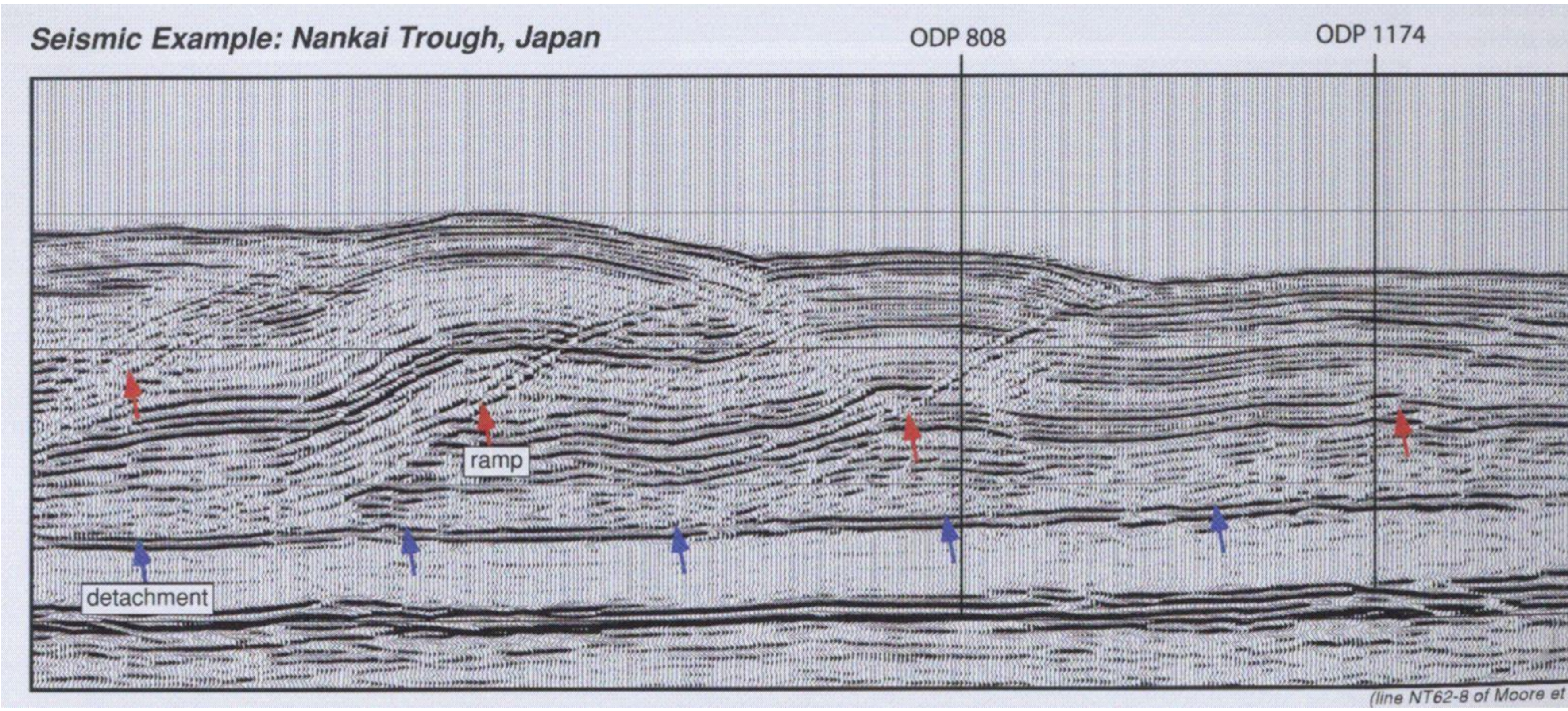
This often determines an alternation of sub-horizontal/flat and inclined/ramp sections of fault, for variable lengths.

Detachment Faults



The **detachment faults** lie along one or more stratigraphic horizons, therefore with a horizontal or slightly inclined setting. In fold and thrust chains, they are also referred as "decollement".
They are not always directly interpretable along the seismic profiles (they coincide with a lithological discontinuity), but they can be deduced at the base and/or at the top of the thrust ramps.

Example of *detachment* along a seismic profile (reflector evidenced by the blue arrows)



The red arrows evidence the "*ramps*"

Compressive faults produced by gravity: example from the Brasilian *offshore*

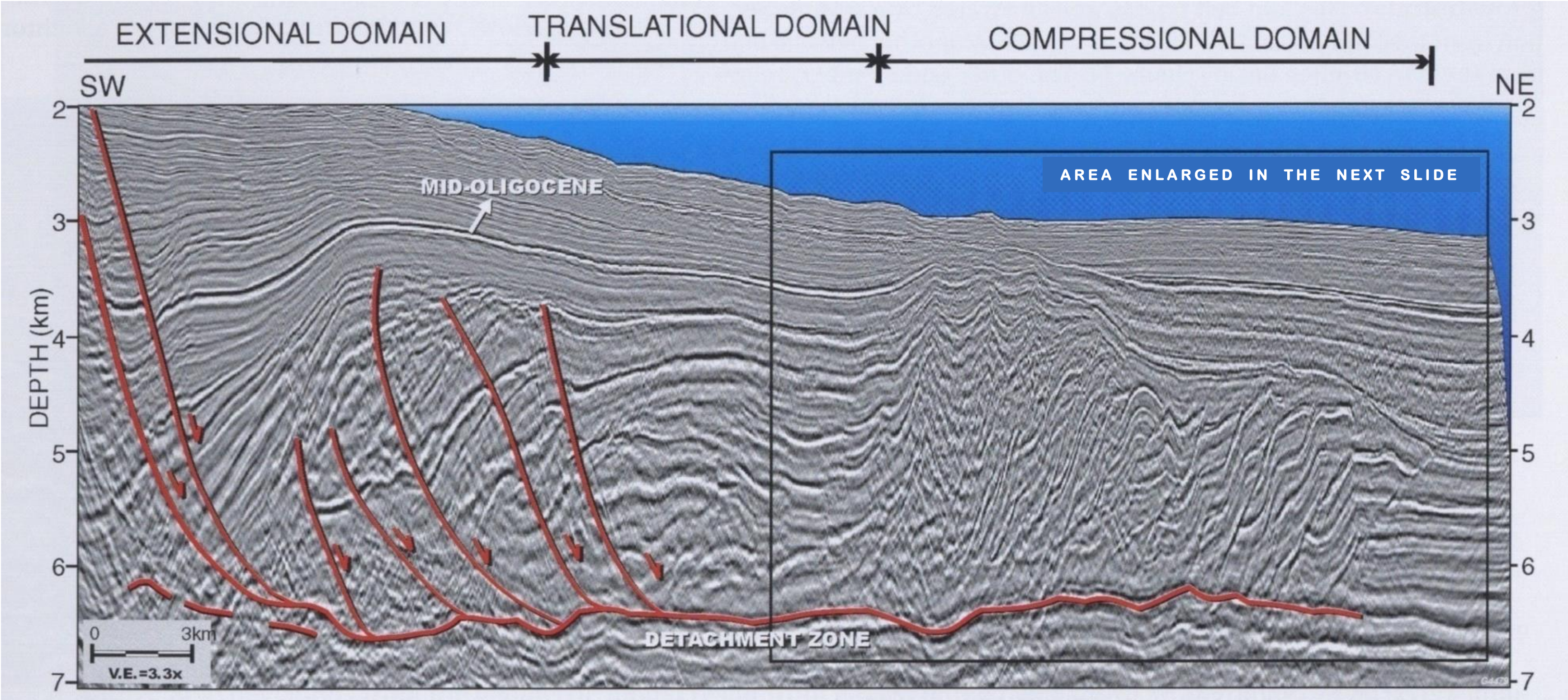
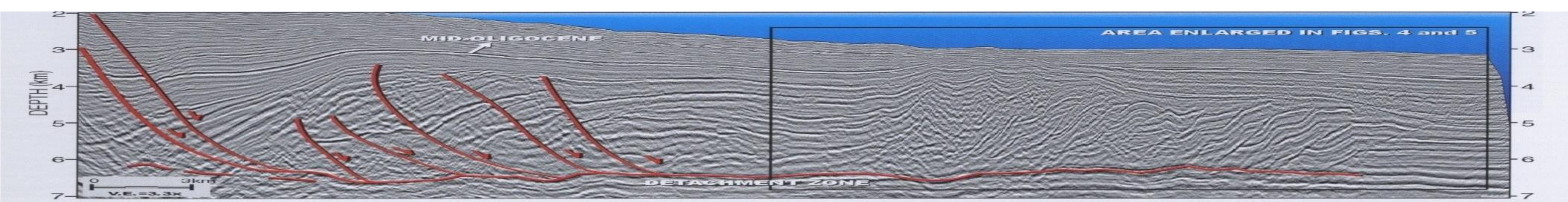
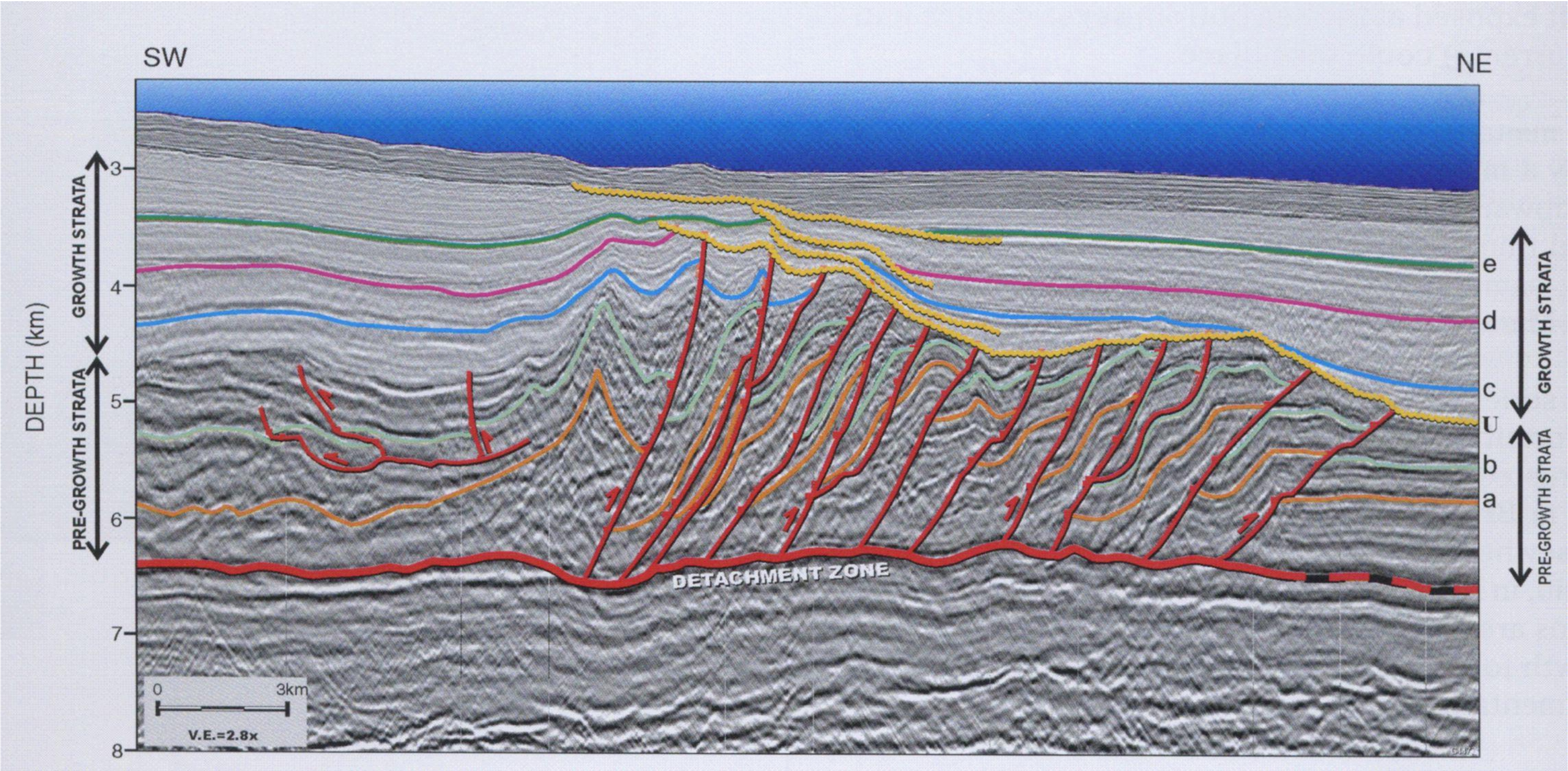


Figure 3: *Depth-migrated seismic section from the Pará-Maranhão GFTB. The major components of a linked extensional-compressional system are clearly visible: The extensional, translational, and compressional (GFTB) domains and the linking detachment zone.*

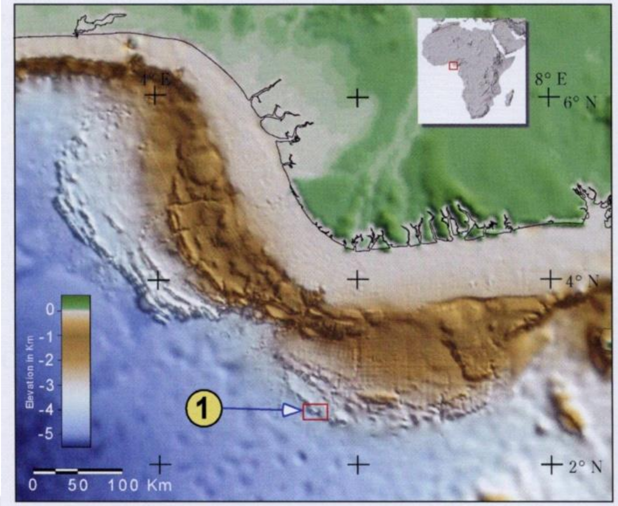
The *detachment* represents the decollement surface related to the extensional/gravitation tectonics (on the left) and compressive tectonics (on the right). Below, the same profile without vertical exaggeration.

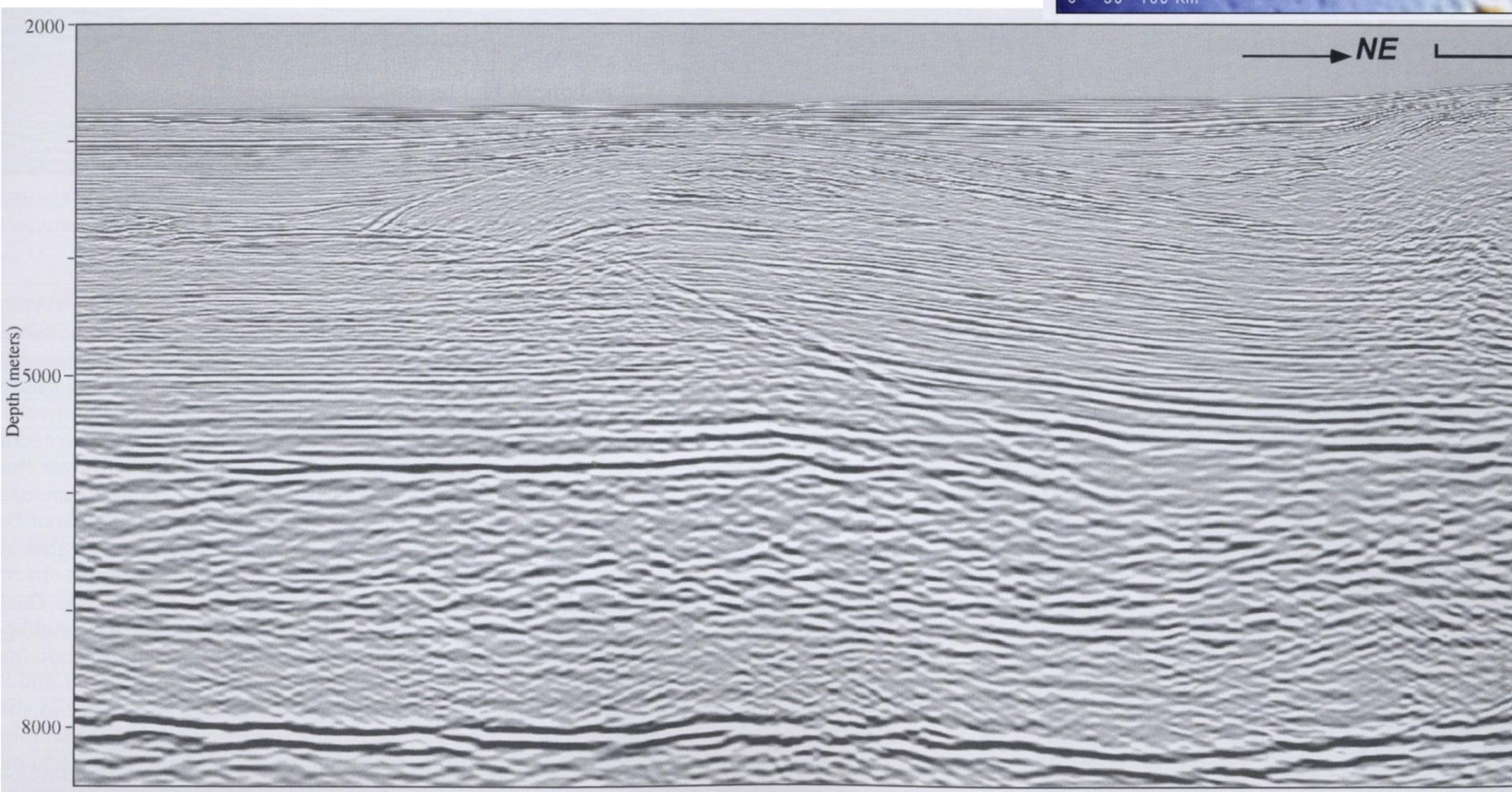


Detail of previous slide: compressive domain



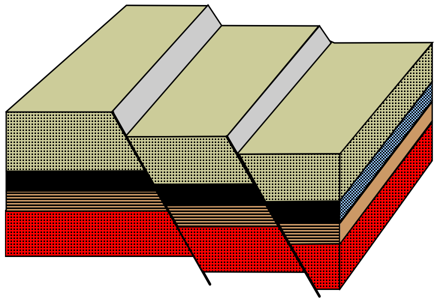
Compressive faults produced by gravity,
example in the Niger delta:
the marine clastic deposits, of Cretaceous-Present age,
lay above oceanic crust or above blocks
of thinned continental crust.
The compressive structures are due to gravitative collapse,
that is active upstream, along the continental slope.

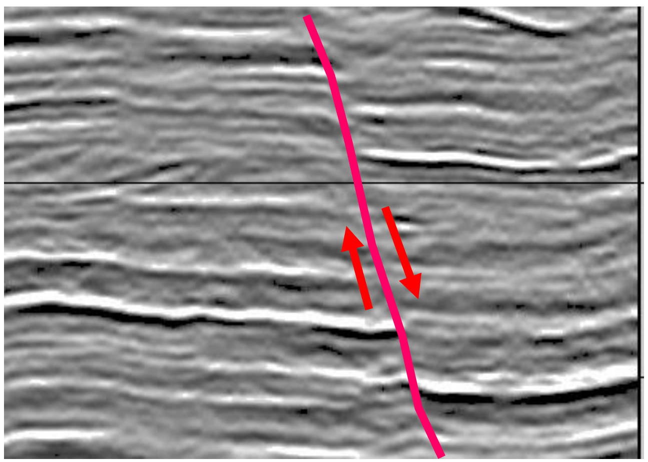


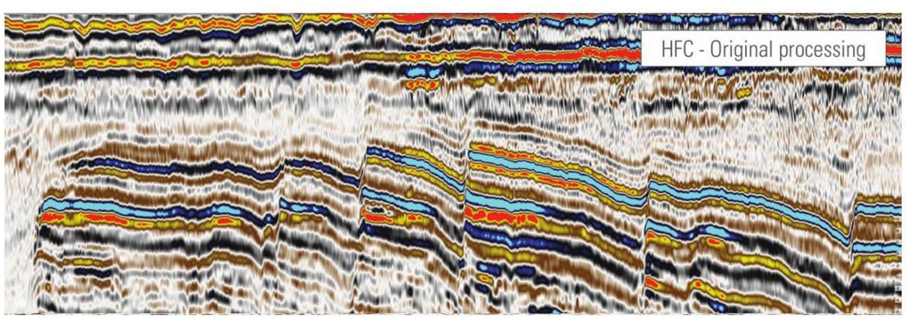


Normal faults

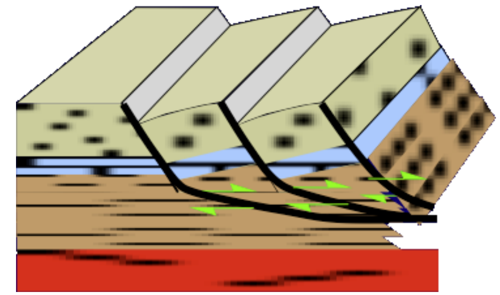
Planar

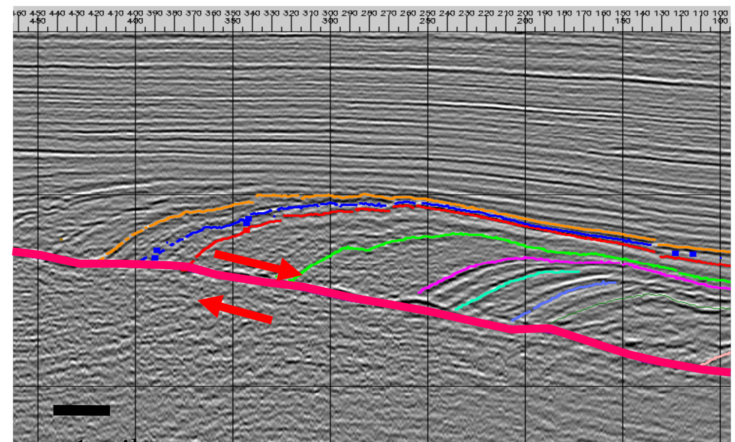


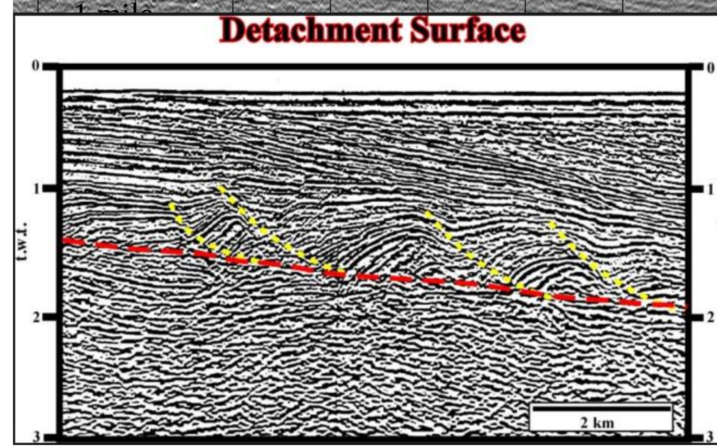




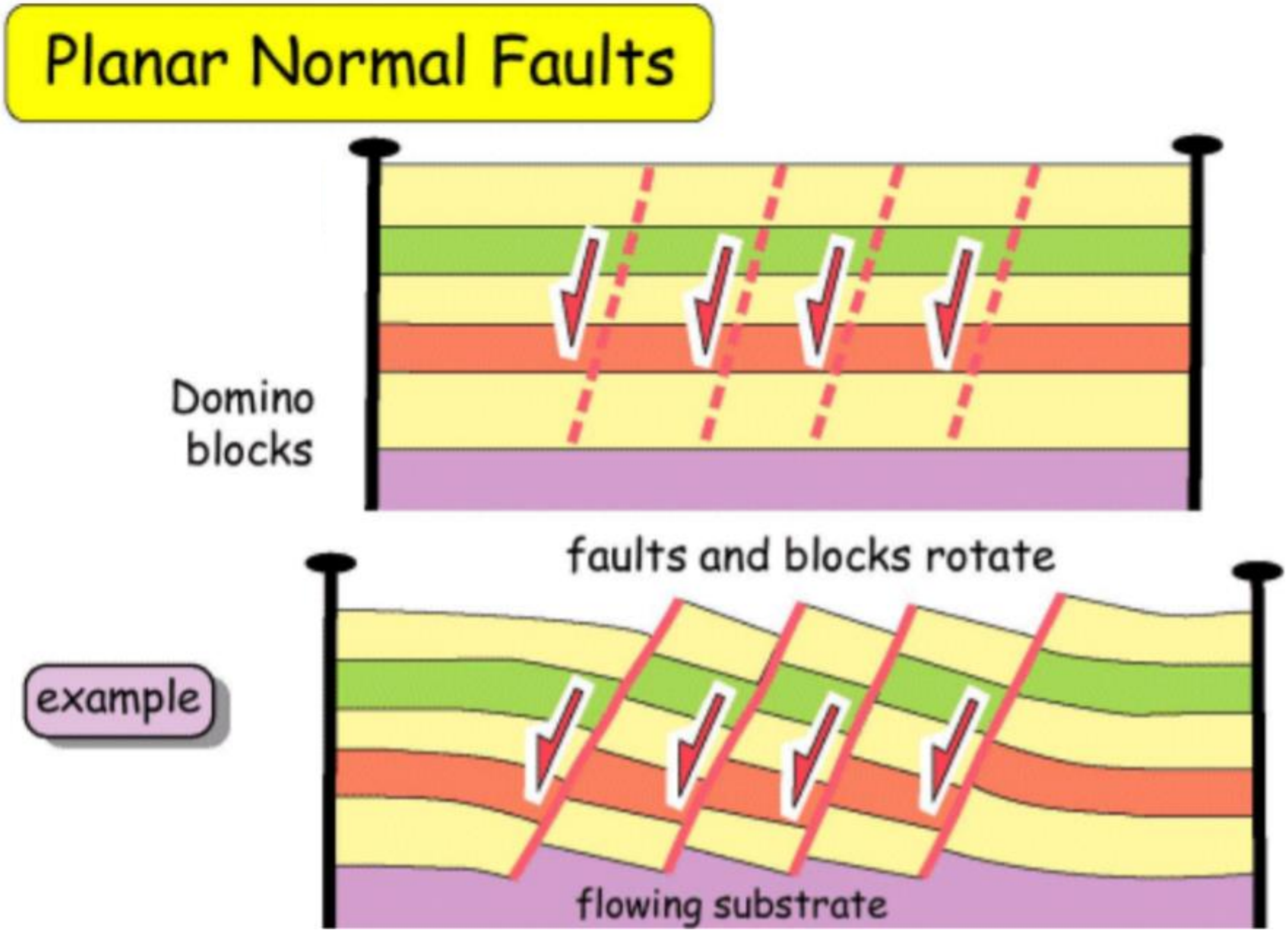
Listric







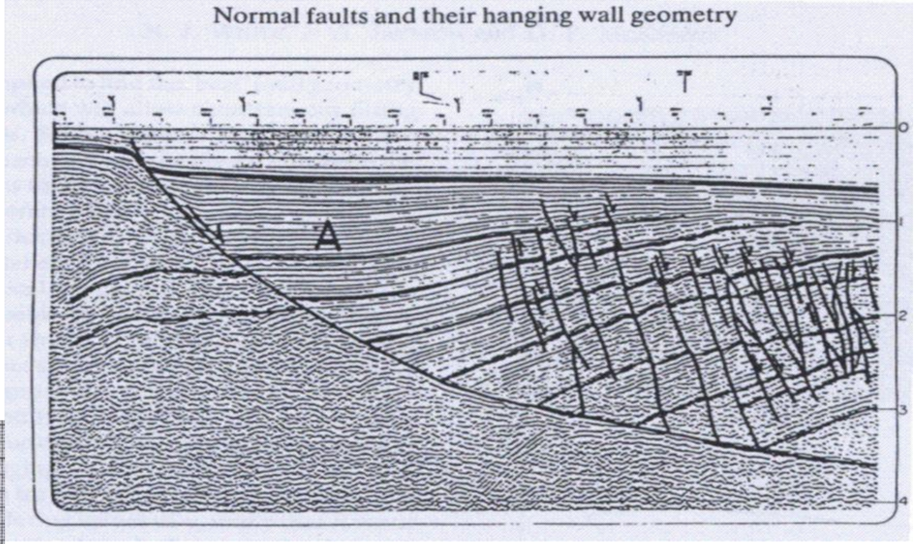
domino system

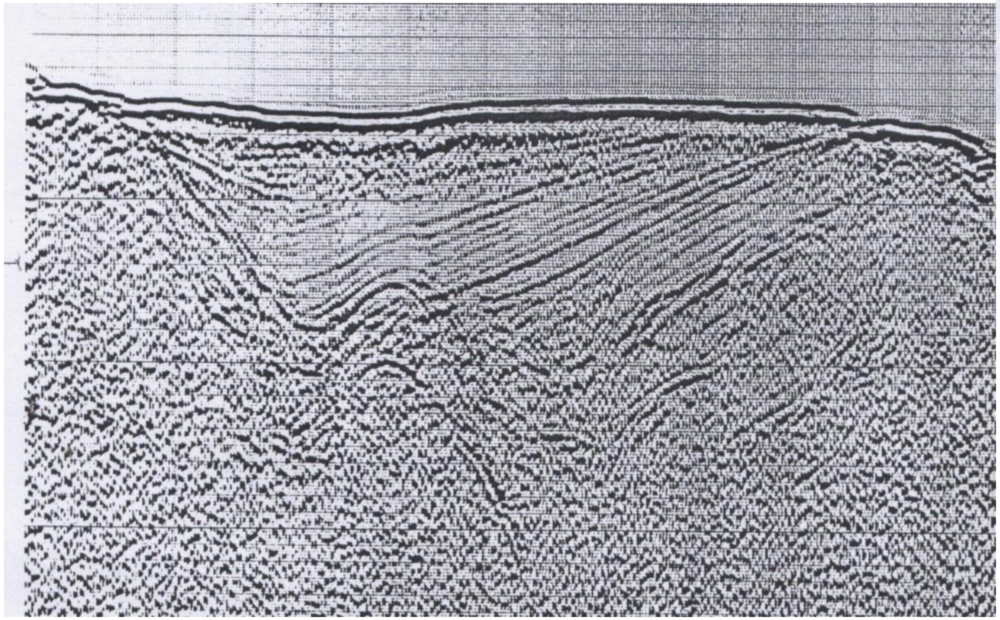


GROWTH (o SYNTECTONIC) STRATA

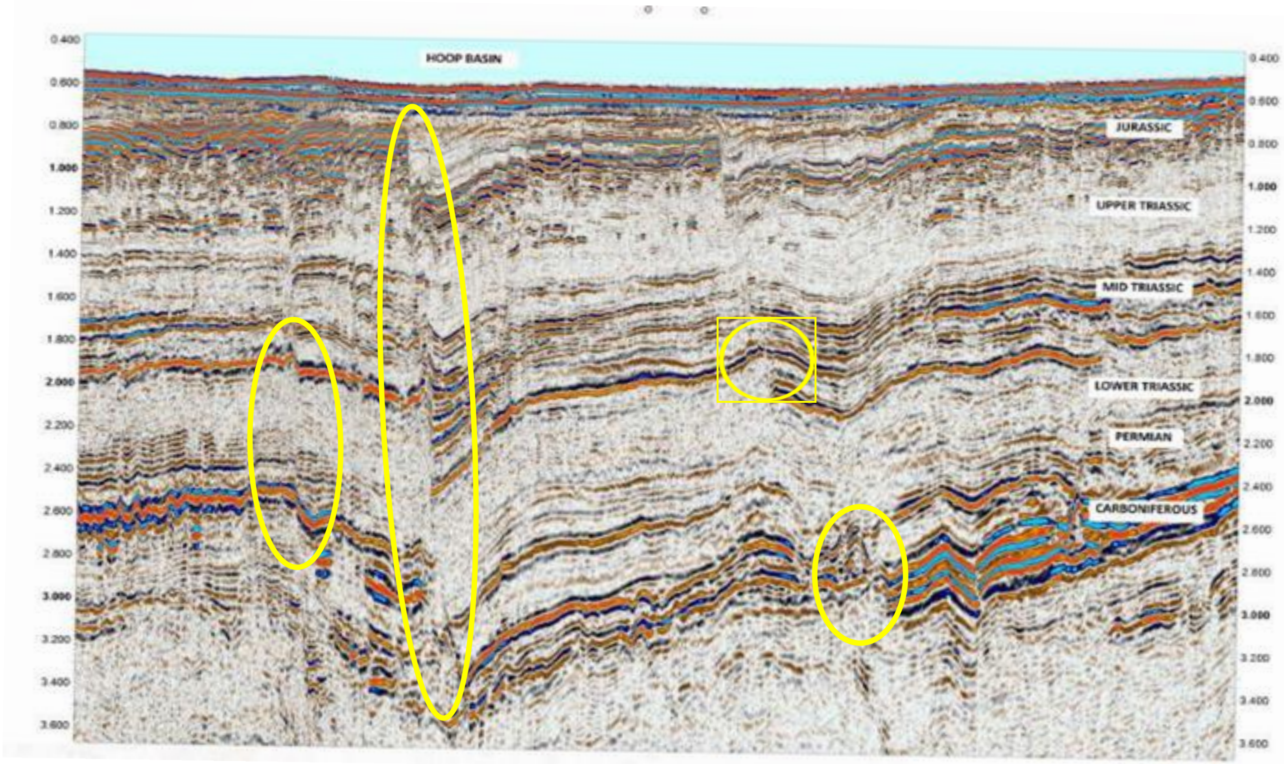
They are stratigraphic intervals **deposited during the deformation**.
Their age defines, therefore, the age of the deformation.

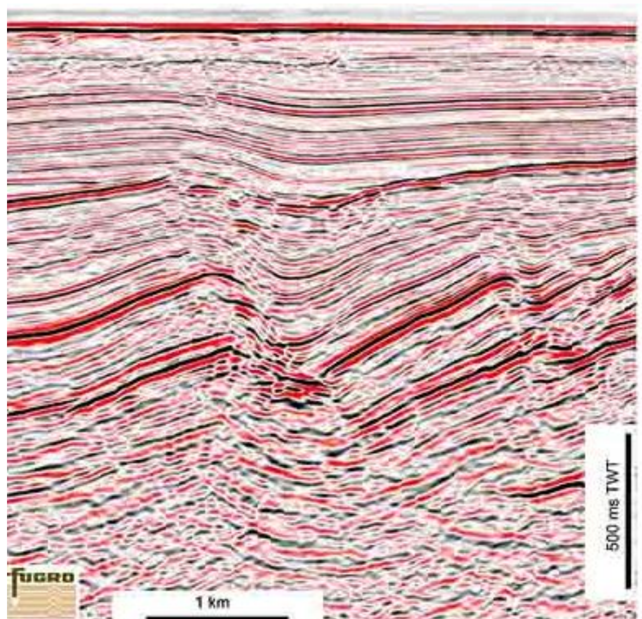
An extensional regime produces a characteristic **sedimentary wedge**: in this context, *tuning* phenomena can assume a great importance.

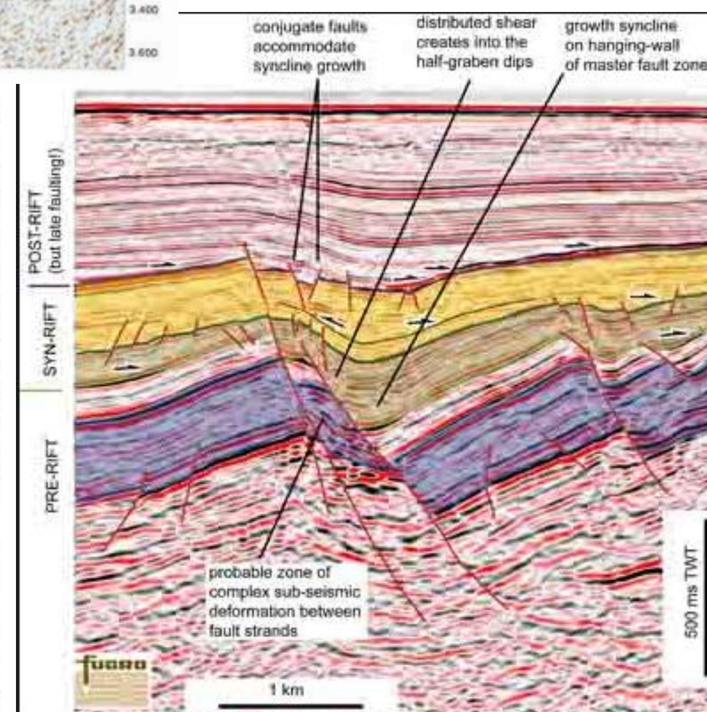




To the left: sintectonic sedimentary wedge in the west Ionian Sea, testifies a deformation with an extensional character.







Del Ben Anna - Interpretazione Sismica - Faglie

Example of a *Growth Stratum* in the Southern Appennine

Il *growth stratum is* evidenced by the yellow (sintectonic) arrow: to the left with *pinch-out* terminations, to the right with *on-lap* terminations. The sub-horizontal overlaying sequence, with *on-lap* termination on both the sides, follows the tectonic phase.

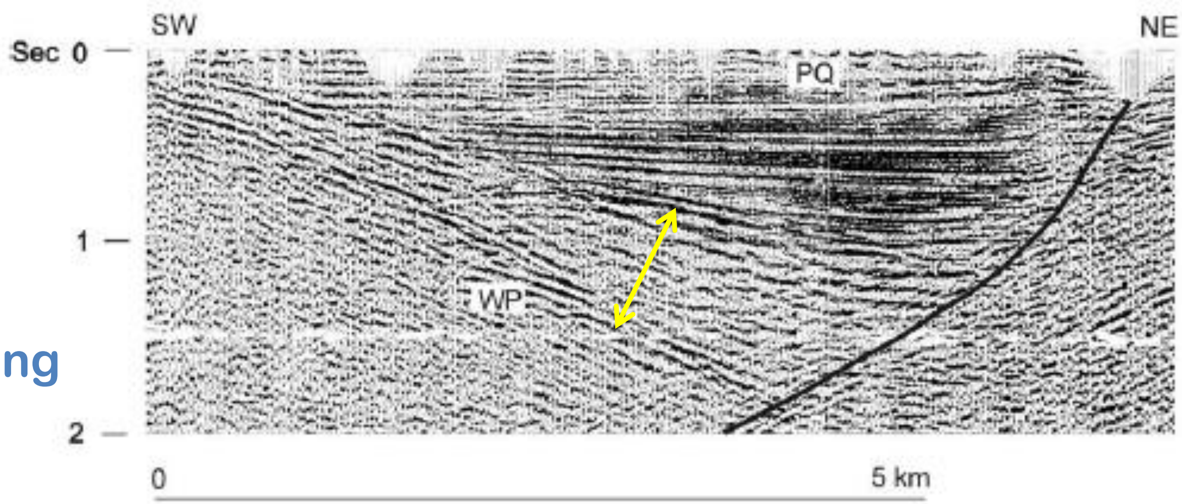
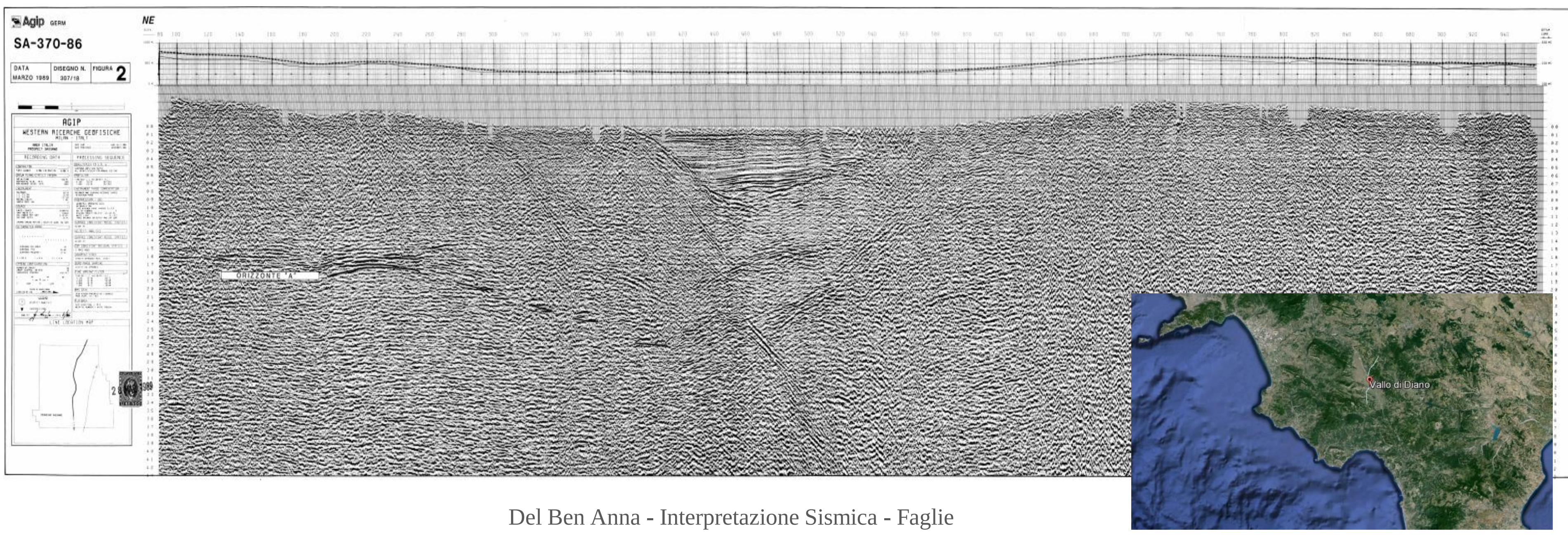
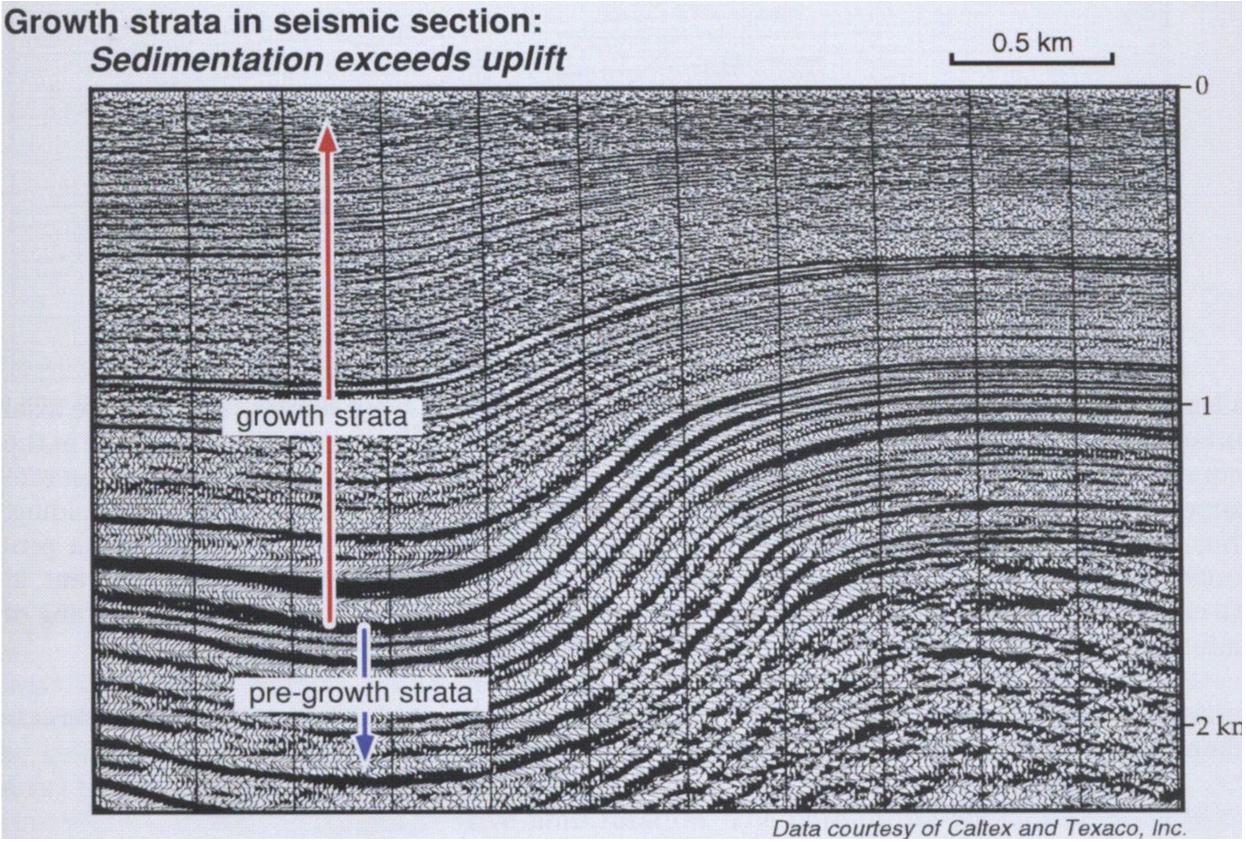


Figure 9. Seismic line over the Vallo di Diano Basin.



GROWTH o SYNTECTONIC STRATA



In regime compressivo i *growth strata* si assottigliano verso l'alto strutturale.

La variazione laterale di spessore denota la sedimentazione sintettonica.

Importance of depth conversion/migration in imaging a prospect

Fig. 2.

This is a full offset stack section of a proprietary data line, which is a dip line across a major fault. The stratigraphy is annotated to highlight the major growth intervals. Note the area of shallow gas and associated multiples between shotpoints 400 and 440.

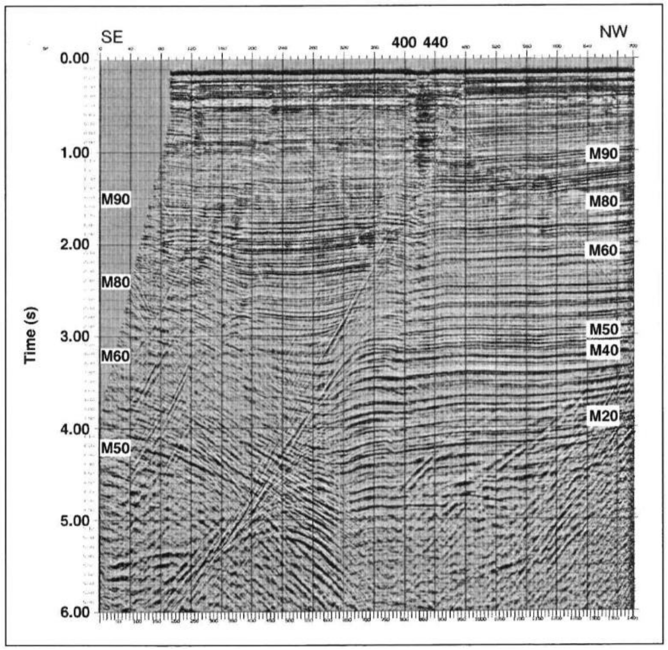


Fig. 3.

An iso-velocity plot of the stacking velocities clearly displays the slower velocities in the hanging wall section, when compared to the equivalent times in the footwall. Also, the stacking velocities vary rapidly between shotpoints 330 and 480 because of the nonhyperbolic moveout of the raypaths in the gathers across the fault.

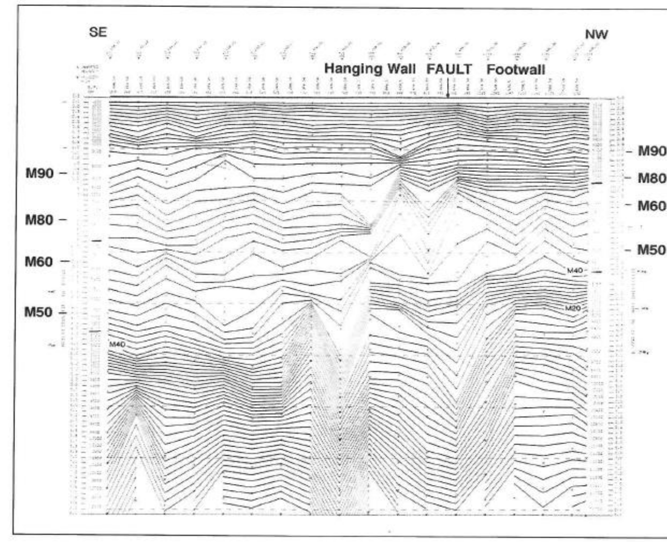
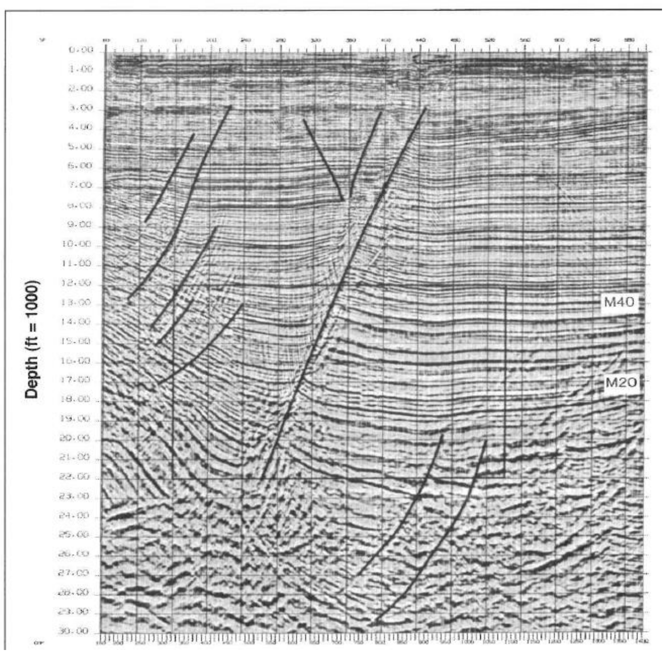
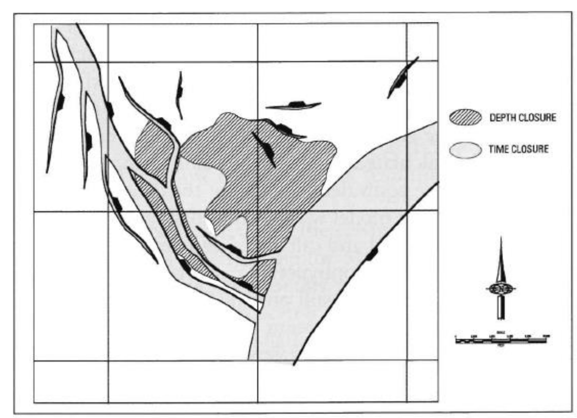


Fig. 16.

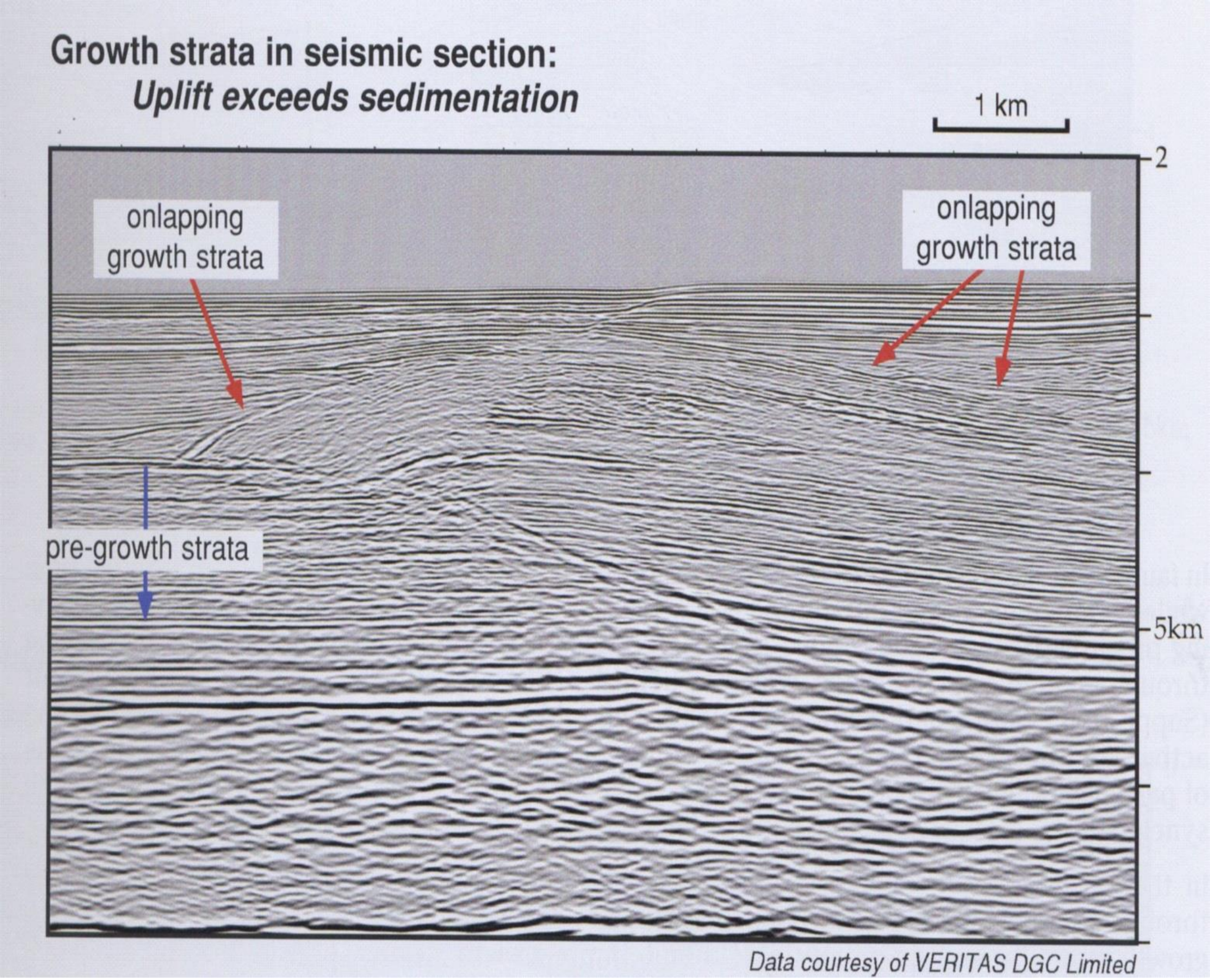
This is the poststack depth migration generated using the derived velocity model (Fig. 16). A comparison with Fig. 14 shows improved imaging of the M20 in the vicinity of the fault, and significant enhancement in imaging below M20.





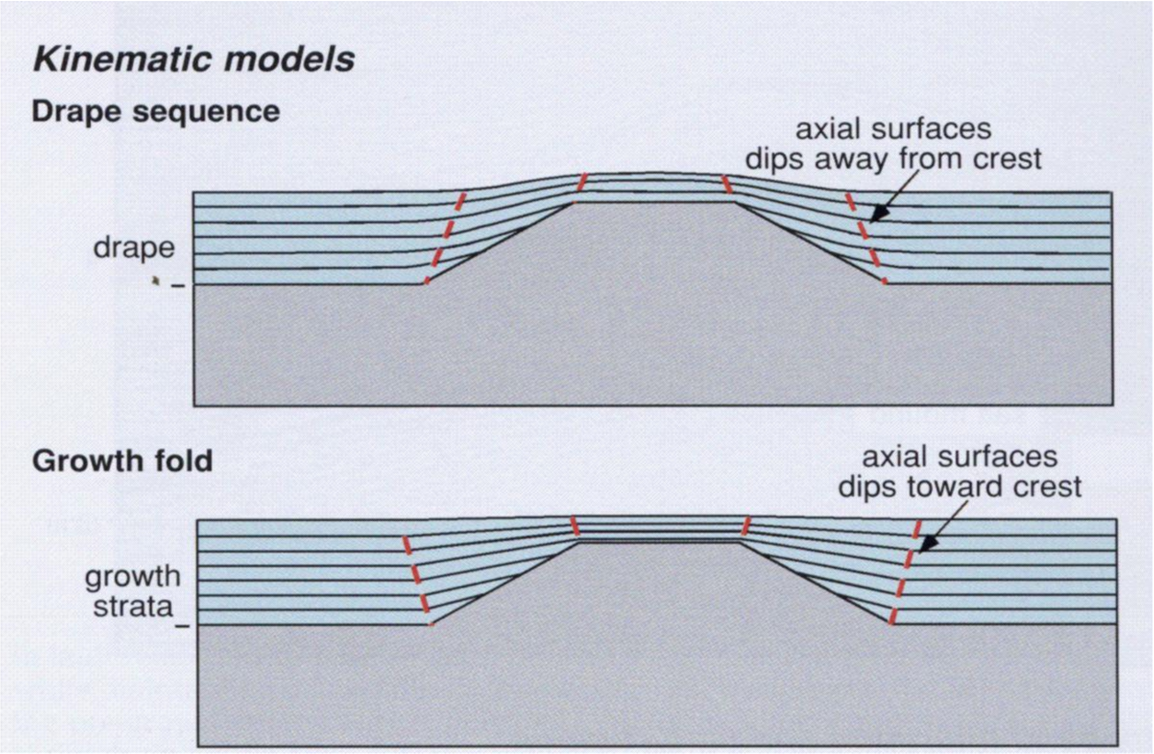
GROWTH STRATA - Example

In genere i *growth-strata* non sono presenti sopra il culmine della struttura piegata, ma accompagnano spesso il piegamento ai lati della struttura stessa, terminando in *on-lap* su di essa. Sono solitamente ricoperti da sedimenti post-tettonici (paralleli e orizzontali).



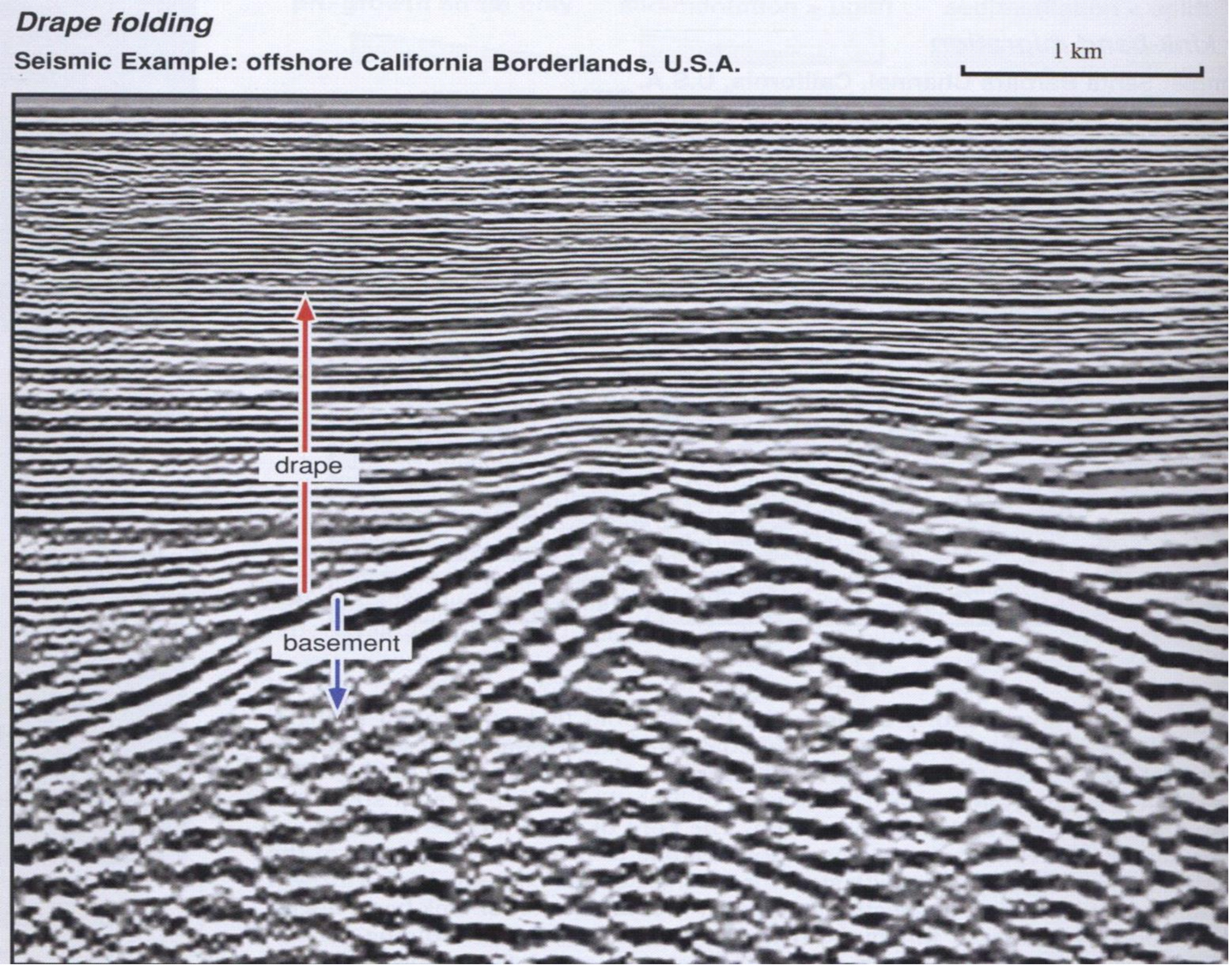
Analogia tra “*growth folding*” e “*drape folding*”

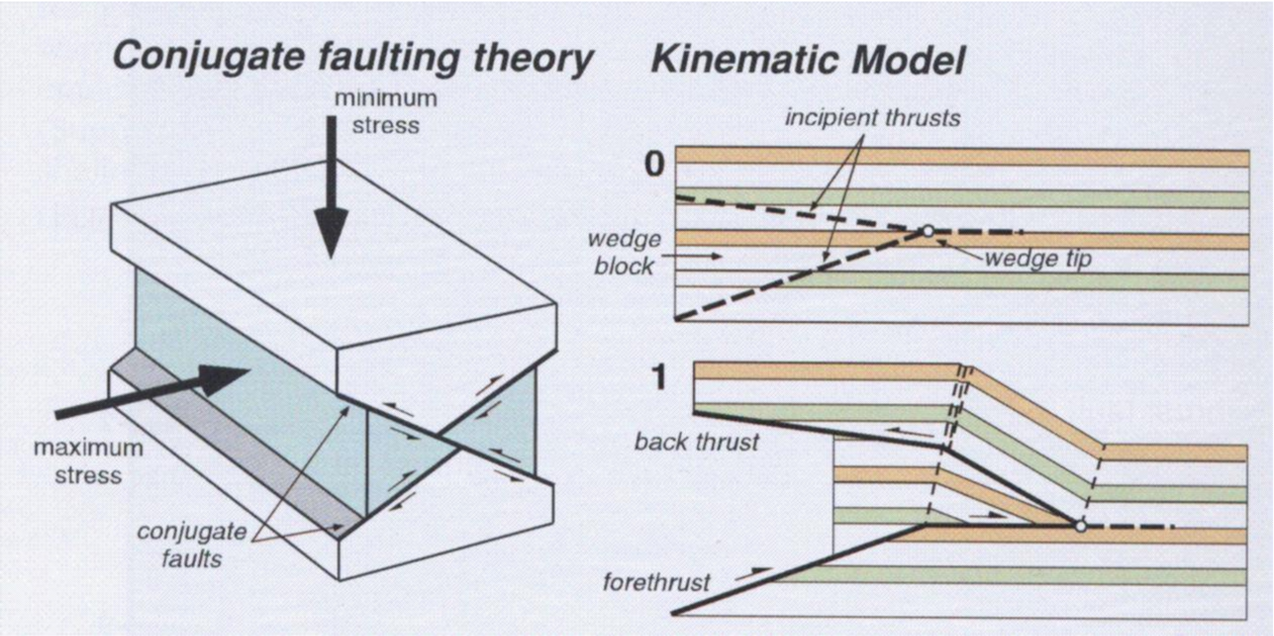
A “*sedimentary drape sequence*” is a stratigraphic interval deposirted above a structure after that deformation ended. The sediments can be inclined, due to both the primary deposition and the differential compaction.



Sometimes these sequences can appear as *growth strata*, leading to a not correct evaluation of the deformation timing. Also if they are not easy to distinguish, we can recognize the different stratigraphic setting: note different vergence of the axial surfaces.

Example of a silicoclastic *drape sequence on-lapping* a structural high composed by metamorphic rocks



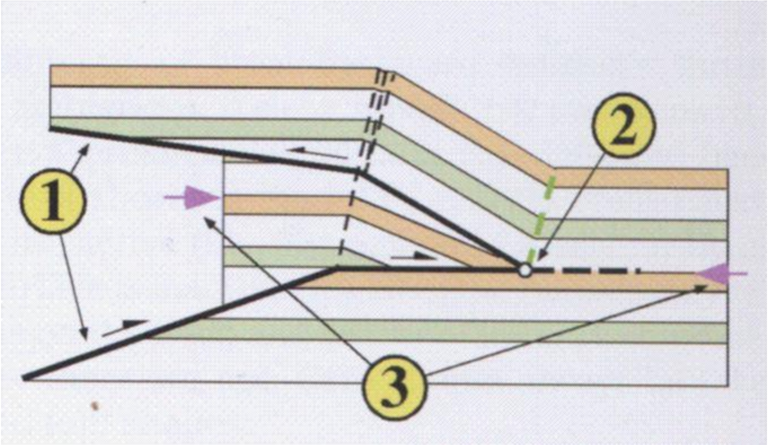


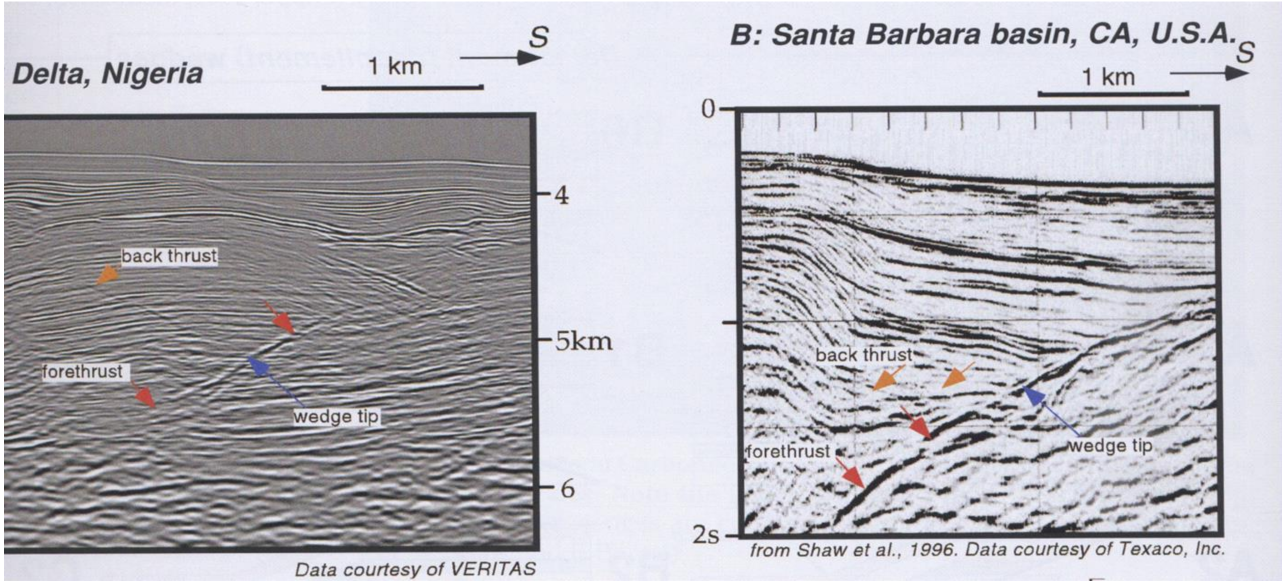
La fratturazione per compressione spesso porta allo sviluppo di due *thrust faults* coniugate con pendenze opposte.
I piani di debolezza (per esempio superfici tra strati, ma anche antiche superfici di frattura), possono svilupparsi come piani di *detachment*.

I due *thrusts* coniugati limitano un ***wedge-shaped block*** e convergeranno nel ***wedge tip***. Lo scivolamento lungo entrambe le faglie causa la propagazione del *wedge*.
Il *thrust* inferiore è generalmente definito ***forethrust*** o ***sole thrust***, quello superiore ***back o roof thrust***.

I *wedges* in regime compressivo possono assumere geometrie molto varie, comunque si possono riconoscere alcune caratteristiche comuni:

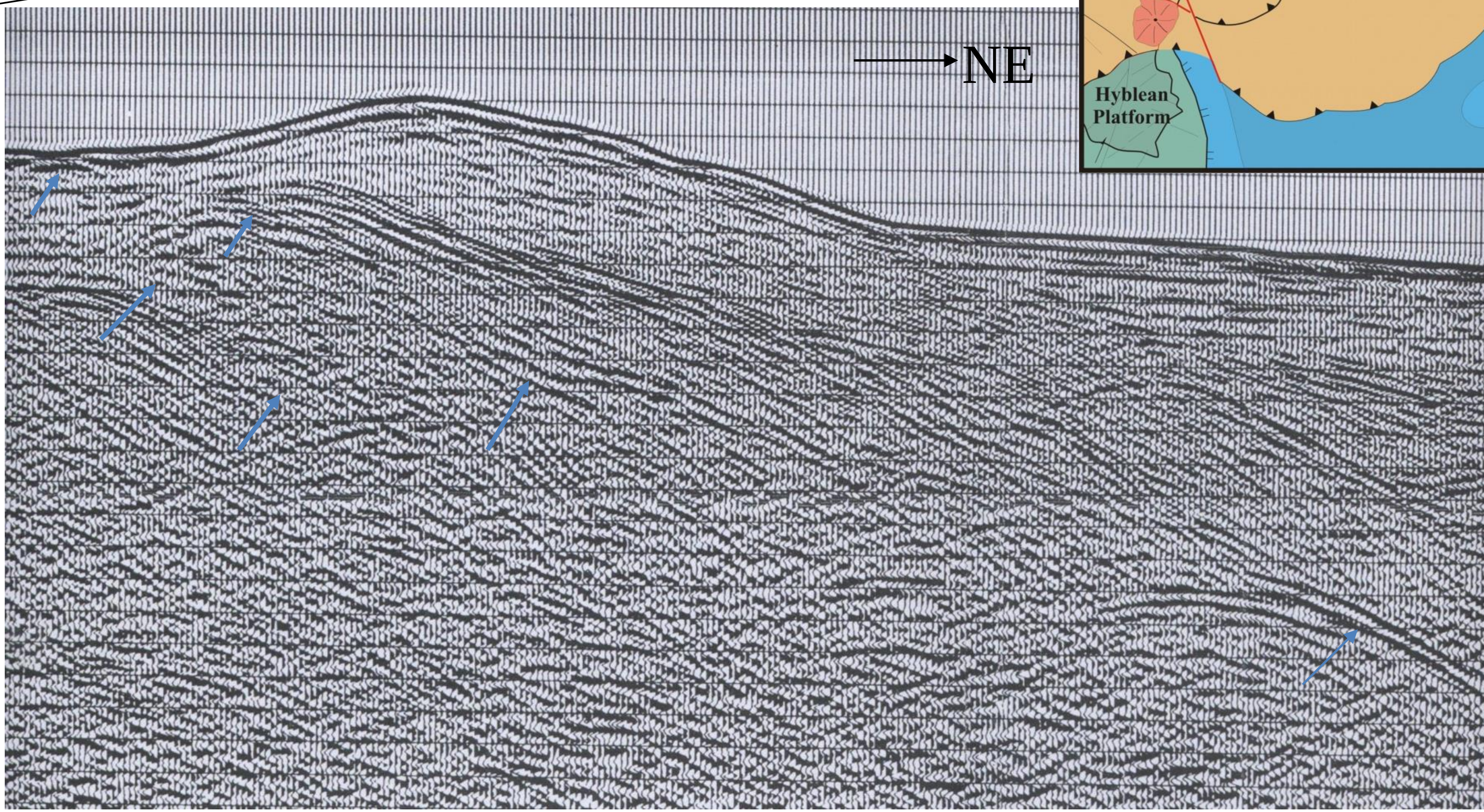
1 – presenza di ***fore- thrust*** e di ***back-thrust*** coevi
2 – piega localizzata lungo una superficie assiale attiva che parte dal ***wedge tip***
3 – pieghe nel ***footwall*** del *back-thrust* che producono un rilievo.

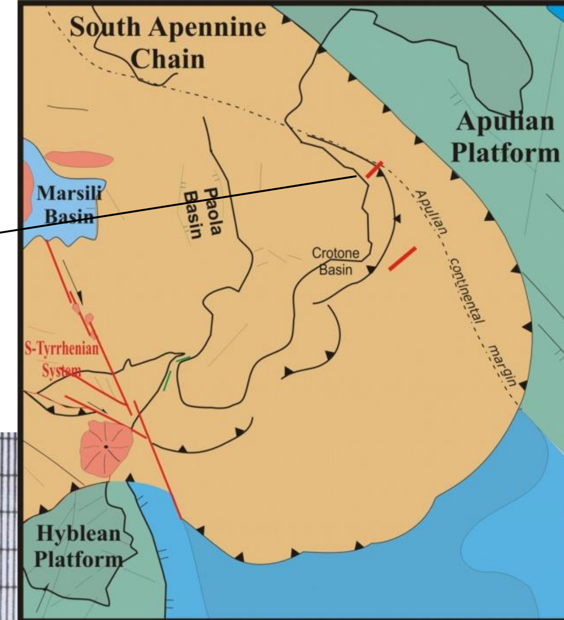




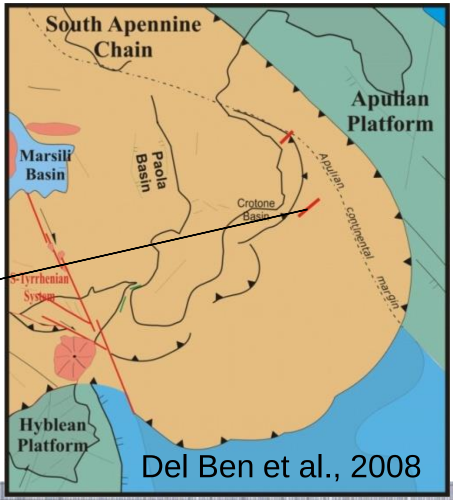
Fault-bend folds e *back-thrust: esempi*

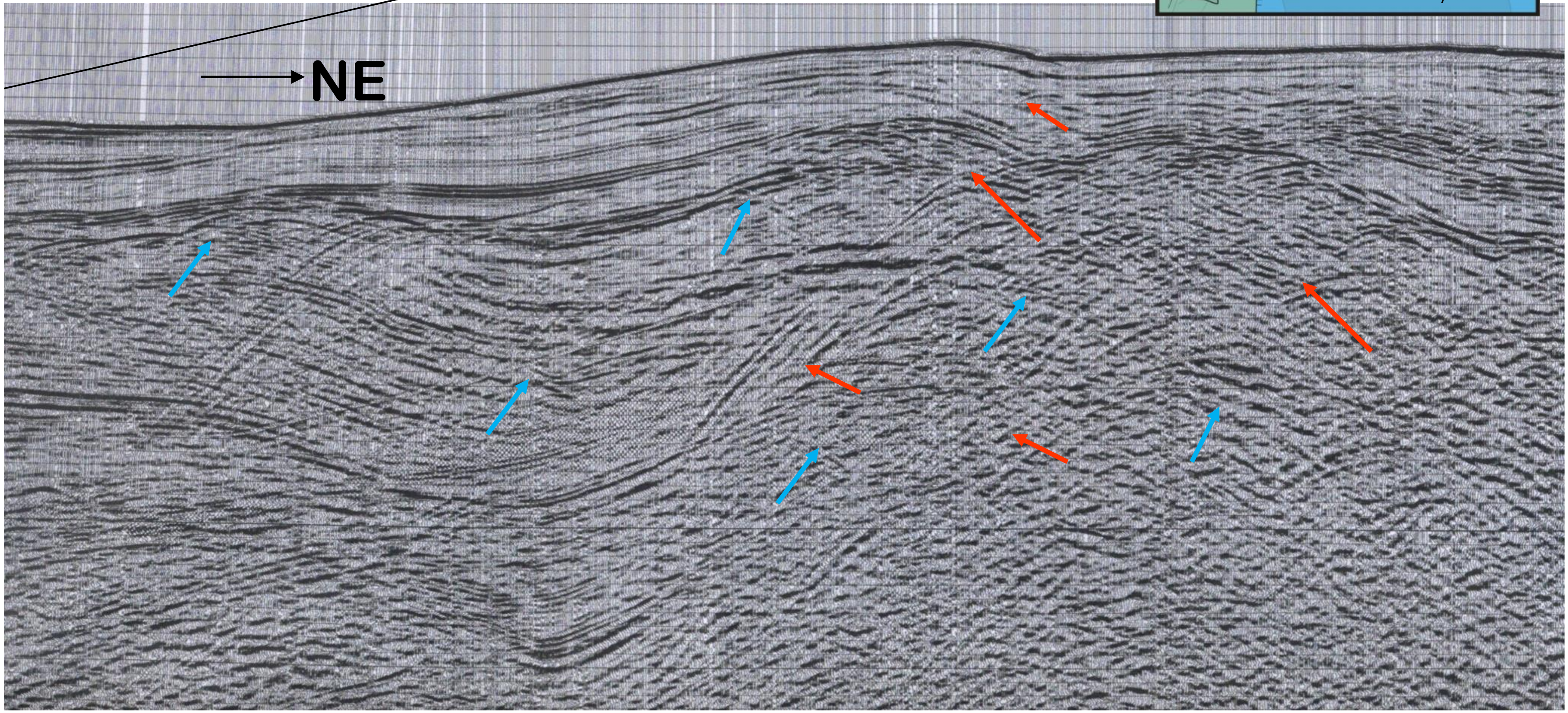
Back-thrust nell'offshore Calabro





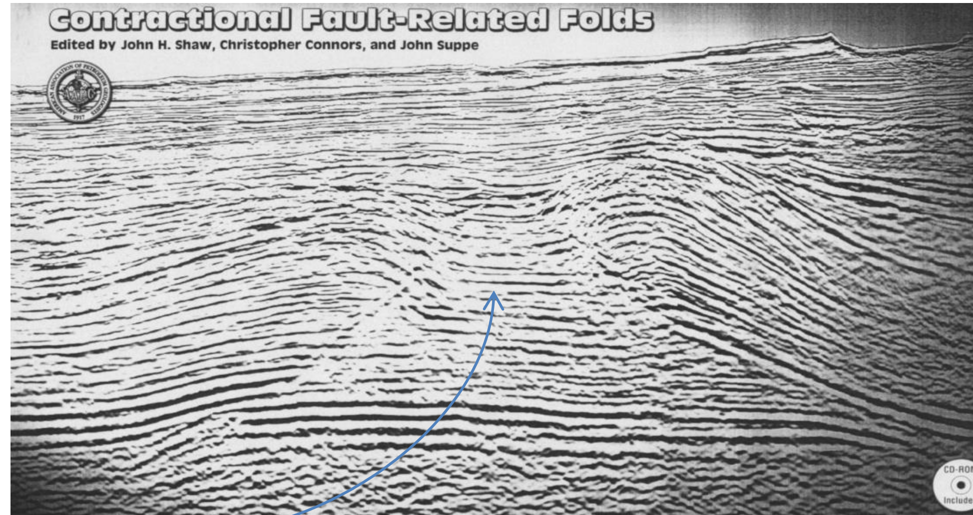
Thrust ╲ e *Back-thrust* ╱
nell'offshore Calabro

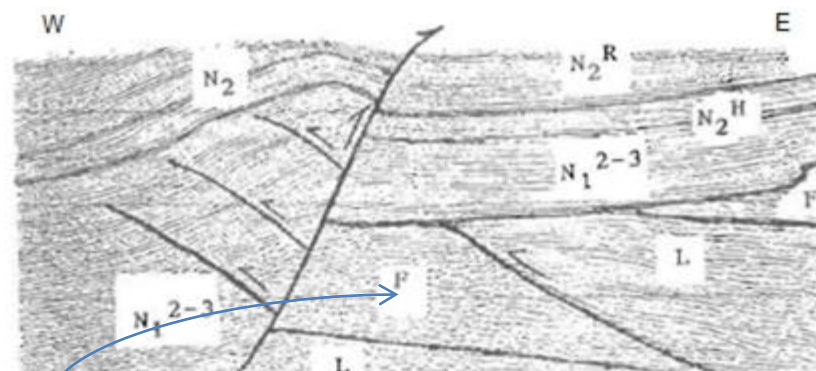


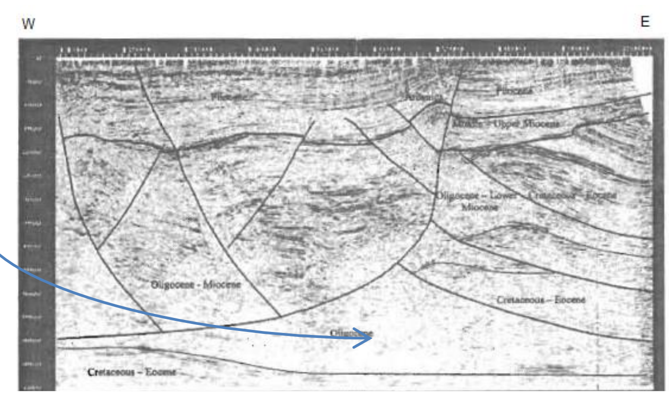


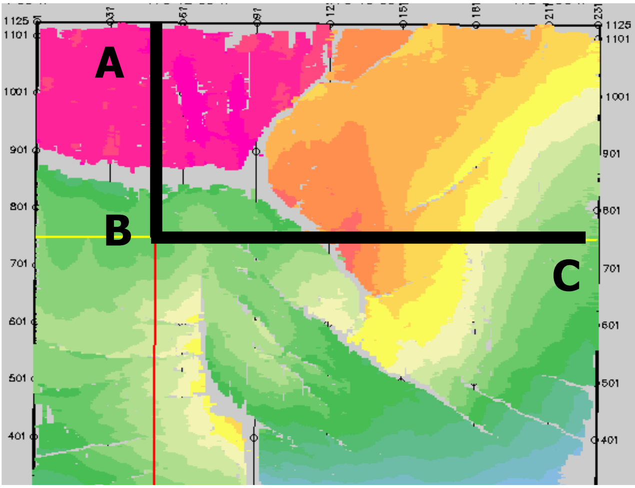
Triangle Zone

Una combinazione data da *thrust* e *back-thrust* associati allo stesso piano di scollamento, può definire una zona a forma triangolare interposta tra tali faglie, dando luogo a tipiche strutture definite come "*triangle zones*"

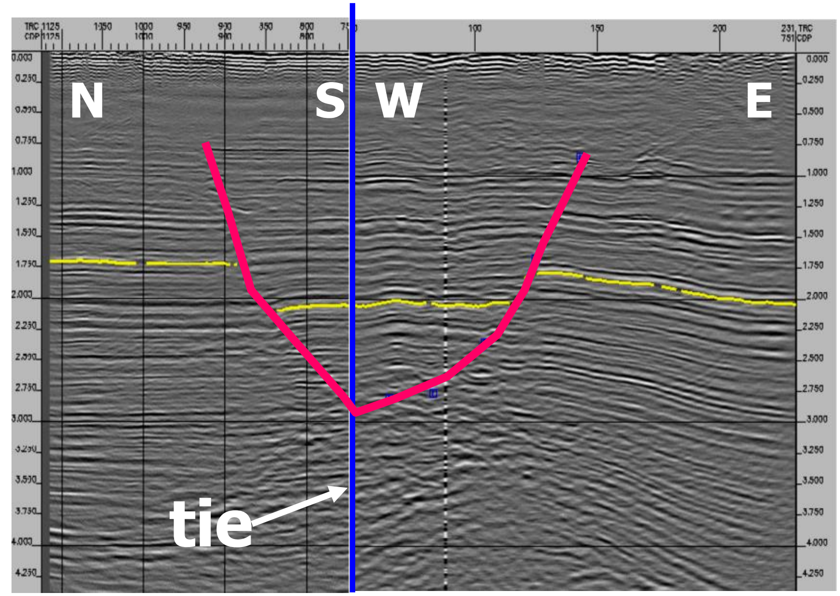


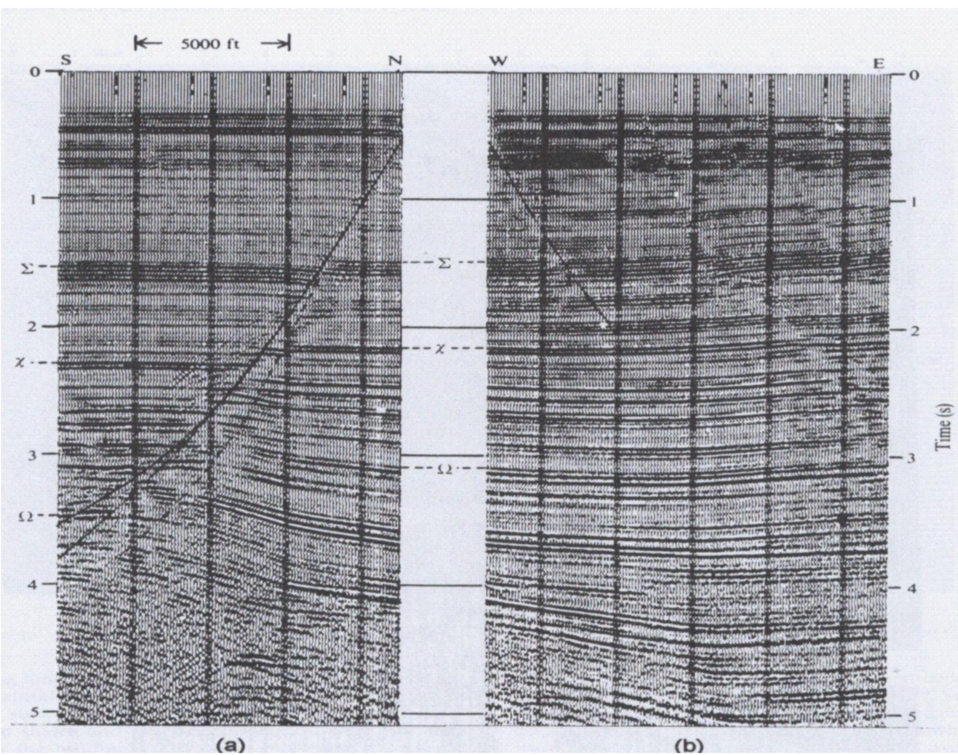






Faults must tie on intersecting lines, or the interpretation is not internally **consistent**





If a fault cuts a seismic profile, the fault plane should be recognized by cutoffs, king-bands and (eventually) reflection from the plane.

A crossing profile has to see the same fault at the same depth...

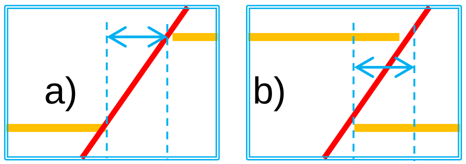
...you have to consider if you are interpreting stack or migrated profiles!!

Mapping a fault

Faults are generally represented by an inclined plane.

First of all we have to distinguish between different types of faults:

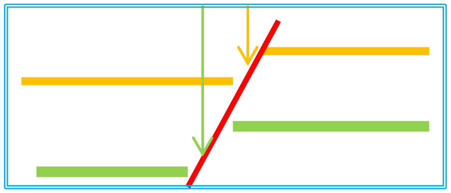
faglia normale faglia compressiva



- **Extensional faults** are characterized by "not-existent" reflector along a strip corresponding to the horizontal throw of the fault for that reflrector;
- **Compressive faults** are characterized by overthrusting, therefore by strip where the reflector is repited at different depths;
- ***Strike-slip* faults** are related to vertical surface with horizontal throws along the fault plane ➔ condition of "not-existent" or double reflector can eventualy be related to secondary components, that are transtension or trasprression.

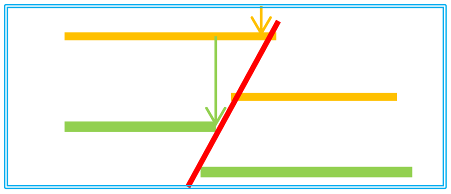
Fault position in the map

➔ How and where we have to indicate faults in the map?

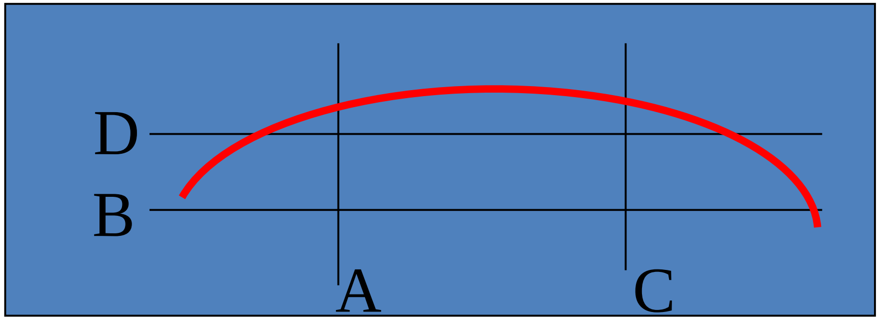


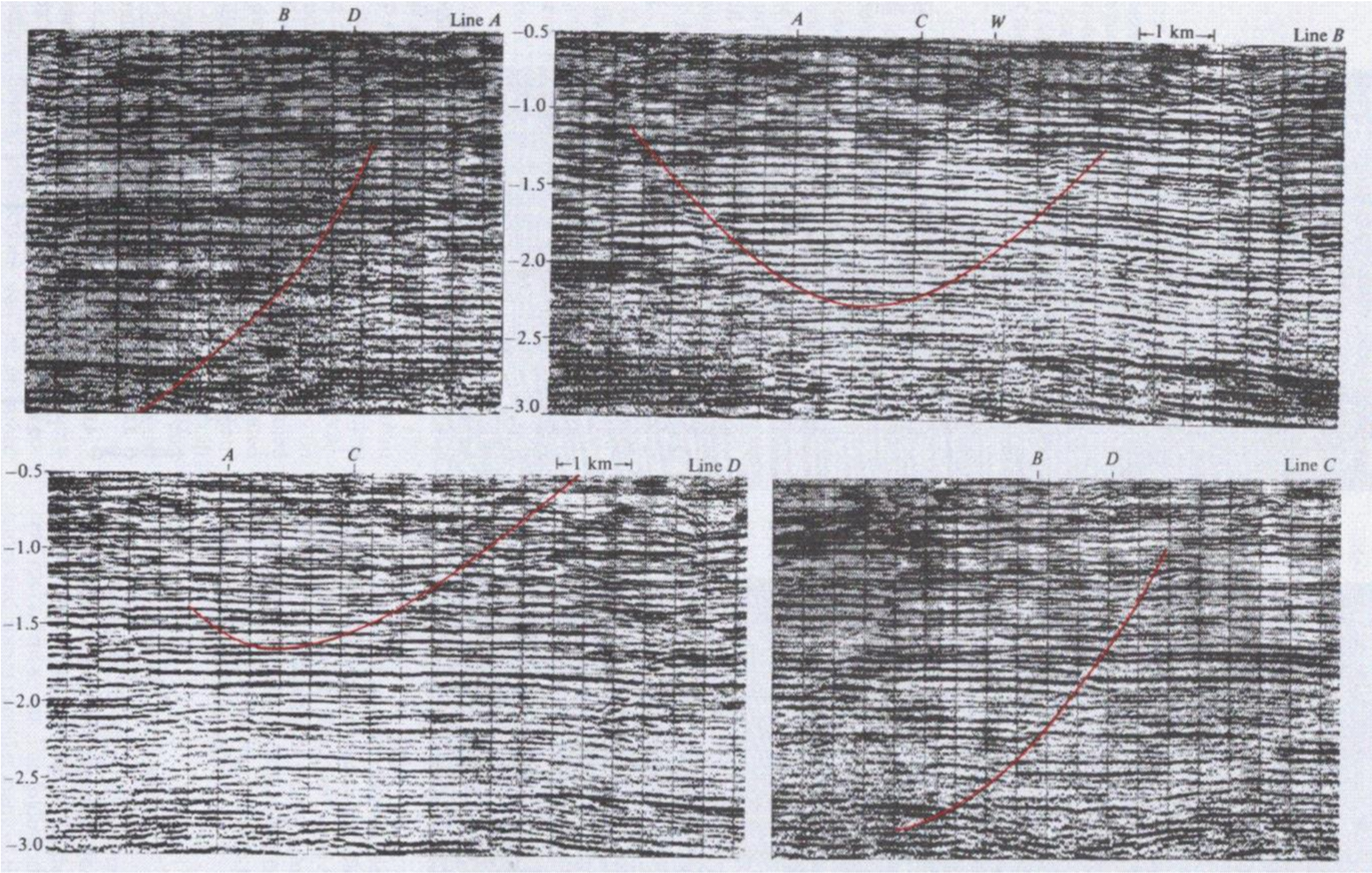
The fault should be indicated as a line (planare or listric, but we have always to consider deformation due to twt!). Its position will be in the *cutoff* of the mapped horizon; different position for differtent horizons.

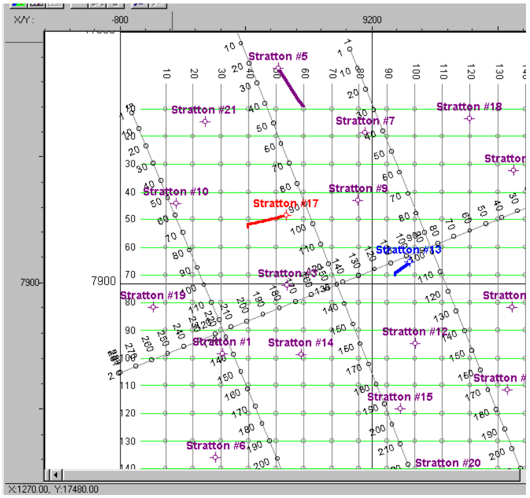
For the compressive faults we generally consider the *cutoff* of the *hanging wall.*

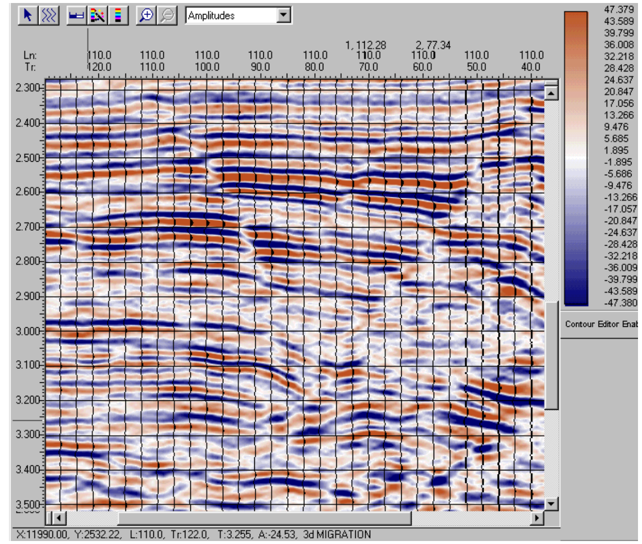


Evidenze di faglia distensiva su più profili

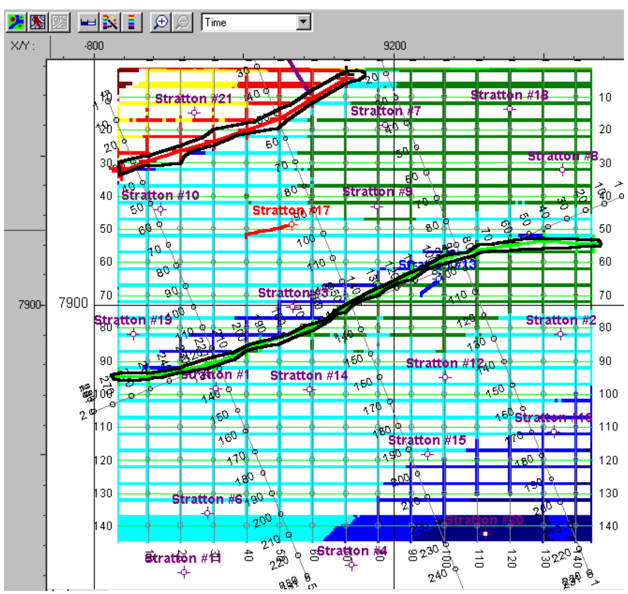


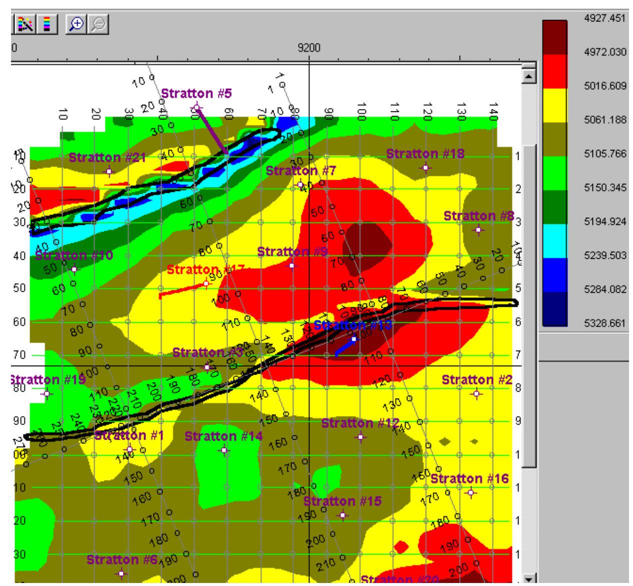




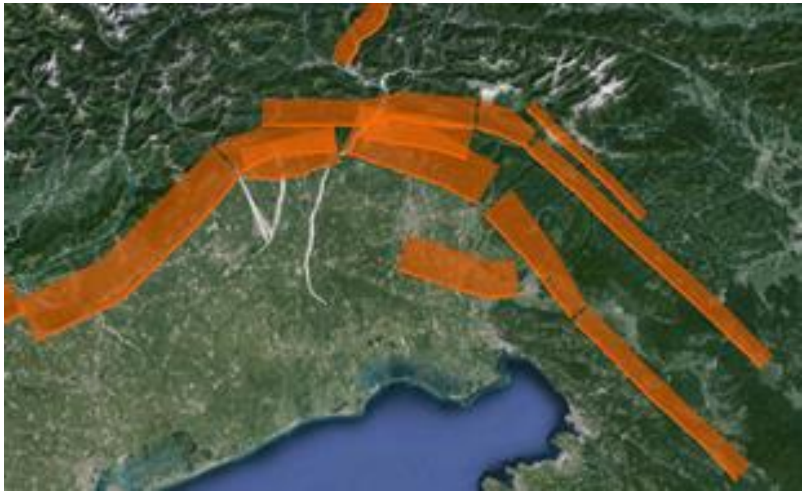


Una faglia distensiva potrà eventualmente diventare una fascia più o meno larga.
La larghezza in mappa rappresenta il rigetto orizzontale dell'orizzonte mappato.





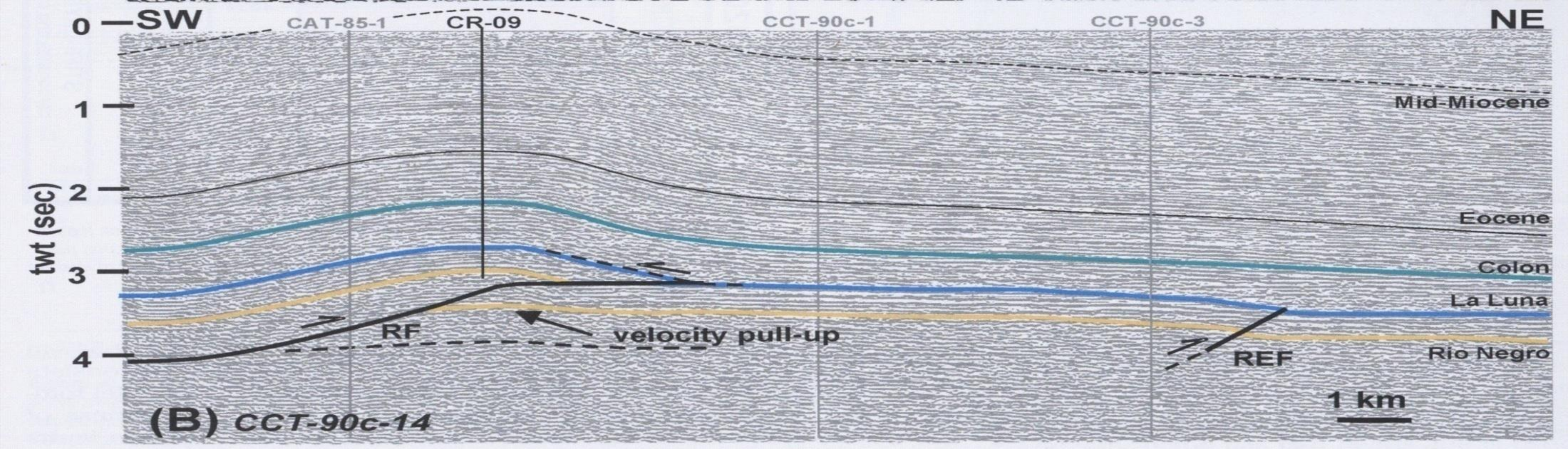
Faults position on maps: DISS



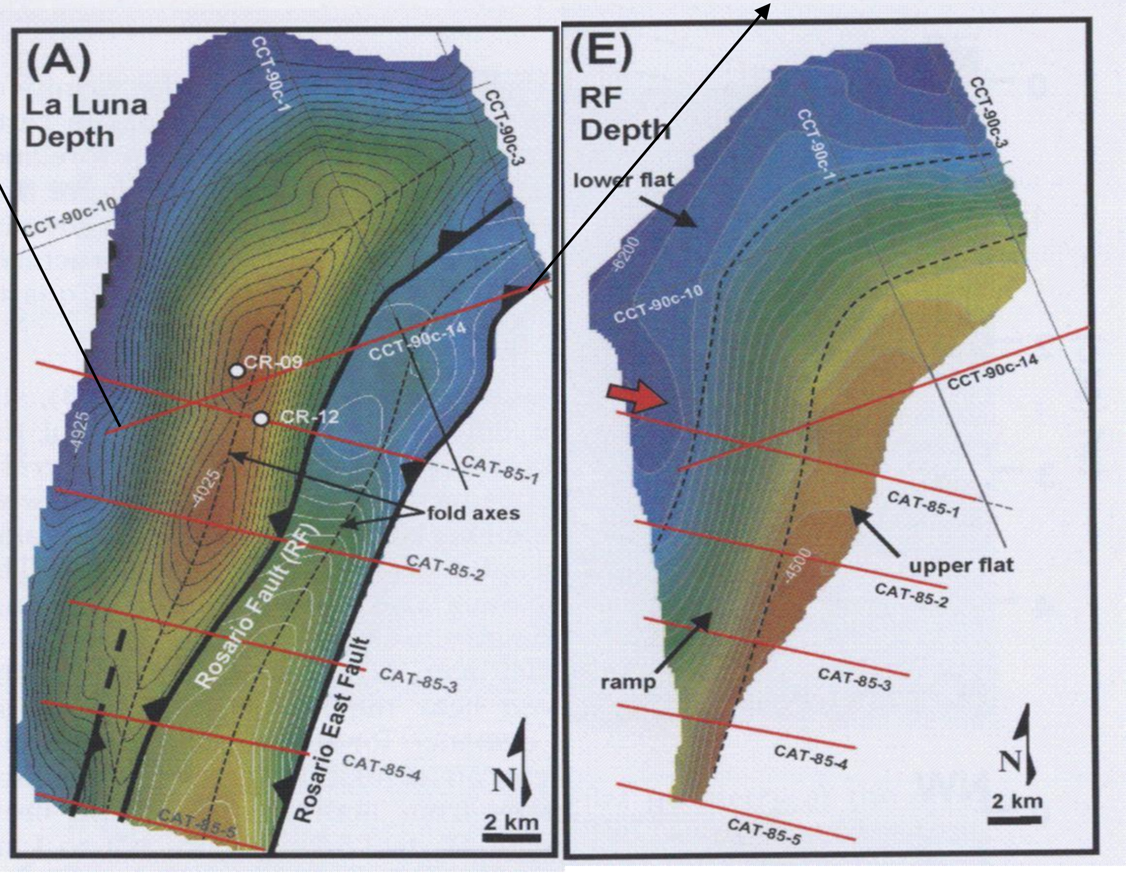
DISS: Database of Individual Seismogenic Sources (DISS), Version 3.2.0:
A compilation of potential sources for earthquakes larger than M 5.5 in Italy and surrounding areas. http://diss.rm.ingv.it/diss/, © INGV 2015 - Istituto Nazionale di Geofisica e Vulcanologia

Il DISS ha lo scopo di definire i piani di faglia lungo cui potrebbero generare importanti terremoti: per questo motivo, oltre all'emersione superficiale delle faglie (linea arancione) vengono rappresentate anche le loro superfici in profondità.

Le faglie compressive avranno una maggiore larghezza (maggiore pendenza) rispetto alle faglie distensive; le faglie trascorrenti, essendo dei piani di faglia sub-verticali, saranno generalmente molto più ristrette arealmente (teoricamente delle linee)



Example of
“*flat & ramp*” geometry in the *Rosario*
Field of *Maracaibo Basin*
in Venezuela.
The *Rosario Fault*,
has been mapped in (E)
as a lithological
discontinuity:
in this way the
“*flat*” (distant *contour* lines)
and “*ramp*” (closer lines) sectors
have been evidenced.



Effetto di una faglia inversa in un profilo sismico a riflessione. Esempio con graduale aumento di velocità intervallare

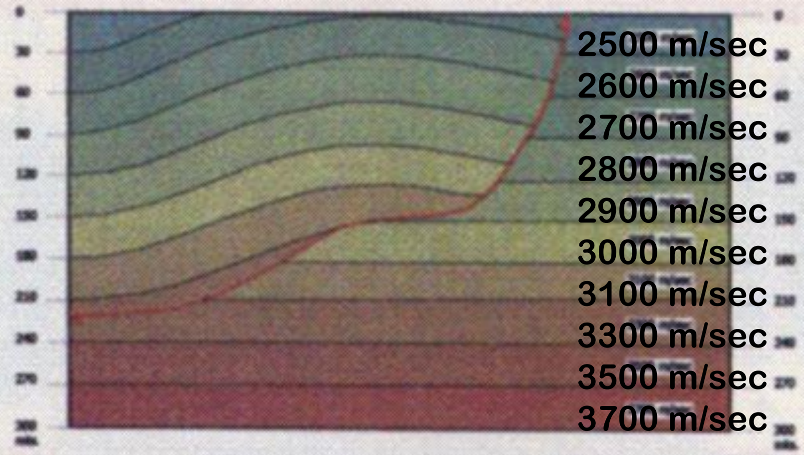


Figure 9. Geologic model (reverse fault) (depth).

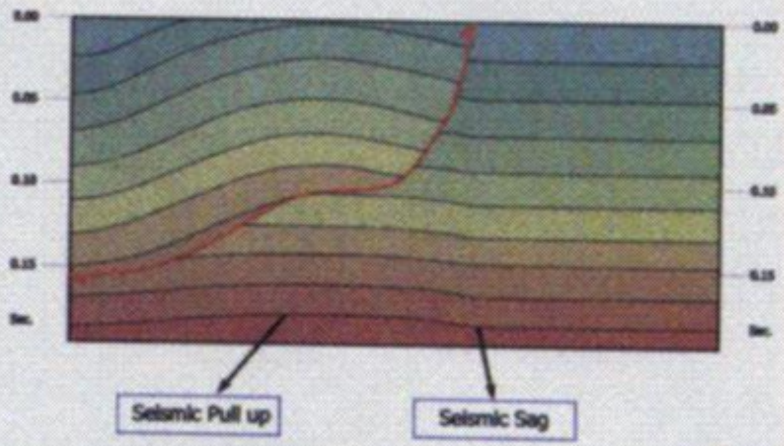


Figure 10. Geologic model (reverse fault) (time).

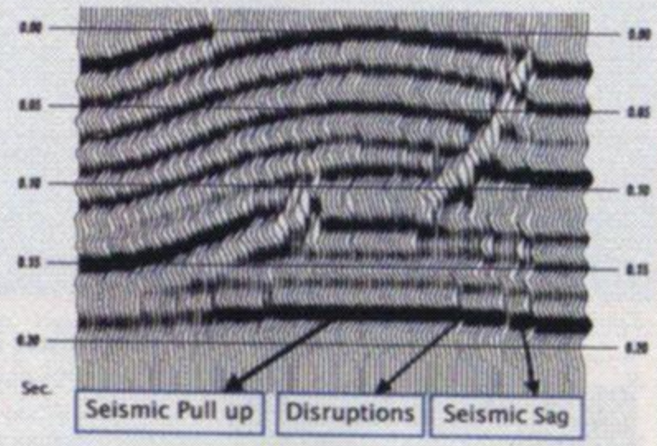


Figure 11. Normal incidence fault propagation fold model (reverse fault) (wiggle trace).

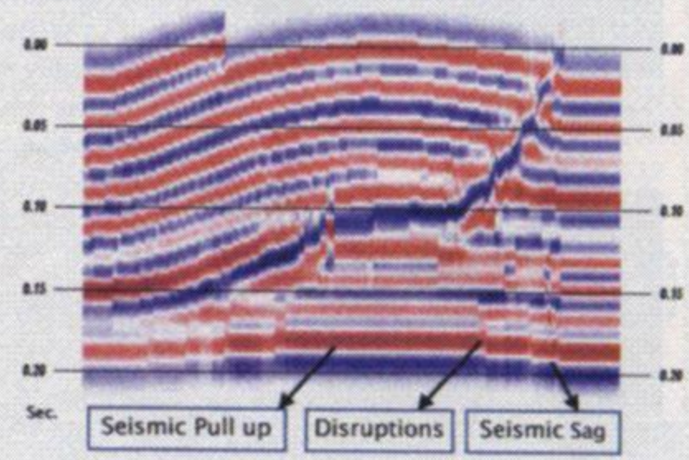


Figure 12. Normal incidence fault propagation fold model (reverse fault) (variable density).

Una faglia compressiva genera solitamente un *pull-up velocity*; localmente si possono avere avvallamenti (*sag*) con generale deterioramento del segnale

Effetto di una faglia normale in un profilo sismico a riflessione. Esempio con strato ad alta velocità intervallare

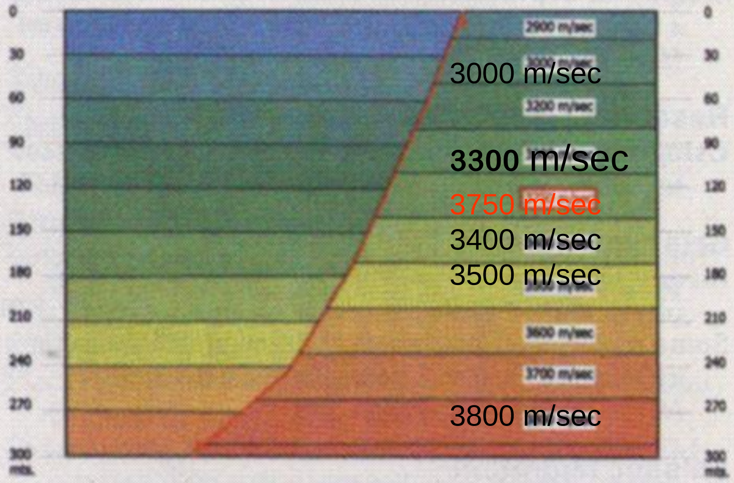


Figure 1. Geologic model (normal fault) (depth).

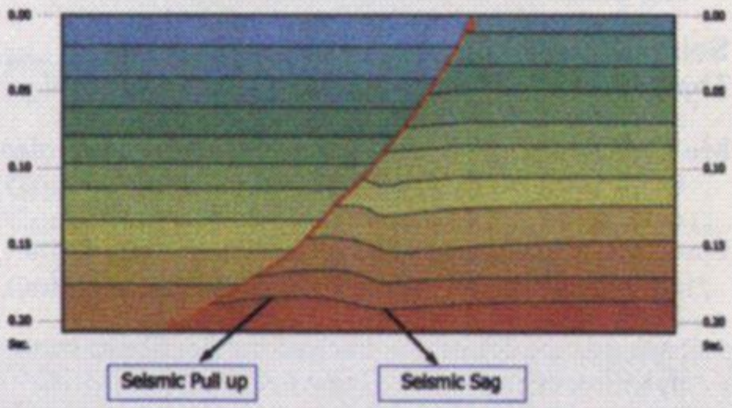


Figure 2. Geologic model (normal fault) (time).

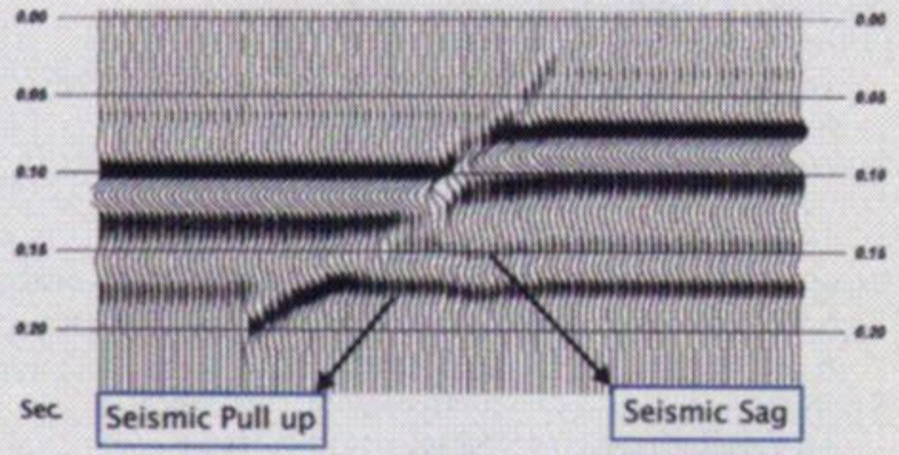


Figure 3. Normal incidence wiggle-trace model.

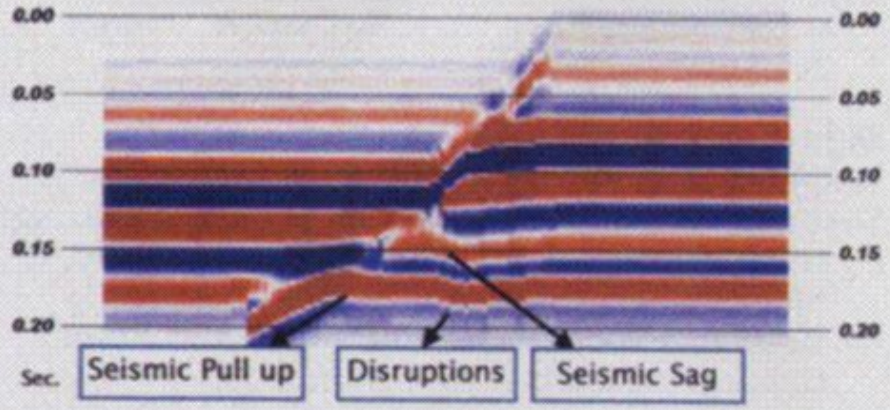


Figure 4. Normal incidence variable density model.

Effetto di una faglia normale in un profilo sismico. Esempio con strato a bassa velocità intervallare

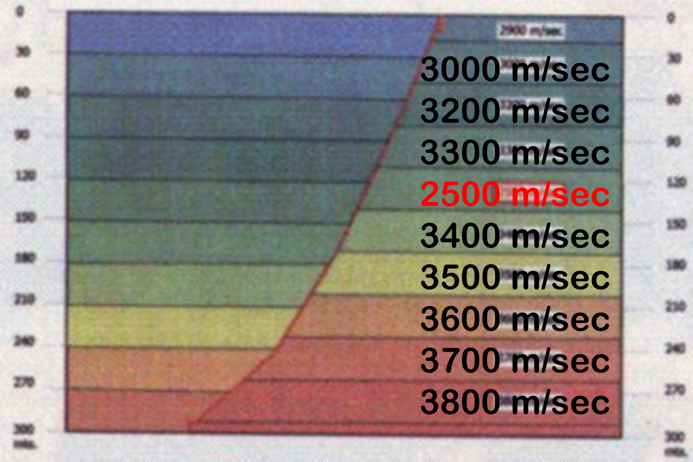


Figure 5. Geologic model 2 (normal fault) (depth).

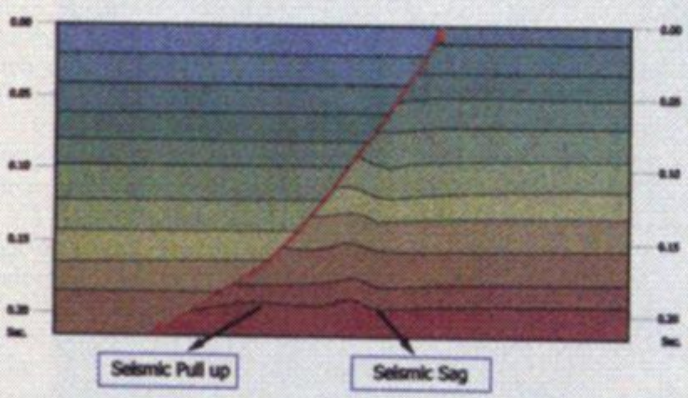


Figure 6. Geologic model 2 (normal fault) (time).

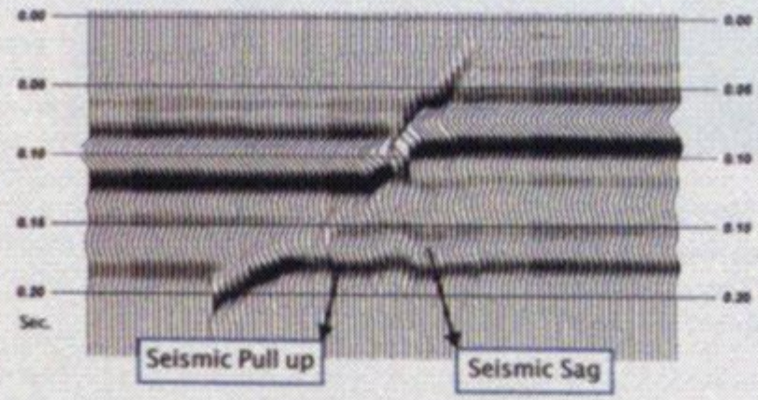


Figure 7. Normal incidence seismic model 2 (normal fault) (wiggle trace).

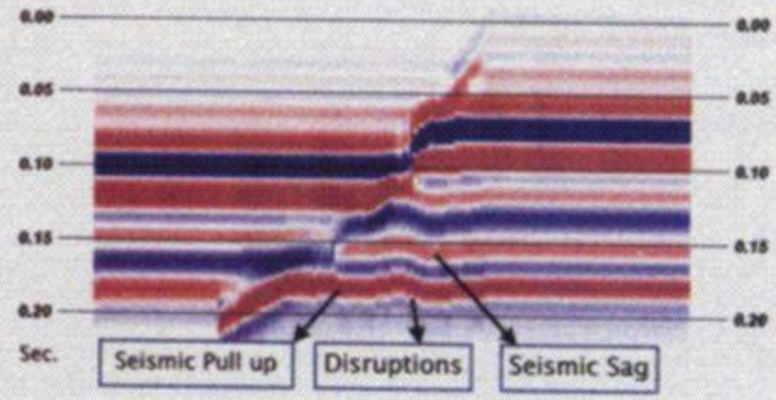
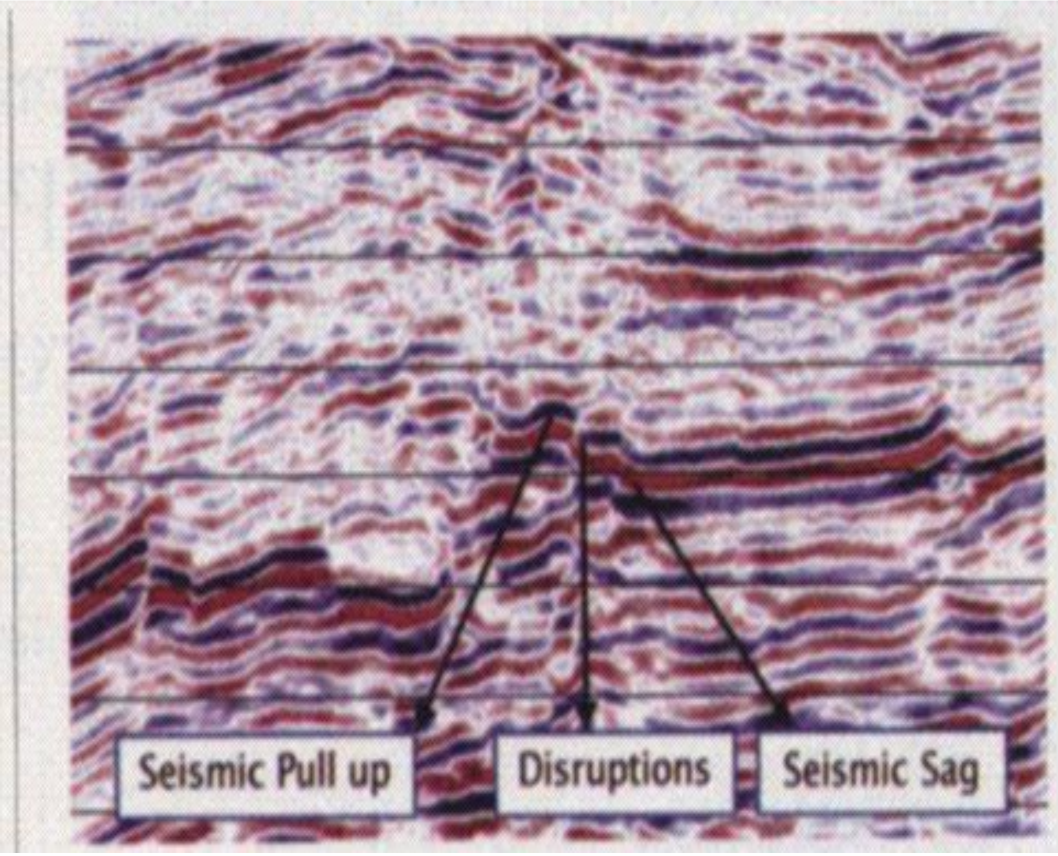
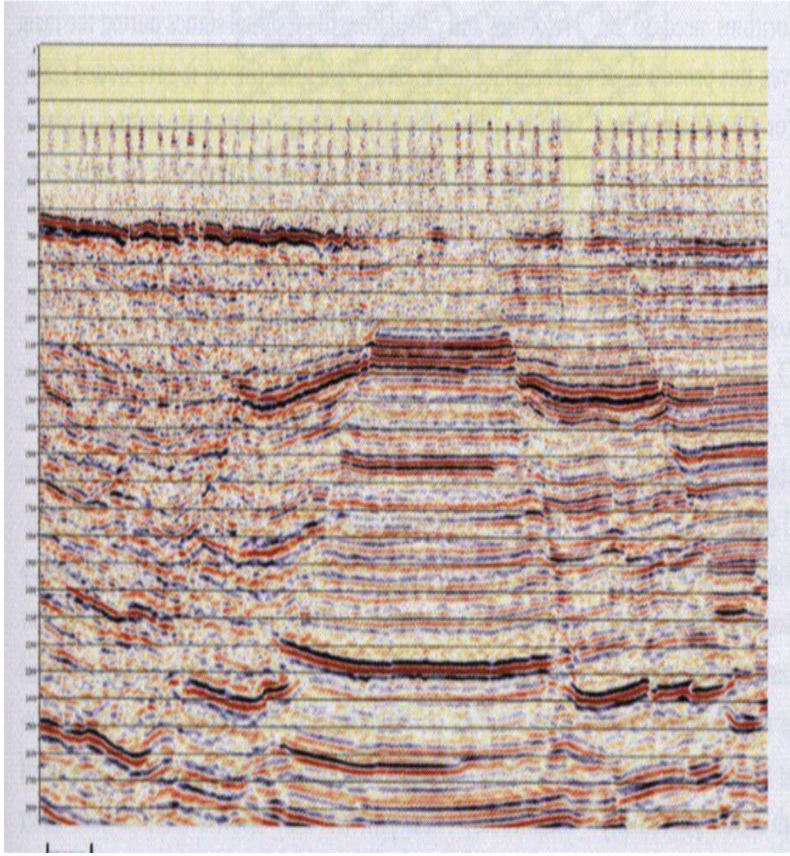


Figure 8. Normal incidence seismic model 2 (normal fault) (variable density).



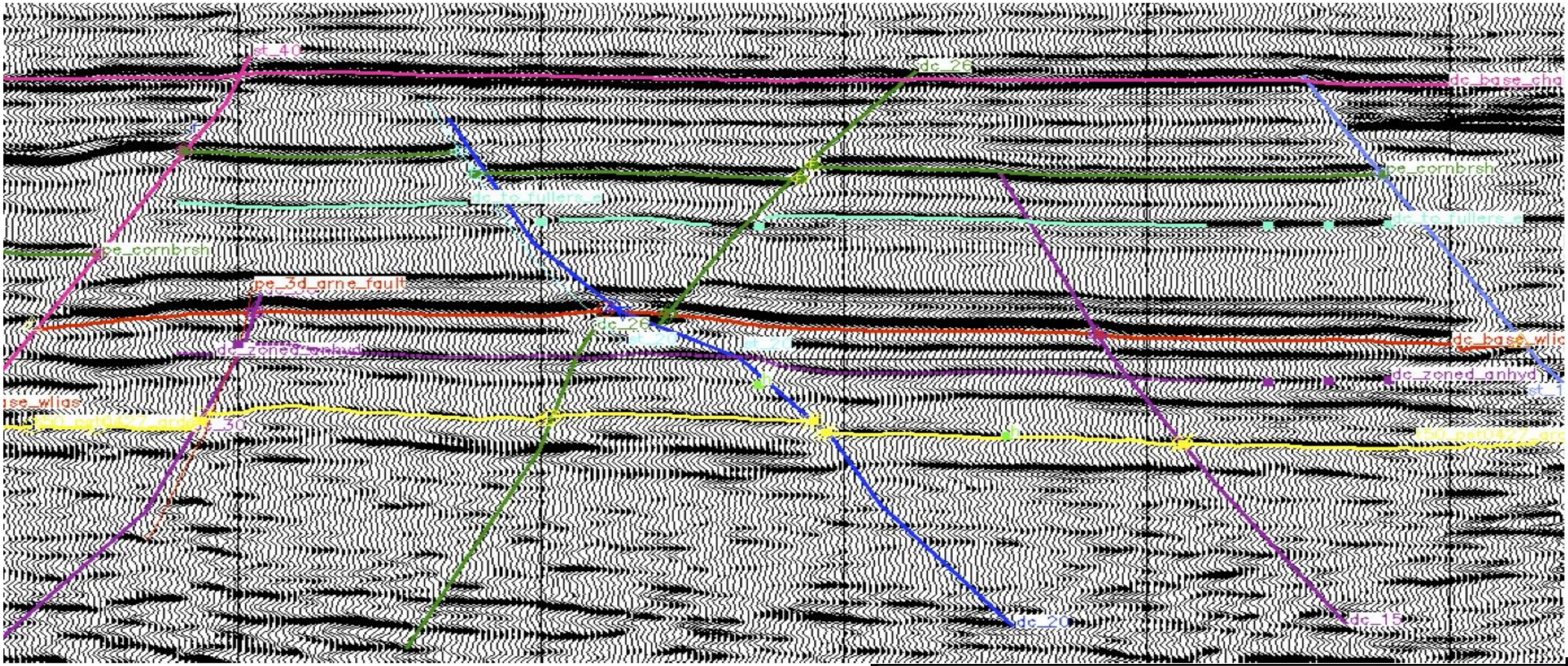
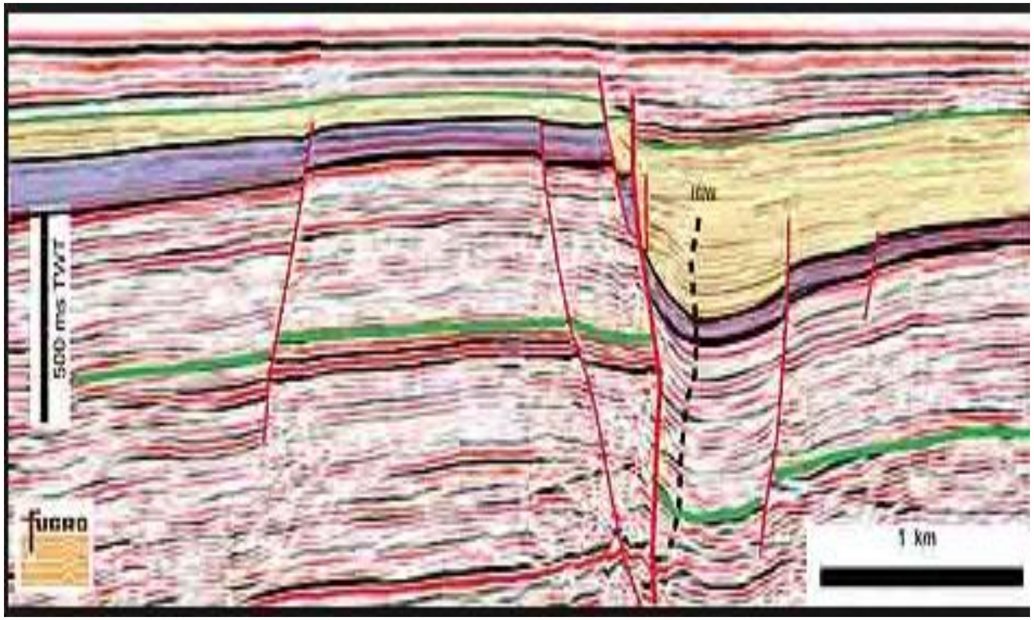
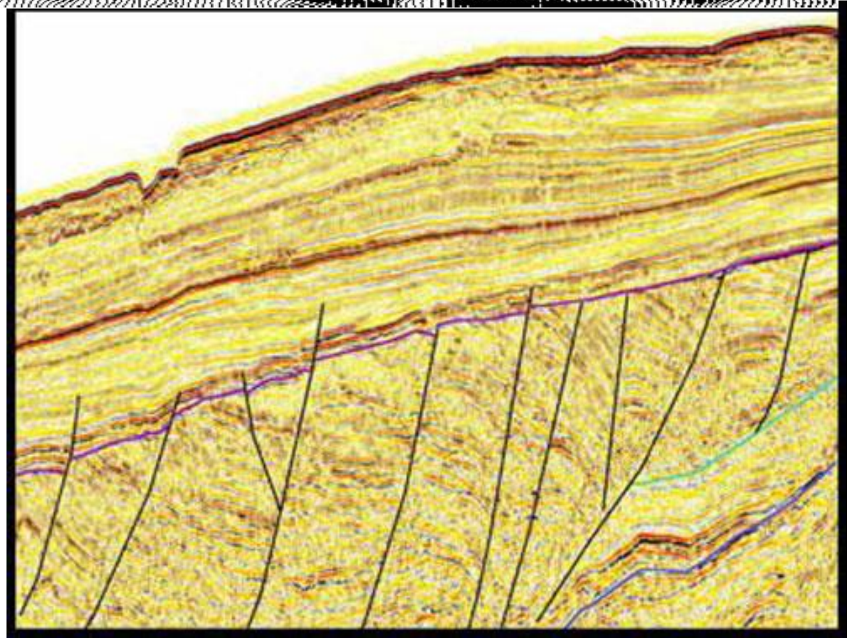


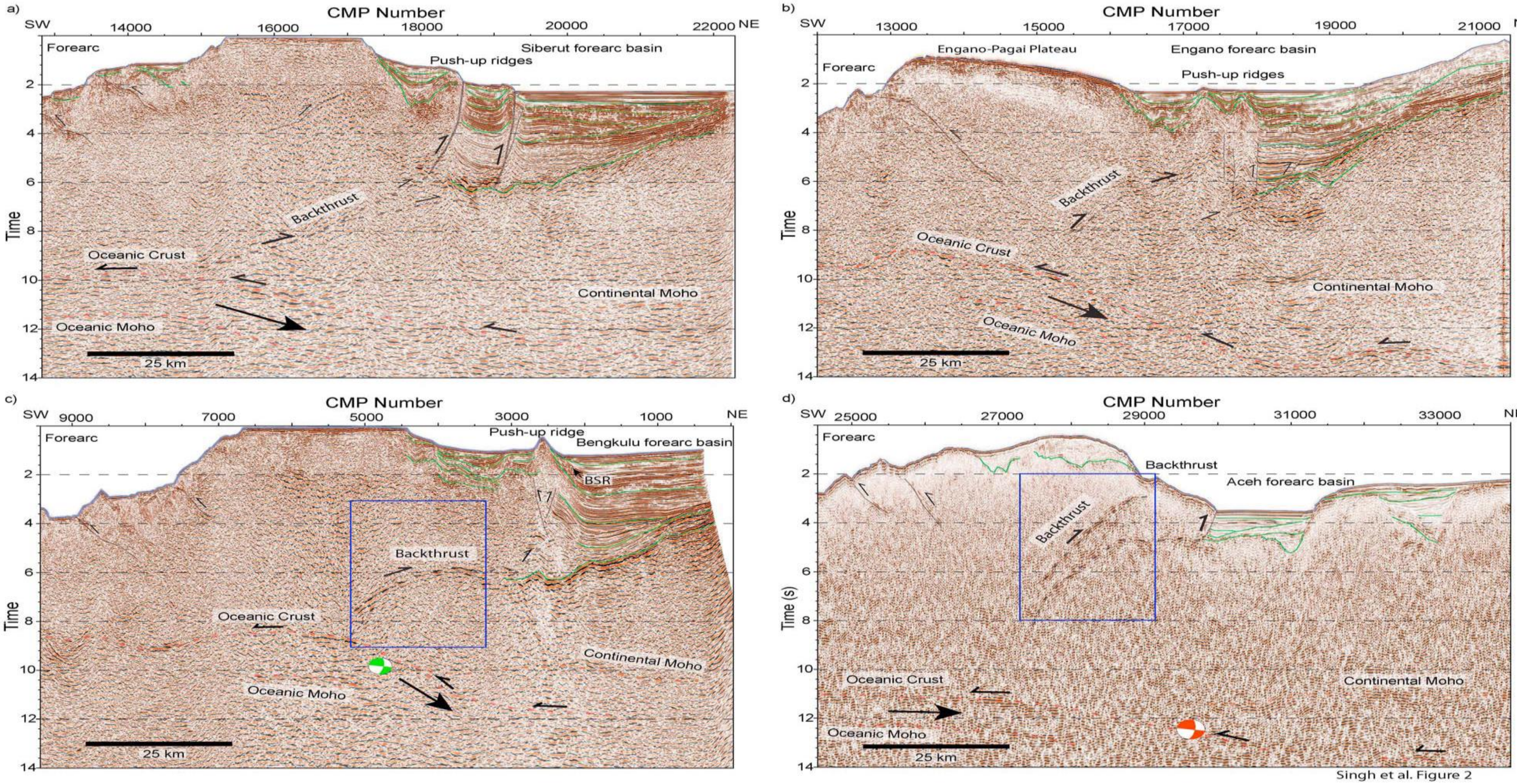
Talvolta il piano di faglia può originare un riflettore continuo, ma in genere è troppo verticale per dare riflessioni utili: la sua ubicazione sarà data dall'allineamento dei *cut-off* dei riflettori

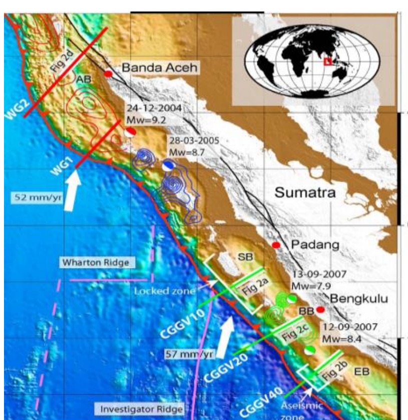
Fault Shadow : i contrasti di velocità lungo il piano variano notevolmente: ciò genera distorsioni tali da determinare spesso una zona d'ombra, di difficile interpretazione, sotto la faglia stessa.

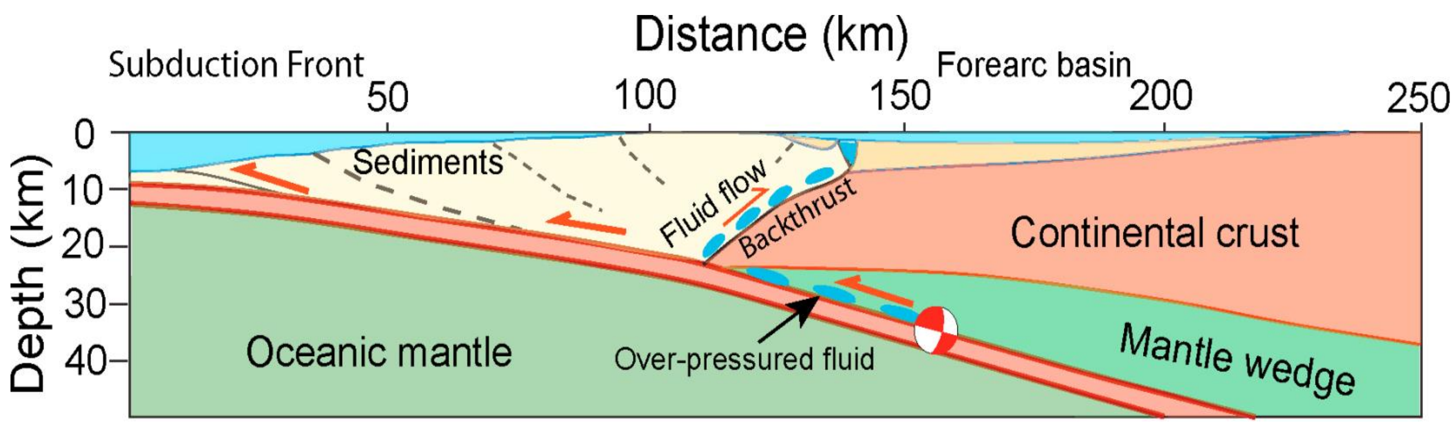
Sistema di fratture diffuse nel volume di sedimenti.

L'interpretazione del sistema di faglie deve partire dalle fratture principali, gli obiettivi specifici determinano il dettaglio dell'interpretazione.


st_40
dc_26
pe_cornbrsh
dc_to_fullers_e
pe_3d_arne_fault
dc_zoned_anhyd
dc_20
dc_15

500 ms TWT
FUGRO
1 km








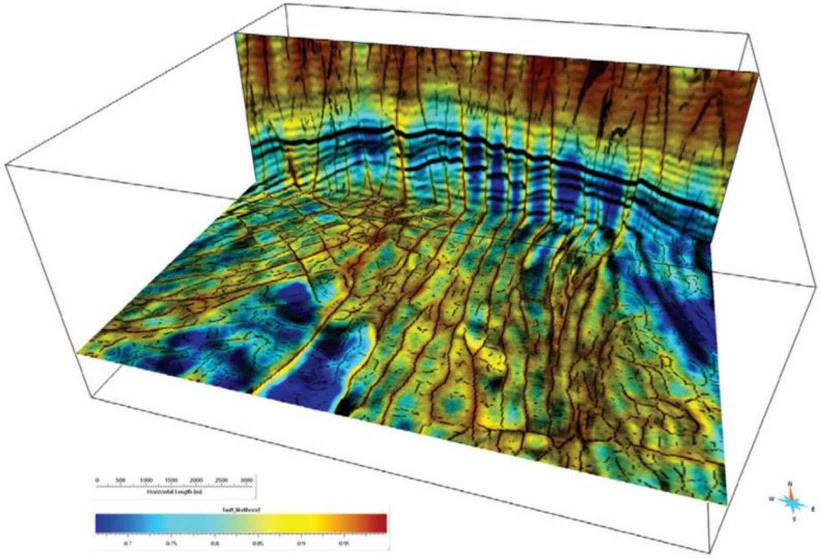
CRUSTAL SEISMIC INTERPRETATION

ATTRIBUTI SISMICI per interpretare le faglie

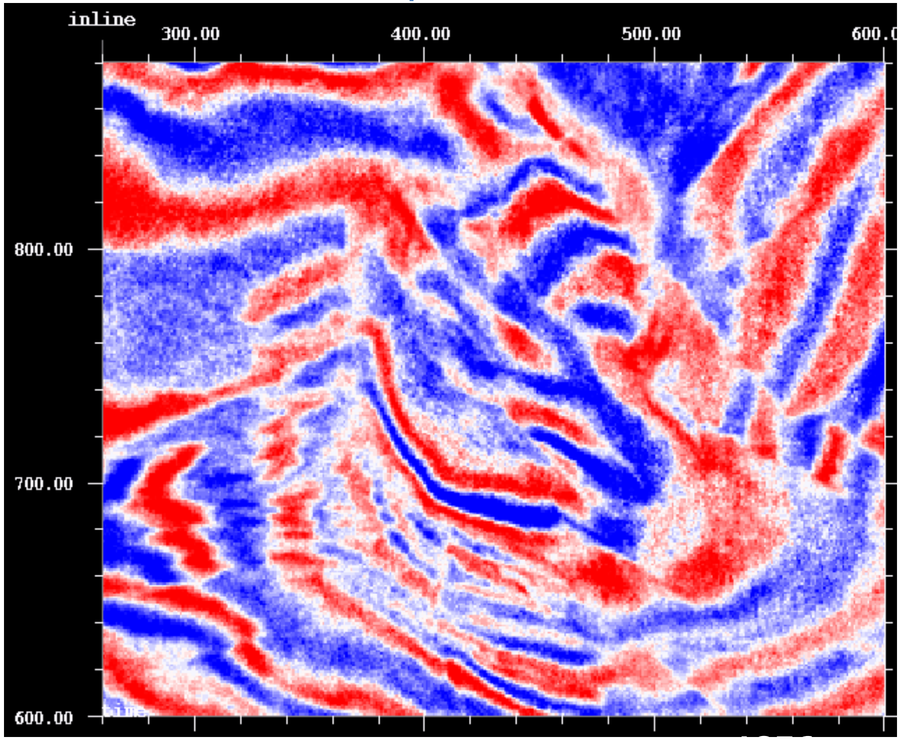
3D volume interpretation of faults by seismic attribute Coherency, also known as Discontinuity or Variance, is a derivative data volume based on trace-to-trace correlation.

Data range from 0 to 1,

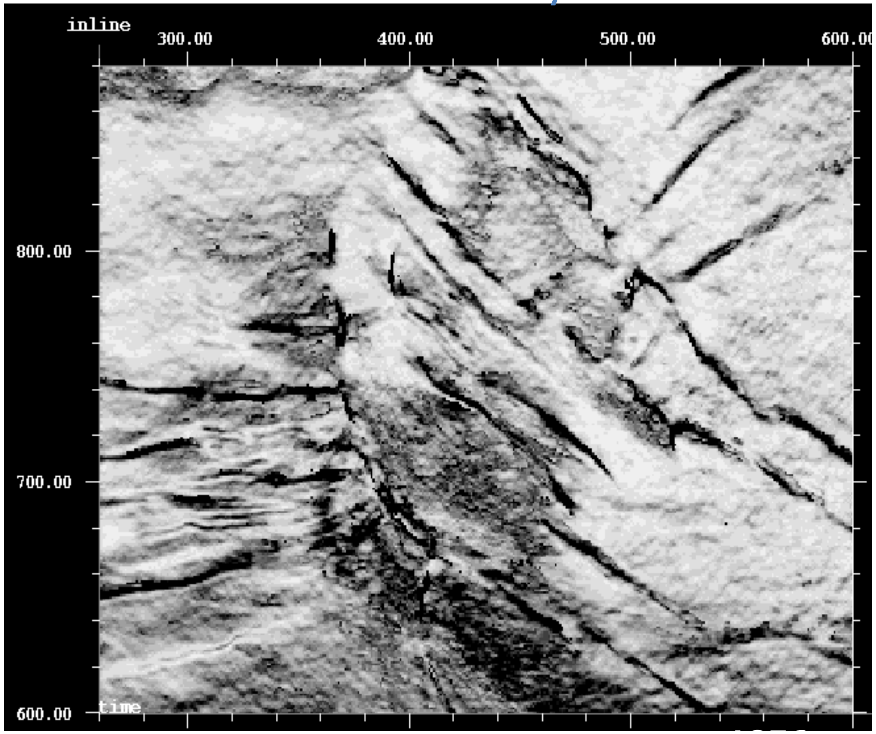
(1 = neighboring traces are identical

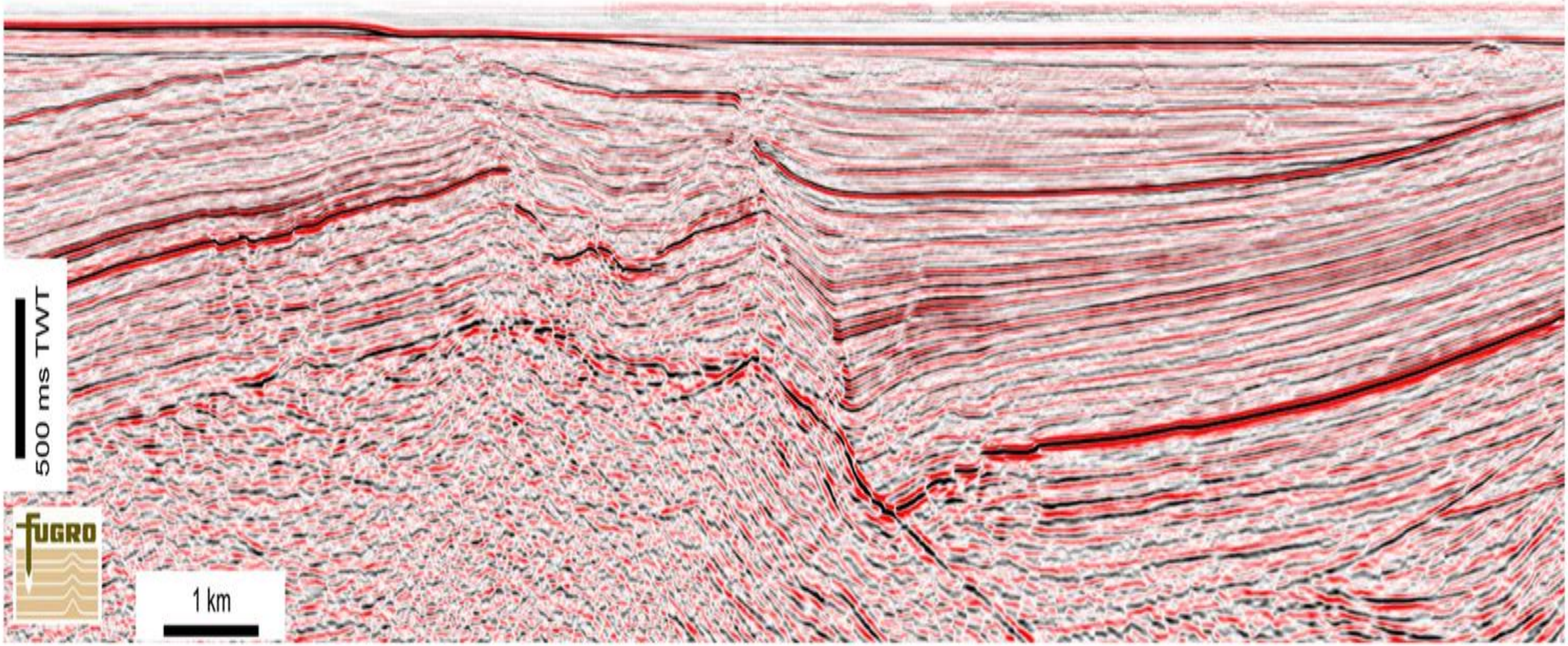


Amplitude Data

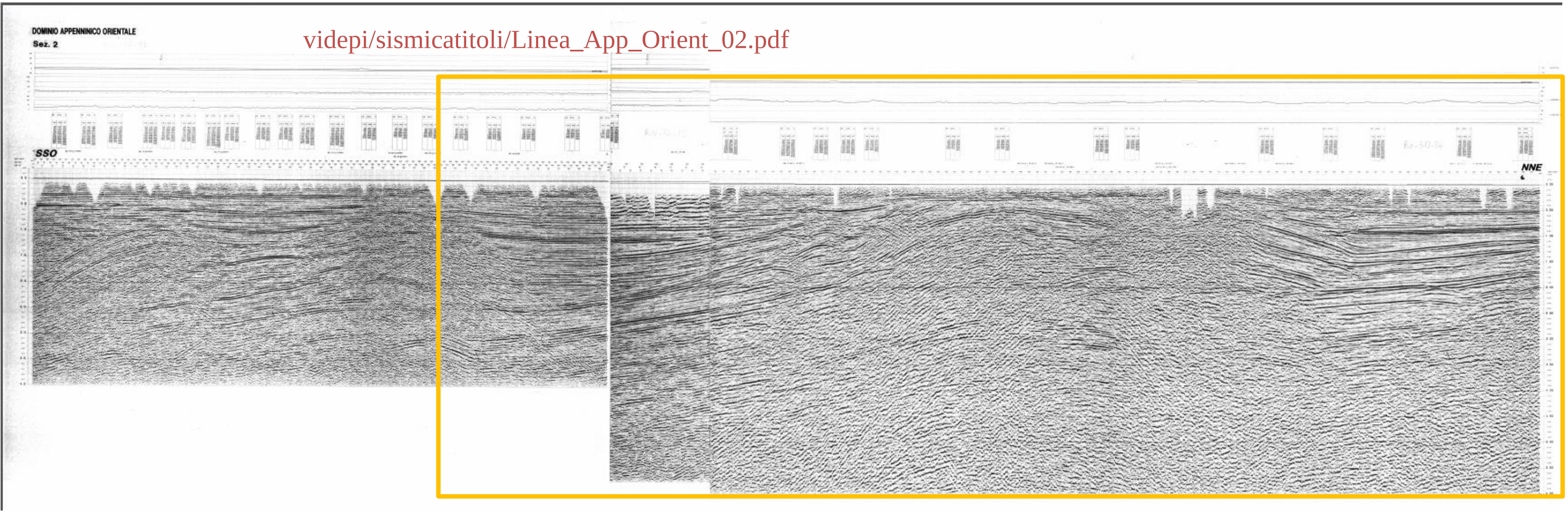


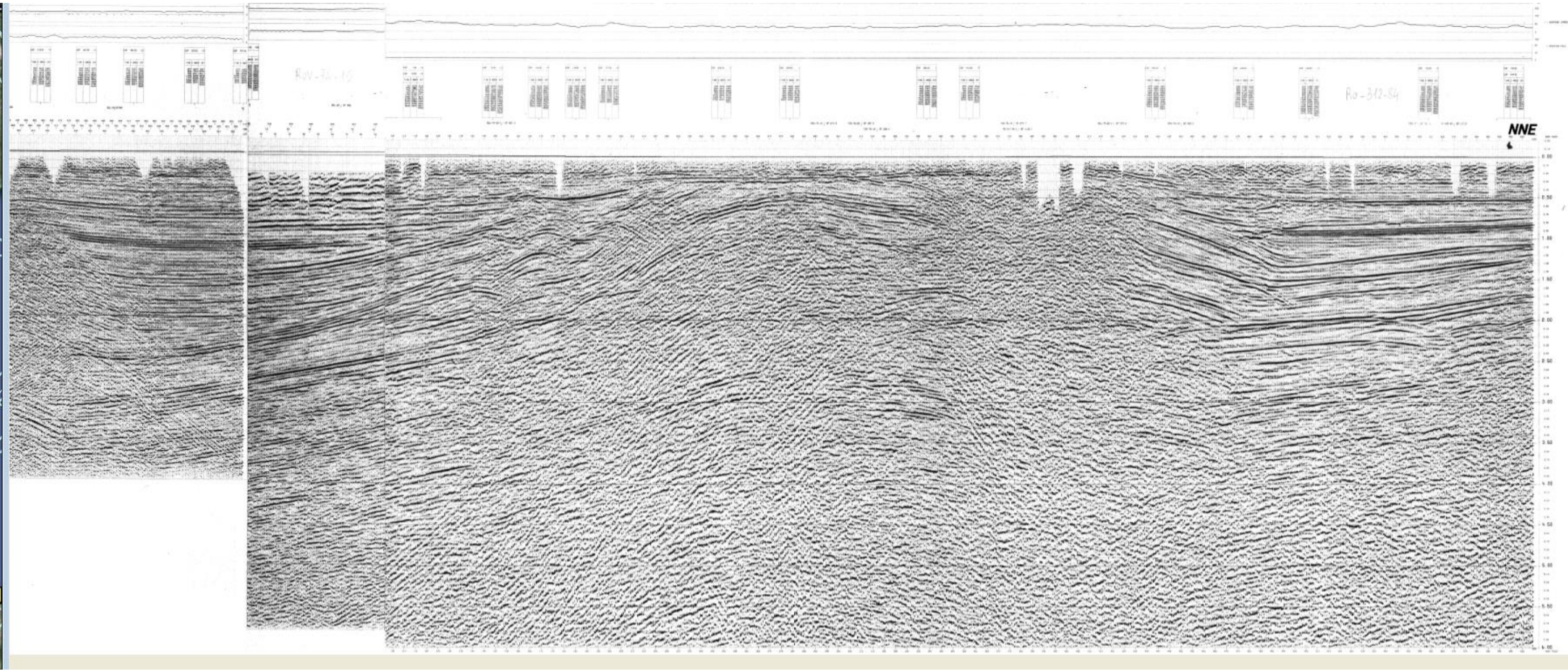
Coherency Data

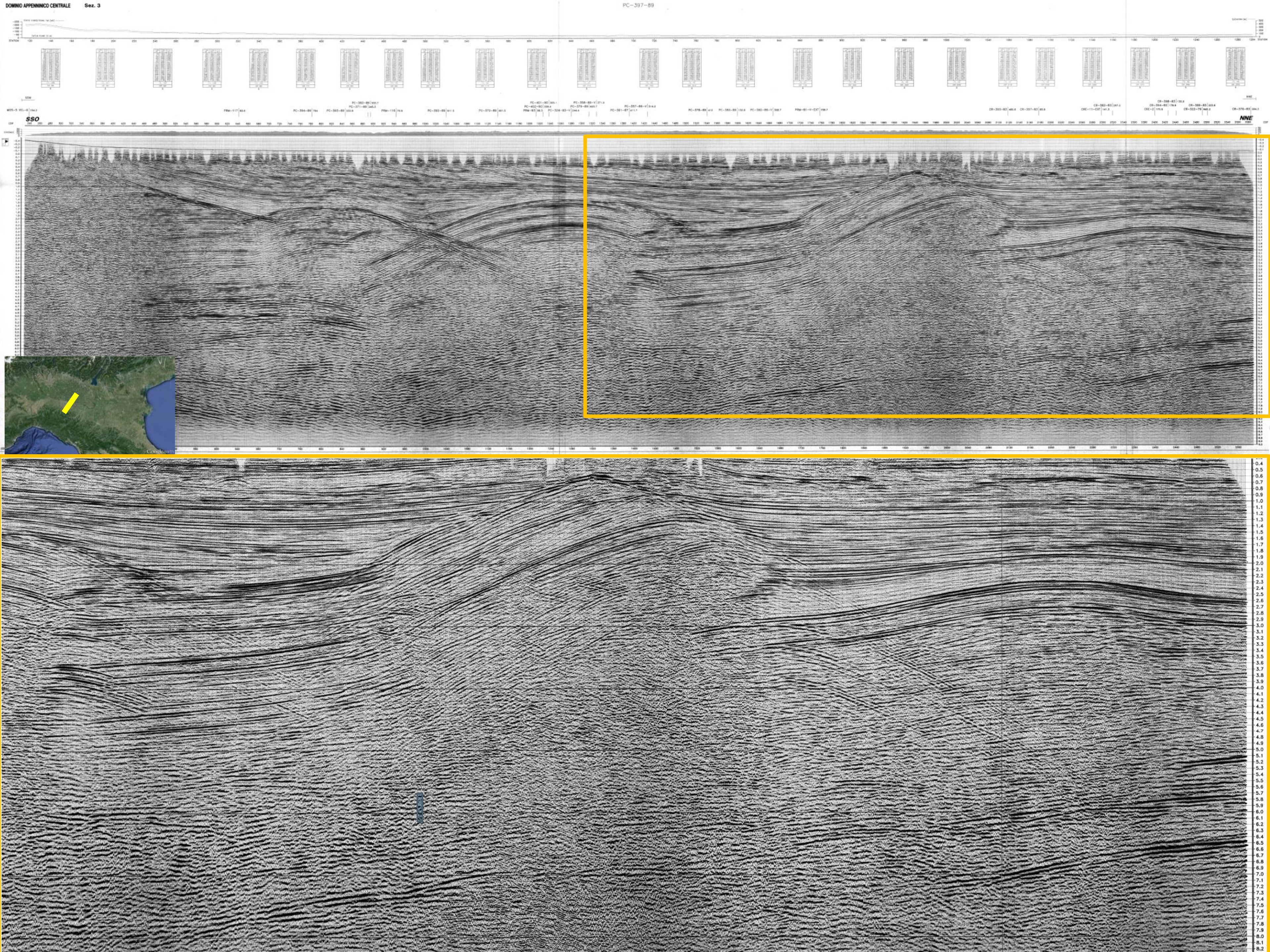



500 ms TWT
1 km

videpi/sismicatitoli/Linea_App_Orient_02.pdf






DOMINIO APPENNINICO CENTRALE
Sez. 3
PC-397-89
SSO
NNE