Submarine Canyon Fill (SCF)

&

Incised Valley Fill (IVF)

Submarine Canyon Fill

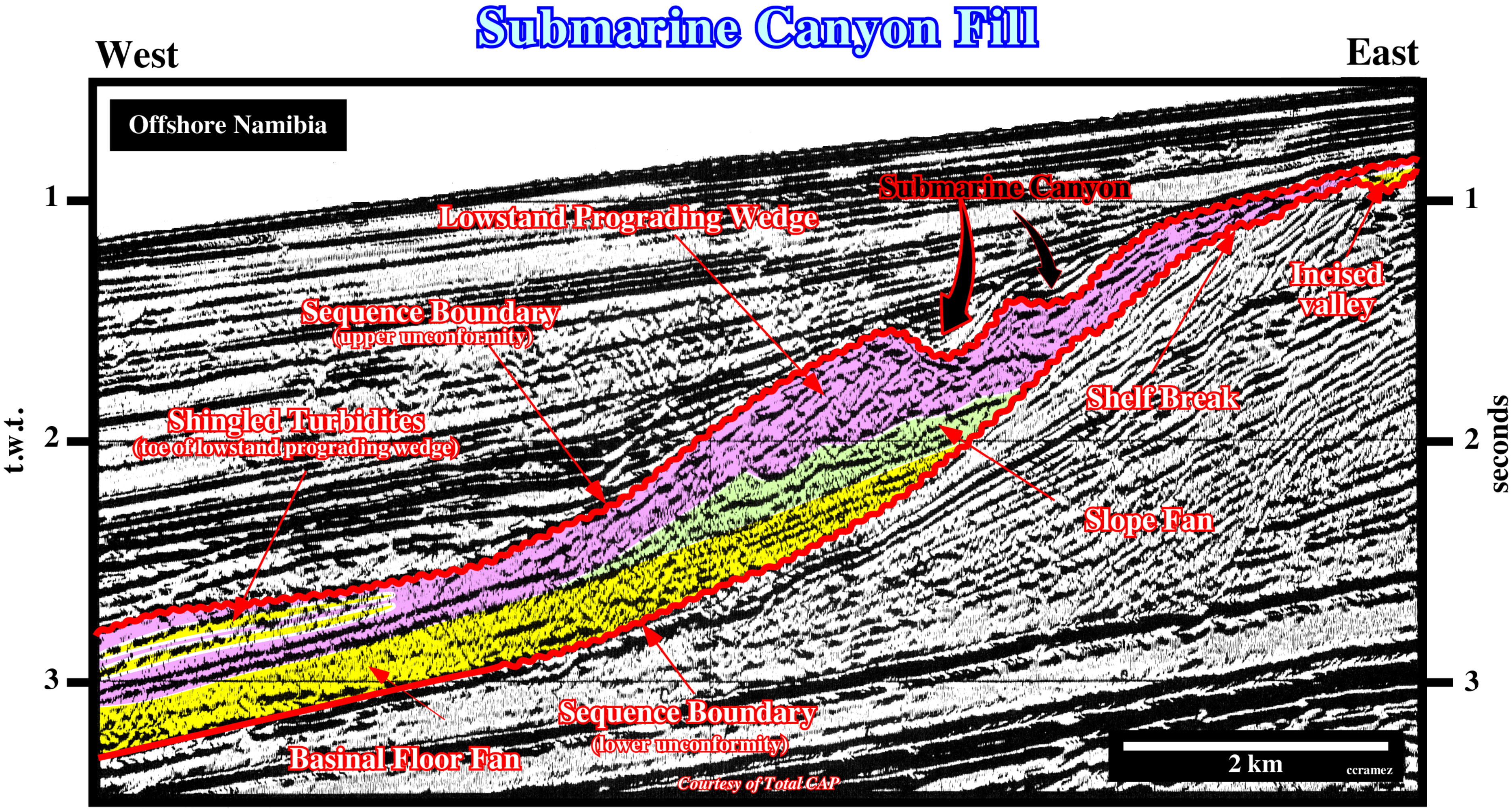


Fig. 76- Submarine canyons and incised valleys are associated with the upper limit of lowstand systems tracts, which often corresponds to a sequence cycle boundary, as illustrated on this seismic line, or in certain particular cases, with the limit with the overlying transgressive systems tract, when the sequence cycle is complete. In the next figures seismic examples and log patterns of these erosional features.

Submarine Canyon Fill

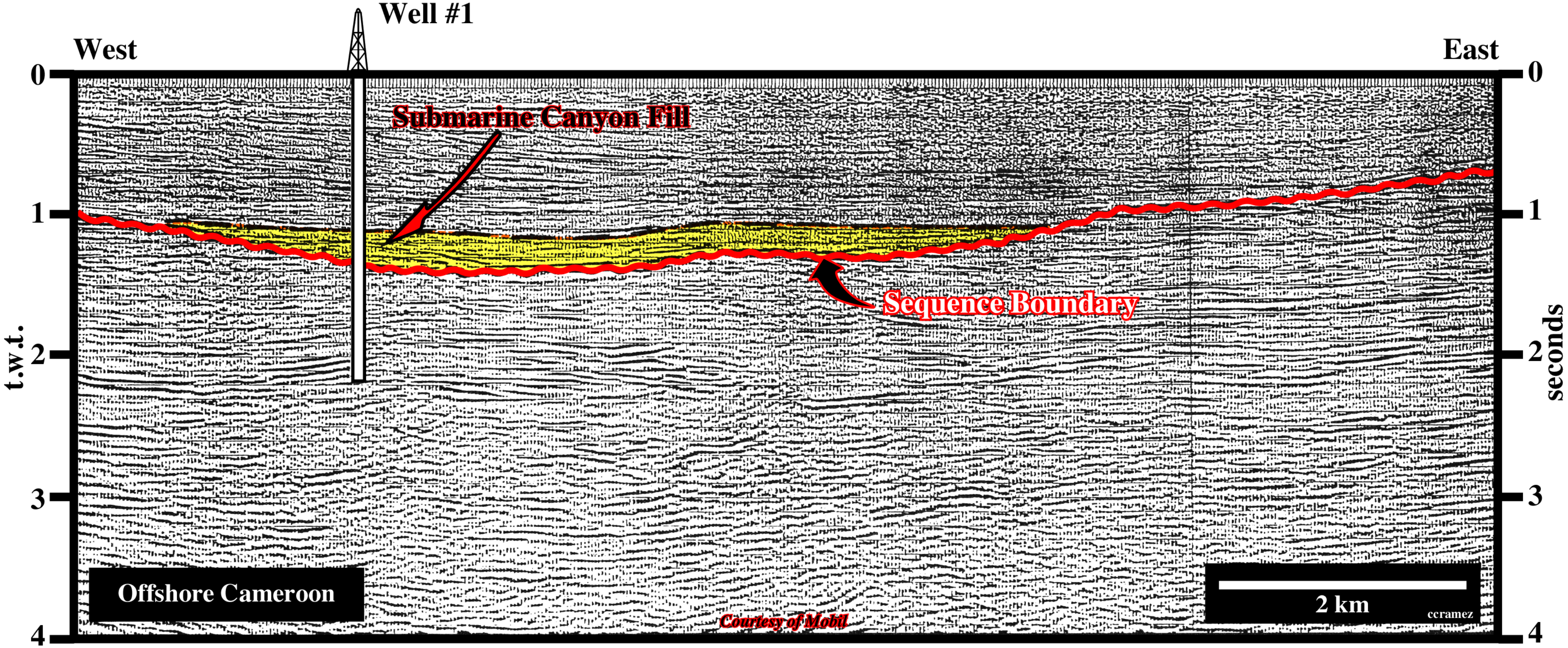


Fig. 77- On this seismic line of the conventional offshore of Cameroon, large submarine canyons are associated with the Oligocene SB. 30 Ma sequence boundary. Several exploration wells, targeting deeper potential reservoirs, in slope fans, have found small non-economical oil and gas accumulations in submarine canyon fills, as shown on this seismic line. The log patterns of such sedimentary infills are quite characteristic as illustrated on the next figure (fig. 78).

Submarine Canyon Fill

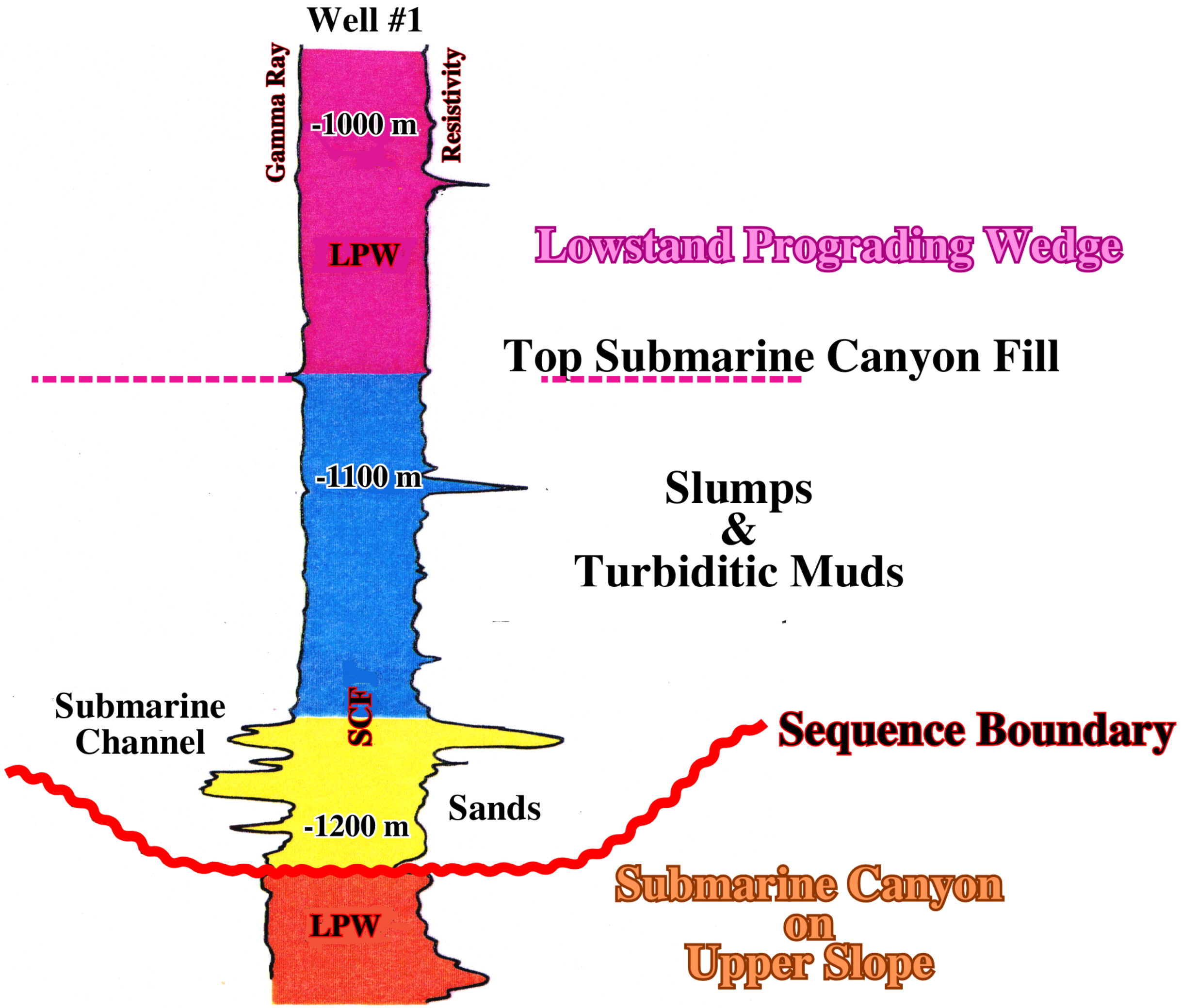


Fig. 78- The log patterns of the well #1, located in the conventional offshore of Cameroon (see fig. 77), illustrate above, indicate, at the bottom of a submarine canyon, the presence of relatively thin sandstone layers. Some of which are saturated with hydrocarbons. The upper part of the submarine canyon fill is fundamentally shaly with abundant slumps and turbiditic muds. The bottom of the submarine canyon is marked by a sequence cycle boundary, which is particularly well recognized in the dipmeter log.

Submarine Canyon Fill

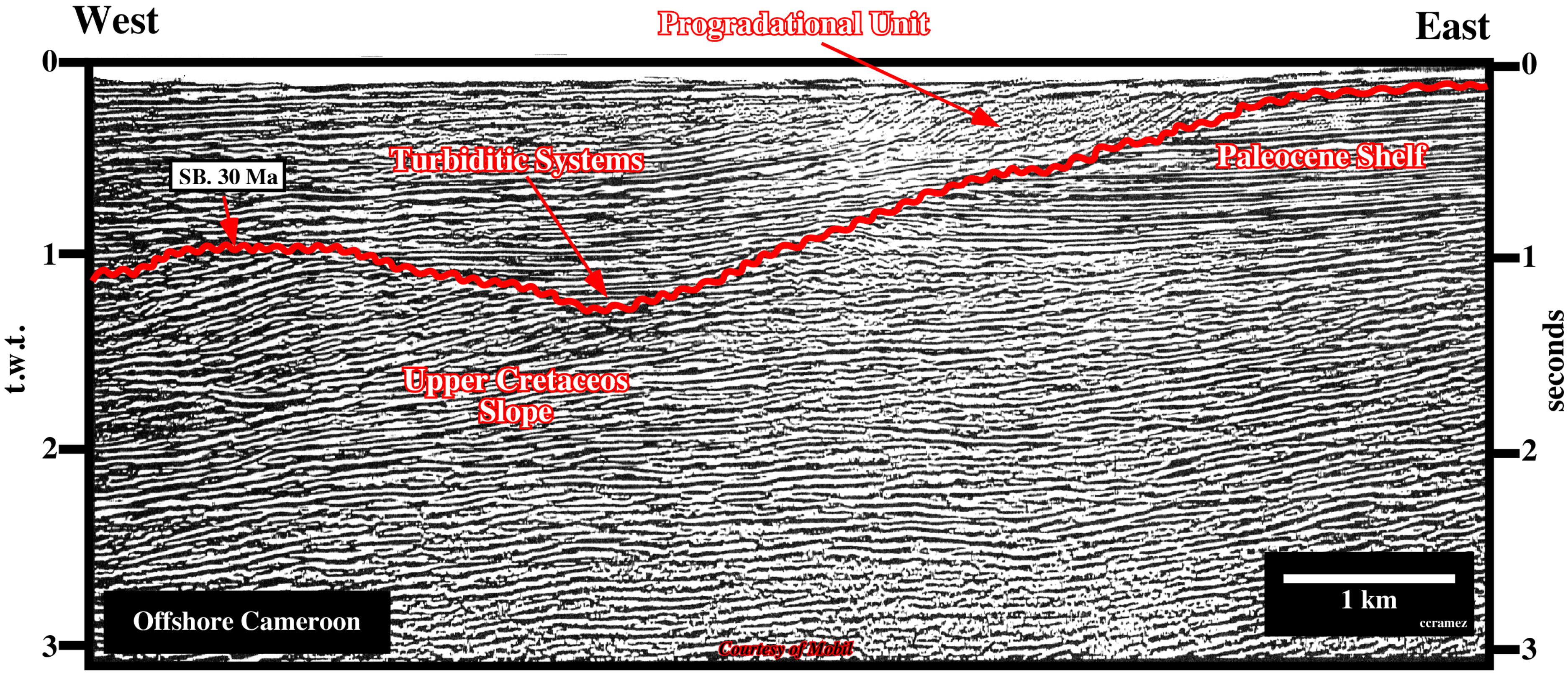


Fig. 79- On this seismic line, an Oligocene submarine canyon (see fig. 78) eroded the Paleocene platform (on the upper right part of the line) and the Upper Cretaceous slope. The parallel internal configuration of the submarine canyon fill (at least in this line) suggests the presence of turbidite depositional systems at the base of the upper progradational interval. The sequential analysis of this line, proposed in the next figure (fig. 80), corroborates a turbiditic infilling of the submarine canyon. On the contrary, during the late stage of prograding complex, relatively shallow water sediments filled river valleys, incised in the shelf.

Submarine Canyon Fill

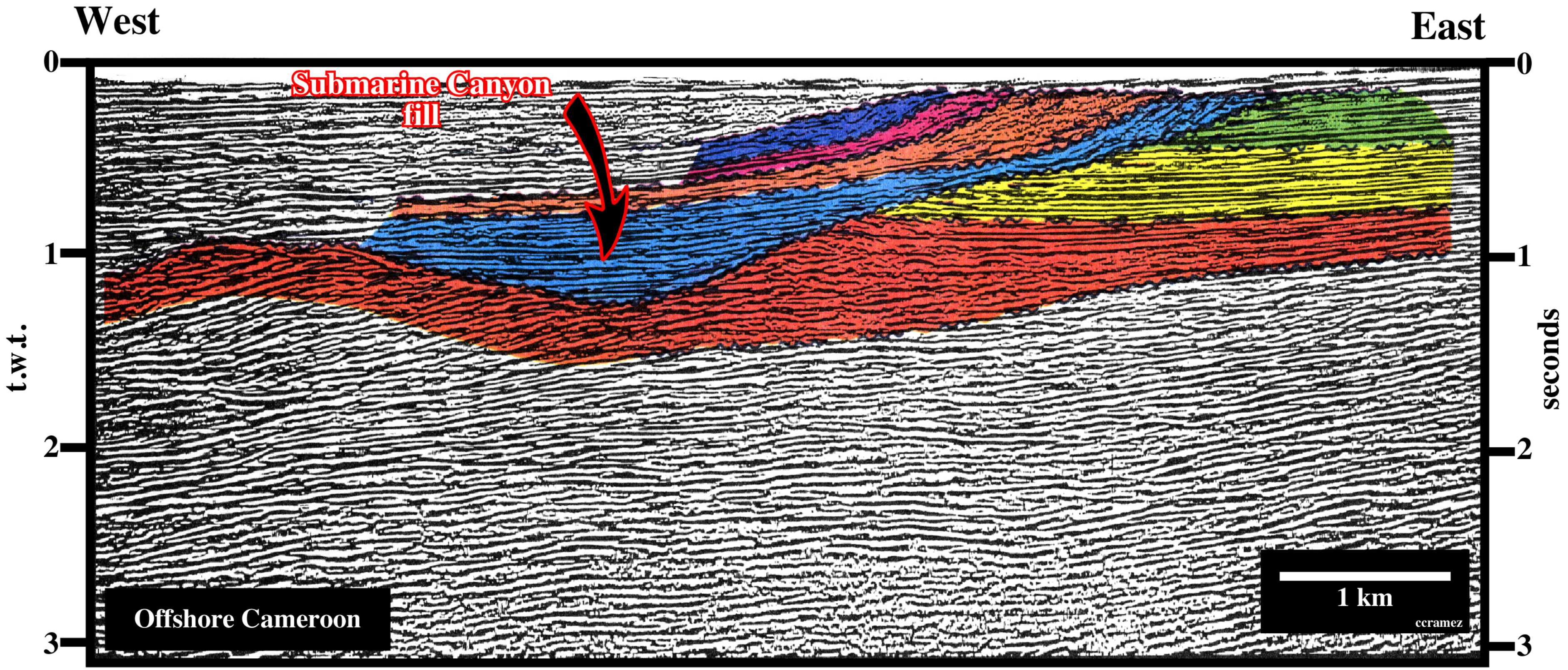


Fig. 80- This sequential analysis of the previous line strongly suggests that the submarine canyon was filled by depositional systems of a lower systems tract belonging to the light blue sequence cycle (slope or basin floor fans).

Submarine Canyon Fill

Exploration Applications

1) RESERVOIR

- Very variable;
- Submarine channel sands, turbidites;
- Poor continuity;

2) MIGRATION

- Uncertain;
- Vertical migration via faults may be best;

3) SOURCE

- Uncertain;
- Contemporaneous source is probable gas prone;

4) TRAPS

- Stratigraphic pinch-outs;

5) SEAL

- Local shale seals;

Submarine Canyon Fill

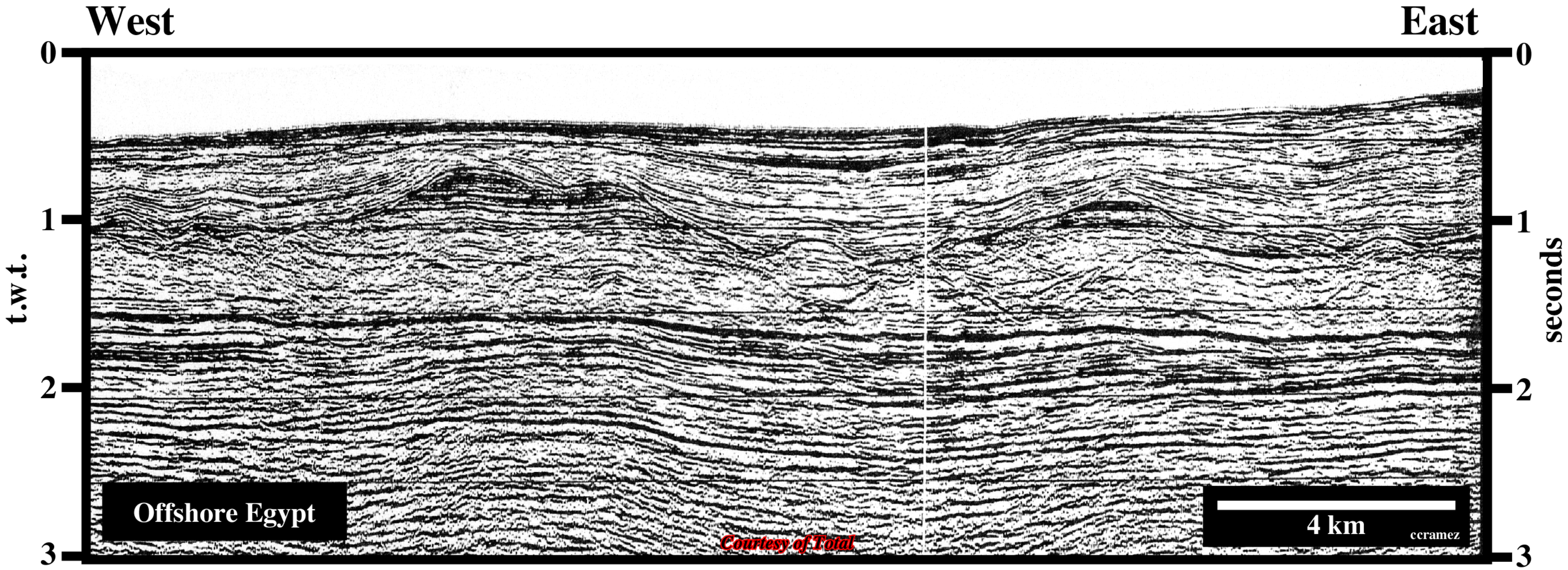


Fig. 81- This seismic line from offshore Egypt, cuts several times a submarine canyon, which deeply eroded the old slope sediments. So, the internal configuration of the submarine canyon fill, as well as the actual geometry of the reflection terminations, can only be determined with a set of lines striking more or less perpendicularly. Indeed, explorationists should never forget that the geometric relationships recognized in a seismic line could be apparent. Similarly, the geometric relationships have a geological meaning when they are in their original position, that is to say when the tectonic deformation is taken away.

Submarine Canyon Fill

Exercises

Submarine Canyon Fill

Exercise

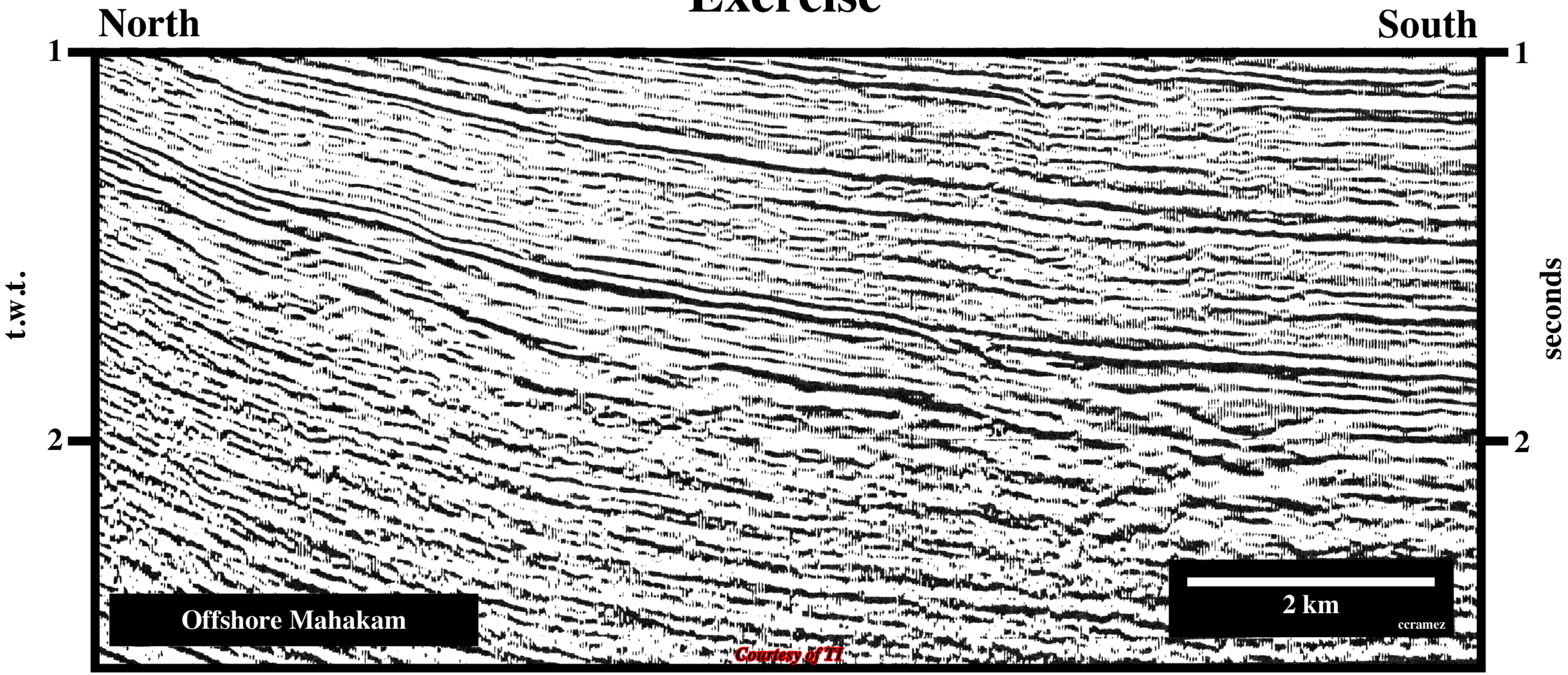


Fig. 82- On this seismic line from offshore Indonesia, there are three sequence cycle boundaries, that is to say, three unconformities, which are easily recognized by the associated submarine canyons. Knowing that the lower submarine canyon cuts at least twice the seismic line, can you pick the unconformities? Then, criticize your interpretation and the one proposed in the next figure (fig. 83).

Submarine Canyon Fill

Exercise

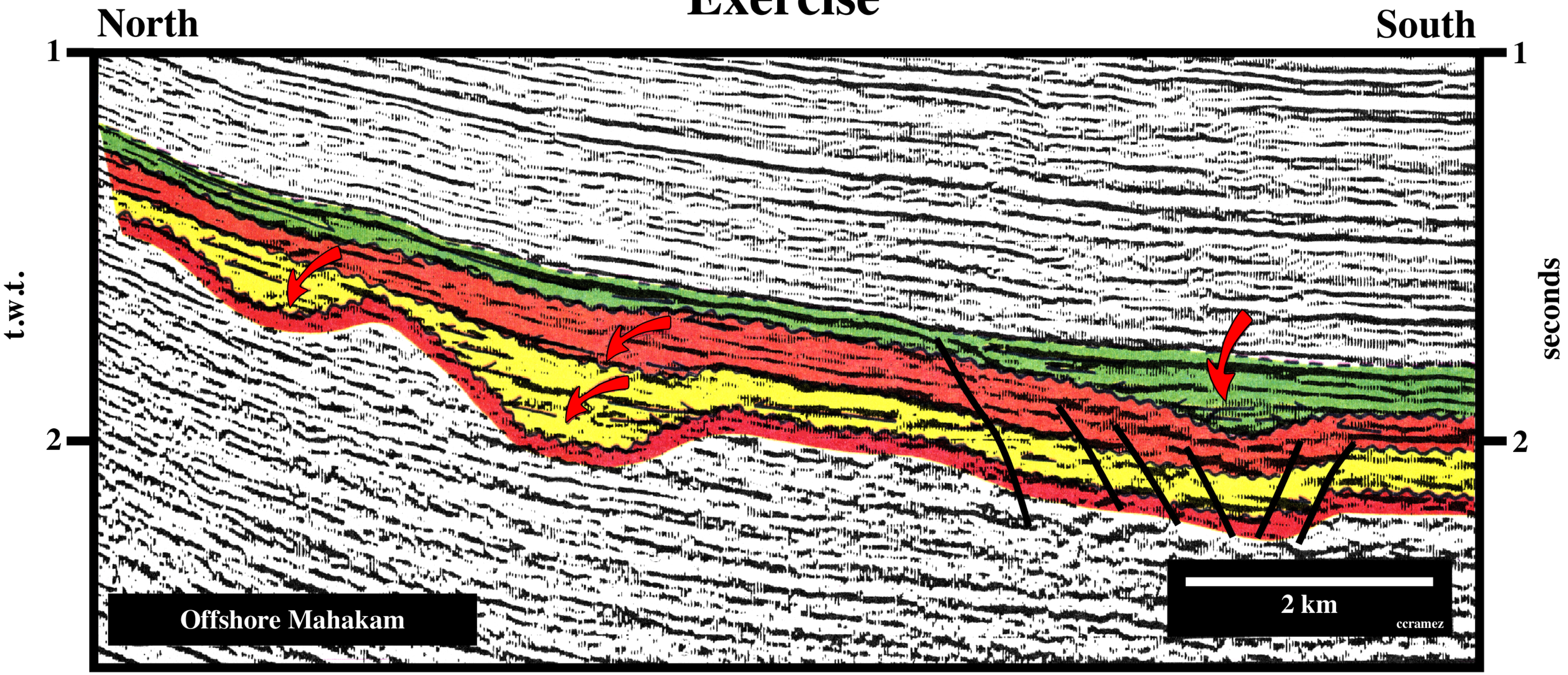


Fig. 83- On this interpretation, three submarine canyons are recognized. However, the lower submarine canyon seems to be cut twice by the seismic line. On the other hand, on the right part of the line, the lower sequence boundaries (below the upper submarine canyon), were lengthened by normal faults rather eroded. However, other explanations cannot be excluded. How did you interpret this area?

Incised Valley Fill

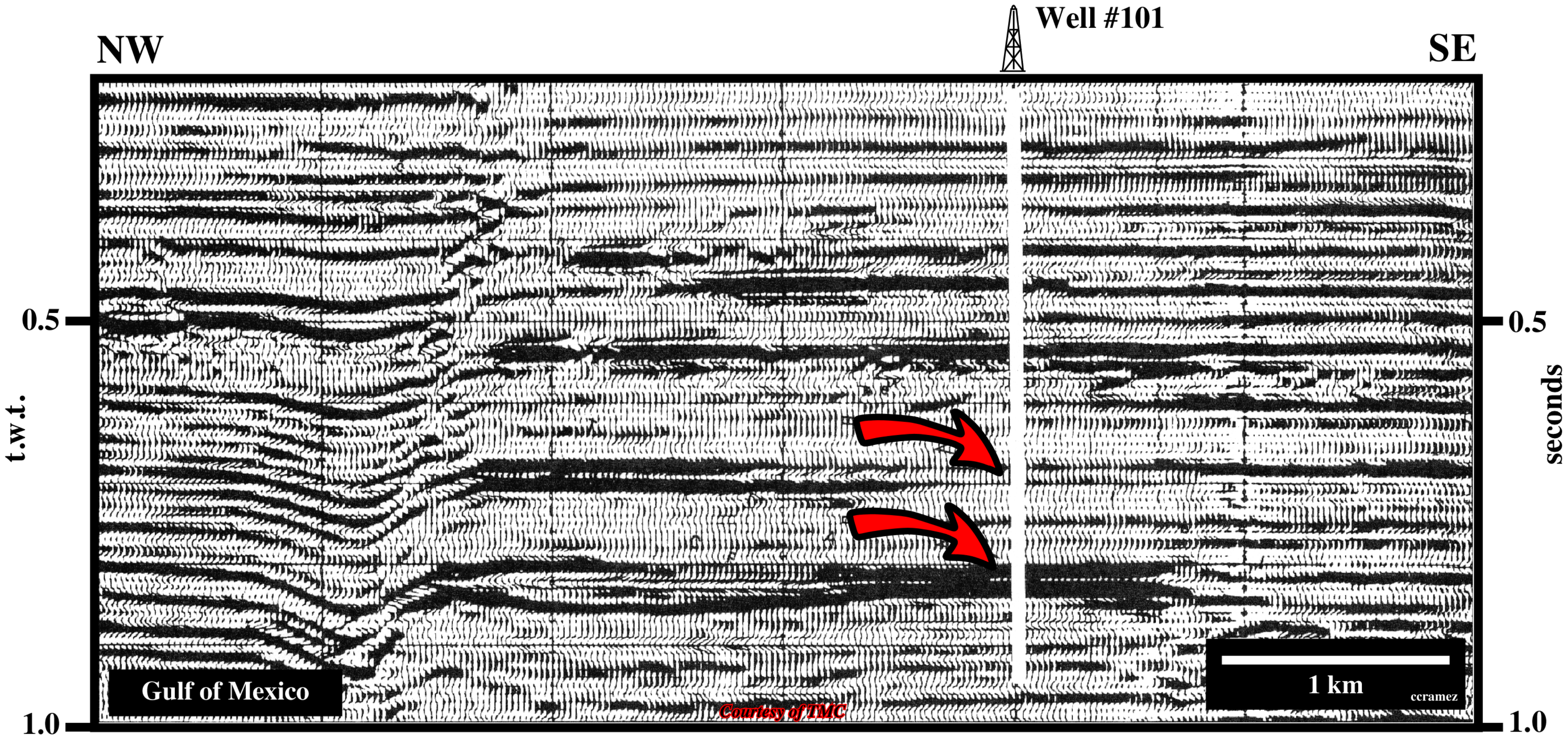


Fig. 84- When relative sea level falls are big enough to exhumed the platform, the equilibrium profile of the rivers is broken, and so, they are oblige to incised their beds to reach a new equilibrium profile creating what we call in sequential stratigraphy an incised valley. Later, when the relative sea level rises, during the deposition of the the upper section of the lowstand prograding wedges, the incised valleys are filled by lowstand sediments forming incised valley fills. On this seismic line, from the Gulf Coast, two incised valley fills were penetrated by well #101. The log patterns of such lowstand intervals are shown in next figure (fig. 85).

Incised Valley Fill

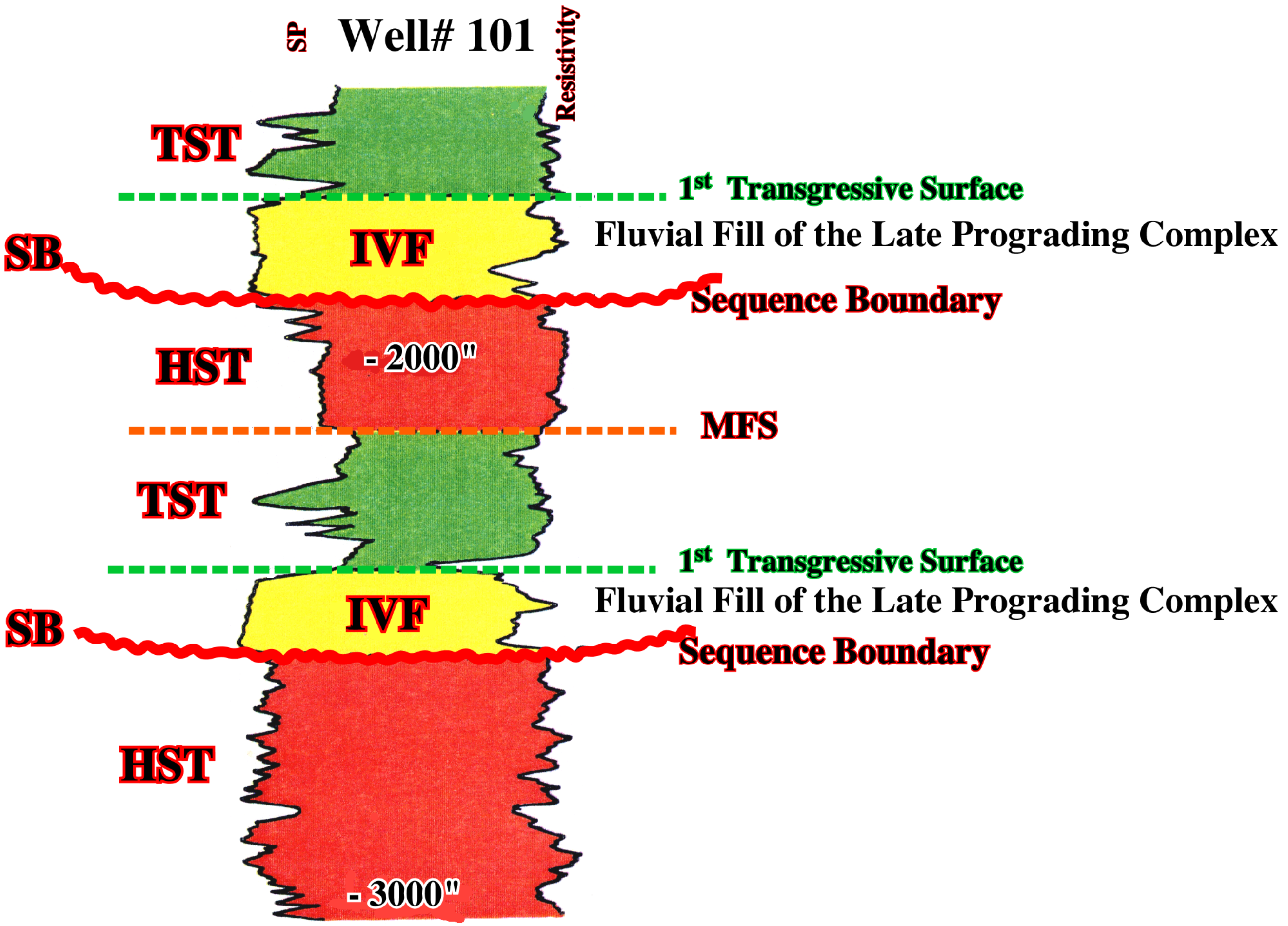


Fig. 85- Two incised valley fills can be recognized on the electric logs of well #101. The SP illustrates that both incised valley fills have sharp limits and and a sandy facies. The lower limits emphasize the upper boundary of the underlying sequence cycle, while the upper limits correspond to the first flooding surfaces of the overlying transgressive systems tracts.

Incised Valley Fill

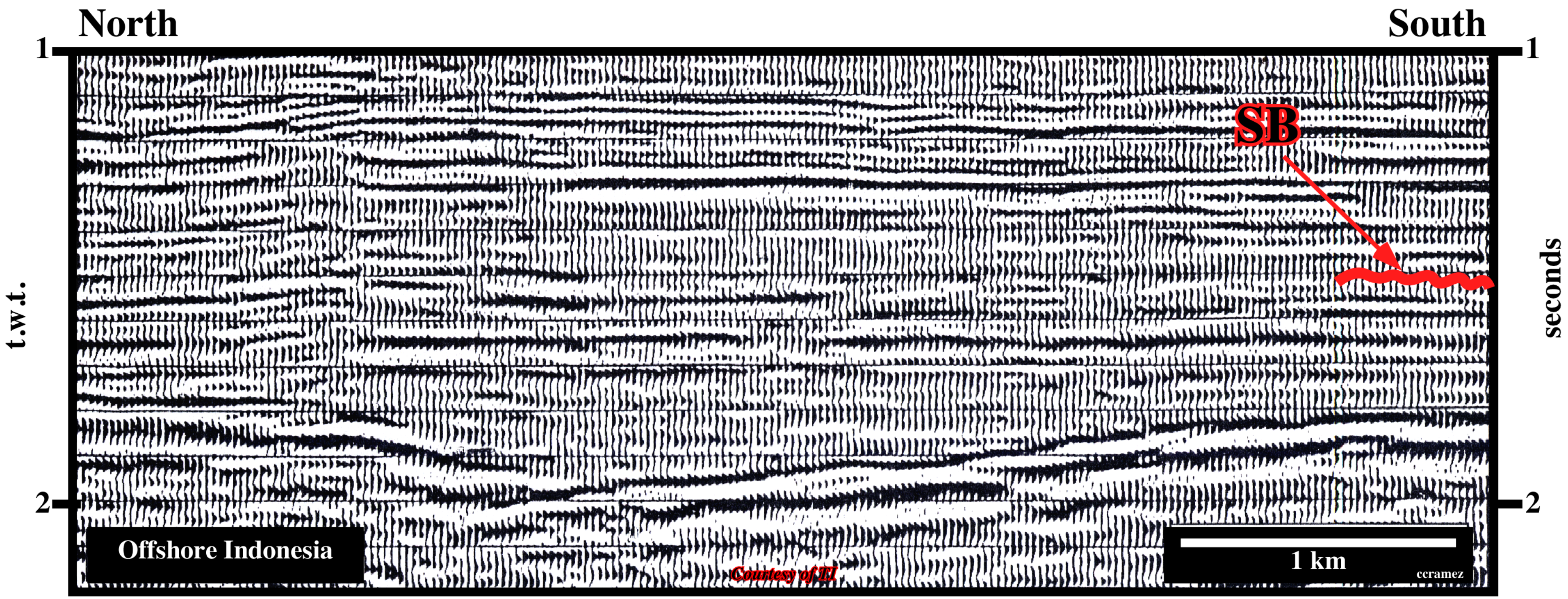


Fig. 86 - Taking into account that the depth of incised valleys, which are smaller than that of submarine canyons, the recognition of incised valleys or incised valley fills can be quite subtle. However, as they are always associated with stratigraphic cycles boundaries, an easy way to recognized them is to pick unconformities near shelf breaks, where seismic surfaces are generally obvious, and follow them landward detecting all associated erosional surfaces. Assuming that on this seismic line, the red colored horizon (SB) corresponds to a sequence boundary, following it northward you will recognize at least two incised valleys as illustrated in the next figure.

Incised Valley Fill

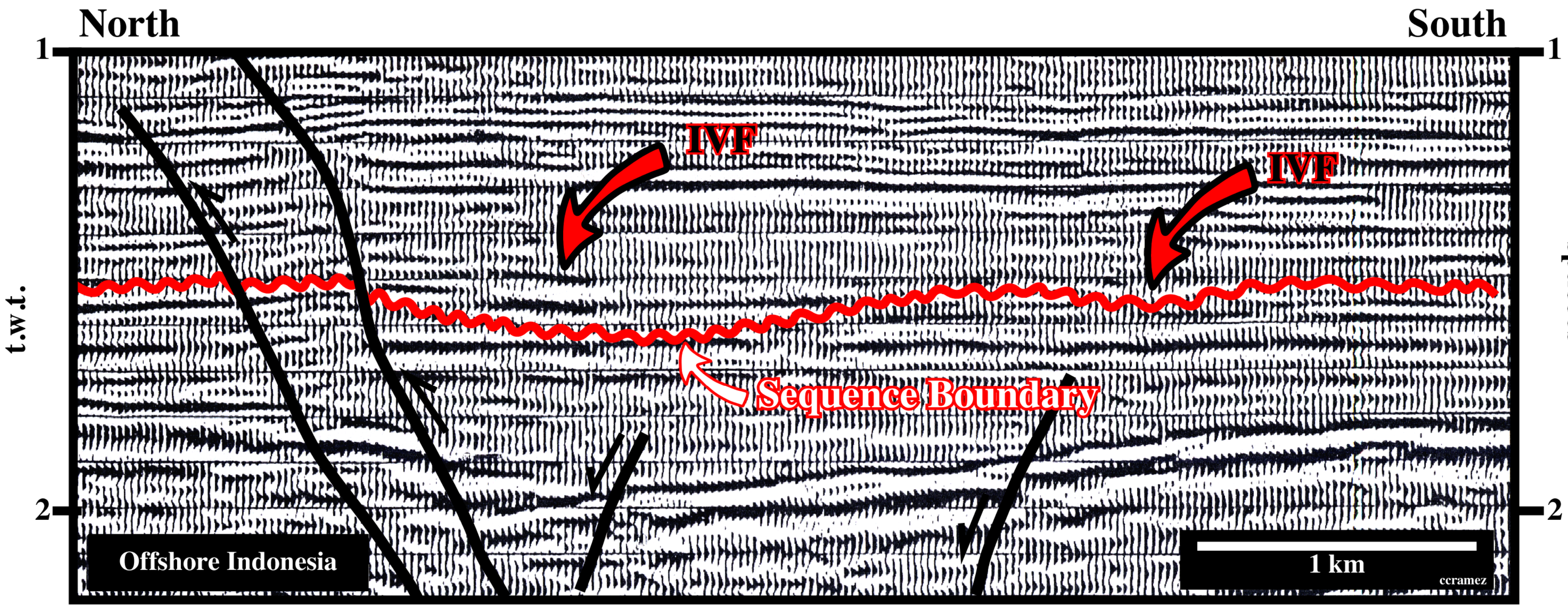


Fig. 87- Generally, in a regional seismic line, an unconformity is picked near the shelf break, where the associated onlap or a toplap seismic surfaces are morphological enhanced. The red marker corresponds to an unconformity, which was calibrated near the shelf break. Thus, all erosional anomalies (see uninterpreted line on fig. 86) associated with it can be likely interpreted as incised valley fills. Often, it is the recognition of incised valleys that allows to pick the exact location of unconformities. That is particularly true, in platform environments when unconformities are not tectonically enhanced.

Incised Valley Fill

Exploration Applications

1) RESERVOIR

- Braided stream sands typical;
- Good to fair continuity;

2) MIGRATION

- Downward from TST possible vertical via faults;

3) SOURCE

- Top source from TST possible deep sources;

4) TRAPS

- Typically requires structural closure or nose;

5) SEAL

- TST shales; Poor lateral seal;

Incised Valley Fill

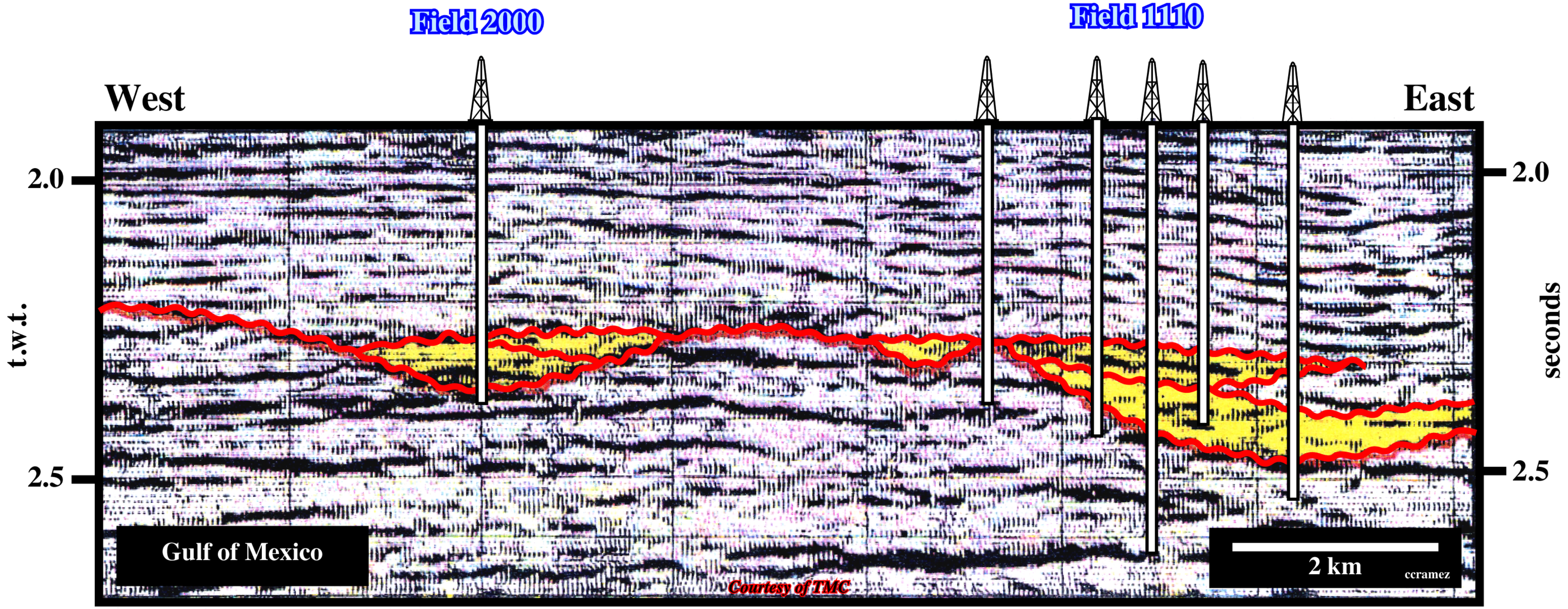


Fig. 88- In the Gulf of Mexico, often, incised valley fills are important migration / entrapment petroleum subsystems, that is to say, they contain the principal reservoir-rocks and create, at least partially, the trapping mechanism as illustrated next.

Incised Valley Fill

Field 1110

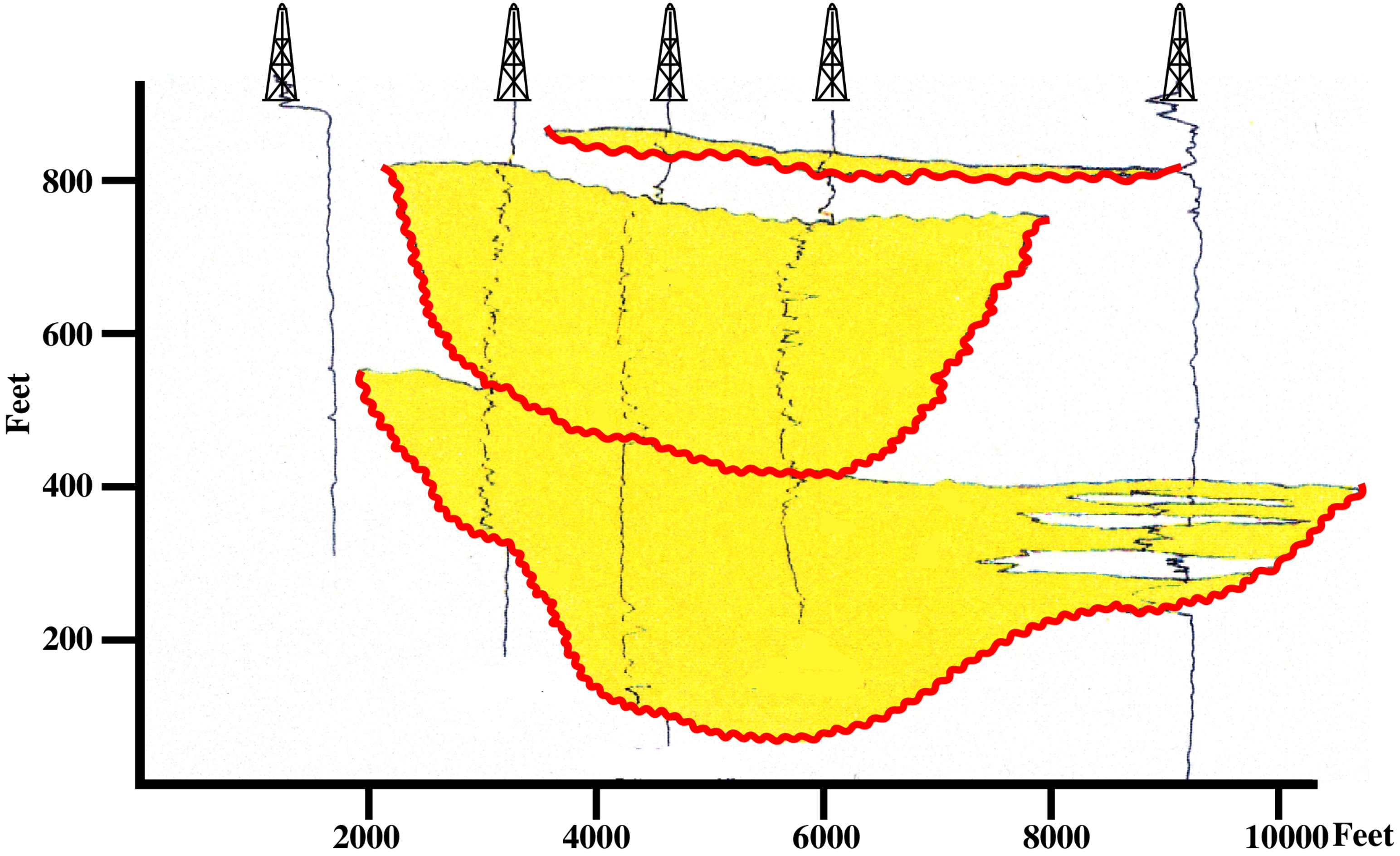


Fig. 89- The field 1110 shown on the seismic line (fig. 88), is here illustrated by the Gamma Ray log of five wells. In spite of the fact that incised valley fills are, locally, stacked, the proposed structural correlation corroborates a stratigraphic trapping. Note that a corroboration of a hypothesis means just that the data did not refuted it. In other words, new geological or seismic data can refute the hypothesis of a stratigraphic trapping.

Incised Valley Fill

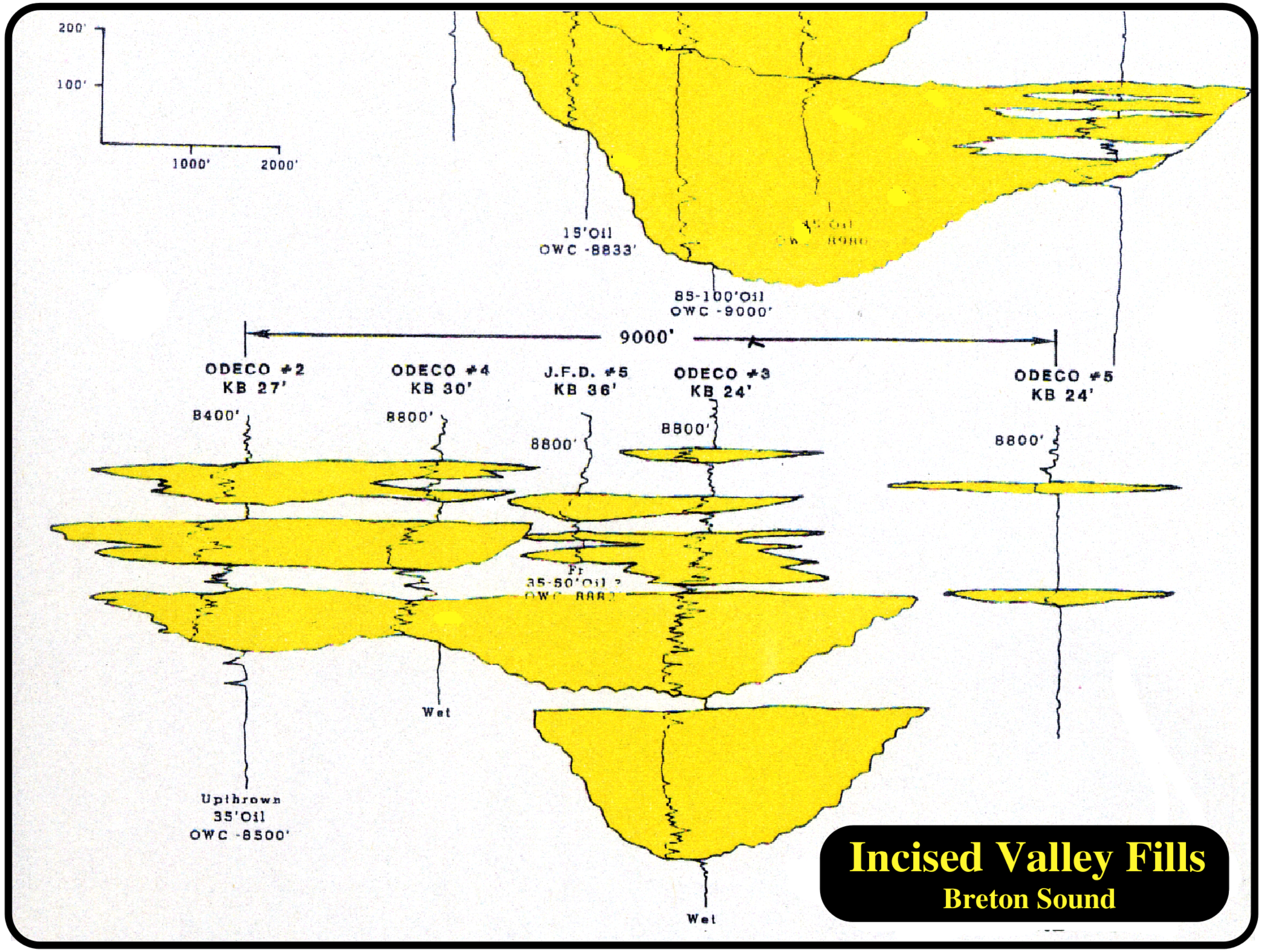


Fig. 90- On these structural correlations, the incised valley fills can be connected vertically, but also laterally. So, when the lateral sealing is assured, as the overlying transgressive shales are excellent sealing-rocks, significant stratigraphic traps are likely. Note, that the majority of these non-structural traps were discovered due to the associated seismic amplitude anomalies. When there are no amplitude anomalies associated with the accumulations (below the inversion surface), detailed sequential stratigraphic analyses are required to localize potential traps. Unfortunately, the majority of explorationists working in the GOM are enabling to perform them.

Exercises

Incised Valley Fill

Exercise

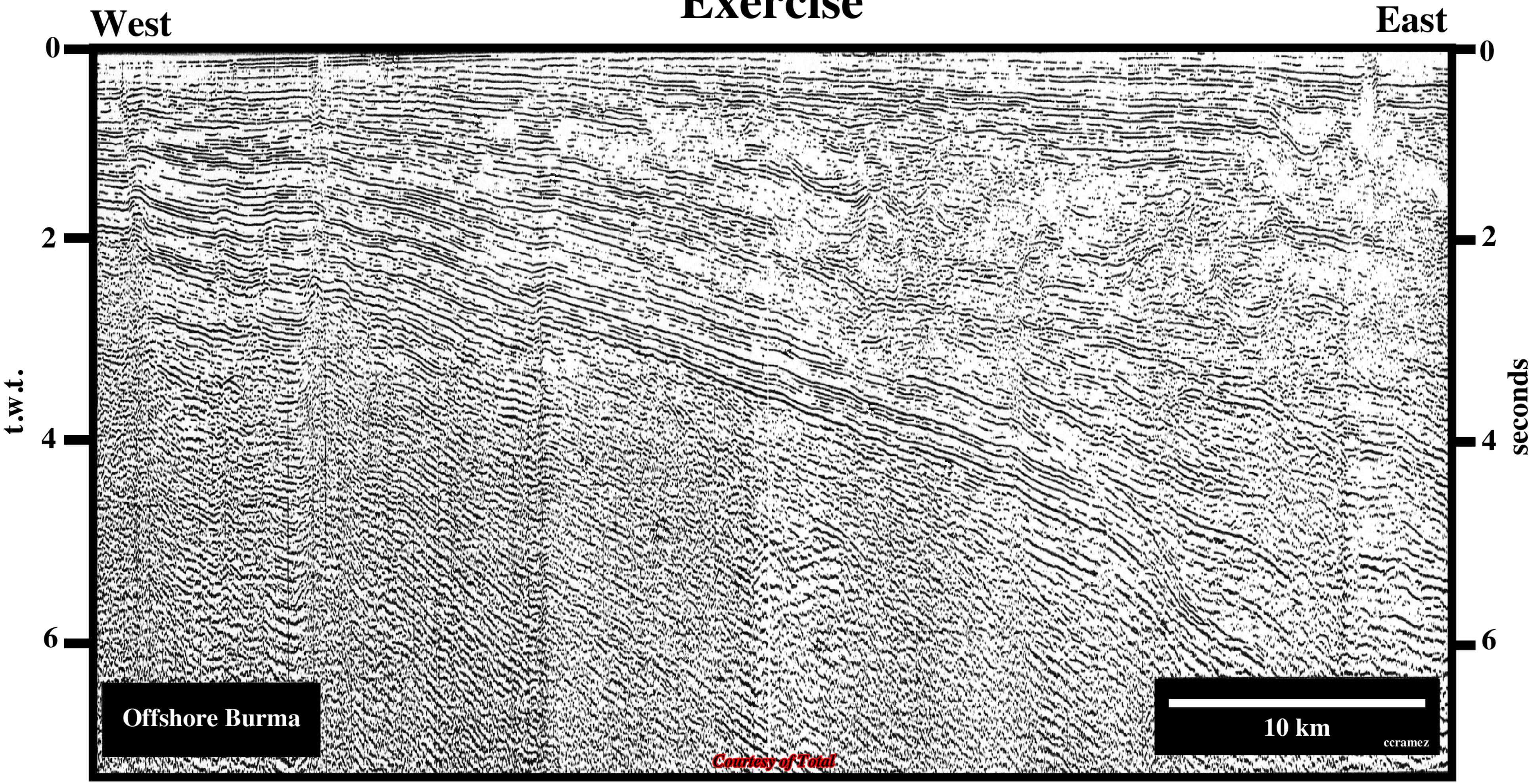


Fig. 91- The sequential analysis of this regional seismic line from offshore Myanmar indicates several unconformities emphasized by incised valleys and submarine canyons. Using the enlarged right part of this line, illustrated on fig. 92, pick the more evident unconformities.

Incised Valley Fill

Exercise

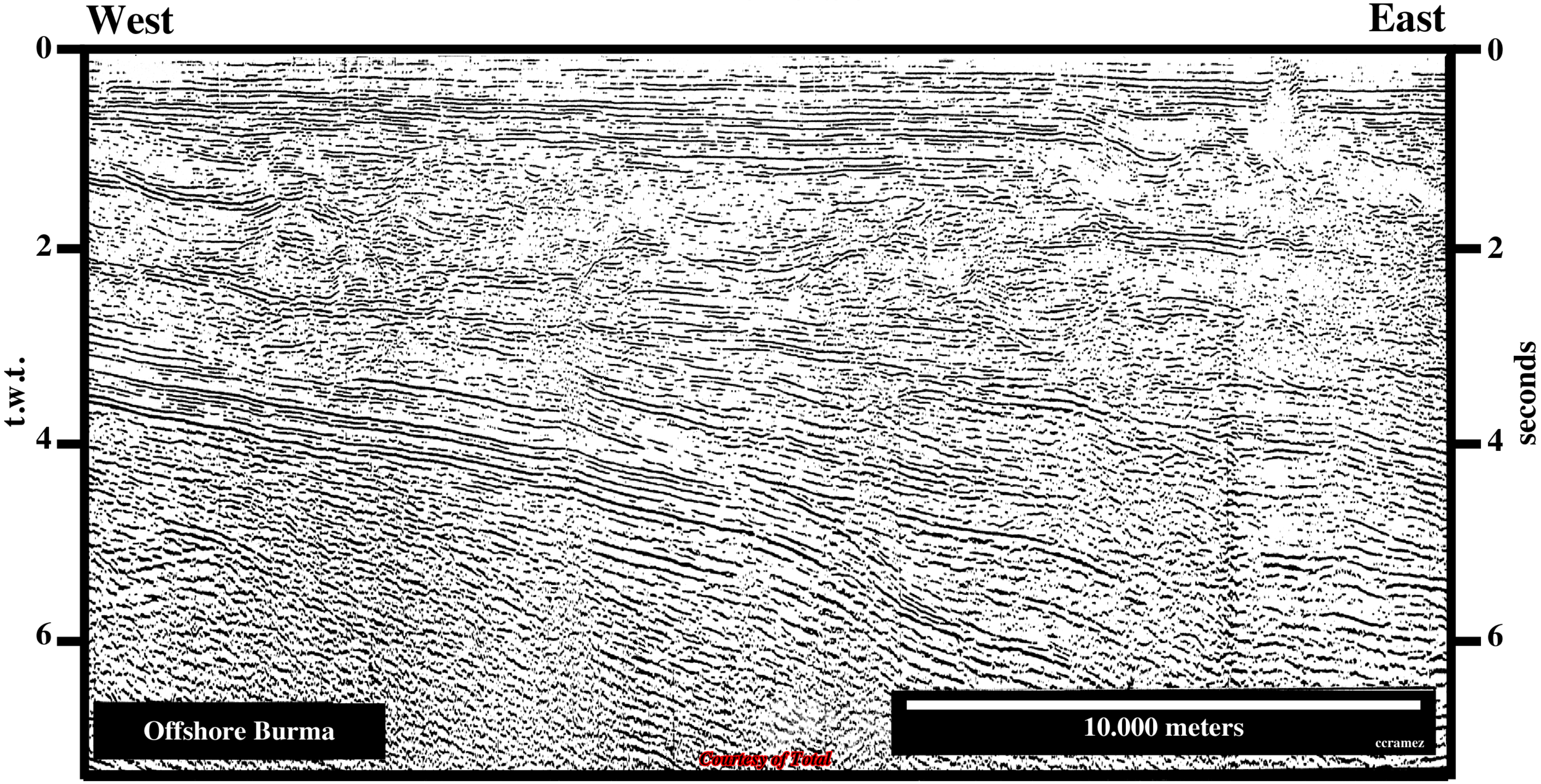


Fig. 92- Use this enlargement of the previous seismic line (fig. 91), to pick the more evident unconformities, either using onlap seismic surfaces or incised valley and submarine canyon fills, which are easily recognized in the upper part of the line. As you already noticed, you will be obliged to hypothesize the trace of the unconformity surfaces in the areas where the seismic quality is bad. Don‘t forget that the best seismic interpreter is the one that with less data can better encorporate the Geology of the area where the seismic line was shot.

Incised Valley Fill

Exercise

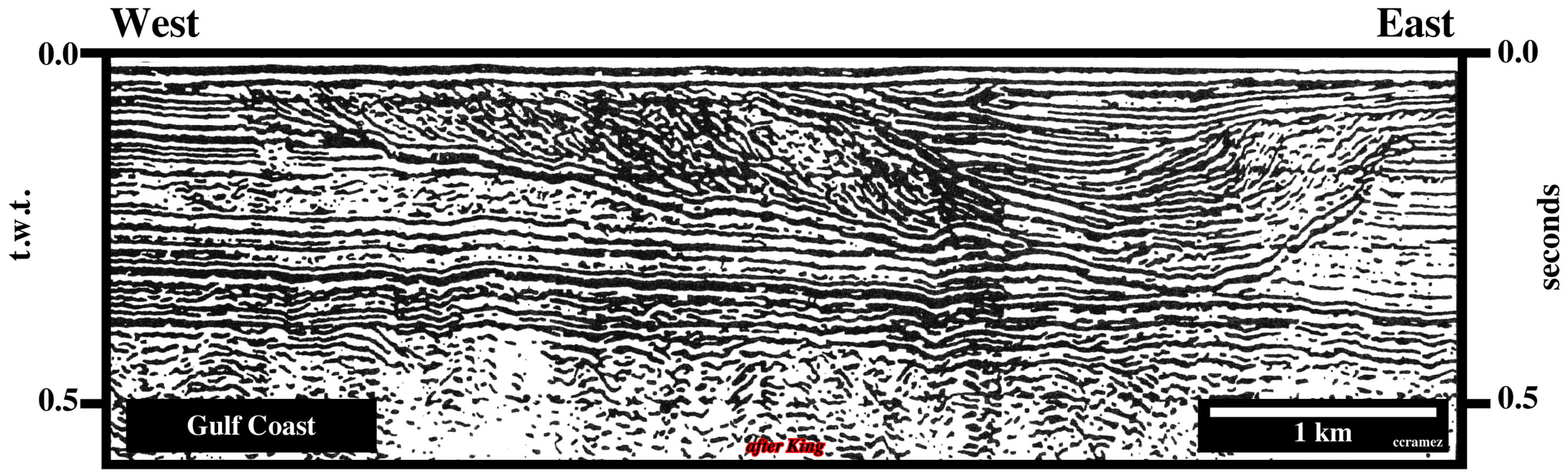


Fig. 93- Using this seismic line, you surely recognized a point bar partially filling an incised valley, pick all reflection terminations and seismic surfaces. Then explain why the onlap surfaces recognized within the infilling sediments are not generally considered as unconformities (take into account the time of deposition and the time of erosion).

Incised Valley Fill

Exercise

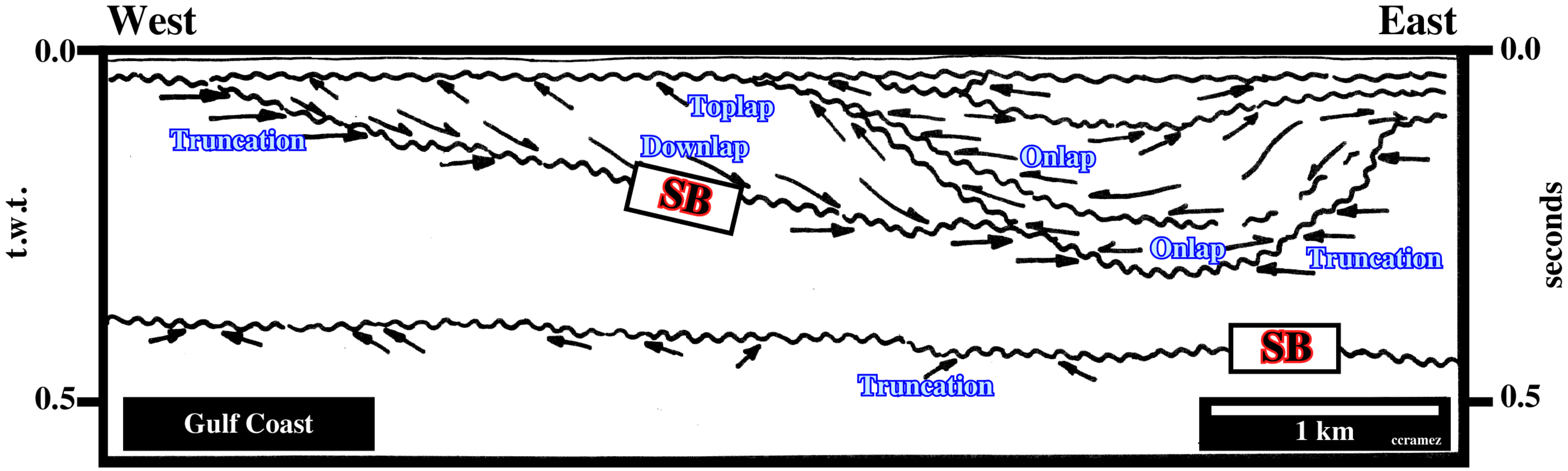


Fig. 94- The majority of the reflection terminations of the seismic line illustrated on fig. 93 are depicted above. Note that it is the truncated seismic surfaces the represent the most missing time, and thus serve as cycle boundaries. The other seismic surfaces, particularly the onlap surfaces, cannot be considered as unconformities because the time of erosion is too small, in geological terms, and in addition deposition is coeval with erosion.

Incised Valley Fill

Exercise

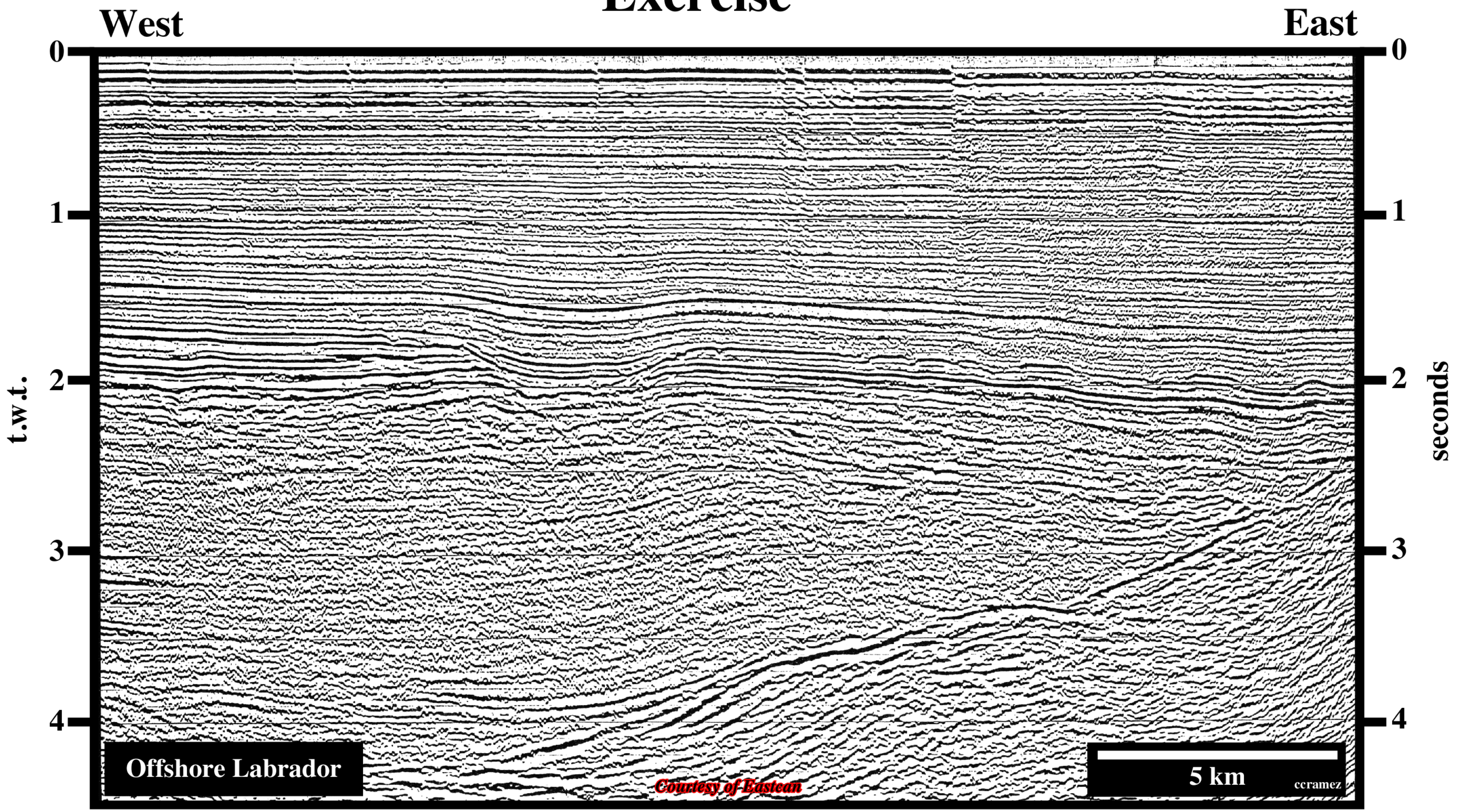


Fig. 95- A major relative sea level fall seems to end a transgressive interval at around 2 seconds depth. Pick, in detail, the chrono-stratigraphic surface emphasizing such a sea level fall. Then, pick the other evident unconformities, that is to say, those underlined by onlap and truncation surfaces.

Incised Valley Fill

Exercise

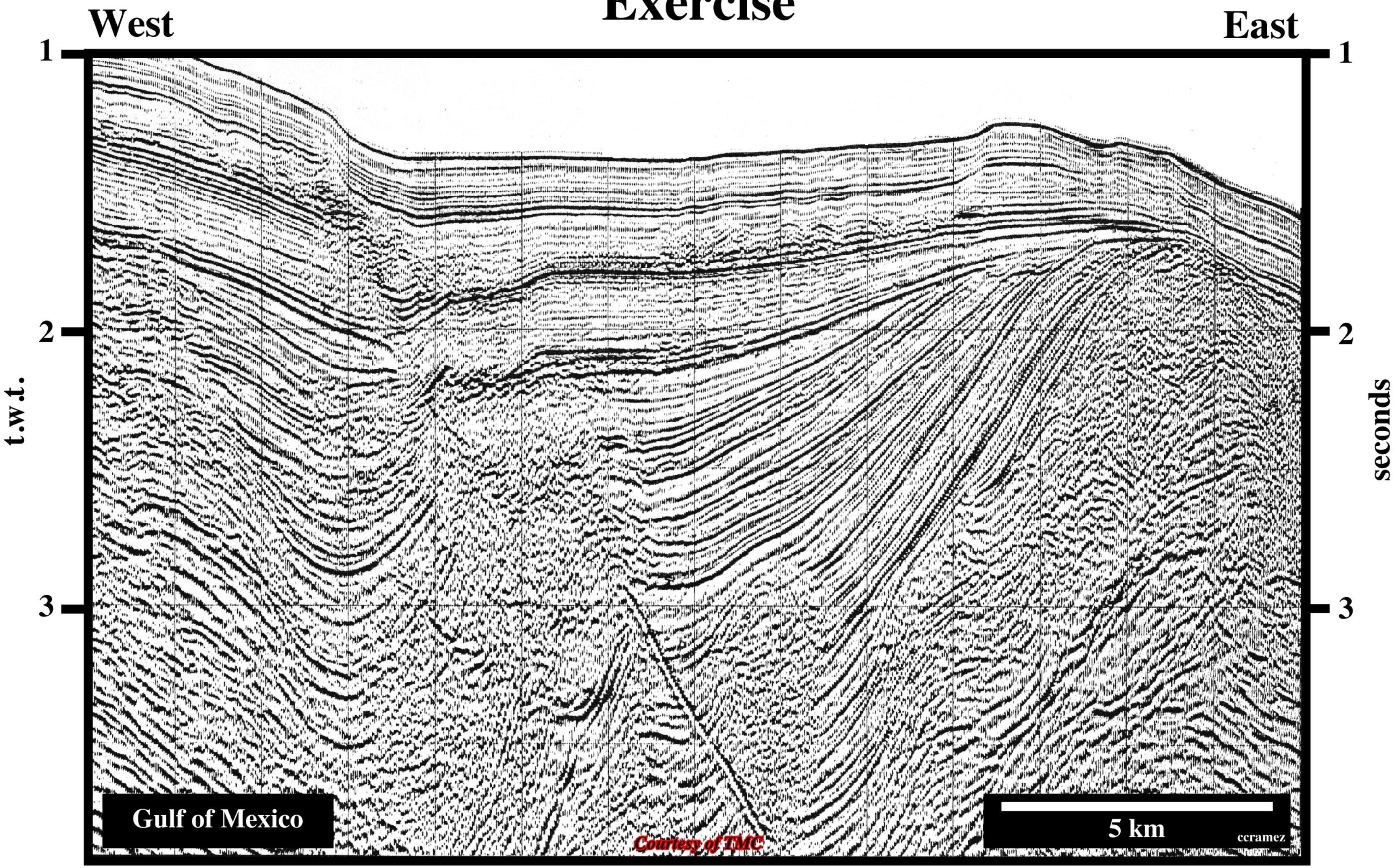


Fig. 96 - On this seismic line from the deepwater of Gulf of Mexico, pick the salt tectonically enhanced unconformities and the associated incised valleys or submarine canyons.

Incised Valley Fill

Exercise

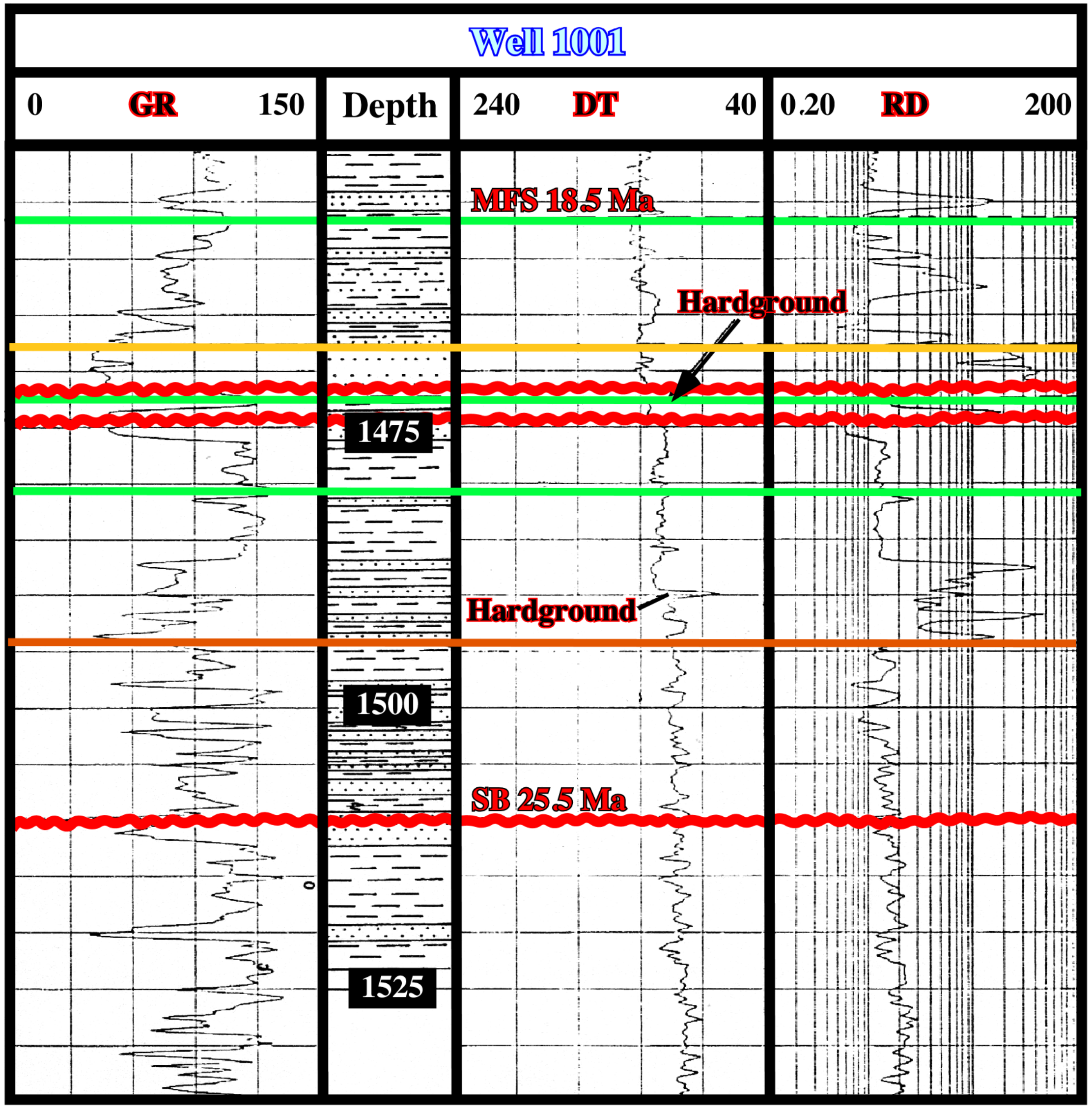


Fig. 97- Interpret these electrical logs in terms of sequential stratigraphy taking into account the proposed unconformities. Then propose an interpretation of the next seismic line.

Incised Valley Fill

Exercise

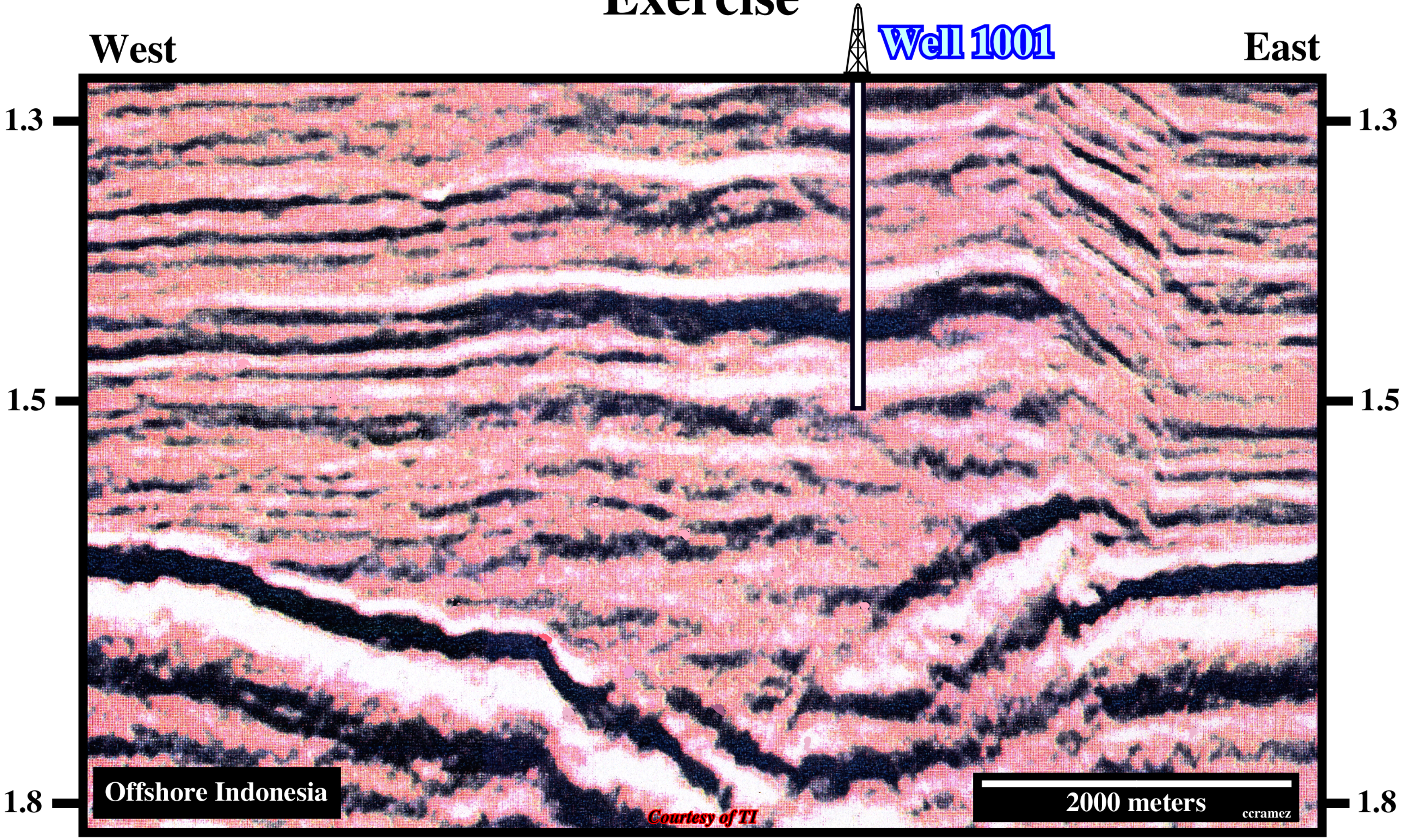


Fig. 98- Interpret this seismic line in terms of sequential stratigraphy, however do not forget that you must find several unconformities, and particularly an unconformity underlined by incised valley fills. In fact, on the electrical logs illustrated in fig. 97, at least, an incised valley is likely. Criticize your interpretation with the one proposed next (fig. 99).

Incised Valley Fill

Exercise

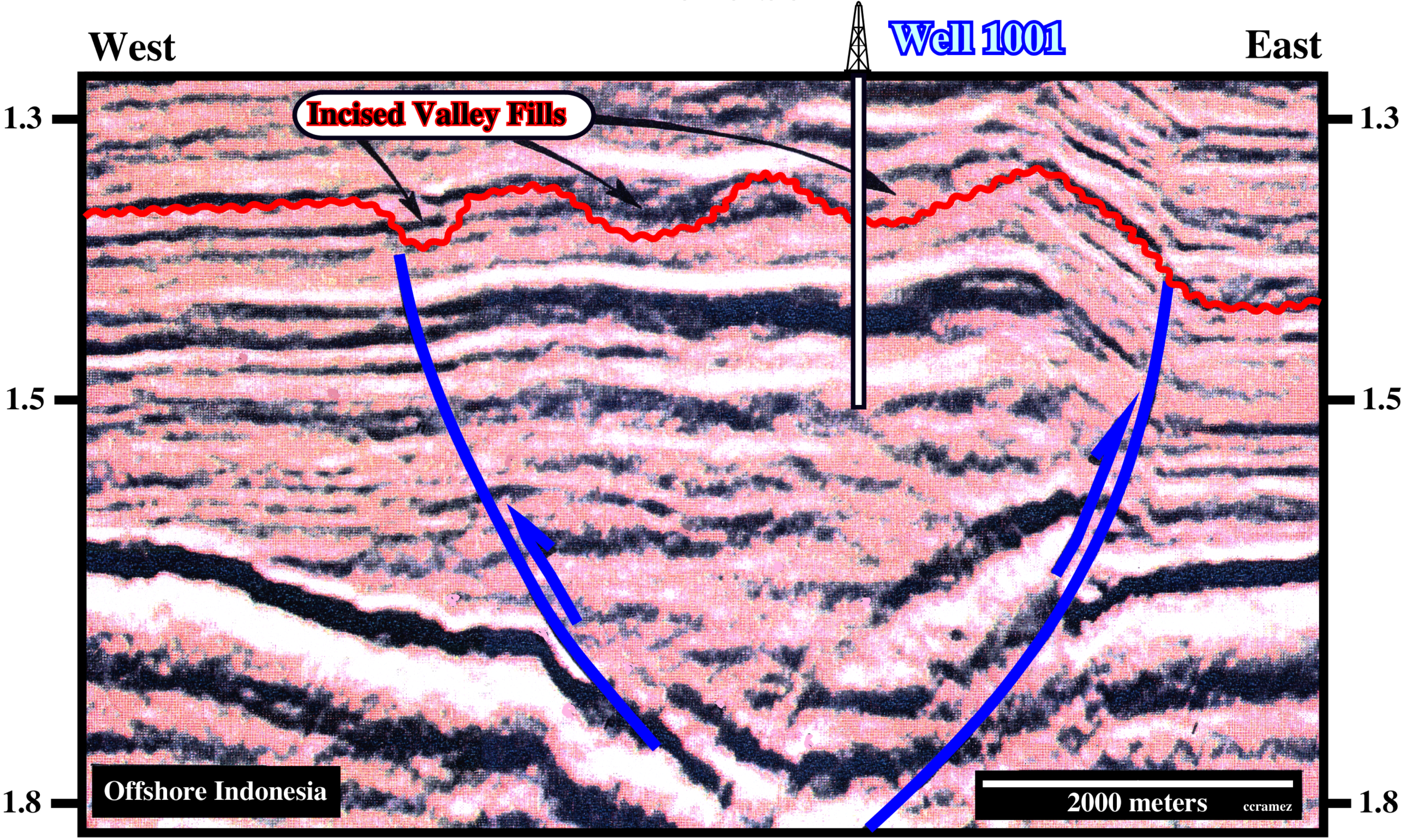


Fig. 99- On the interpretation of this line, the most likely unconformity with associated incised valleys seems to be the one indicated above. The fault movements indicated above are the most recent. In a first phase, these faults played as normal, during the rifting phase of the back-arc basin, but later, during the compressional tectonic regimes, they replay as reverse faults.

Incised Valley Fill

Exercise

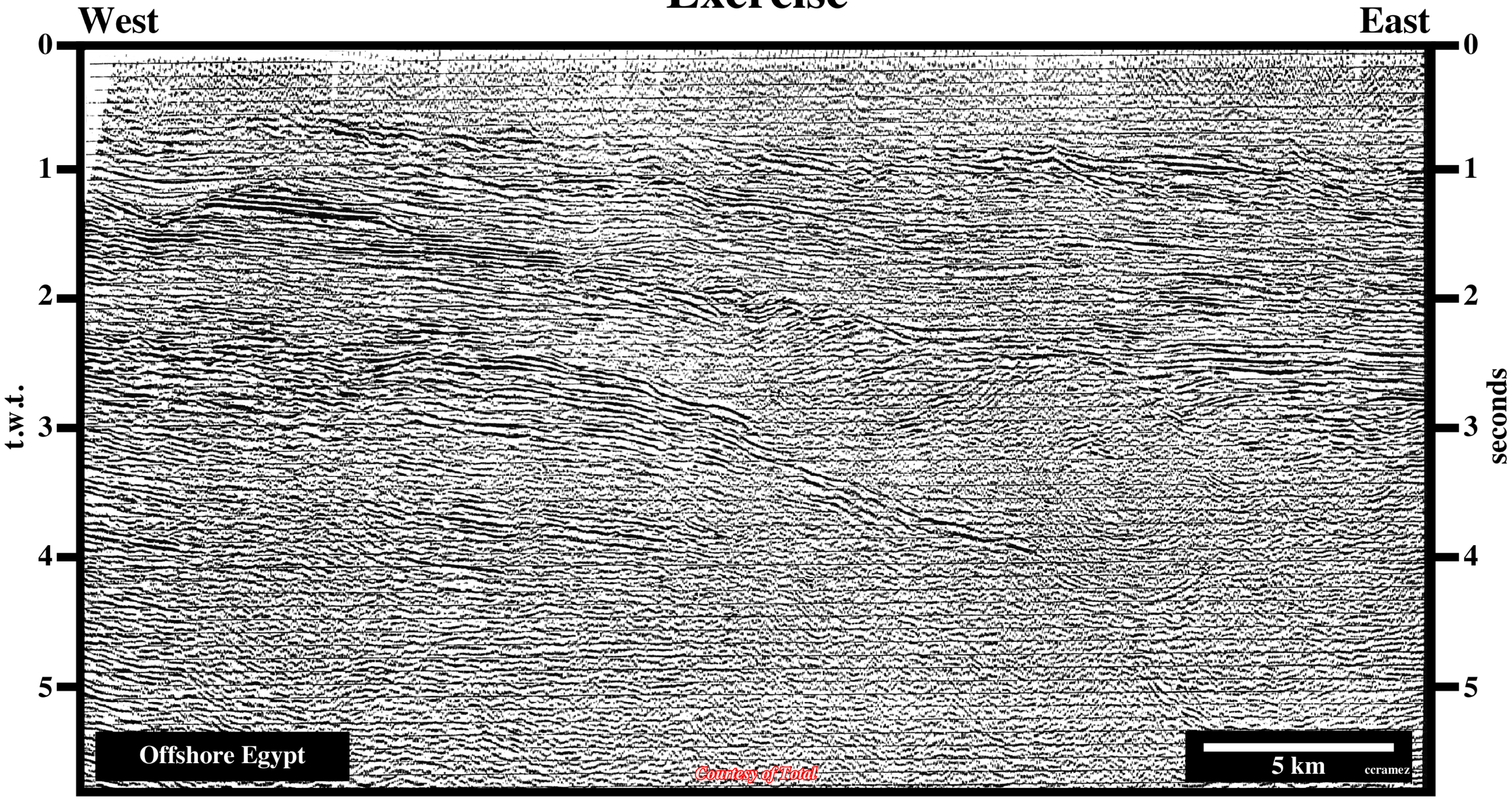


Fig. 100- On these line, pick the principal unconformities. For that use the reflections terminations, that is to say the seismic surfaces and the incised valley or submarine canyon fills as reference.

Transgressive Systems Tract (TST)

Transgressive Systems Tract

Transgressive sands have long been a favorite target in HC exploration

1) Sands are reworked and well sorted by coastal processes. Reservoir quality sands vary from good to poor, depending upon grain size and cementation and tends to be parallel to the ancient coastline.

2) The continuity of transgressive sands is typically good along depositional strike, but may vary in the depositional dip direction.

3) The backstepping nature of transgressive deposits tends to produce interbedded sands and shales in a terrigeneous clastic environment and packstones and mudstones in a carbonate environment. Multiple pay reservoirs may result and reservoir units are interbedded with potential hydrocarbon source units.

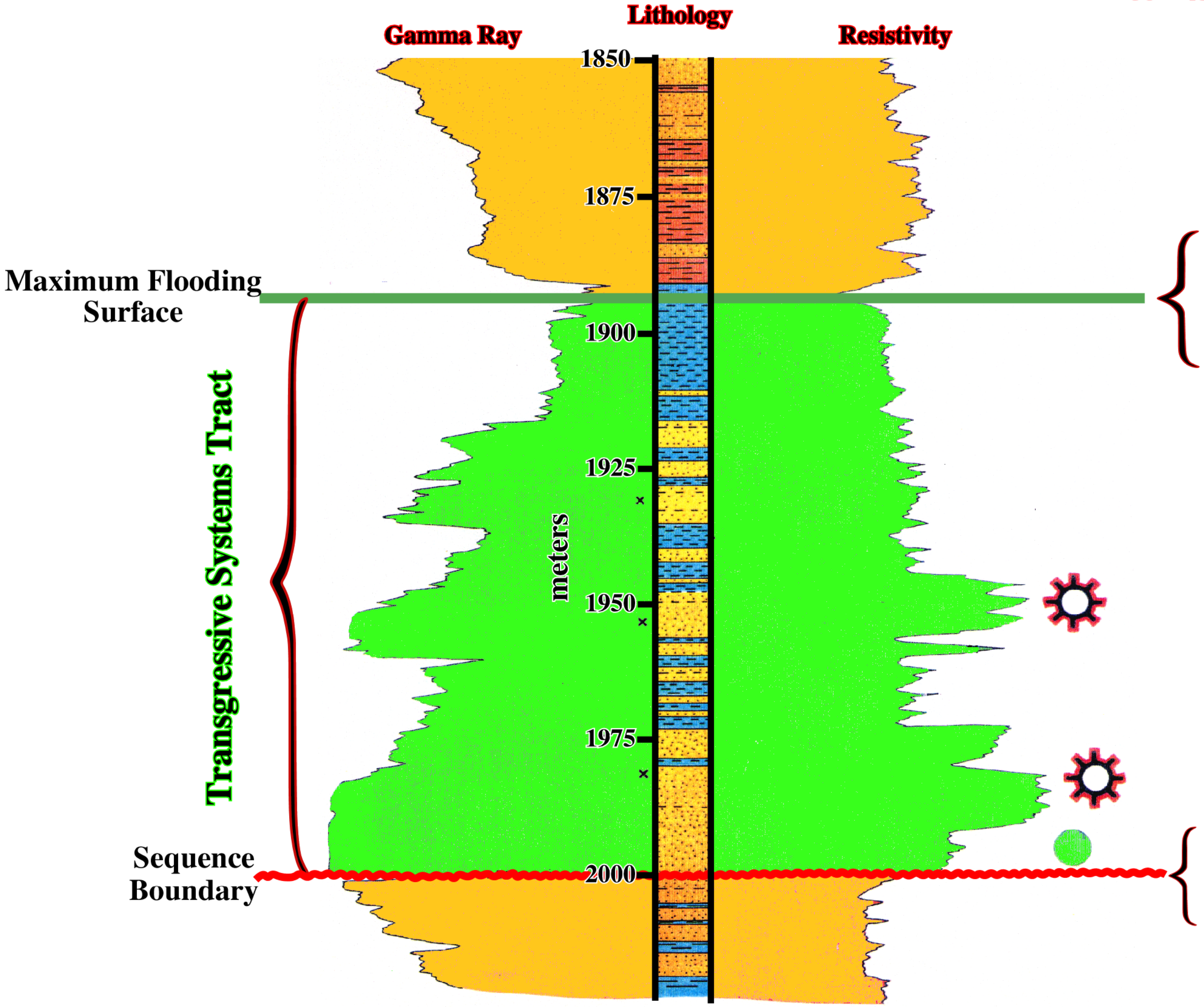
4) Because of their degree of interbedding and their onlapping nature updip pinchouts may also produce stratigraphic entrapment of transgressive reservoir sands.

5) Transgressive systems tract sediments tend to be overlain by a continuous shale seal that may also be a hydrocarbon source, that is to say, the condensed section.

6) If high sediment discharge rates coincide with moderate rates of marine onlap, then braided stream deposits may cover all or portions of the exposed shelf during lowstand and early transgressive systems tracts time. This can provide an excellent sheet reservoir sand

7) If marine onlap extends high on the shelf and thereby encroaches the area of where alluvial fan deposits formed during late highstand time, the alluvial gravels may be reworked by coastal processes. The resulting coarse clastic sands are of reservoir quality because they are winnowed clean of their fine fraction by wave and current action.

Transgressive Systems Tract



- Lowest Resistivity; Highest Gamma Ray
- Most Clay Rich Shale
- Planktonic Abundance Peak
- Apparent Truncation Below Boundary

- Fines and Thins upaward
- Neritic Shales Near Top
- Beach and Shoreface Sands near Base
- Basinal Equivalent is Pelagic Shale
- Correlation is Good, but Backstepping
- Parasequences are Time-Transgressive
- Sands Often Better Sorted than HST

- Lowstand Incisions
- Onlap on Boundary

Fig. 101- The main characteristics and the log patterns of a transgressive systems tract are summarized above. Notice that the lower limit of a transgressive systems tract is generally a flooding surface (1st transgressive surface), but, in certain geological conditions, it can be a sequence cycle boundary. The upper limit is generally a maximum flooding surface, but a sequence cycle boundary cannot be excluded, particularly when a relative sea level fall takes place following an expected tectonic event.

Transgressive Systems Tract

Geological Model

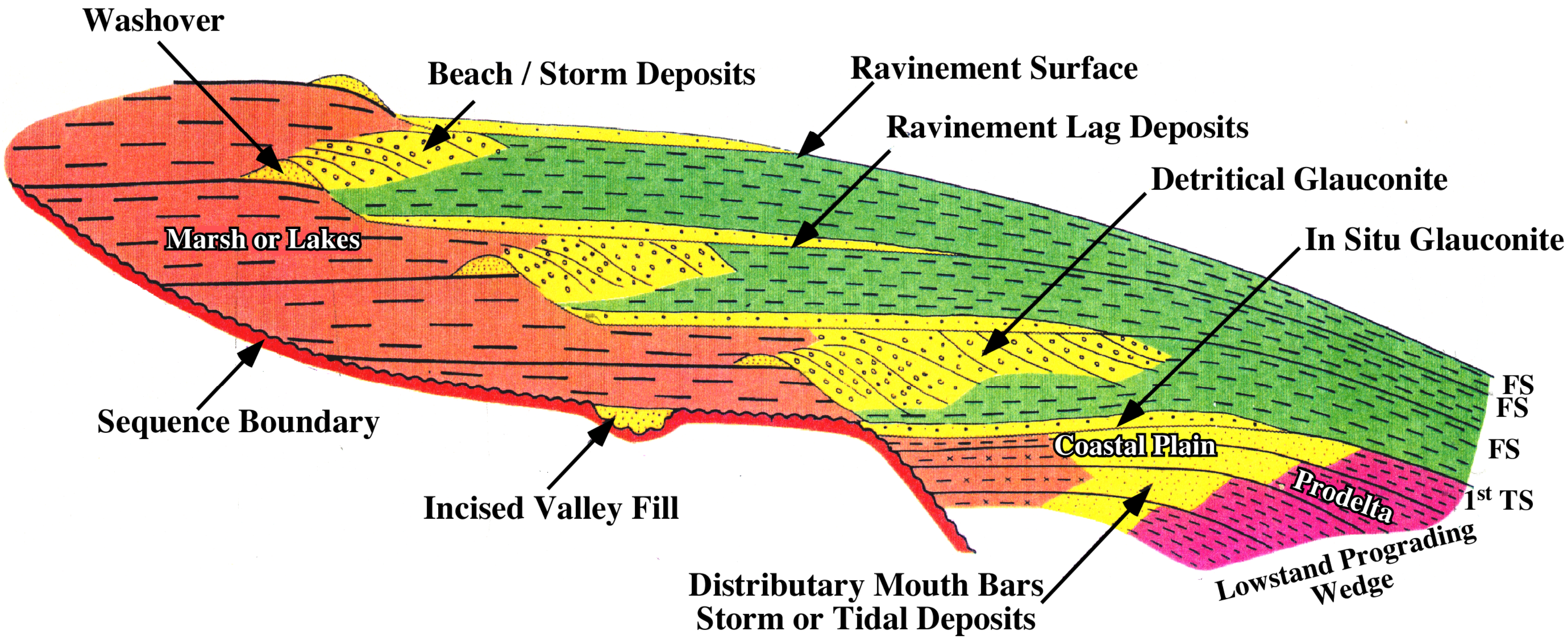


Fig. 102- On this geological model of a transgressive systems tract, it is quite important to notice that the backstepping (retrogradational) geometry is in fact a stacking of regressive episodes that progressively prograde less and less. In other words, at each sea level rise increment (flooding), the depositional coastal break (roughly the shoreline) is displaced far away landward, creating at the top of the deposited sediments a ravinement surface. Then, as sediments are deposited, the depositional coastal break is progressively displaced seaward, but without reaching the position that it had before the rise of sea level took place. A new increment of sea level rise increases the shelf accommodation displacing again the depositional coastal break landward and creating another ravinement surface. Then, again, deposition takes place and the depositional coastal break is progressively displaced seaward, ... and so forth.

Transgressive Systems Tract

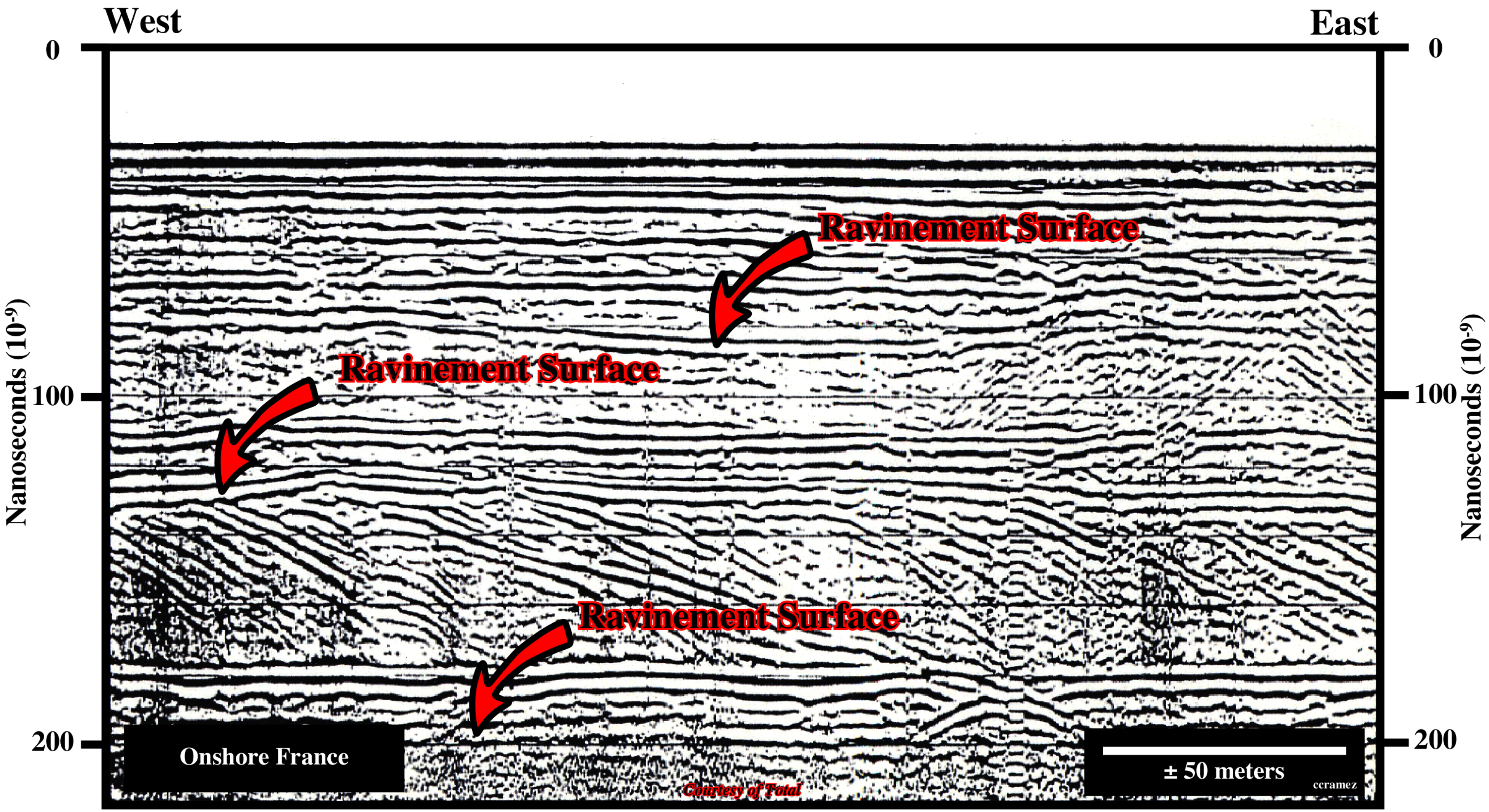


Fig. 103- On this geo-radar line from onshore France (notice that the vertical time scale is in nanoseconds, that is to say, 10-9 seconds), ravinement surfaces are clearly recognized in association with flooding surfaces. In other words, during a transgressive systems tract, at each relative sea level rise increment, the base level erodes the sea floor before being overlain by progradational sediments.

Transgressive Systems Tract

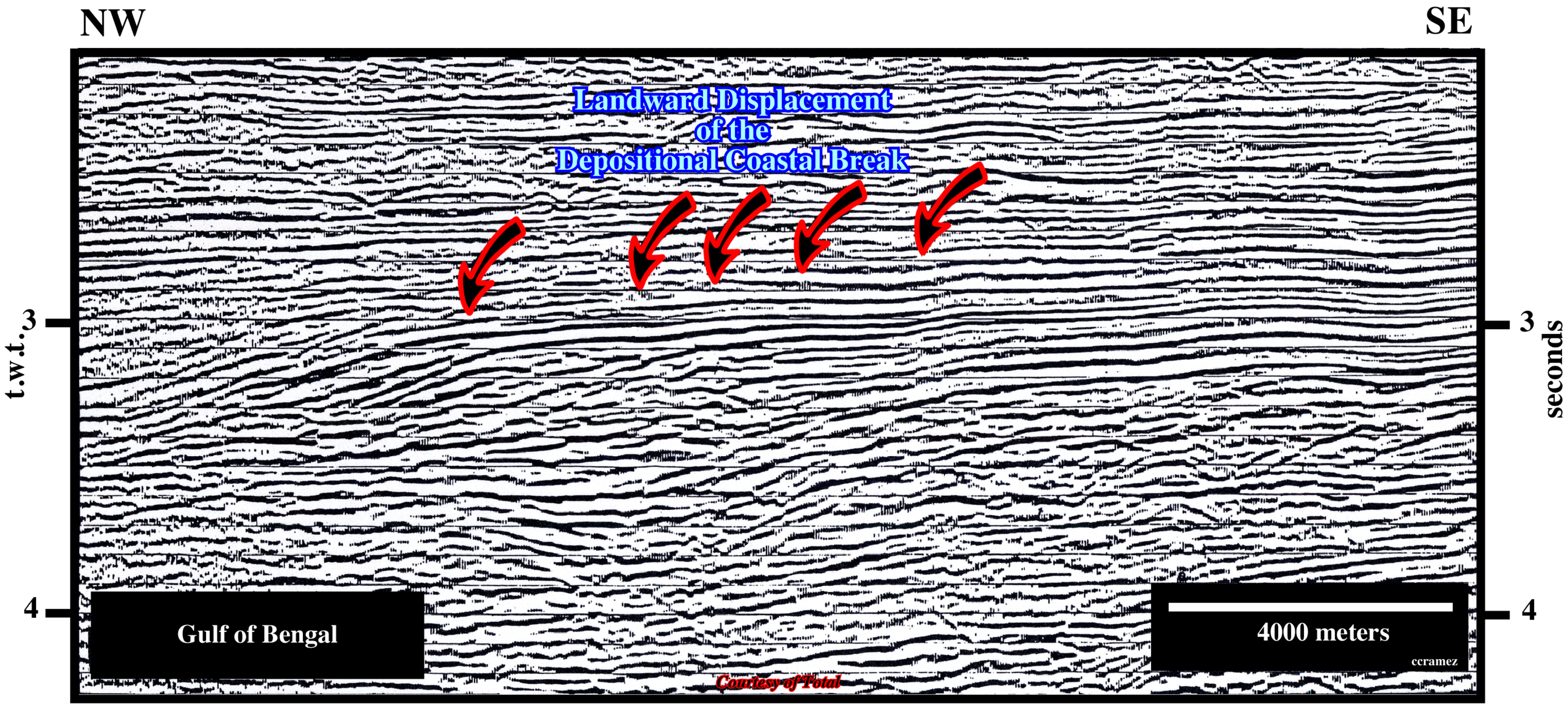


Fig. 104- On this seismic line from the Gulf of Bengal, above a progradational interval, in which successive relative sea level falls induced the seaward deposition of different lowstand prograding wedges or shelf margin systems, a transgressive systems tract was deposited. The recognition of this transgressive systems tract can be based on the retrogradational displacements of the depositional coastal break, which creates a backstepping geometry. Such geometry implies the progressive development of a shelf environment as the depositional coastal break, individualized from the shelf break, and progressively displaced landward.

Transgressive Systems Tract

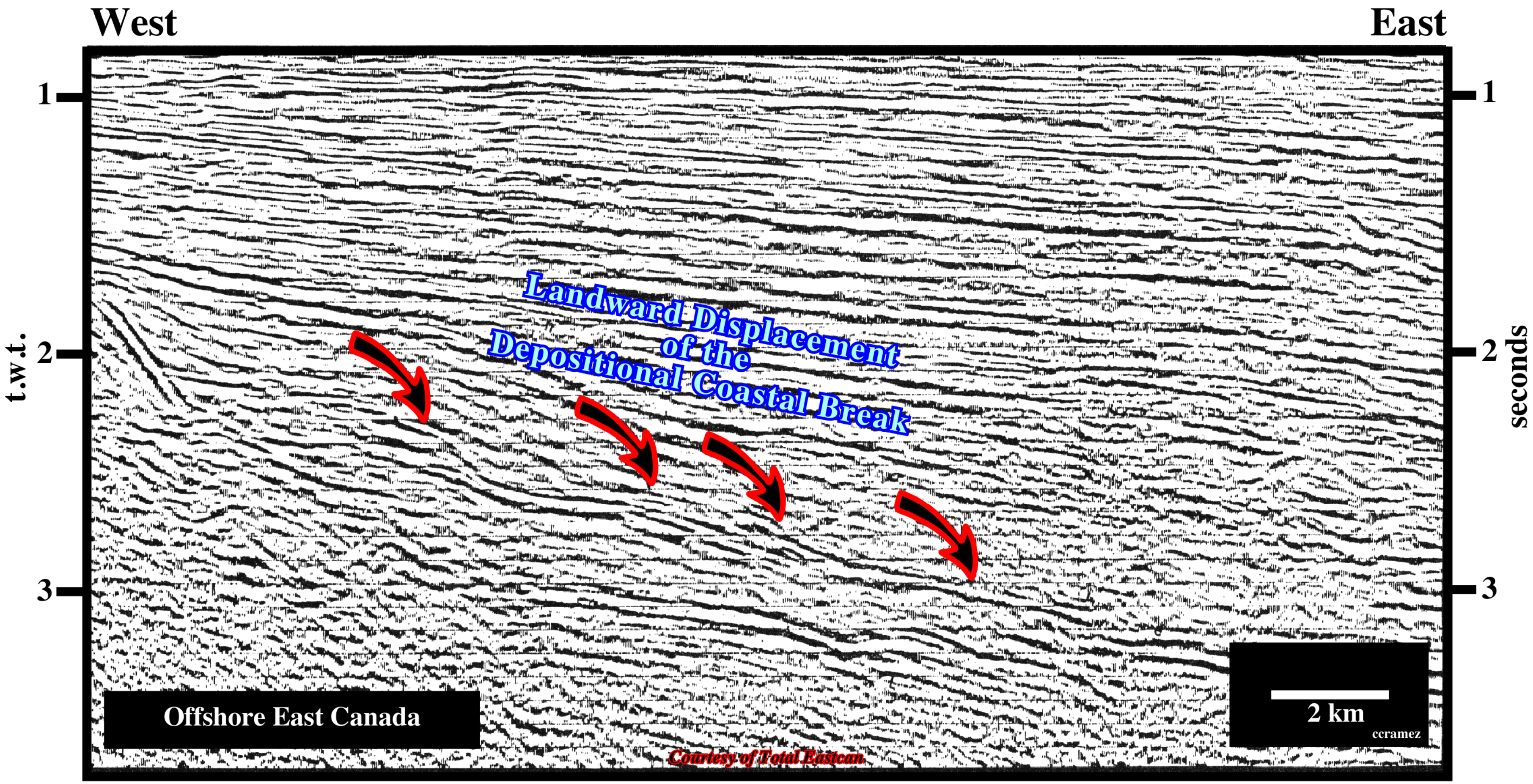


Fig. 105- On this line from offshore Labrador, that you already saw twice, a transgressive systems tract is easily recognized by the progressive landward displacement of the depositional coastal break. Actually, it is this displacement that allows geologists to say that transgressive systems tracts thicken landward before onlap against the lower sequence cycle boundary

Transgressive Systems Tract

Exploration Applications

1) RESERVOIR

- **Beach-shoreface;**
- **Excellent φ and k;**
- **Predictable linear trends;**

2) MIGRATION

- **Typically downward and laterally within TST;**

3) SOURCE

- **Good on top and laterally;**

4) TRAPS

- **Stratigraphic traps in isolated sands;**
Continuous basal reservoirs require a structural trap;

5) SEAL

- **Good top;**
- **Variable laterally and on base;**

Transgressive Systems Tract

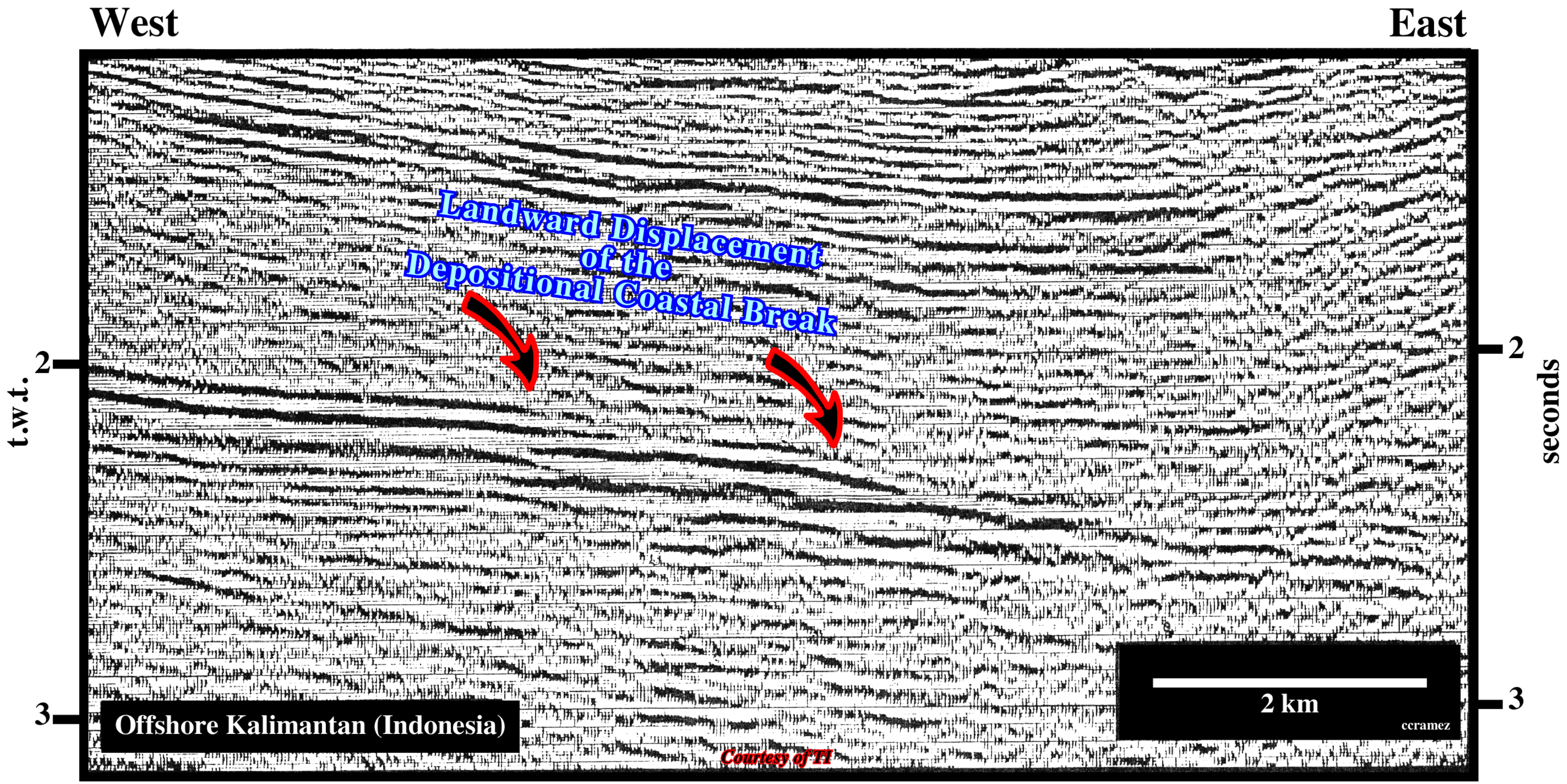


Fig. 106 - This seismic line from offshore East Borneo is often used to show that explorationists cannot correctly interpret a seismic line, in geological terms, when they don’t know Geology and particularly the depositional geological models. Indeed, in this particular example, an explorationist with a poor knowledge in Geology is going to propose an interpretation in which a reflector is faulted by two normal faults. On the contrary, an explorationist knowing what he is doing readily recognizes a transgressive systems tract, thickening westward as the depositional coastal break is displaced landward. In other words, explorationists recognize on a seismic line just what they know.

Exercises

Transgressive Systems Tract

Exercise

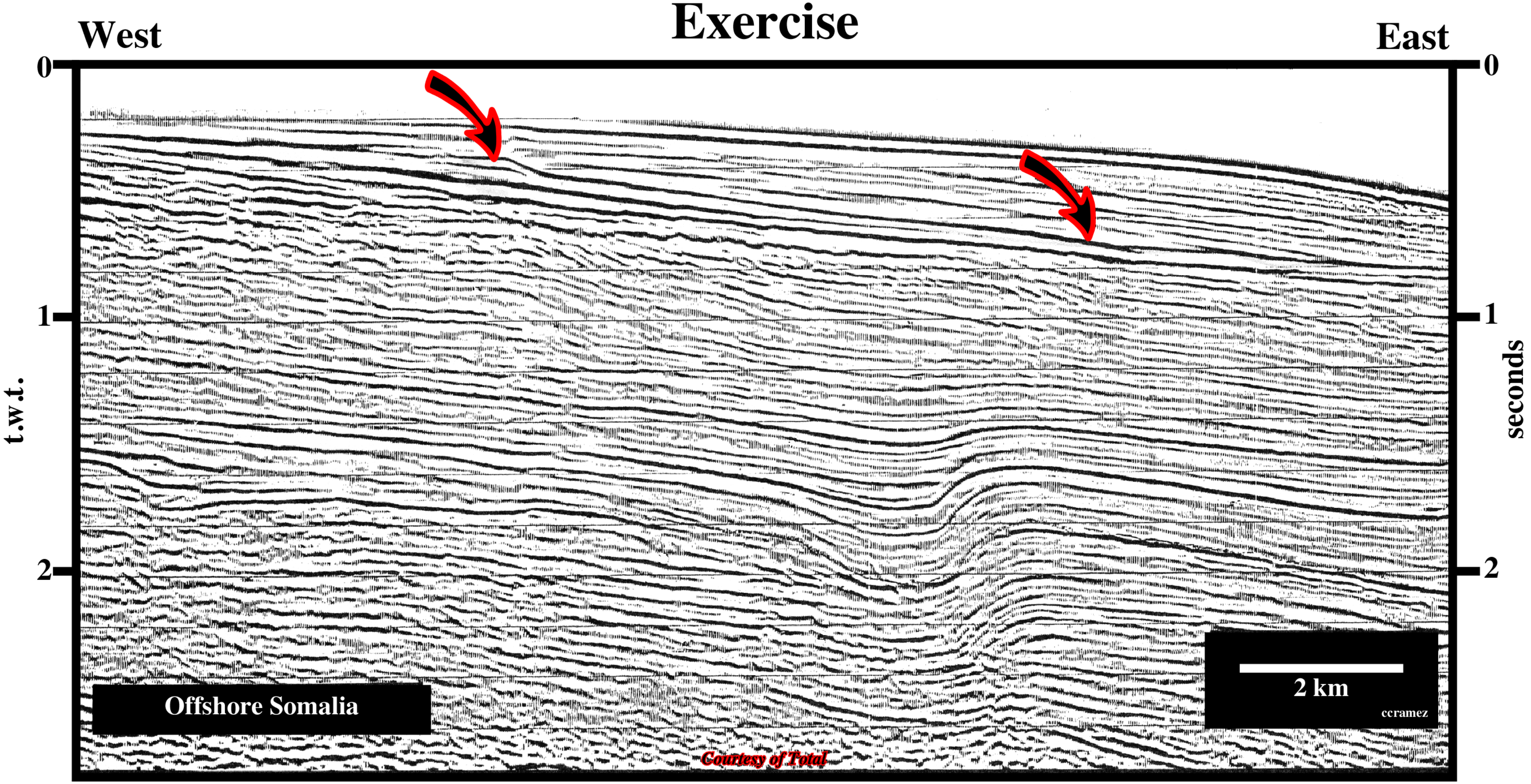


Fig. 107- On this seismic line, start by recognizing the uppermost unconformity, which is the lower boundary of a sequence cycle formed, in this part of the basin, by a transgressive systems tract and a highstand systems tract. Then, pick the transgressive and highstand systems tracts. In what direction is the transgressive systems tract thickening? What are the red arrows supposed to underlined? Do you think that there is an incised valley fill associated with the lower sequence cycle boundary? If you answer yes, with which systems tract do you associate it?

Transgressive Systems Tract

Exercise

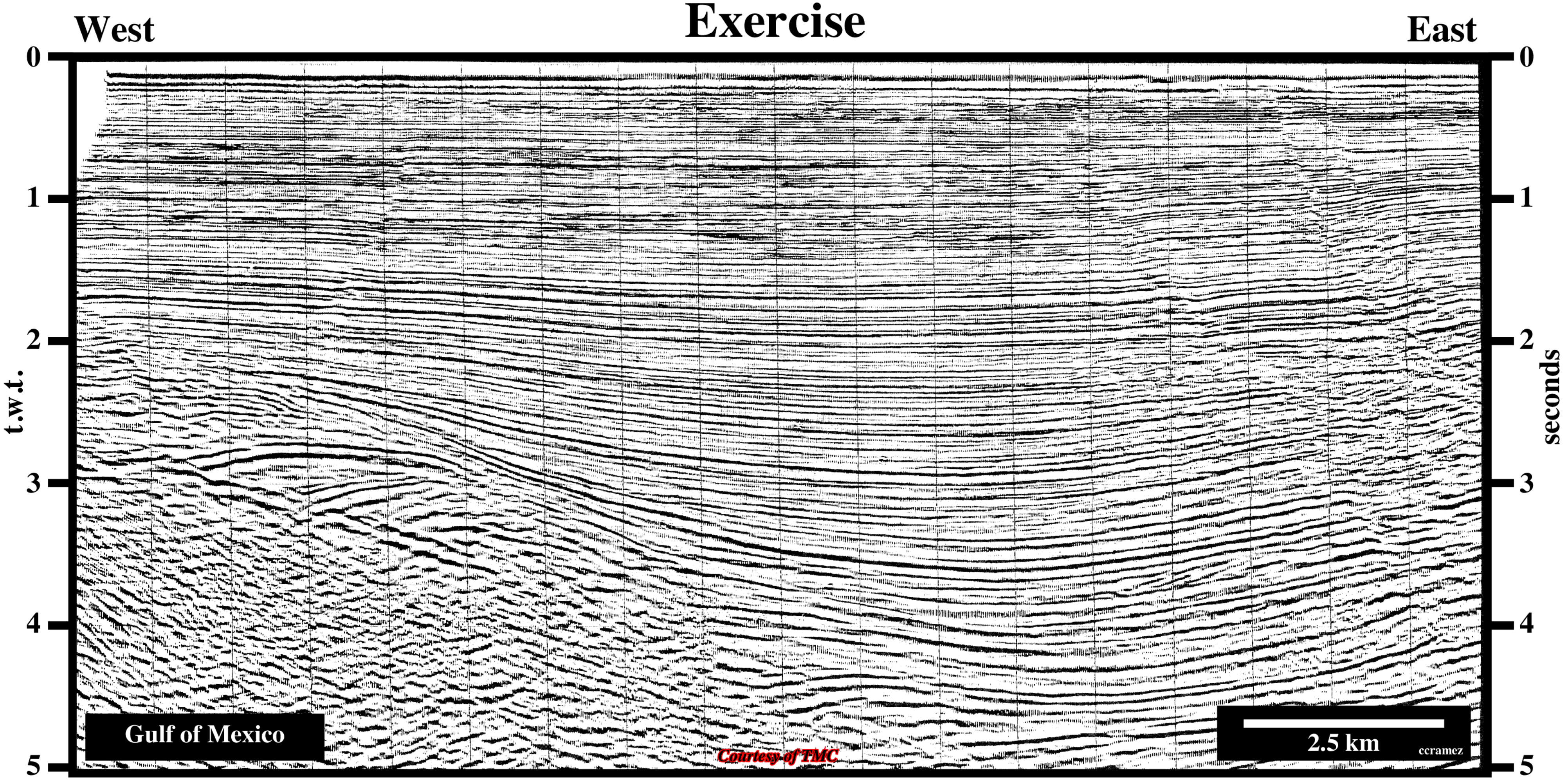


Fig. 108- Making a sequential analysis of this seismic line coming from the conventional offshore of the Gulf of Mexico, you easily recognize the most likely geological settings developed above the salt weld (tectonic disharmony created by total salt expulsion). Where is the most evident transgressive systems tract? Is the sediment supply high or low? Do you see some turbidite deposits? If yes locate them?

Transgressive Systems Tract

Exercise

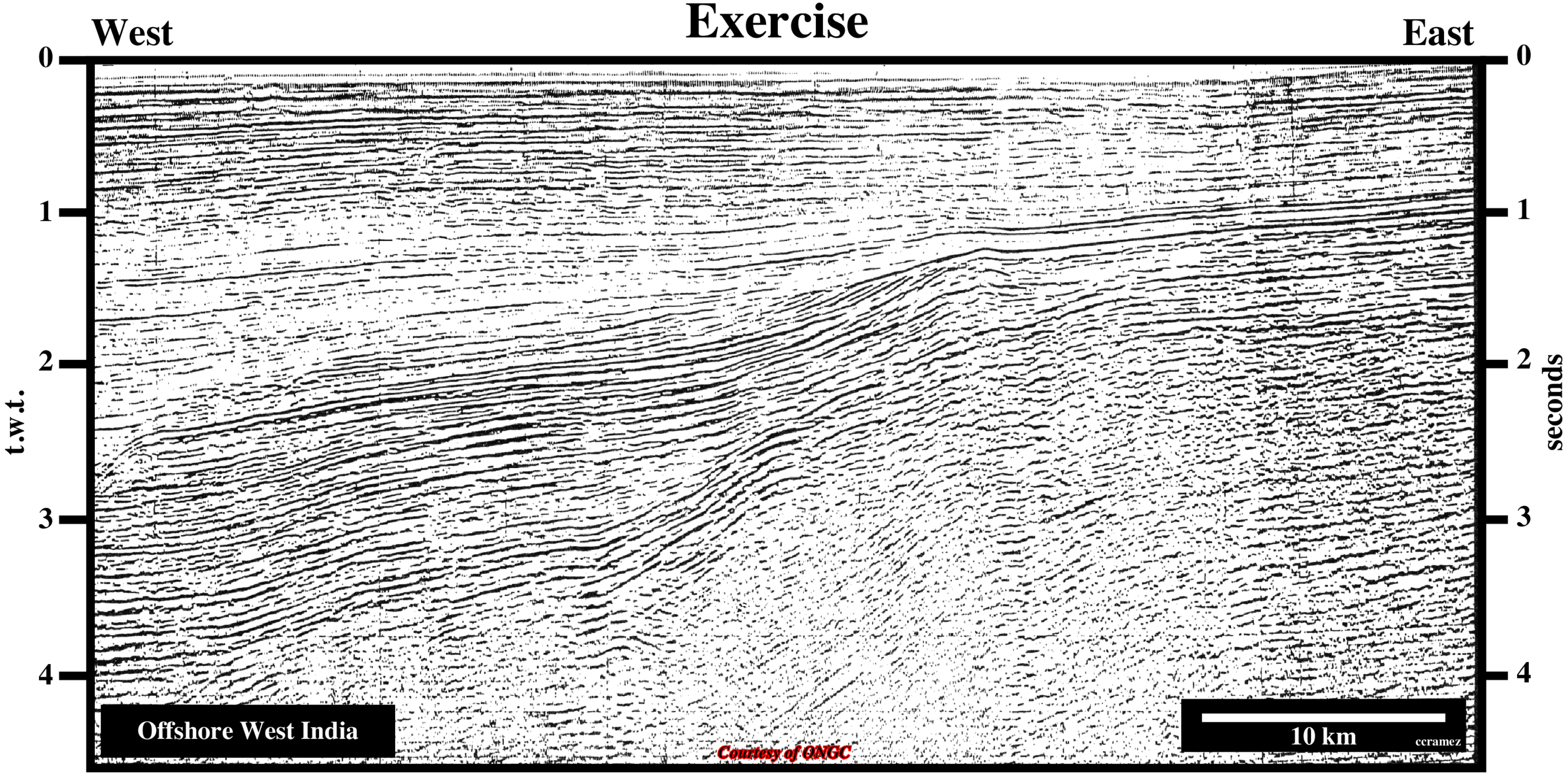


Fig. 109- Pick the more obvious transgressive systems tracts. Then, indicate in which direction the associated depositional systems are thickening. Finally, locate two lowstand prograding wedges.

Transgressive Systems Tract

Exercise

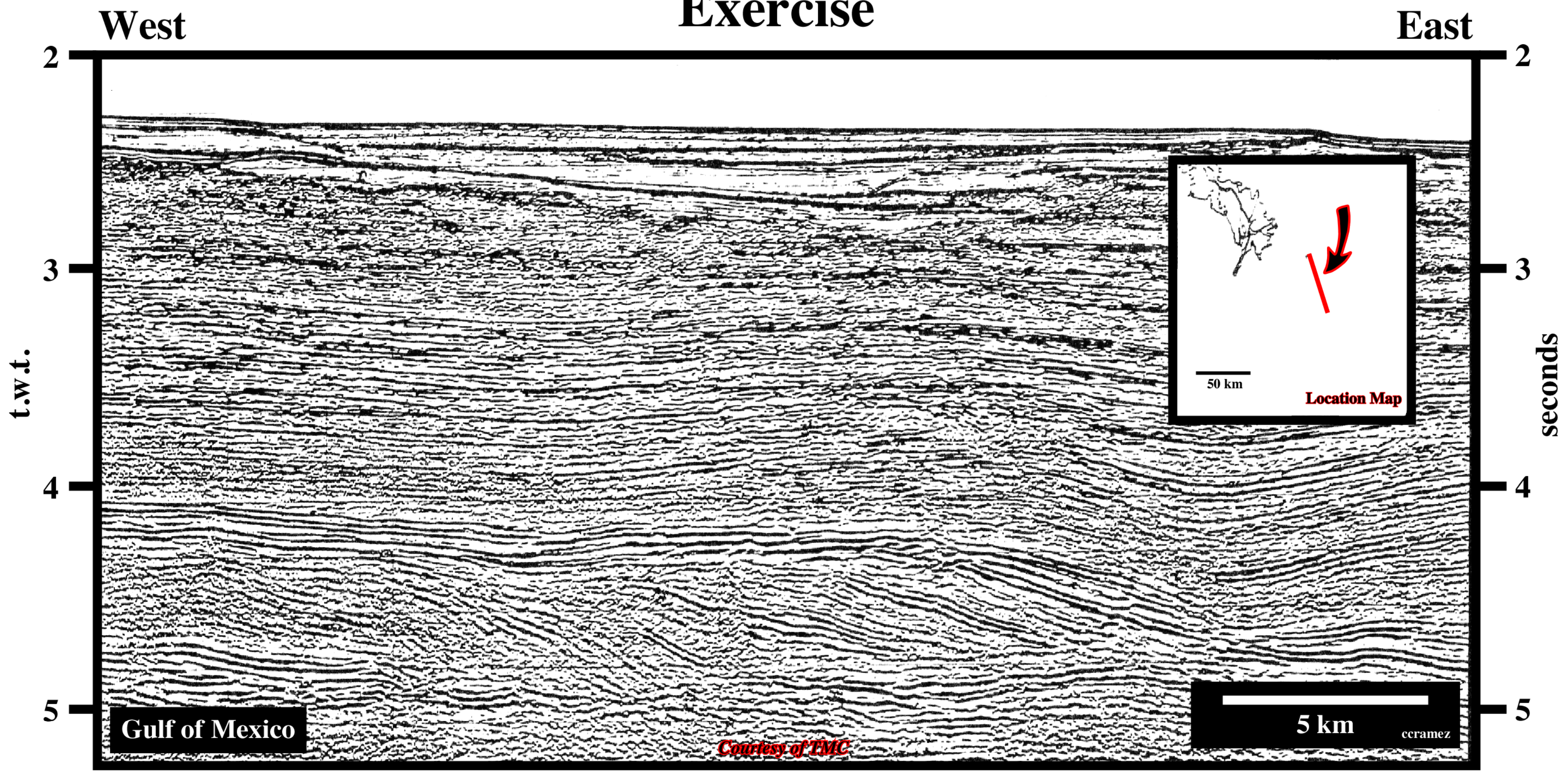


Fig. 110- Knowing that in the Gulf of Mexico, as well as in the majority of petroleum basins, the potential marine source-rocks are associated with the major post-Pangaea downlap surface, can you locate them on this line? At which systems tract do they belong to? Explain the geometry of the reflection and reflection terminations between 6 and 8 seconds. Specifically, are the reflection terminations downlap? Explain your answer.

Highstand
Systems Tract
(HST)

Highstand Systems Tract

1) The time of maximum marine transgression on the shelf marks:

- The updip termination of the marine condensed section;
- The beginning of net regression as the rate of sediment supply begins to overwhelm the low rate of relative coastal onlap;
- The displacement of the shoreline position back toward the shelf margin;
- A downlap surface on the condensed section as highstand sediments prograde;

2) During the highstand systems tract time the rate of eustatic rise slows, reaches highstand conditions and begins to reverse to a slow rate of eustatic fall..

3) In the siliciclastic environments fluvial channel sands are the most common reservoirs.

4) A carbonate highstand systems tract reservoirs consist of a wide variety of shelf limestones and dolomite textural types, but typical are packstyones sediments in which the sand-size grains are skeletal fragments, oolites, pellets or pisolites.

Highstand Systems Tract

5) Trapping of hydrocarbons in this systems tract is a problem because leakage paths are likely to exist into updip sediments.

6) Structural closure entrapment is commonly needed.

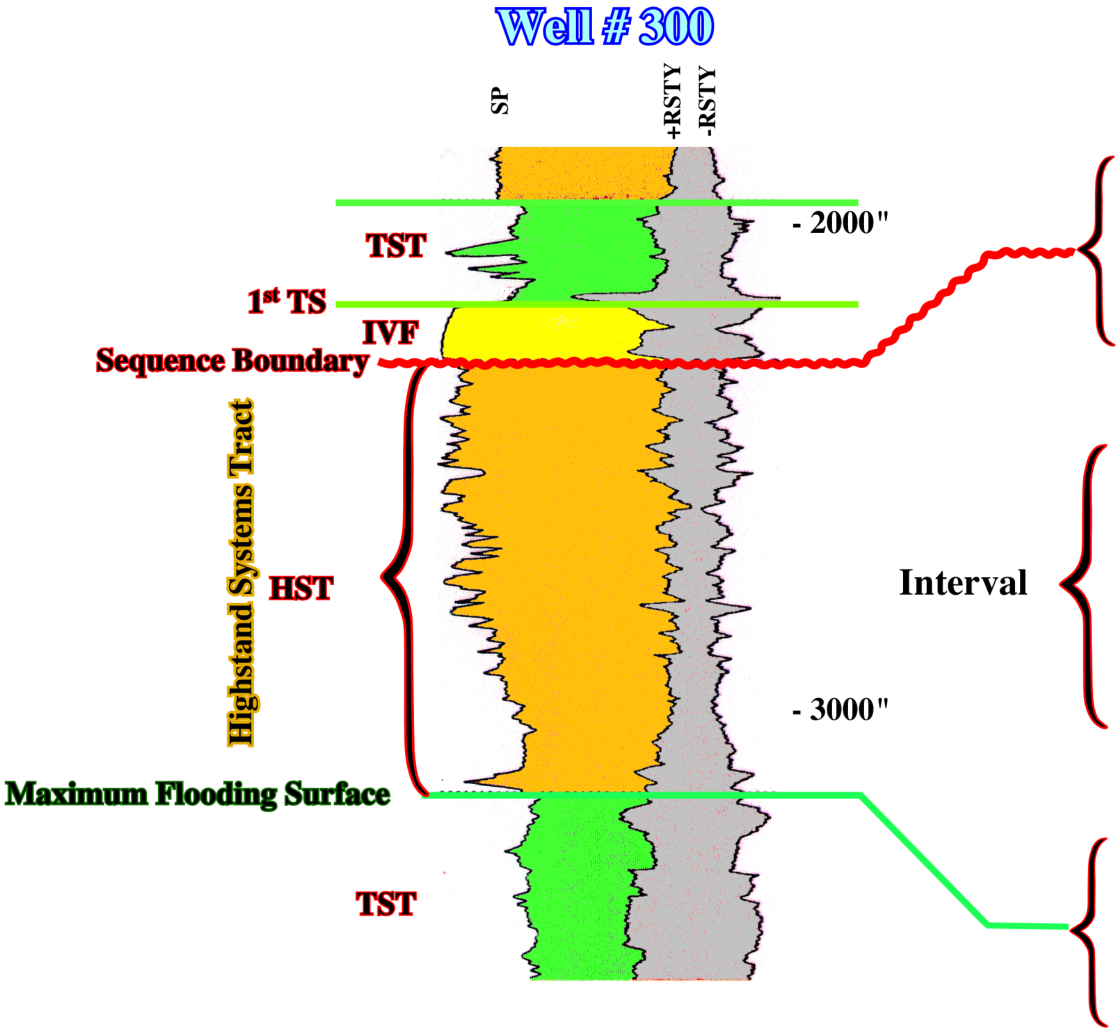
7) Regressive carbonate/evaporite sequences in which salt and anhydrite progressively move in toward the basin can result in a very important stratigraphic entrapment of hydrocarbons in the interbedded marine carbonates that form downdip from sebka and evaporite panenvironments.

8) As highstand systems tract sediments prograde across the outer shelf and shelf margins they may create their own structural traps.

9) Differential loading of underlying mobile sediments results in development of hydrocarbon traps by structures contemporaneous with deposition.

8) Reservoir characteristics of fluvial and deltaic highstand sediments vary widely but complex reservoir complex reservoir continuity and diagenetic cementation are common problems.

Highstand Systems Tract



- Lowstand Erosion on Shelf
- Incised Valleys on Shelf
- Canyon Cuts on Upper Slope
- Truncation or Toplap below Boundary

- Coarsens and Shallows Upward
- Fluvial and Deltaic Sands Near Top
- Progrades Laterally into Neritic Sands
- Basinal Equivalent is Pelagic Shales
- Log Correlation is Difficult
- Reservoir Continuity is fair to Poor

- Lowest Resistivity-Highest Gamma Ray
- Most Clay Rich Shale
- Planktonic Abundance Peak
- Downlap Above Boundary

Fig. 111- The main characteristics of highstand systems tracts are summarized above. The upper limit is always a sequence cycle boundary. The lower limit is often the maximum flooding surface of the underlying transgressive systems tract, but, in certain cases, it can be also a sequence cycle boundary. The log pattern is typical of a coarsening and thickening upward interval.

Highstand Systems Tract

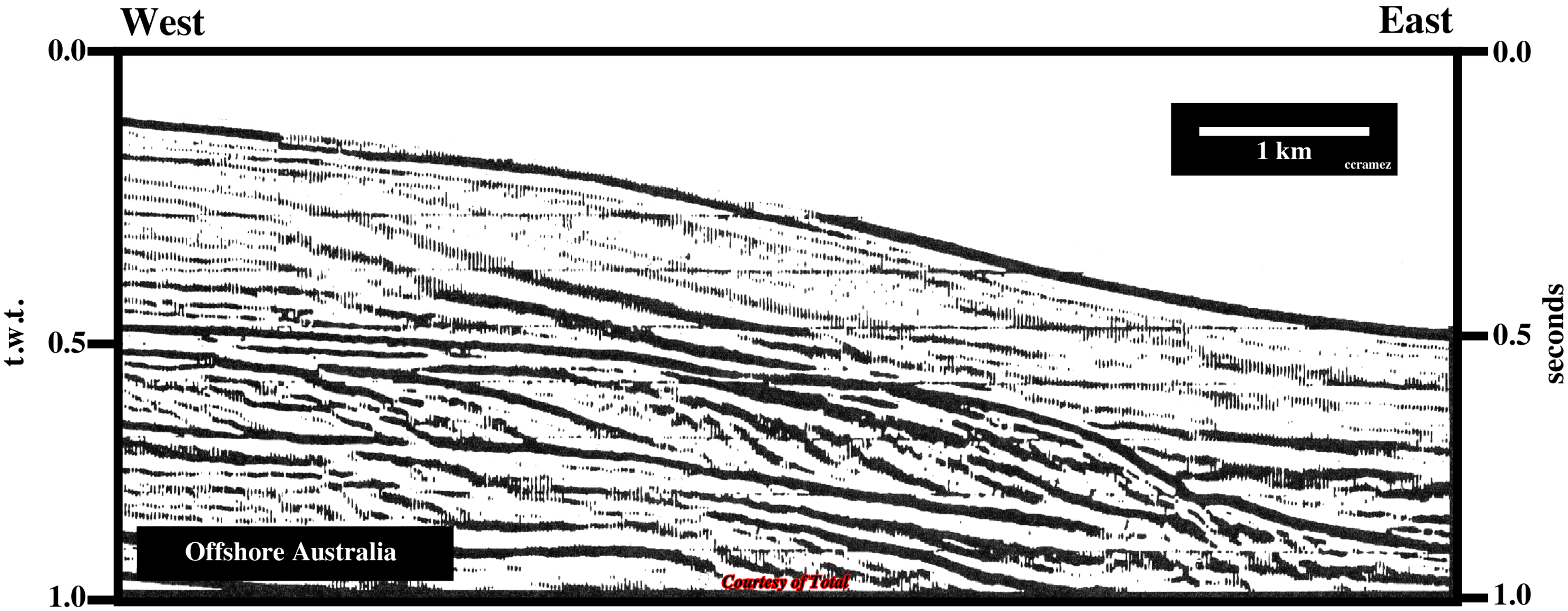


Fig. 112- On this seismic line three highstand systems tracts are easily recognized above transgressive systems tracts. Their lower limits are underlined by an obvious downlap surface, while the upper limit is the upper sequence cycle boundary, that is to say, an unconformity. So, very often, as is the case for two lower highstand systems tract seismic lines, incised valleys can enhance the upper limit of the highstand systems tracts (see the proposed interpretation of this line on fig. 113).

Highstand Systems Tract

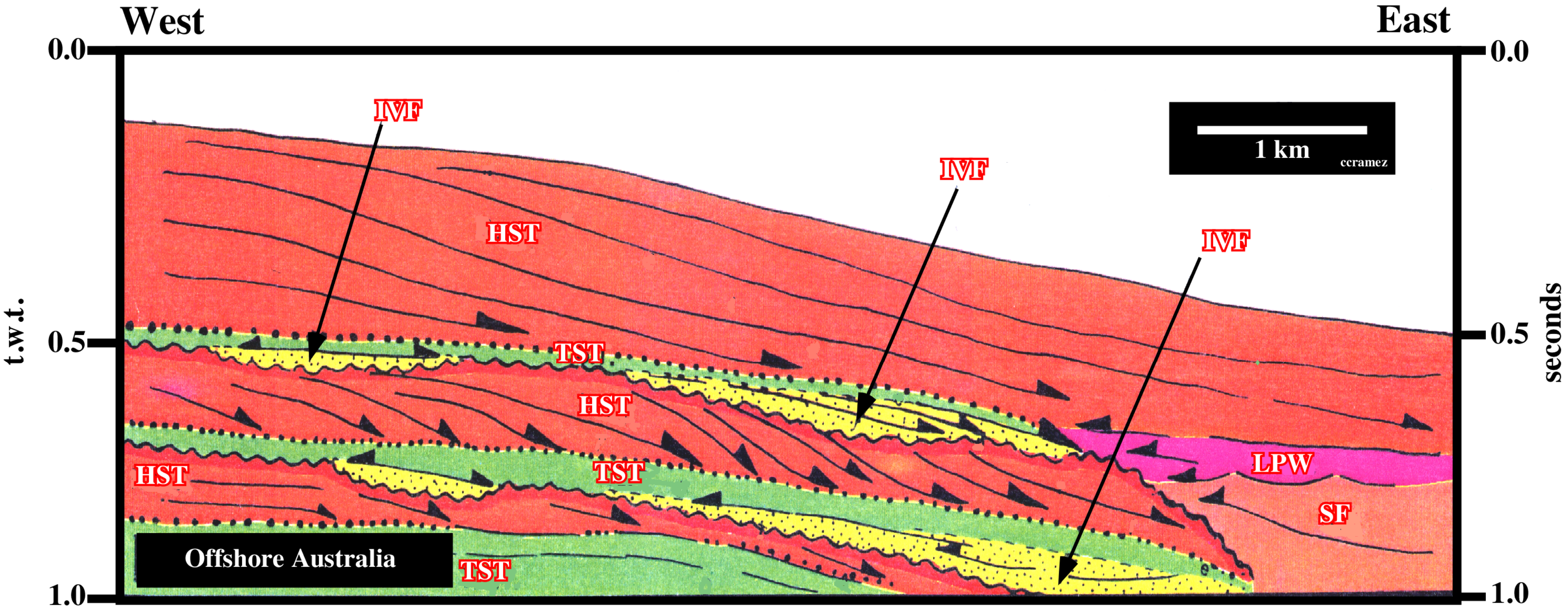


Fig. 113- On this interpretation of the previous line (fig. 112), two highstand systems tracts are limited by unconformities underlined by incised valleys, which were filled by relatively shallow water sediments deposited during the upper lowstand prograding wedge time. The incised valley fills being fossilized by relatively thin transgressive systems tracts, their maximum flooding surface (fossilized later by the downlap surface) mask slightly the upper limit of the highstand systems tracts.

Highstand Systems Tract

Exploration Applications

1) RESERVOIR

- **Discontinuous fluvial, deltaic facies predominane;**
- **Minor shoreface facies;**

2) MIGRATION

- **Gas and lean oil typical from contemporaneous source;**
- **Good oil source often requires vertical fault conduit;**

3) SOURCE

- **Deep source typical;**
- **Often a problem;**
- **HST shales often lean and gas prone;**

4) TRAPS

- **Predominantly structural;**
- **Early timing critical:**

5) SEAL

- **Leaks updip into TST;**
- **Leaks laterally;**
- **Flooding surface usually top seal;**

Highstand Systems Tract

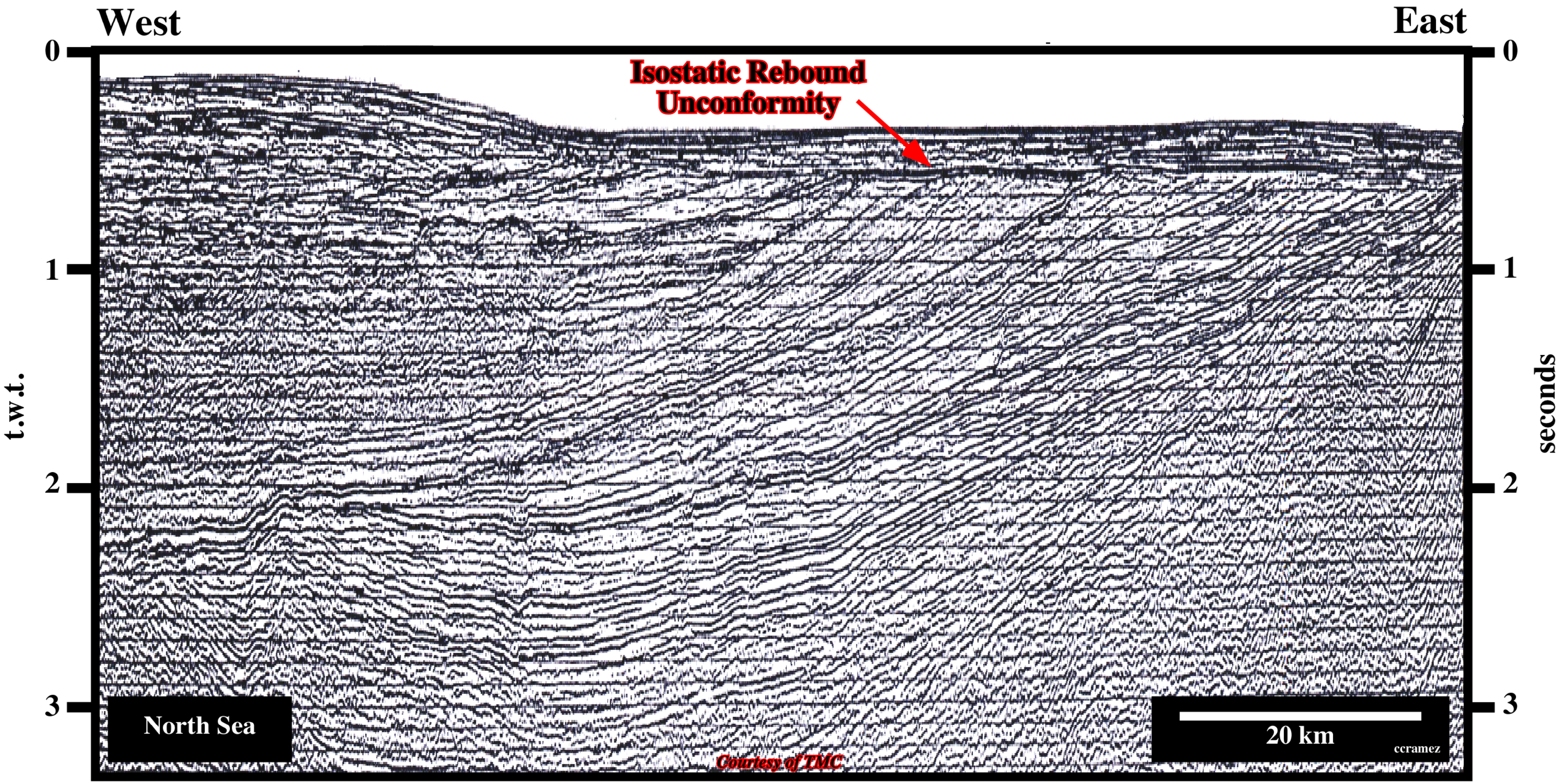


Fig. 114- On this line from the North Sea, the isostatic rebound (uplift of the continental crust following deglaciation) tectonically enhanced the internal configuration and the reflection terminations associated with the highstand systems tracts, which are here limited between downlap surfaces and unconformities as illustrated next (fig. 115).

Highstand Systems Tract

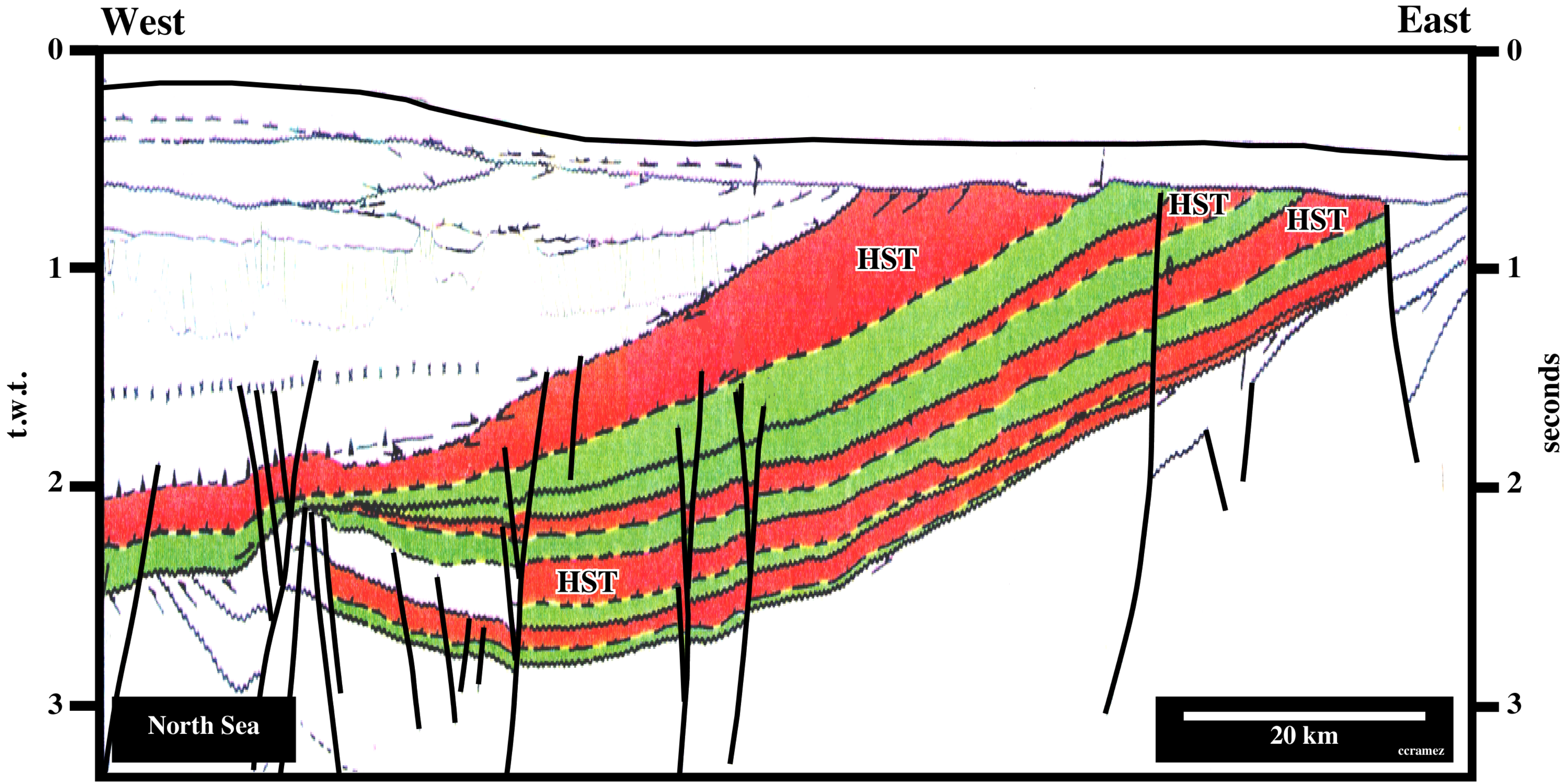


Fig. 115- This interpretation of the previous seismic line (fig. 114) suggests that a staking of transgressive and highstand systems tracts have been uplift following the deglaciation. The highstand systems tracts have a forestepping geometry. They overlie, in downlap, the transgressive systems tracts, which slightly thicken landward due to their backstepping geometry. They are limited between unconformities and downlap surfaces.

Highstand Systems Tract

Exercises

Highstand Systems Tract

Exercise

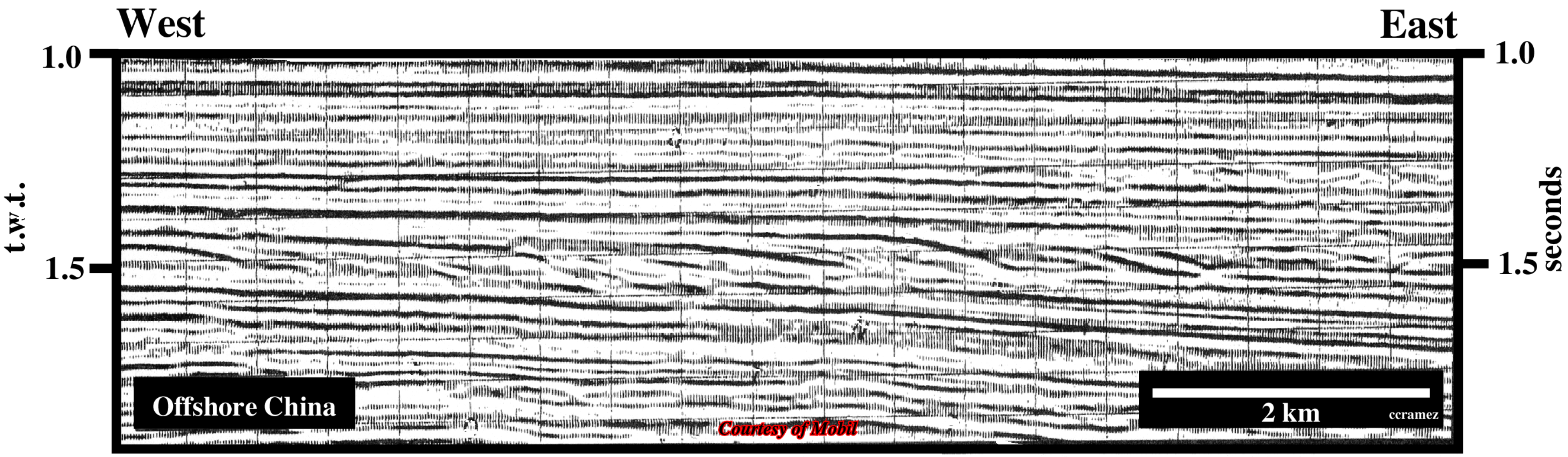


Fig. 116- On this close-up of a seismic line from offshore China, pick the main sequence cycle boundaries and colour, with the conventional colours code (HST in orange, TST in green, LPW in light violet, SF in light pink, BFF in yellow, IVF and SCF in light yellow), the different systems tracts. Then underline and name the different types of reflection terminations. Criticize your interpretation with the one proposed in fig. 117.

Highstand Systems Tract

Exercise

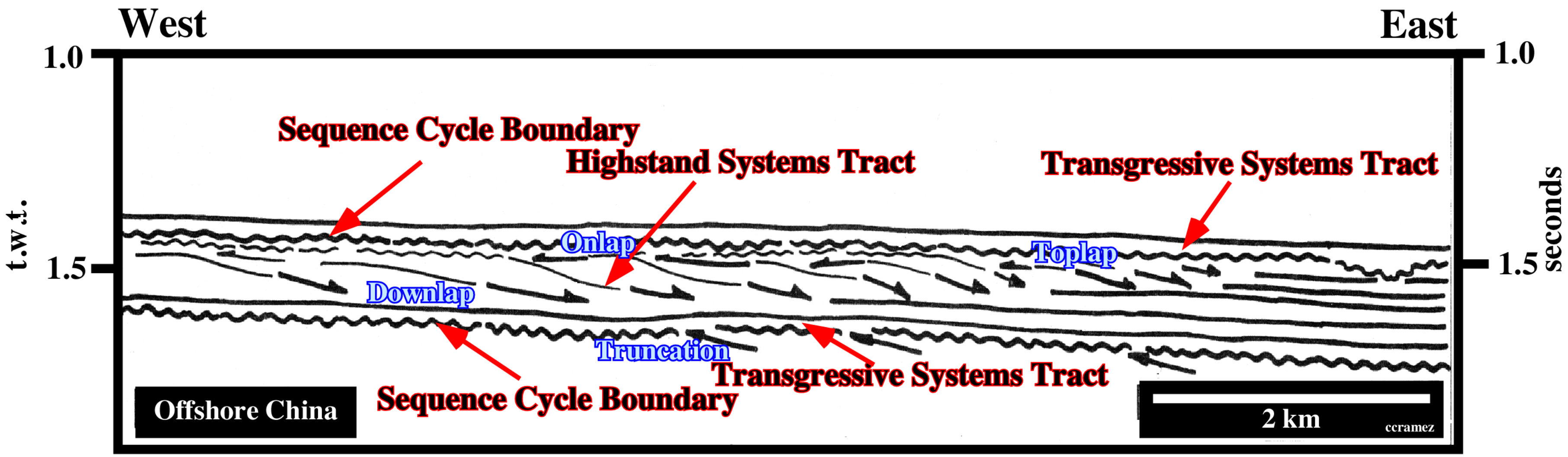
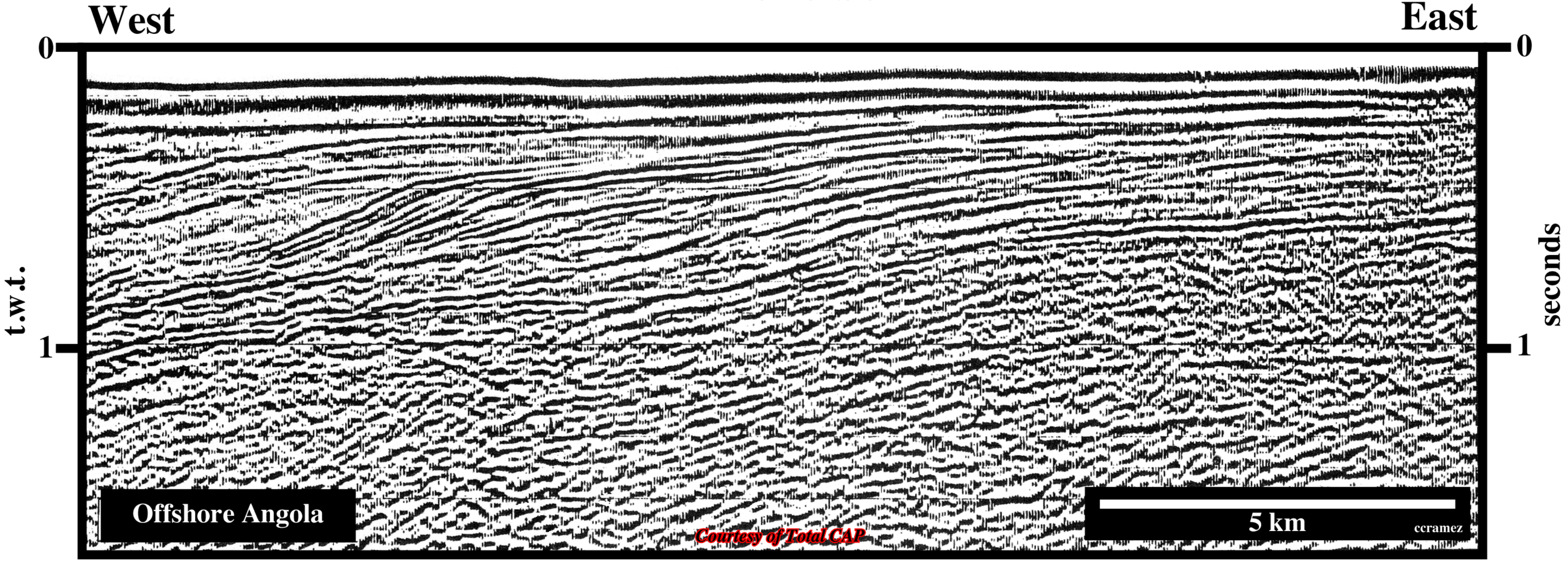


Fig. 117- On this interpretation of the previous line (fig. 116), a sequence cycle bounded by two unconformities is easily recognized when the onlap, downlap and toplap surfaces, defined by the reflection terminations, are well picked.

Highstand Systems Tract

Exercise



Courtesy of Total CAP

Fig. 118- On this line coming from offshore Angola, pick the reflection terminations and then the unconformities bounding the different sequence cycles. Are these sequence cycles complete or incomplete? Justify your answer and criticize it as well as the proposed solution illustrated in next figure (fig. 119).

Highstand Systems Tract

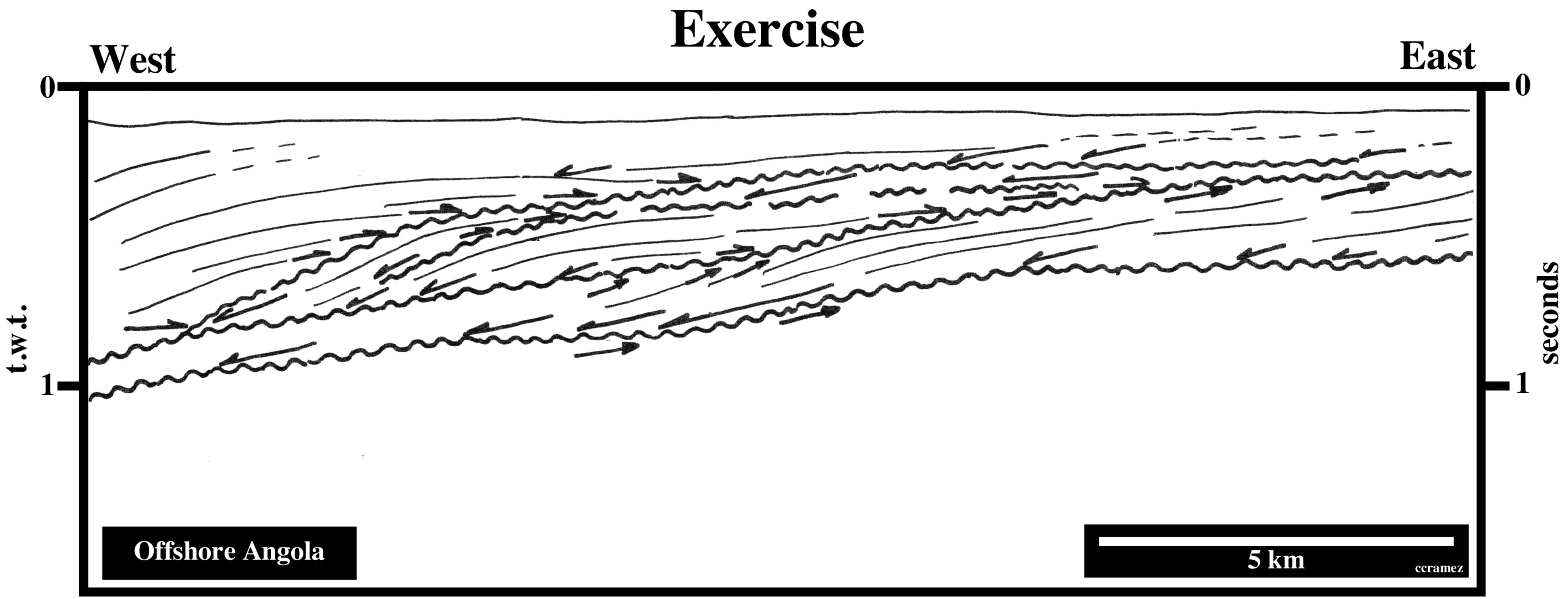


Fig. 119- Above is illustrated the most likely solution of the interpretation of the previous seismic line. The majority of the reflection terminations are indicated and the principal sequence cycle boundaries are picked. The sequence cycles are mainly incomplete since only the highstand systems tract is obvious.

Neogene
Global Stratigraphic
Signature

Neogene Stratigraphic Signature

Geological Model

(modified from P. Vail, 1992)

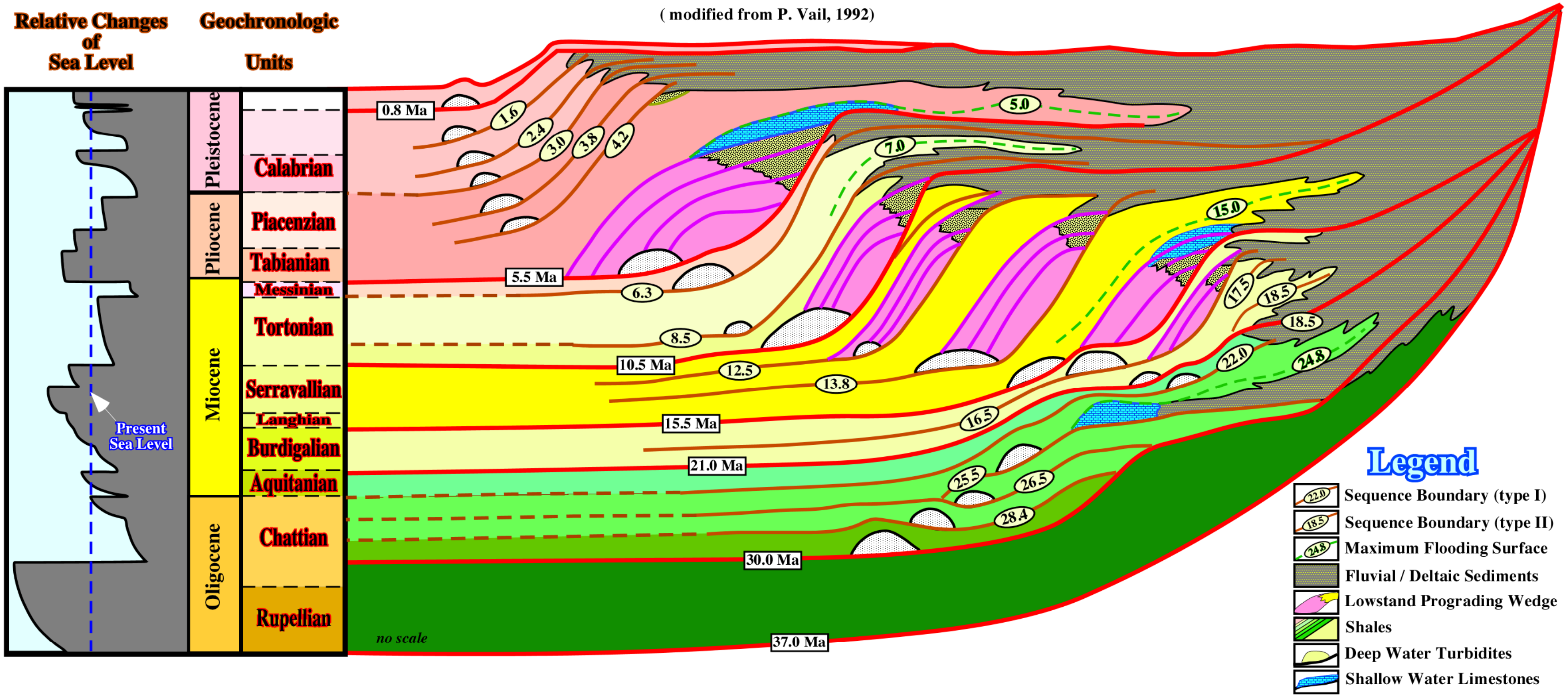


Fig. 120- The Neogene stratigraphic signature, as proposed by P. Vail and his students, is depicted above. In this stratigraphic signature, three major transgressive episodes are associated with the following maximum flooding surfaces: MFS 24.8 Ma, MFS 16/15 Ma and MFS 5.0 Ma (see next).

Neogene Stratigraphic Signature

Stratigraphic Signature

1) Lower Oligocene Landward Thickening;

2) Upper Oligocene Basinward Onlap;

3) Basal Lower Miocene Flooding (MFS 24.8 Ma);

4) Lower Miocene (Aquitanian) Aggradation Commonly Ending with Major Lowstand Deposits (22.0 Ma);

5) Lower Miocene (Burdigalian) Aggradation Commonly Ending with Major Lowstand Deposits (21.0 Ma);

6) Middle Miocene (Langhian & Lowermost Serravallian Flooding (16 / 15 Ma);

Neogene Stratigraphic Signature

Stratigraphic Signature

7) Middle Miocene (Serravallian) Major Progradation (15 / 10.5 Ma);

8) End Middle Miocene Major Downward Shift of Onlap & Low-stand deposits (10.5 Ma);

9) Upper Miocene Aggradation Commonly Ending with Lowstand Deposits (10.5 / 5.0 Ma):

10) Lower Pliocene Flooding (5.0 Ma);

11) Pliocene-Lower Pleistocene Aggradation with Multiple Low-stand Deposits (5.0 / 1.6 Ma);

12) Upper Pleistocene High Frequency Sequence Cycles;

Neogene Stratigraphic Signature

Major Relative Displacements of Coastal Break

30.0---------25.5 Ma	Seaward
25.5---------24.8 Ma	Landward
24.8---------15.5 Ma	Seaward
15.5---------15.0 Ma	Landward
15.0---------10.5 Ma	Seaward
10.5---------5.0 Ma	Landward
5.0-----------0.8 Ma	Seaward

Major Floodings

24.8-----18.5-----15.0-----5.0 Ma

This stratigraphic signature was the result of sequential stratigraphic and geohistory backstripping analysis of data from the western Atlantic- offshore, Gulf of Mexico-Alabama offshore and Texas, Maracaibo Basin (Venezuela), Canterbury (New Zealand), Northeast Java, Mahakam (Indonesia), Sabah, Bahamas and Ross-Sea (Antarctica)

Neogene Stratigraphic Signature

Signatures in the Stratigraphic Record

	Tectonics			Eustasy		Sedim.
Signature	Sedimentary Basin	Major Transgressive Regressive Facies Cycle	Folding Faulting Magmatism Diapirism	Major Continental Flooding Cycle	Sequence Cycle Systems Tracts Parasequences Stacking Pattern Sets Parasequences	Depositional Systems Lithofacies Tracts Markers Beds Bed Sets Bed Laminae Sets Laminae
Distribution in Space	Regional	Regional	Local	Global	Global	Local
Distribution in Time	1st Episodic Event	2nd Order non-periodic	3nd Order Episodic Event	1st Order Cycle	2nd- 5th Order Cycle	Episodic Event
Cause	Crustal Extension Flexure Loading Thermal Cooling	Plate Boundary Readjustment Thermal Perturbations Sediment Supply	Local Regional Stress Release	Change in Ocean Basin Volume	Change in Climate Water Volume	Local Sedimentary Processes

Exercises

Exercises

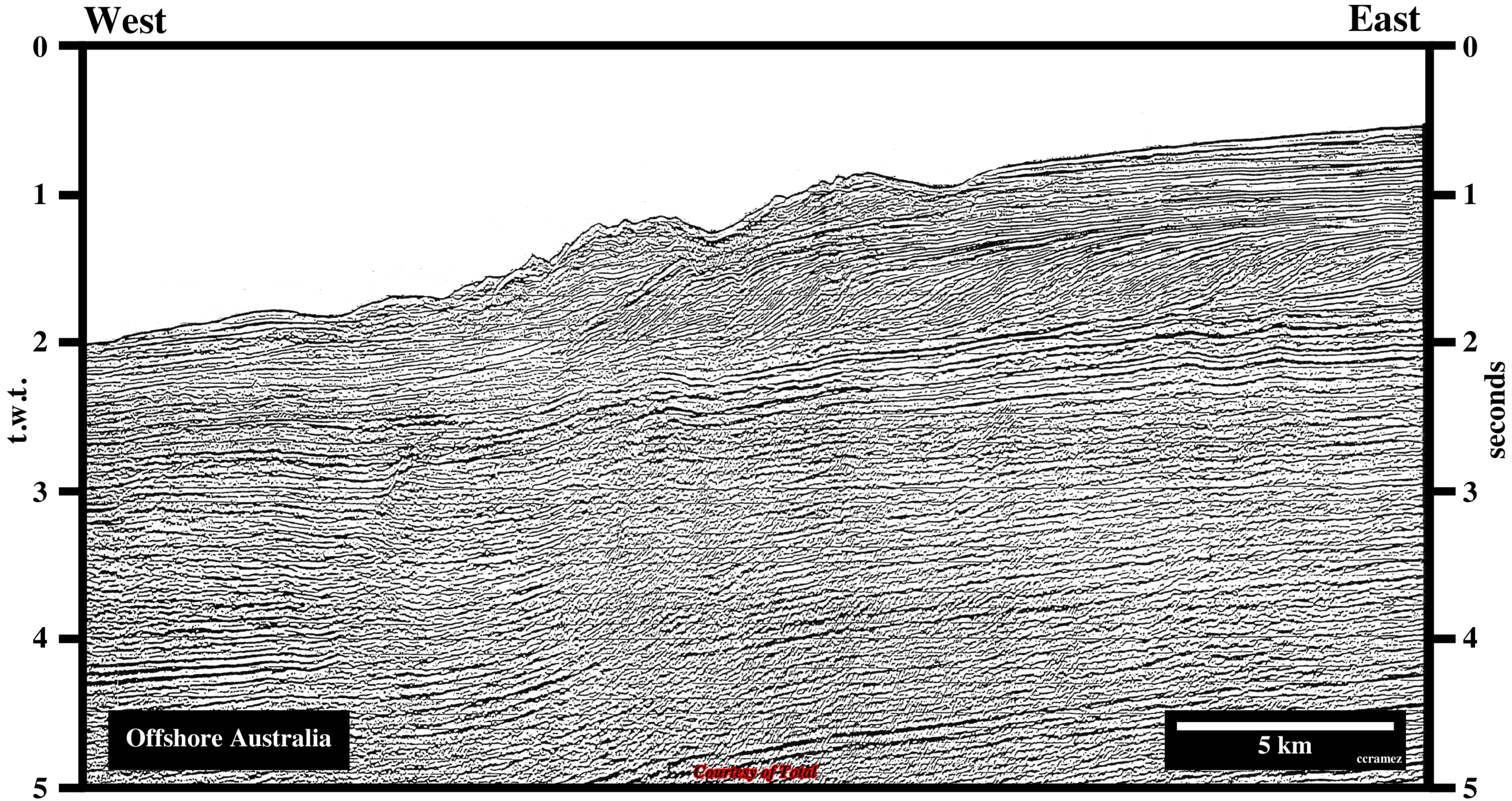


Fig. 121- Make a sequential interpretation of the upper part of this line, which is the seaward continuation of the one illustrated in fig. 122. Then, using the Neogene stratigraphic signature (fig. 120), propose an age for the main unconformities.

Exercises

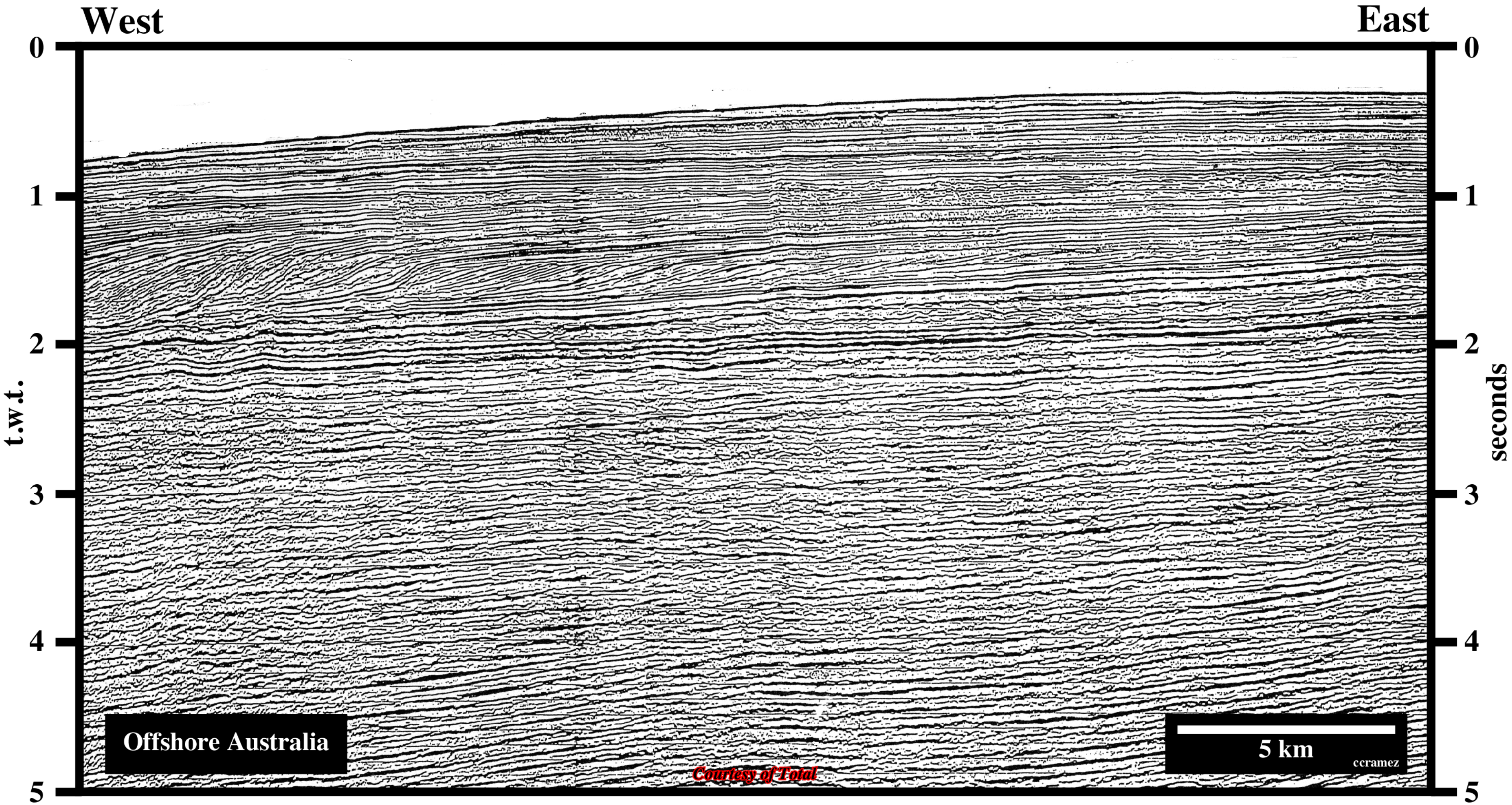


Fig. 122- This line is the landward continuation of the line illustrated in fig. 121. Make the same exercise as the previous, using the a priori knowledge of Vail's Neogene stratigraphic signature.

Exercise

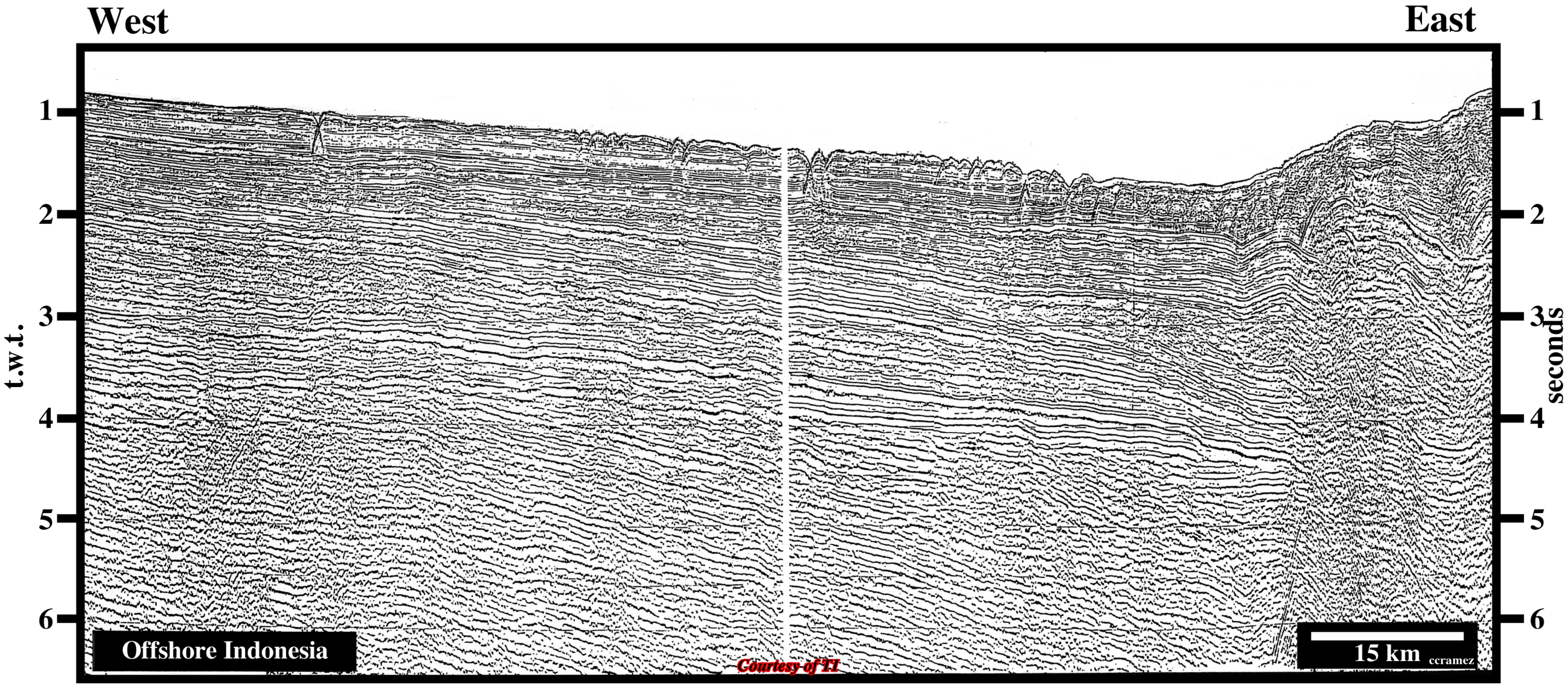


Fig. 123- Make a sequential interpretation of this line from offshore Kaitanimnar. Then calibrate the sequence cycle boundaries using the Neogene stratigraphic signature. Criticize your interpretation as well as the proposed interpretation shown in fig. 124.

Exercise

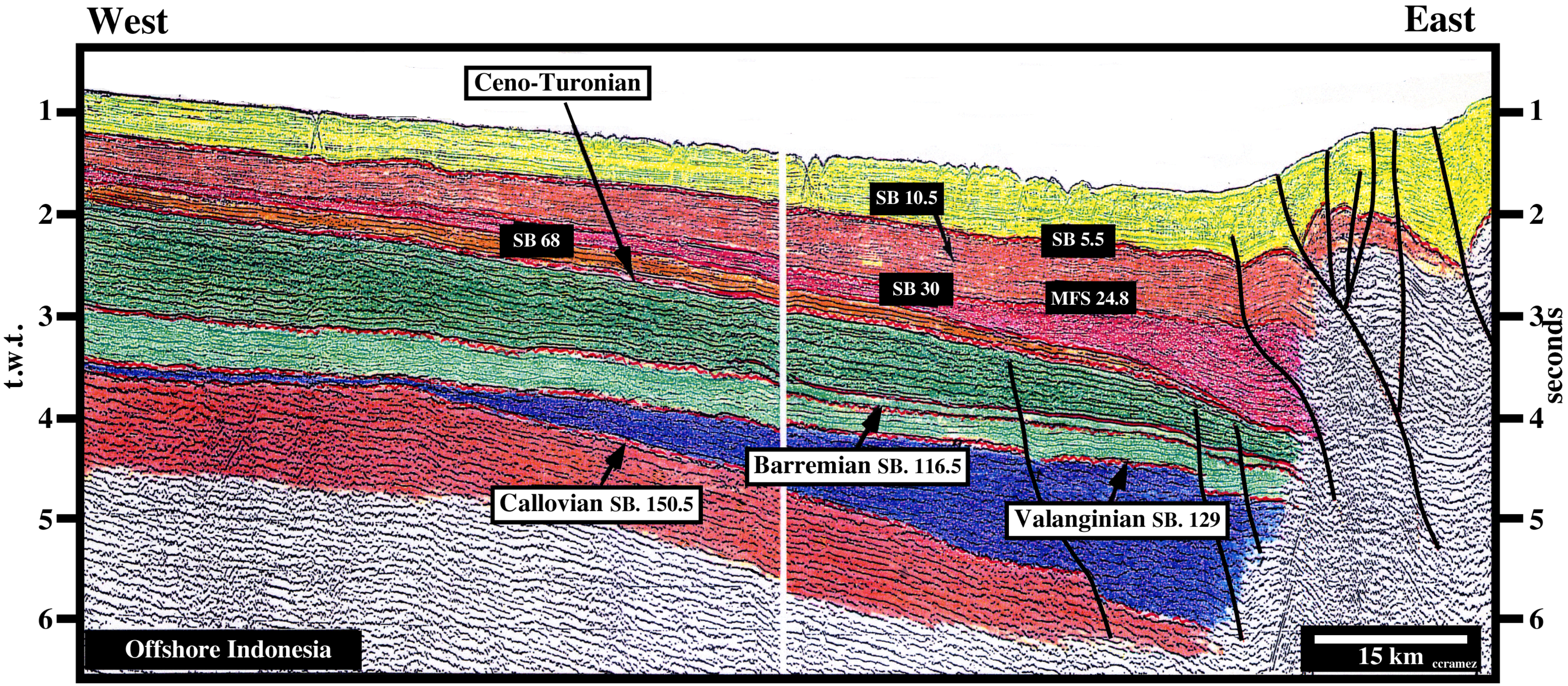


Fig. 124 - On this interpretation, a foredeep basin context is considered to take place at Lower Oligocene (SB. 30 Ma). Callovian, Vallanginian and Barremian unconformities are speculative, while the others are hypothetical, that is to say, determined according the Vail's Neogene stratigraphic signature.

Recapitulation

1)

Sequence Cycle Model
Systems Tracts

Relative Sea Level

Recapitulation

Sequence Cycle Model

Sand - Shale Facies

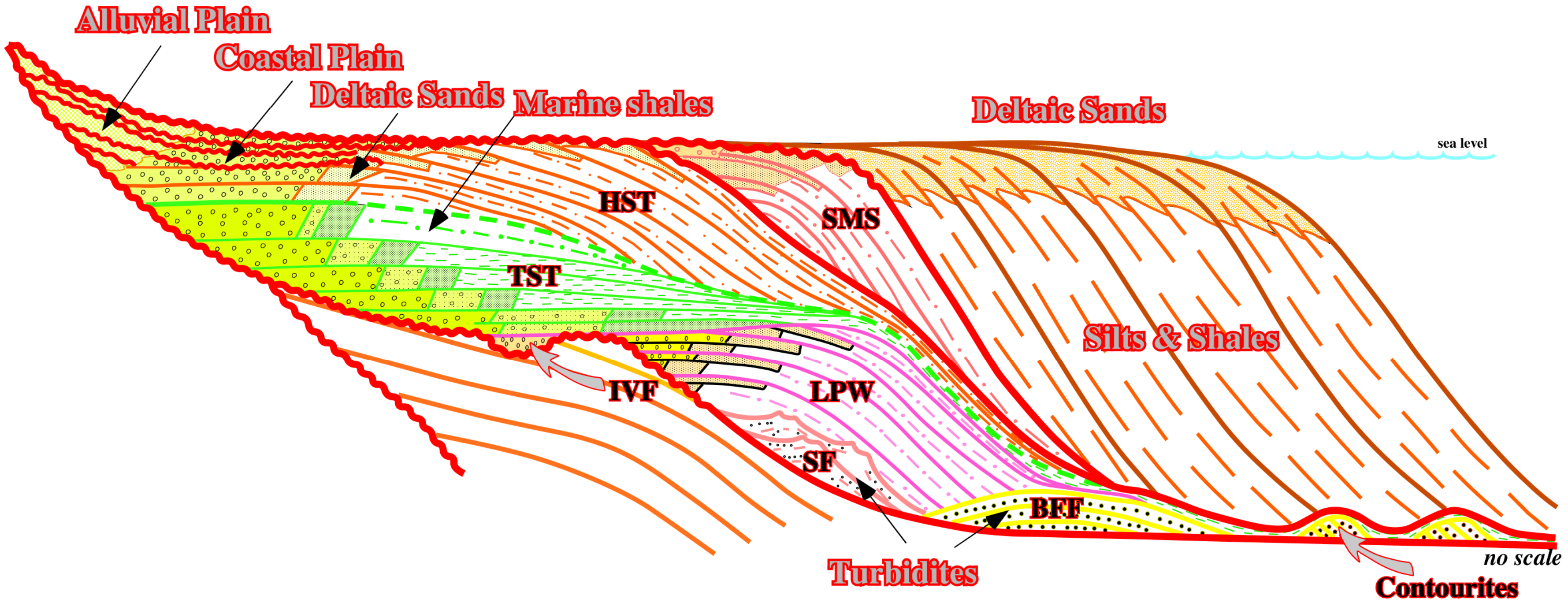


Fig. 125- On this short course we have used the sequence cycle model proposed by P. Vail and his Exxon colleagues. The model illustrated here above is the Vail’s sand - shale model (slightly modified), in which the geological time between each chronostratigraphic line is 100 ky. A complete sequence cycle is illustrated as well as the different systems tract composing it. In addition, within each systems tract the most likely depositional systems are predicted.

Recapitulation

Systems Tracts

HST	Highstand Systems Tract
TST	Transgressive Systems Tract
IVF	Incised Valley Fill
LPW	Lowstand Prograding Wedge
SP / BFF	Slope Fan / Basin Floor Fan
SMS	Shelf Margin Systems

Relative Sea Level

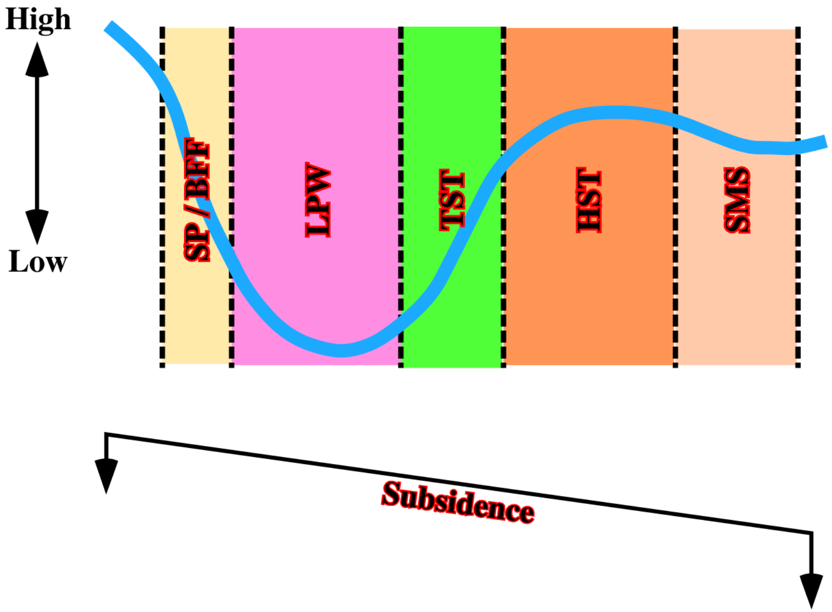


Fig. 126 - In Vail‘s model, within a sequence cycle, there three main systems tracts: Highstand systems tract (HST), Transgressive systems tract (TST) and Lowstand systems tract (LPW). However, the lowstand systems tract can be subdivided in three members: Lowstand Prograding Wedge (LPW), Slope Fan (SF) and Basin Floor Fan (BFF). In relation to the relative sea level curve, the unconformities are created during relative sea level falls, the period during which the slope and basin floor fans are deposited. The lowstand prograding wedge is deposited when the rate of sea level fall becomes decelerated and even when it starts to rise. The transgressive systems tract is deposited when the rise of the sea level is accelerated, while the highstand systems tract is mainly deposited during a decelerated relative sea level rise. The Shelf Margin Systems are deposited when the relative sea level starts to fall slowly (upper part of the relative sea level curve).

2)

Sea Level Responses

Orbital Perturbations

Subsidence

Recapitulation

Sea Level Responses to Orbital Perturbations & Subsidence

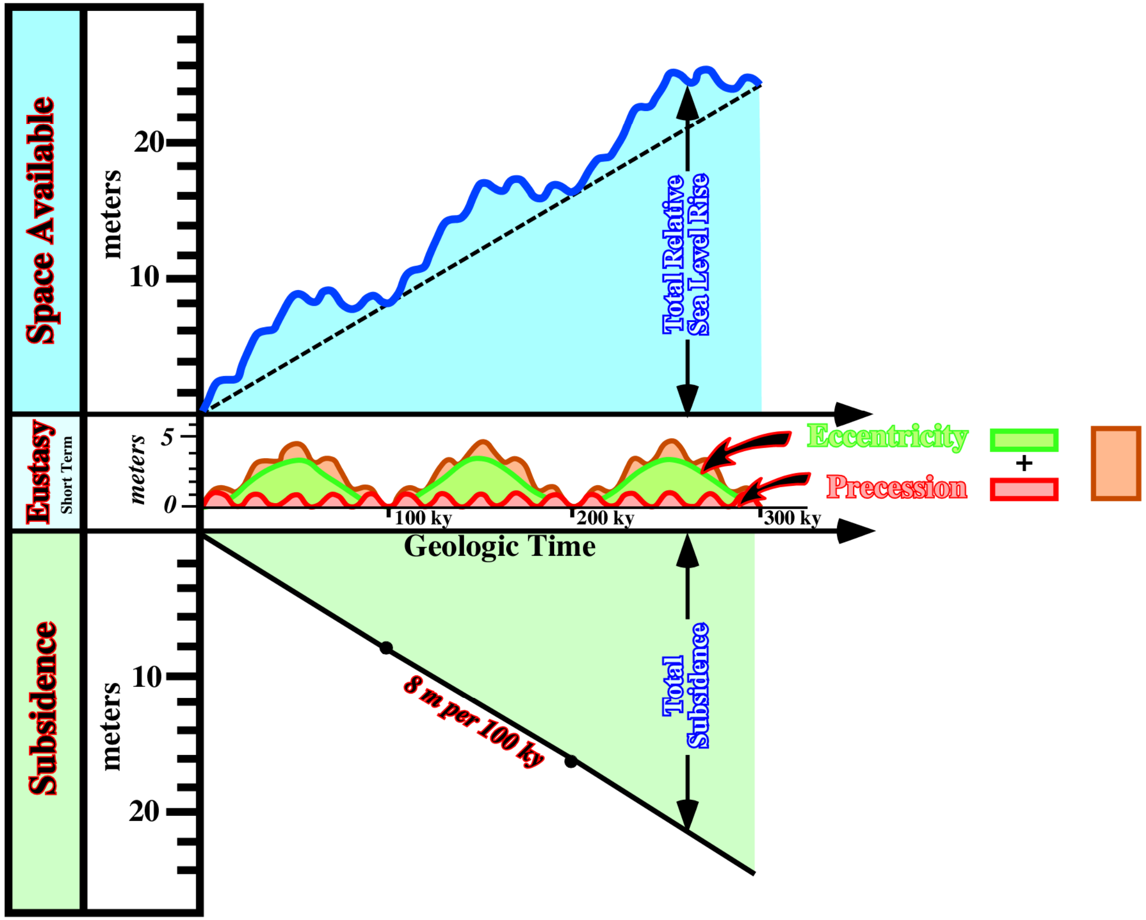


Fig. 127- On these diagrams, where the space available, eustasy (Earth's eccentricity and precession) and subsidence are taken into account, it is quite obvious that eustasy has a preponderant role on variations of the space available for the sediments. Such conjecture seems to be difficult to refute outside of the sedimentary basins developed in a compressional tectonic regimes, particularly in foredeep basins and folded belts.

3)

Major

Transgressive / Regressive

Cycles

Recapitulation

Major Transgressive / Regressive Cycles

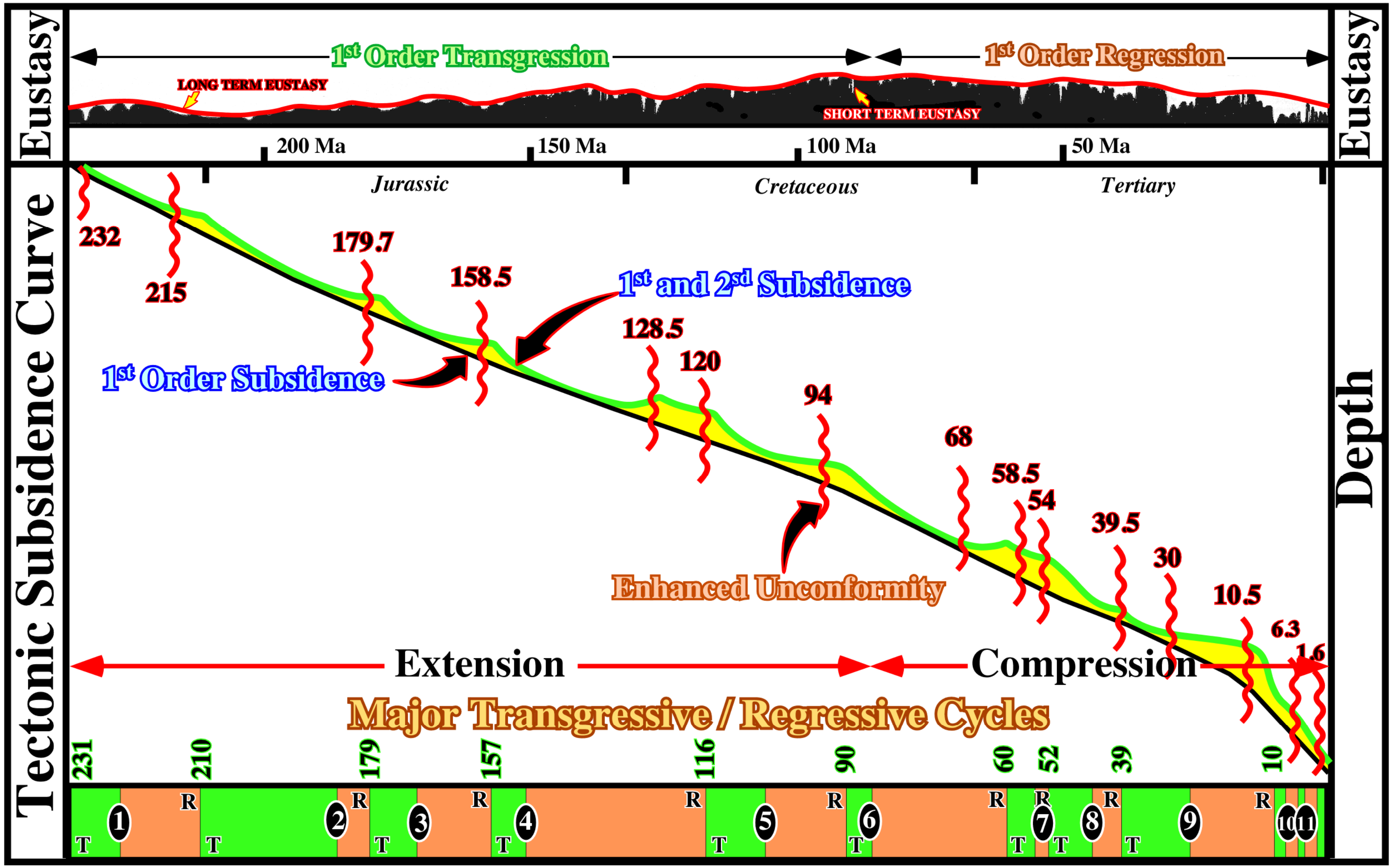


Fig. 128- On this figure are summarized the major Meso- Cenozoic Transgressive / Regressive Cycles, as well as the unconformities between them. The short and long-term eustatic curves are depicted on the top, as well as the 1st order transgression and regression curve.

Recapitulation

Transgressive / Regressive Cycle n° 7

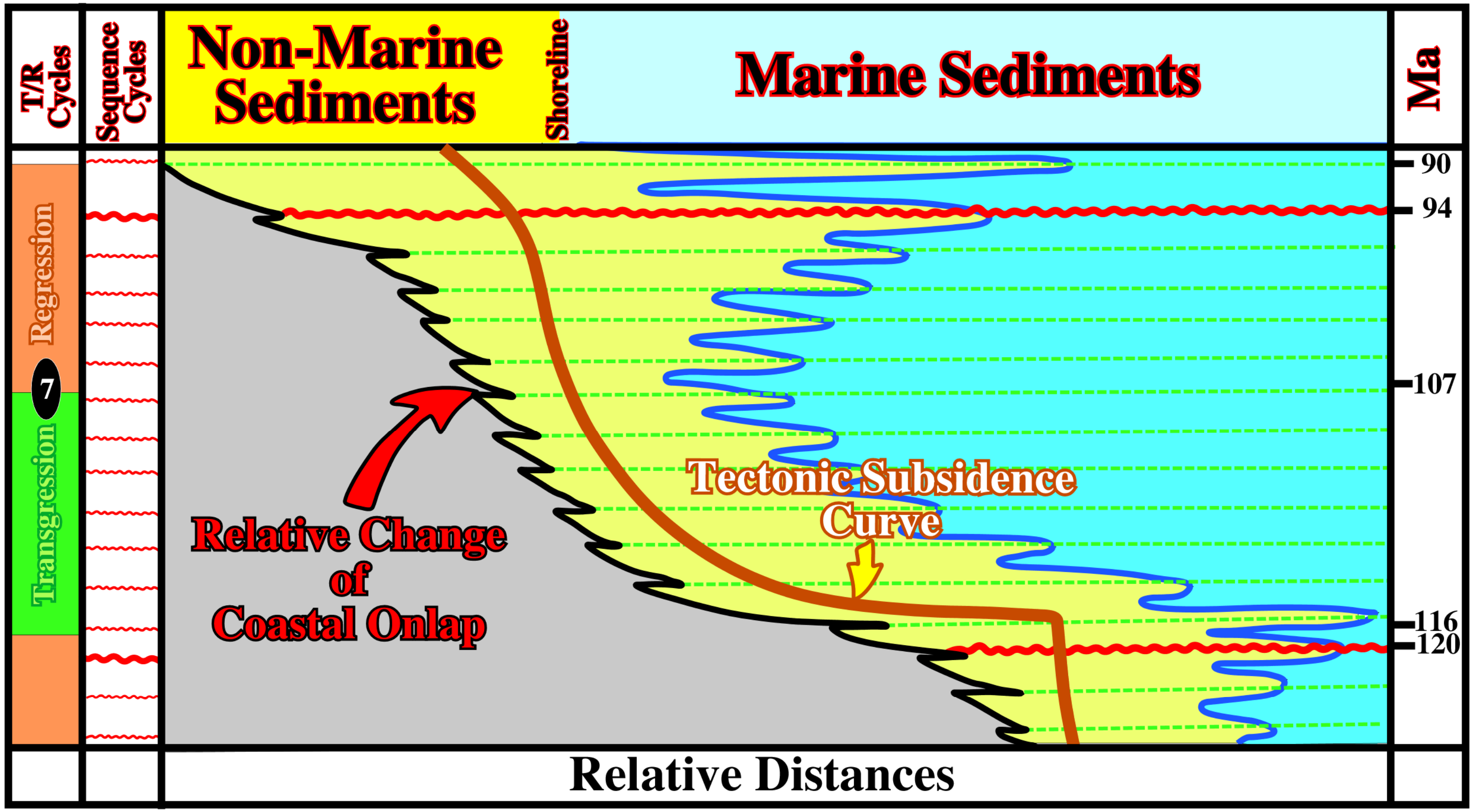


Fig. 129- On this figure is represented the Meso-Cenozoic transgressive / regressive cycle nº 7, the sequence cycles (according to the Haq' curve), the tectonic subsidence, the relative coastal onlap, as well as the displacements of the depositional coastal break (roughly the shoreline).

4)

Space Available

Sediment Supply

Recapitulation

Space Available / Sediment Supply

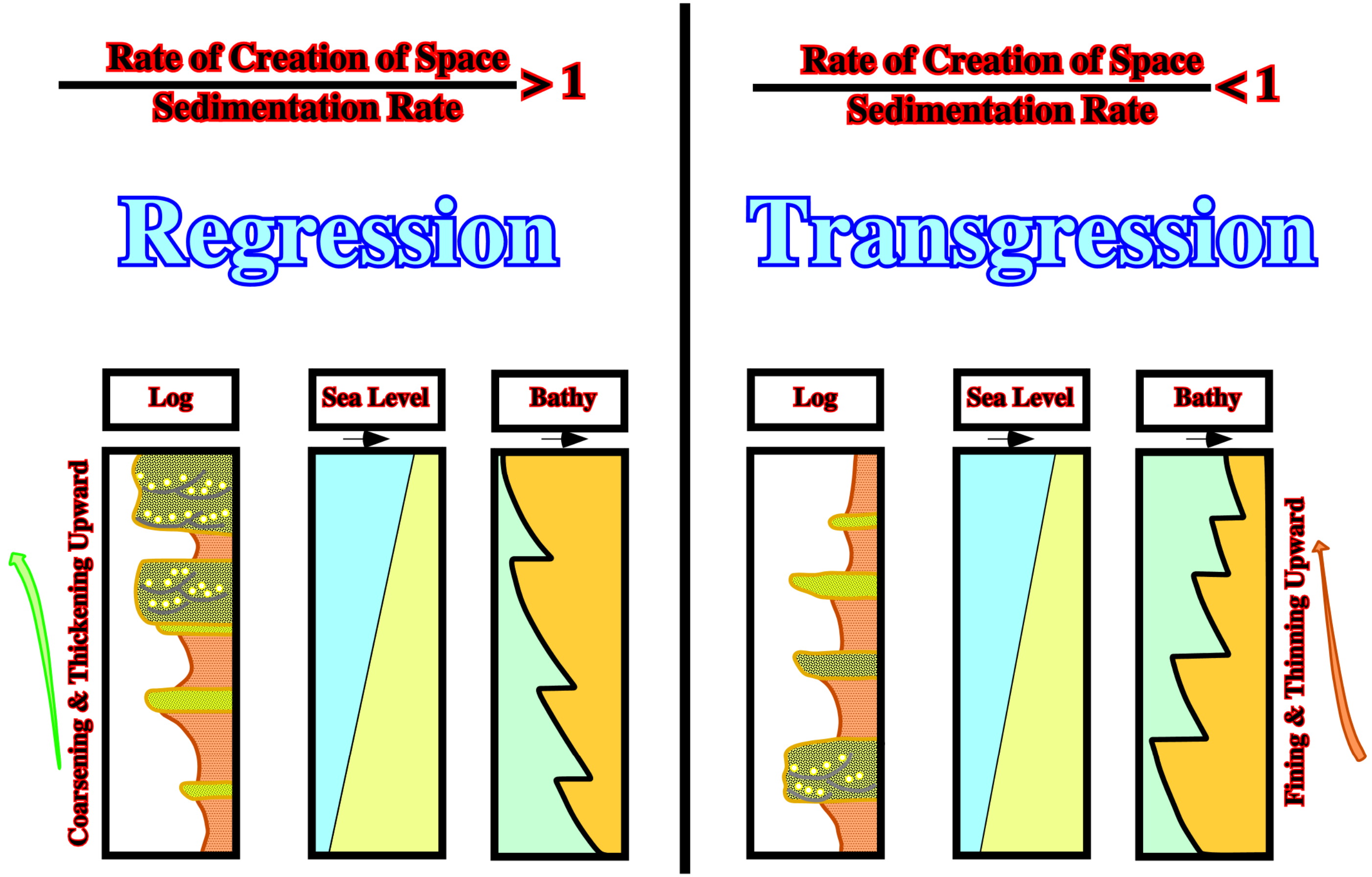


Fig. 130 - As illustrated above, when the ratio between the rate of creation of space and the rate of sedimentation rate is higher than 1 the deposits sediments are coarsening and thickening upward. Contrariwise, when the ratio is smaller than 1, the deposit sediments are fining and thinning upward. In other words, in the first case a regression takes place, while, in the second one, a transgression occurs.

5)

Paleobathymetry
Faunal Peaks
Depositional Systems
Lithofacies
Electric Log Patterns
Dipmeters
Systems Tracts
Color Code

Recapitulation

Sequential Stratigraphy

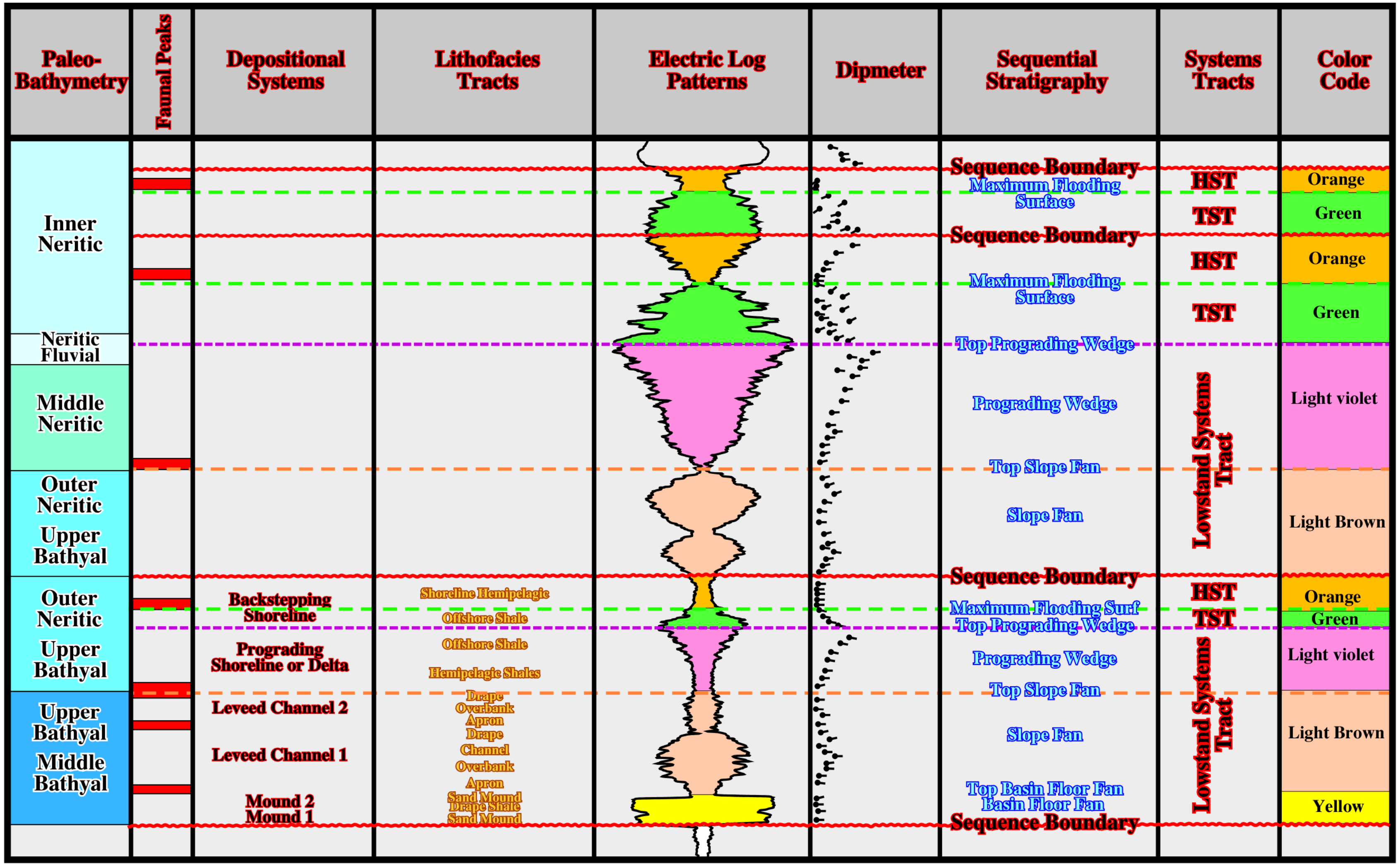


Fig. 131- On this plate is depicted the sequential stratigraphy of a hypothetical well. Notice that the proposed color code is largely adopted by the majority of explorationists using sequential stratigraphic analyses.

6)

Sea Level

Systems Tracts

Recapitulation

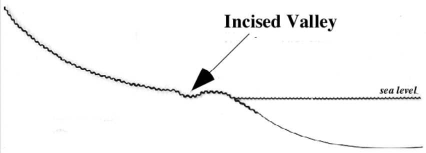
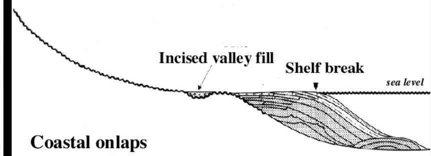
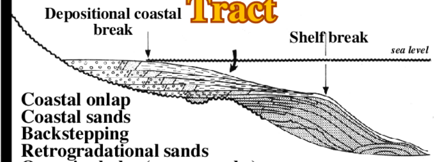
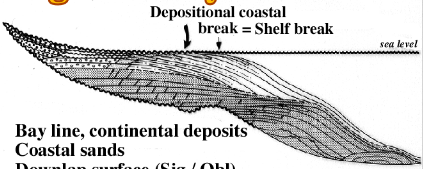
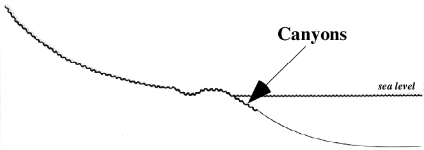
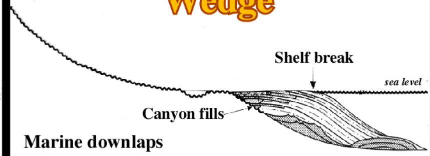
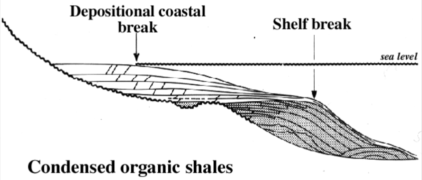
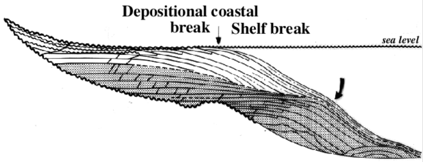
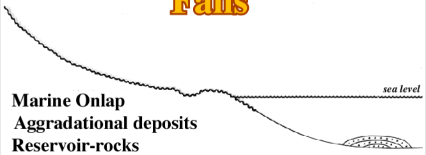
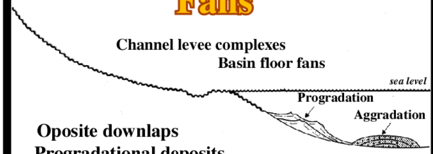
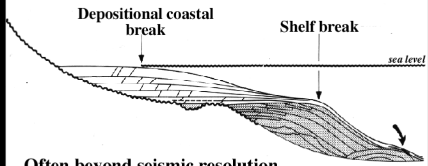
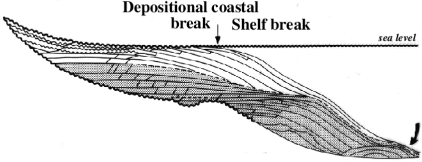
Position in the Basin		Sea Level			
		Low		High	
		Falling ↘	Rising ↗	Rising ↗	Falling ↘
	Shelf	**Erosion**  **Type I unconformity**	**Incised Valley Fill**  Coastal onlaps Aggradational deposits Lowstand deltas Stratigraphic traps	**Transgressive Systems Tract**  Coastal onlap Coastal sands Backstepping Retrogradational sands Organic shales (source-rocks) Reefs Stratigraphic traps Authigenic minerals	**Highstand Systems Tract**  Bay line, continental deposits Coastal sands Downlap surface (Sig / Obl) Silty shales Charbon Seldom stratigraphic traps **Type II unconformity**
	Slope	**Erosion**  **Type I unconformity**	**Lowstand Prograding Wedge**  Marine downlaps Progradational deposits Lowstand deltas Undercompacted shales	**Condensed Section**  Condensed organic shales Hardgrounds Source rocks	**Highstand Systems Tract**  Progradations (Sig / Obl) Slope shales
	Abyssal Plain	**Slope & Basin Fans**  Marine Onlap Aggradational deposits Reservoir-rocks Morphological traps **Type I unconformity**	**Slope & Basin Fans**  Oposite downlaps Progradational deposits Restricted reservoir-rocks Morphological traps	**Condensed Section**  Often beyond seismic resolution Hardgrounds Shales, Diatomites, Cherts, etc.	**Highstand Systems Tract**  Basinal downlap surface Pelagic shales

Fig. 132- On this plate are depicted the different depositional systems developed on the shelf, slope or abyssal plain, when sea level rises or falls whether in lowstand or highstand geological settings.

Recapitulation

Environments & Unconformities

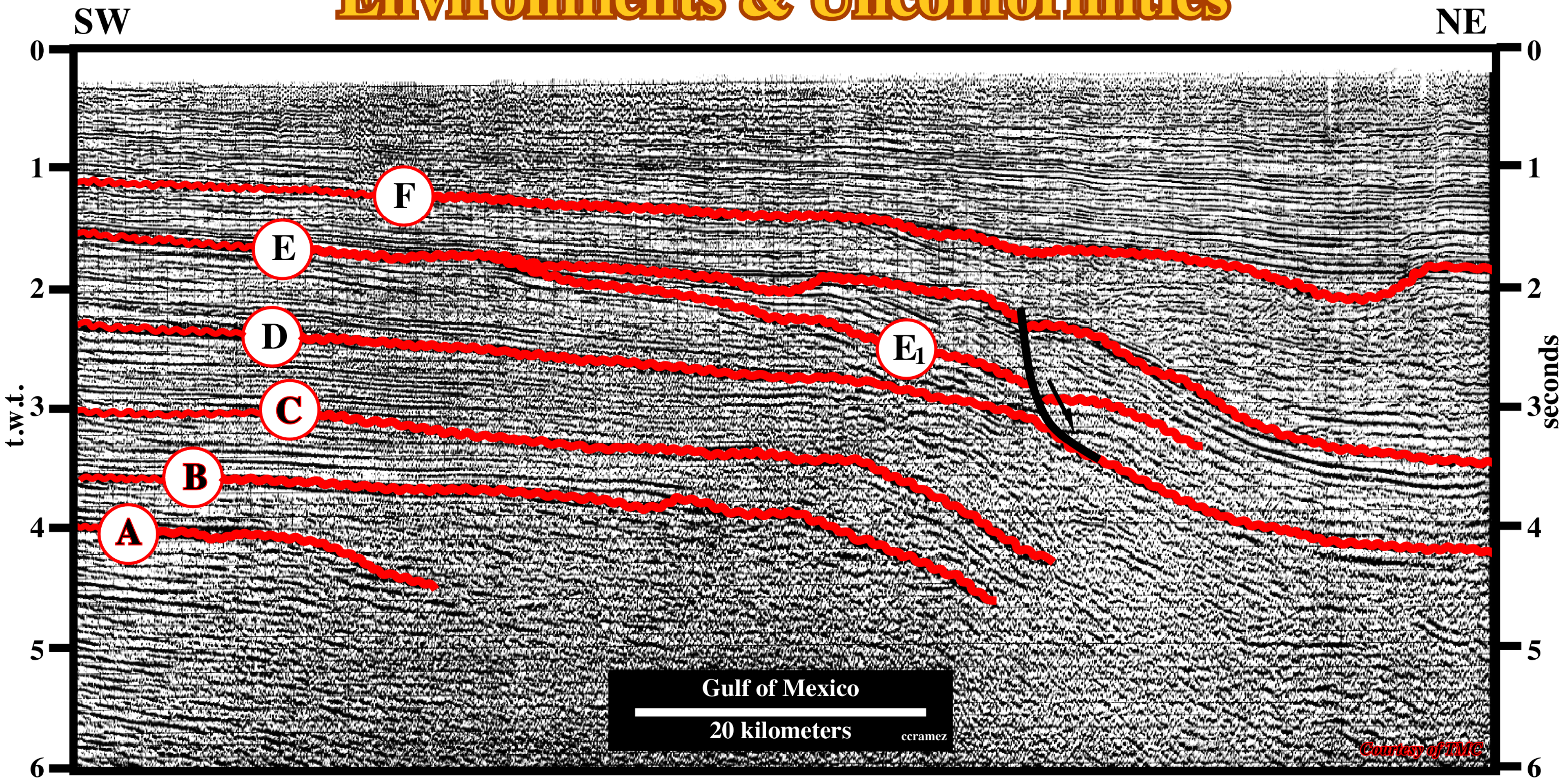


Fig. 133- On this seismic line from the Gulf of Mexico, where the main sequence cycles boundaries, that is to say, the main unconformities are indicated, all depositional hypotheses depicted on the fig. 132 can be illustrated as shown in next figure (fig. 134),

Recapitulation

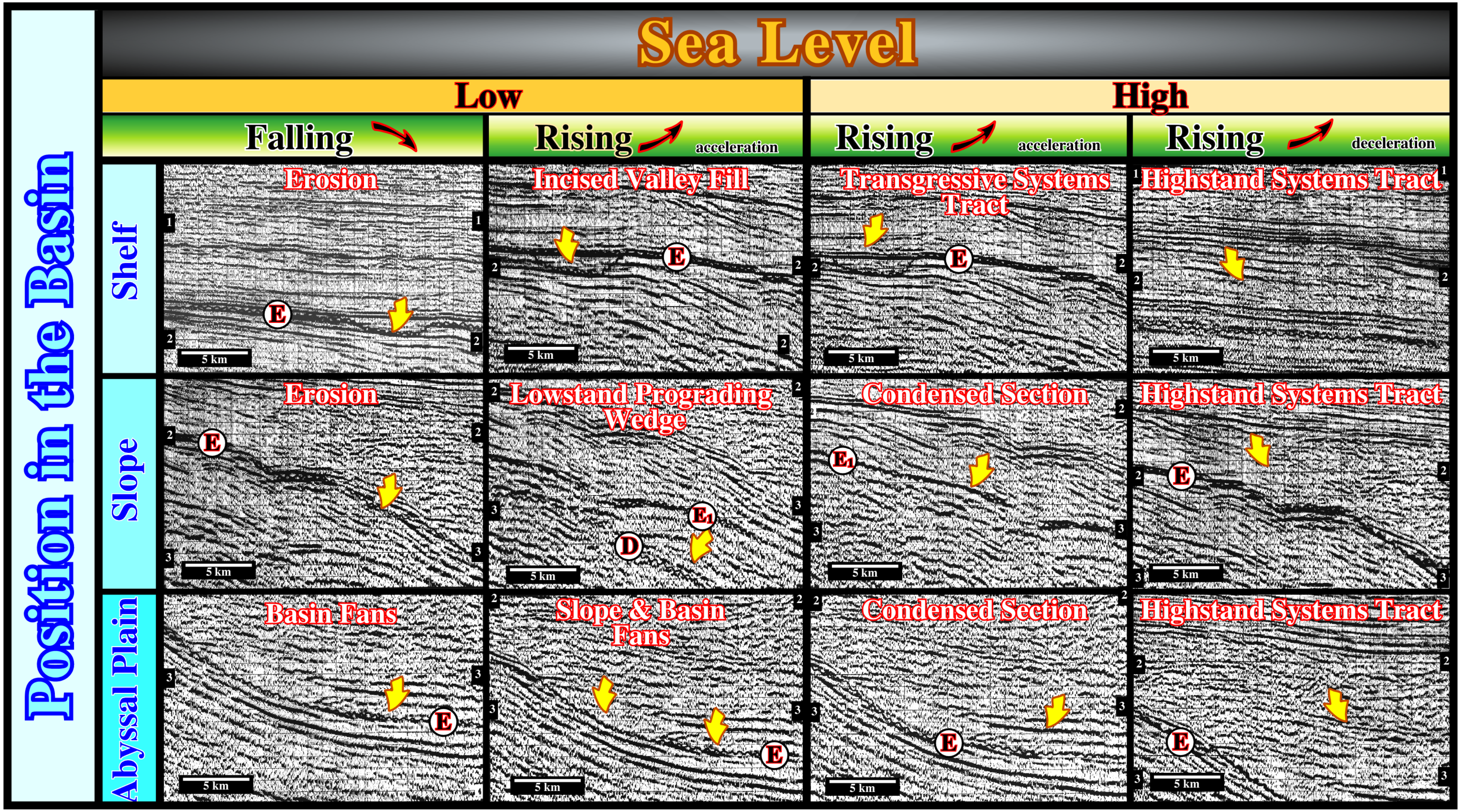


Fig. 134 - All depositional systems depicted on fig. 132 are illustrated above by close-ups of the seismic line shown in fig. 133. Each of these close-ups is detailed next (figs. 134 to 145).

Recapitulation

Low Sea Level, Falling, Shelf

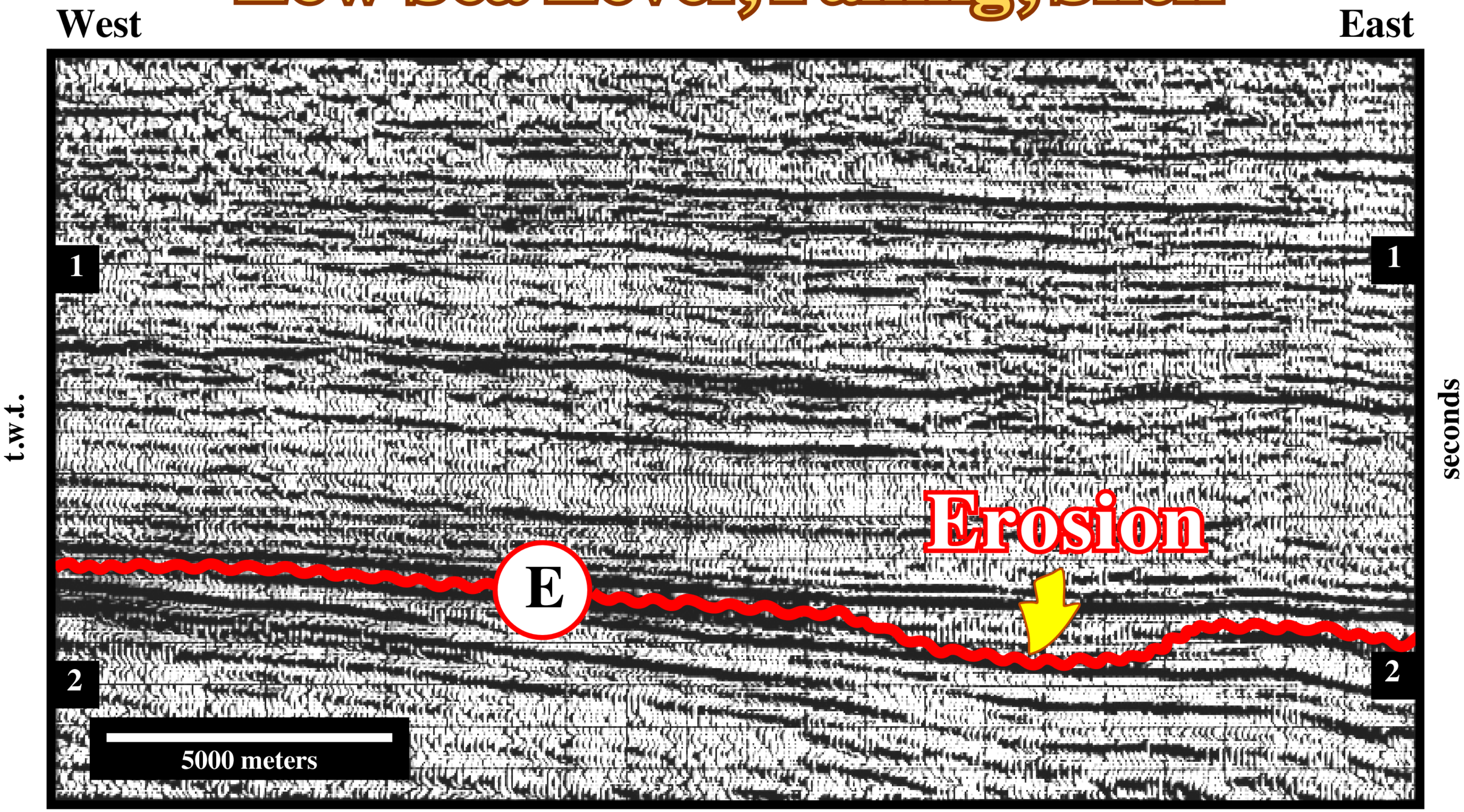


Fig. 135 - On this close-up, an incised valley, probably filled by shaly sediments (absence of differential compaction), suggests not only the most likely location of a sequence cycle boundary, but also: (i) a low sea level geological context due to a significant relative sea level fall and (ii) an exhumed coastal plain.

Recapitulation

Low Sea Level, Rising, Shelf

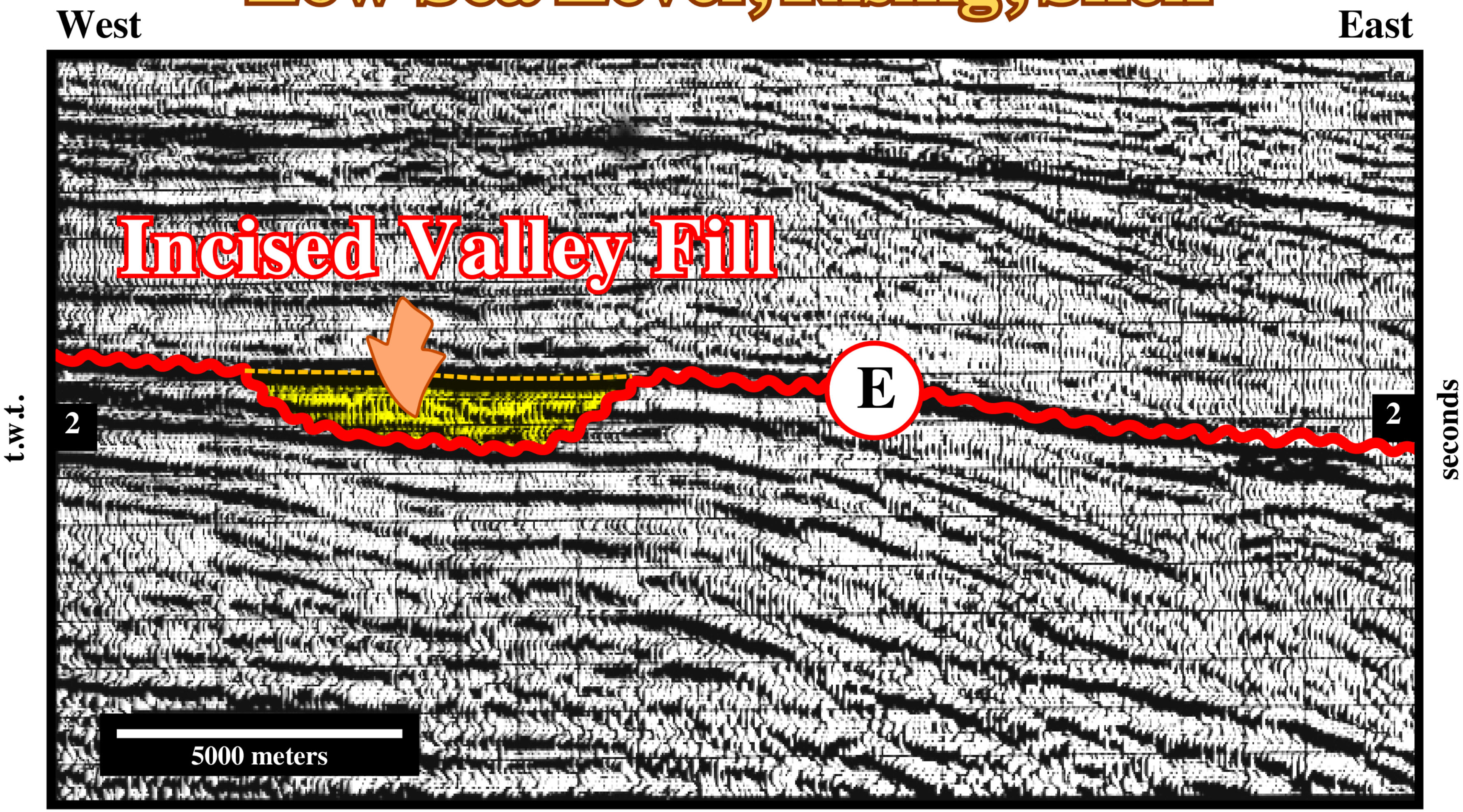


Fig. 136- Here, the filling of an incised valley, that is to say, the incised valley fill not only enhanced the E sequence cycle boundary but also allow explorationists to recognize: (i) an exhumed shelf environment and (ii) rising of the relative sea level in a lowstand geological setting.

Recapitulation

Low Sea Level, Falling, Slope

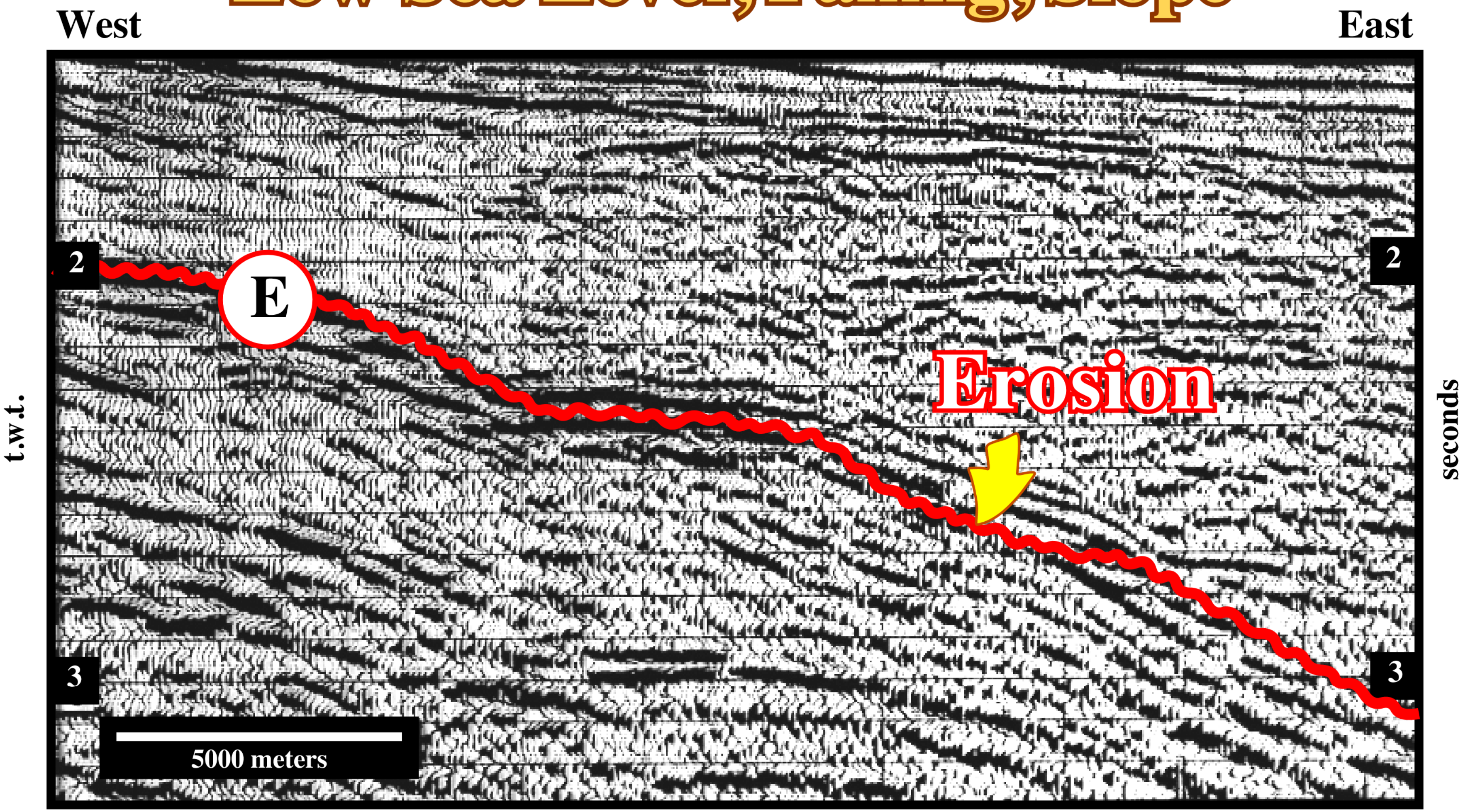


Fig. 137- On this close-up, the erosion (submarine canyon) in the upper slope of the E sequence cycle boundary, suggests not only an obvious slope environment, but also a relative sea level fall responsible for the lowstand geological setting.

Recapitulation

Low Sea Level, Rising, Slope

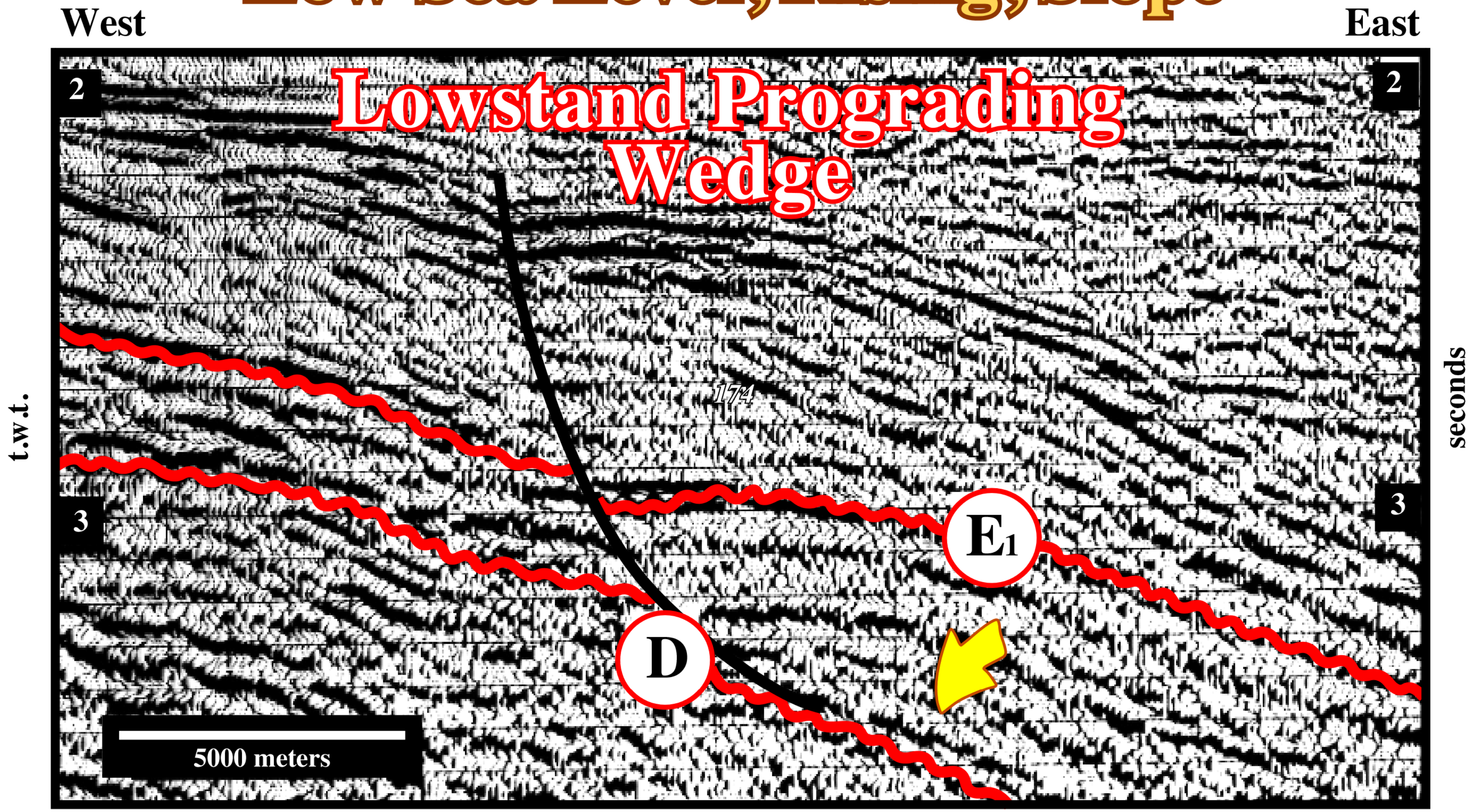


Fig. 138 - On this close-up, two sequence cycle boundaries are illustrated. The shelf break at the D unconformity is enhanced by the listric normal fault. On the other hand, the lowstand prograding wedge, underlined by the yellow arrow suggests not only a slope environment, but a rising of the relative sea level in a lowstand geological context as well.

Recapitulation

Low Sea Level, Falling, Abyssal Plain

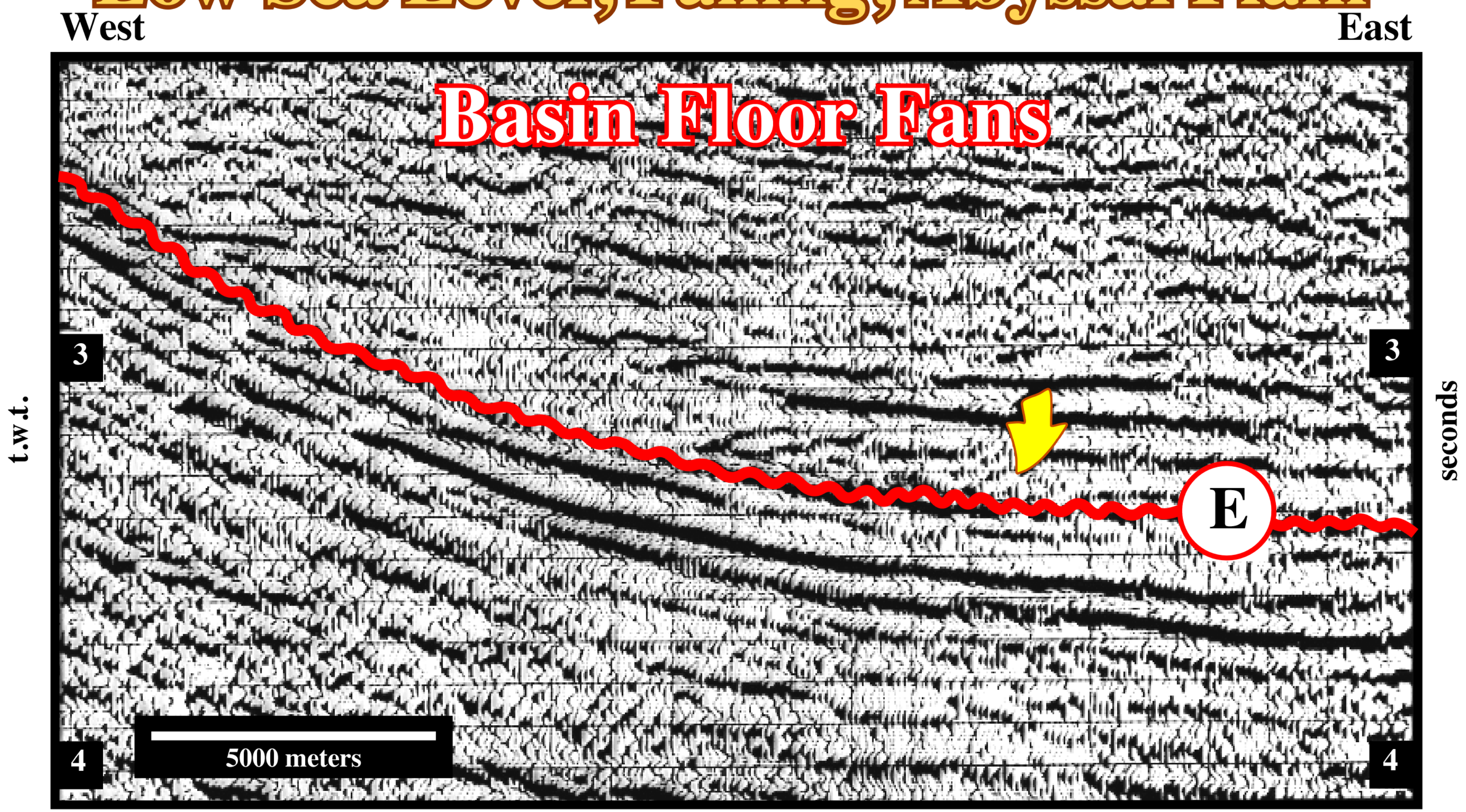


Fig. 139 - Here, the sedimentary anomaly at the bottom of the slope of the E sequence cycle boundary, suggests a falling of the relative sea level, which created a lowstand situation and deposition on the abyssal plain of a basin floor fan, which onlapping against the sequence cycle boundary is quite evident.

Recapitulation

Low Sea Level, Rising, Abyssal Plain

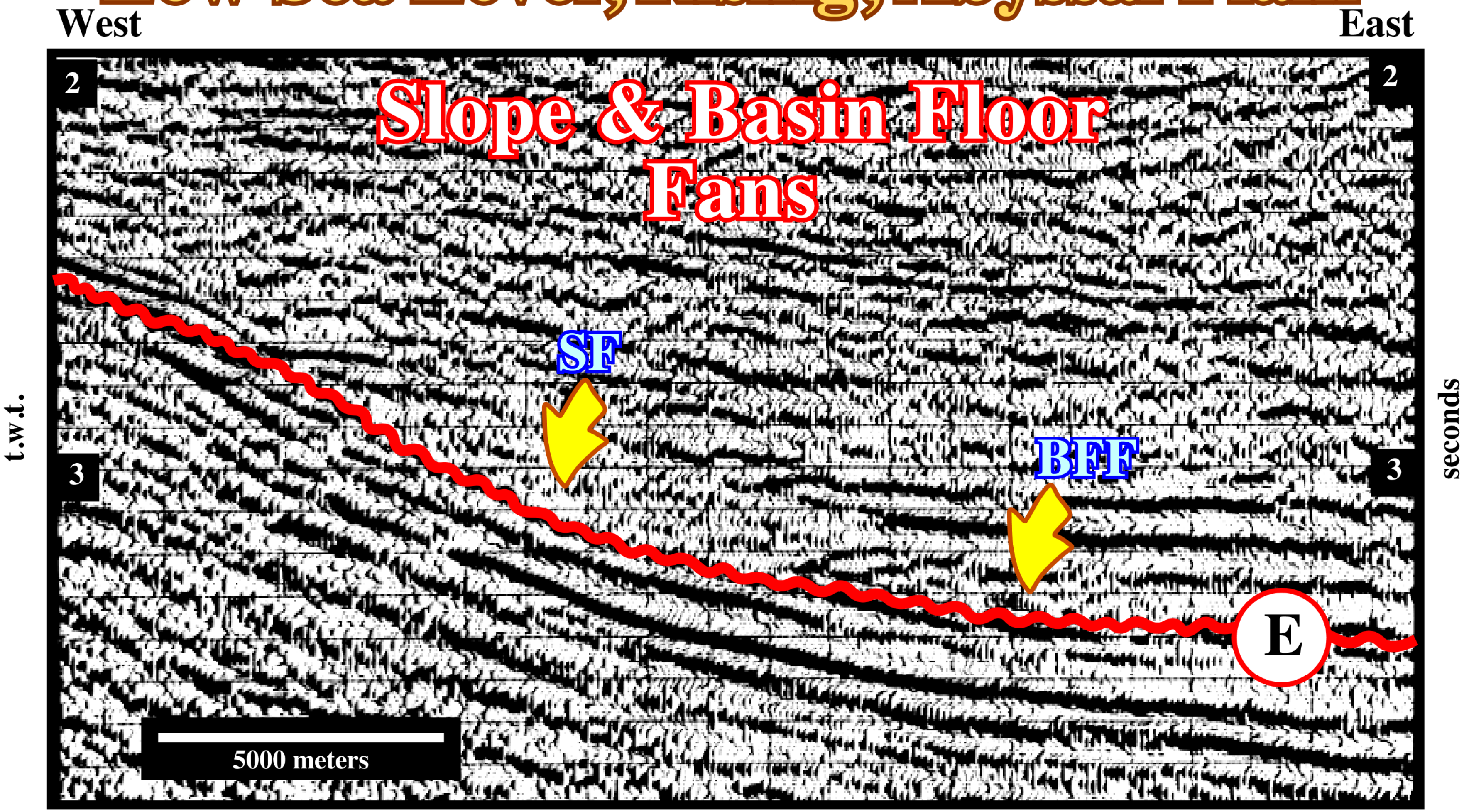


Fig. 140 - The deposition of a slope fan (SF) above the basin floor fan (BFF), readily recognized on this line near the toe of the slope of the E sequence cycle boundary and abyssal plain, suggests, in addition tothe depositional environments, a lowstand setting with a rising of the relative sea level.

Recapitulation

High Sea Level, Rising, Shelf

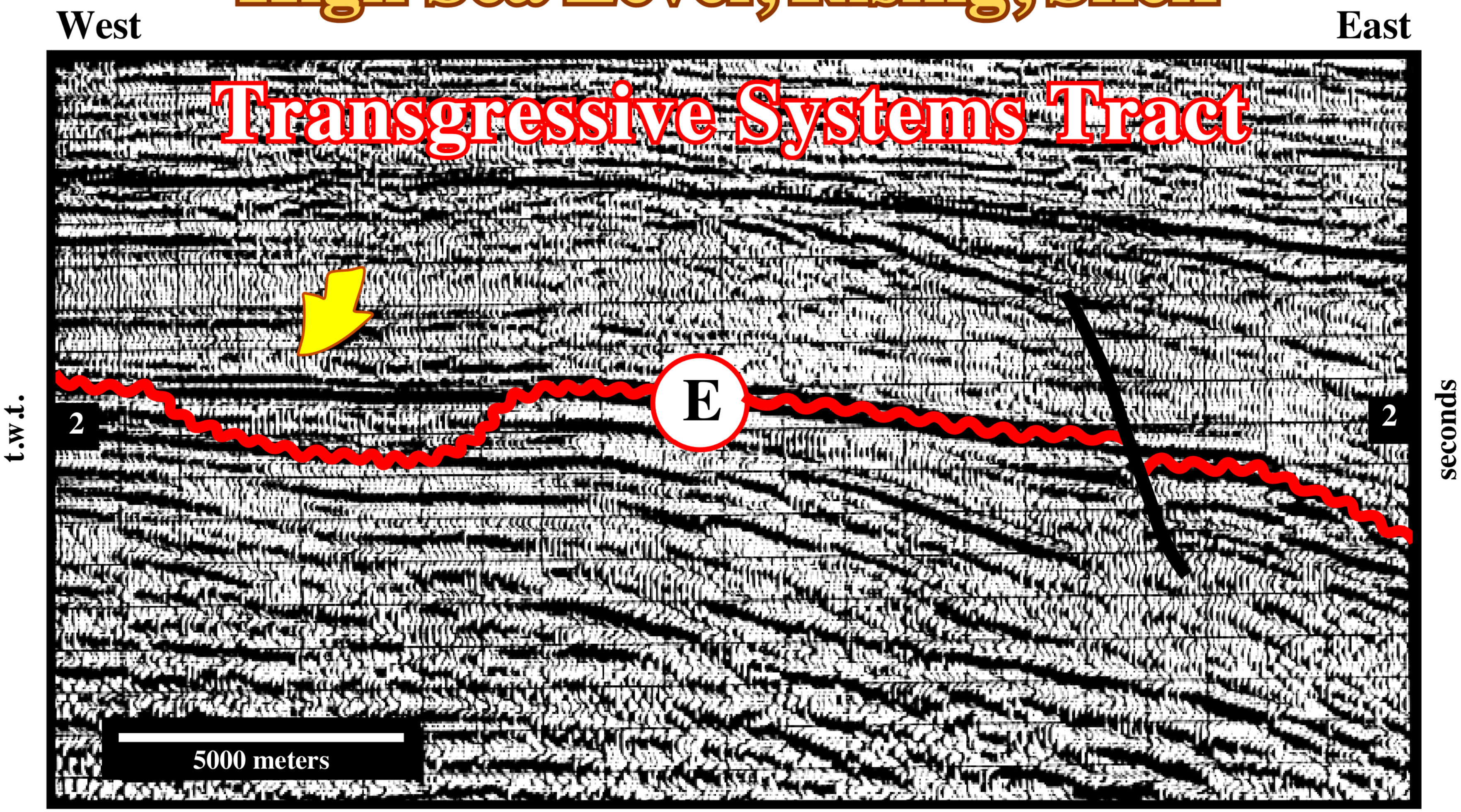


Fig. 141- On this close-up, above the incised valley fill, that is to say, in a shelf environment, the deposition of a transgressive systems tract, underlined by the yellow arrow, indicates a rising of the relative sea level and the development of a highstand geological setting with creation of a shelf (platform).

Recapitulation

Low Sea Level, Rising, Shelf

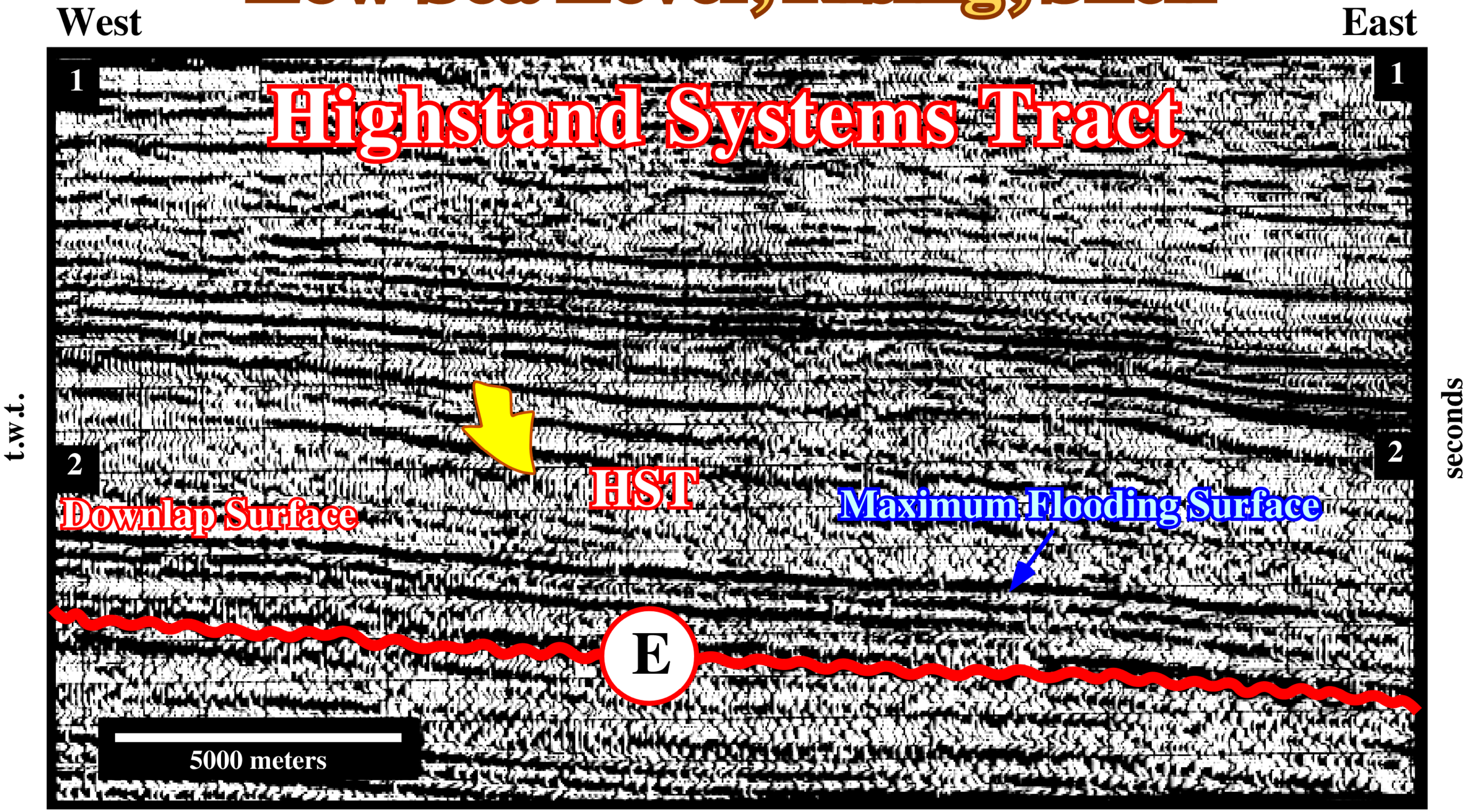


Fig. 142 - The highstand systems tract (HST) recognized above the maximum flooding surface, which limits the underlying transgressive systems tract suggests a shelf environment (when overlying the transgressive systems tract), a highstand geological situation and a decelerated relative sea level rise, that is to say, a relative sea level rise with a decreasing rate.

Recapitulation

High Sea Level, Rising, Slope

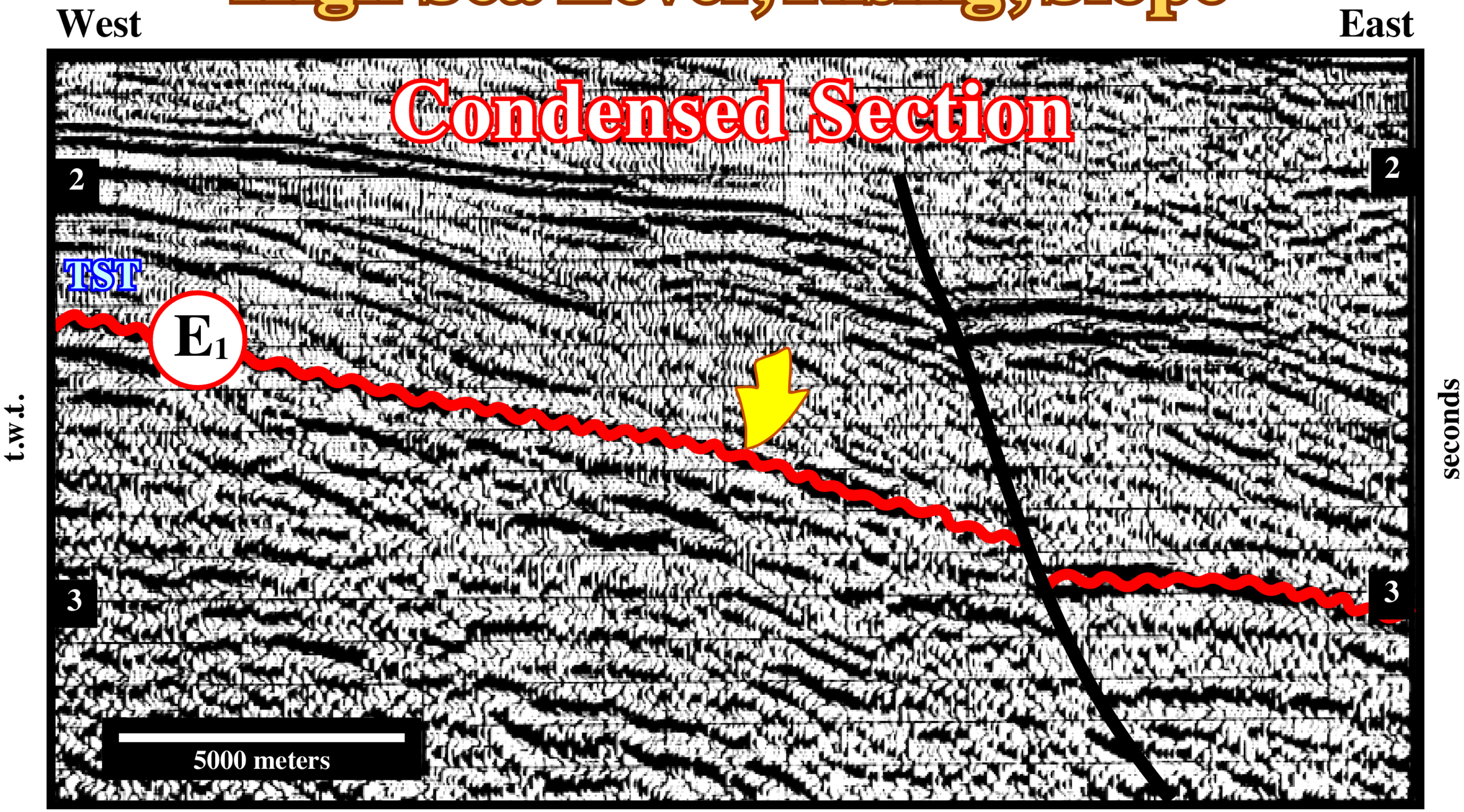


Fig. 143- Here above, in association with the distal shelf and upper slope of the unconformity E, that is to say seaward of the transgressive systems tract (TST) condensed stratigraphic section can be considered as basinward equivalent of the backsteeping transgressive sediments. Briefly speaking, condensed sections in the shelf and upper slope suggest relative rise of the sea level and highstand situations.

Recapitulation

High Sea Level, Rising, Slope

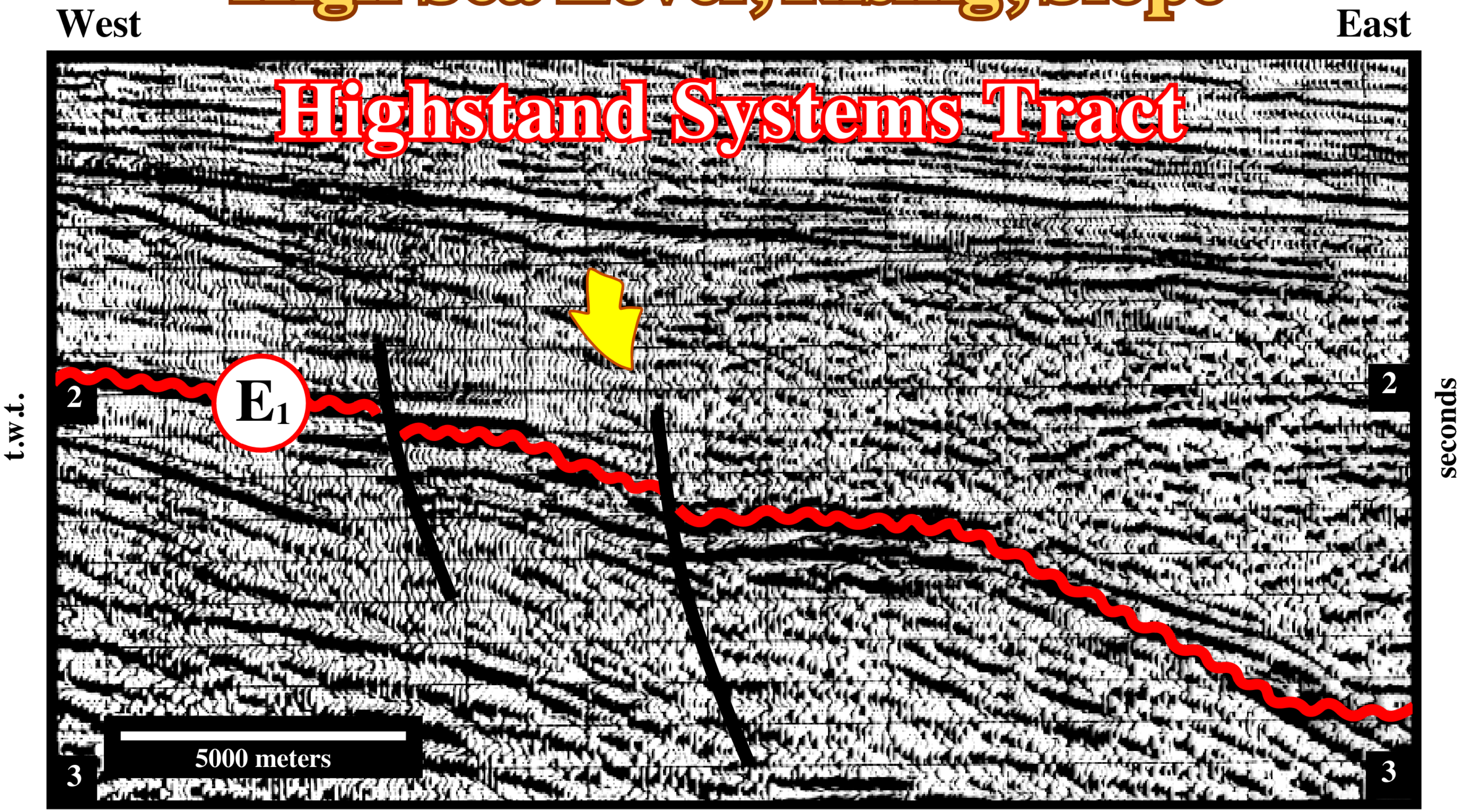


Fig. 144- When highstand systems tracts overly condensed sections correlable updip with transgressive systems tracts, they suggest: (i) a slope environment, (ii) a sea level rise with a decreasing rate and highstand geological situations, that is to say, a sea level higher than the shelf break.

Recapitulation

High Sea Level, Rising, Abyssal Plain

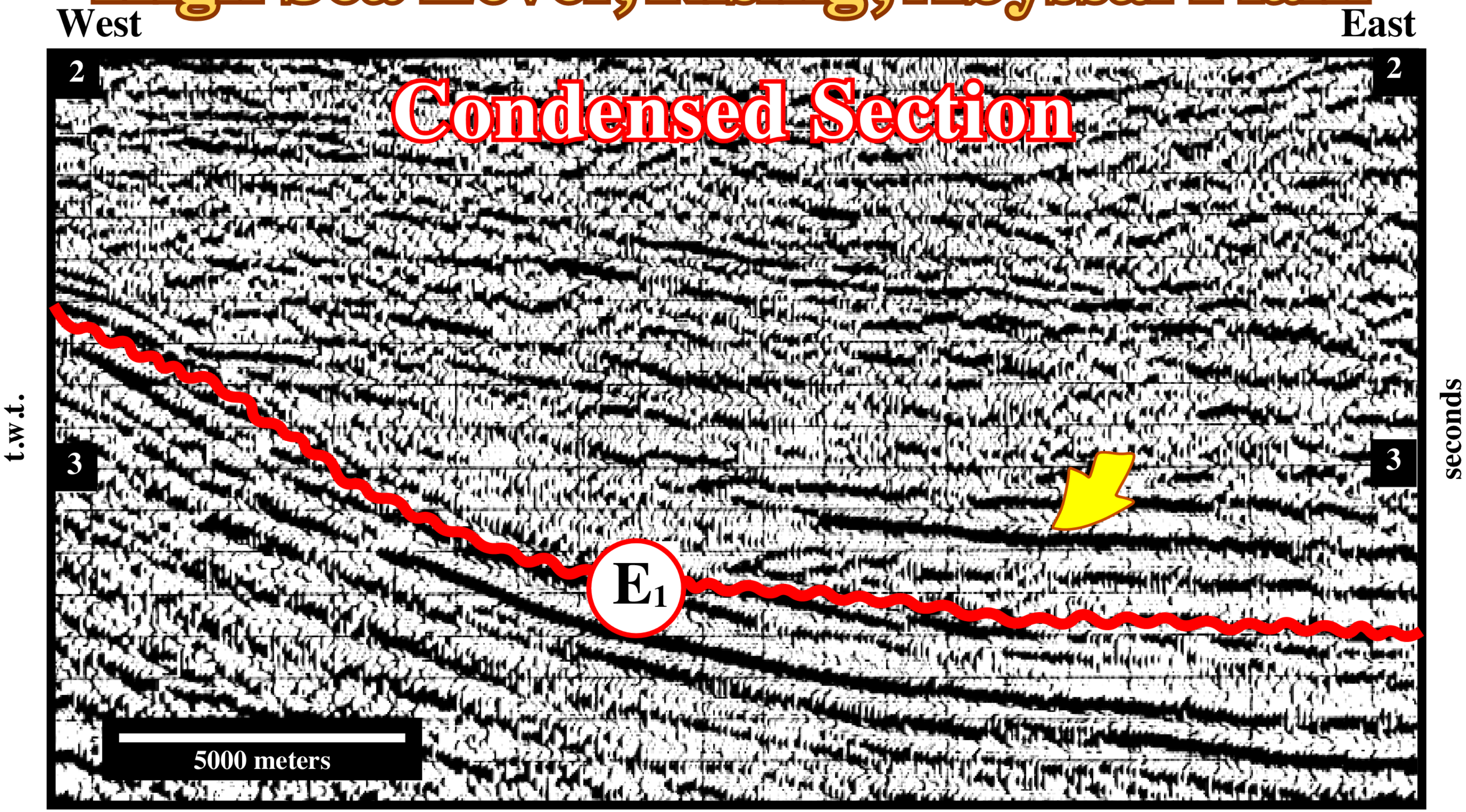


Fig. 145- Condensed stratigraphic section on the bottom of slope of abyssal plain suggest highstand geological conditions, a decreasing rate of the sea level rise and often a basin without a platform (shelf), that is to say, when the depositional coastal break and the shelf break are coincident.

Recapitulation

High Sea Level, Rising, Slope

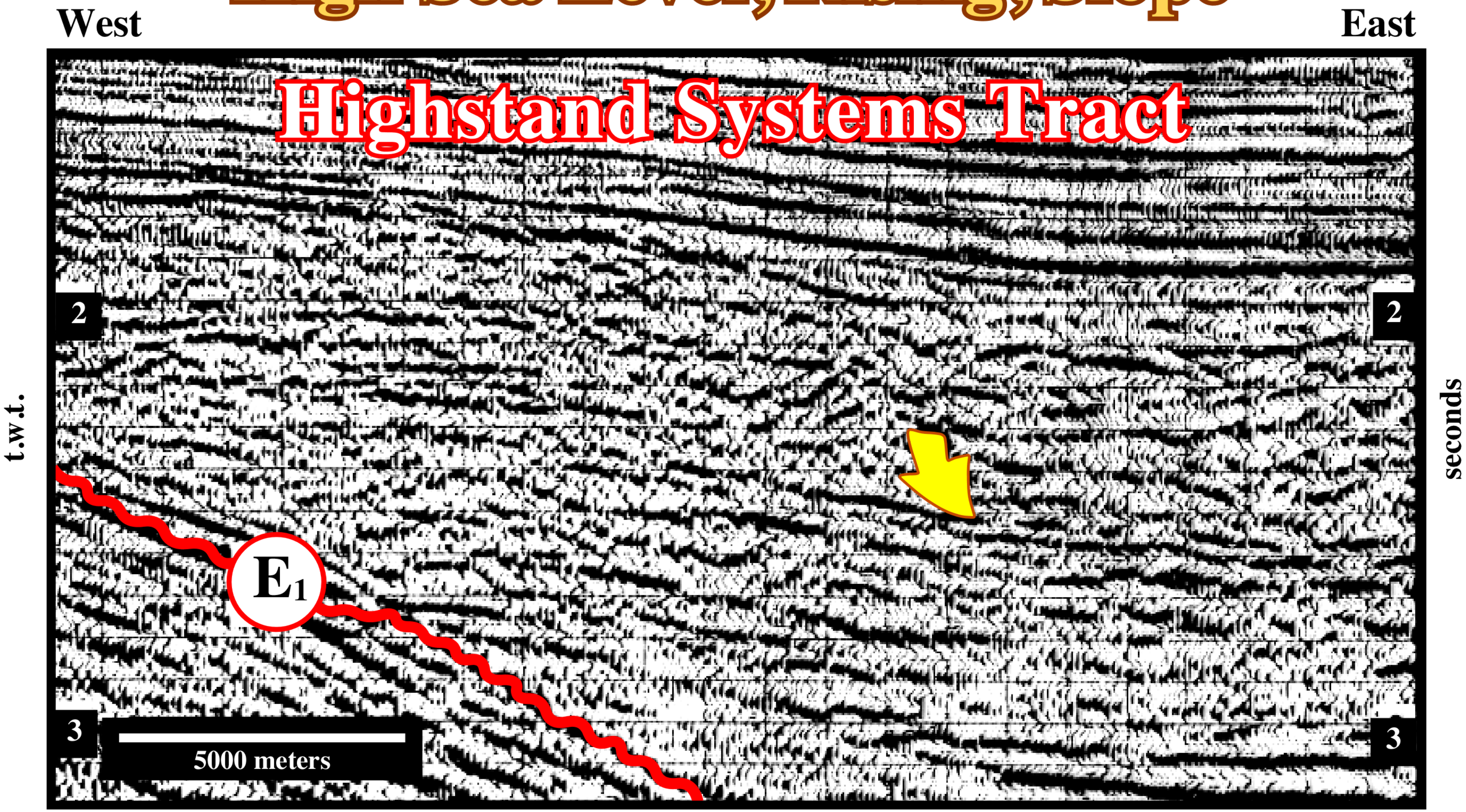
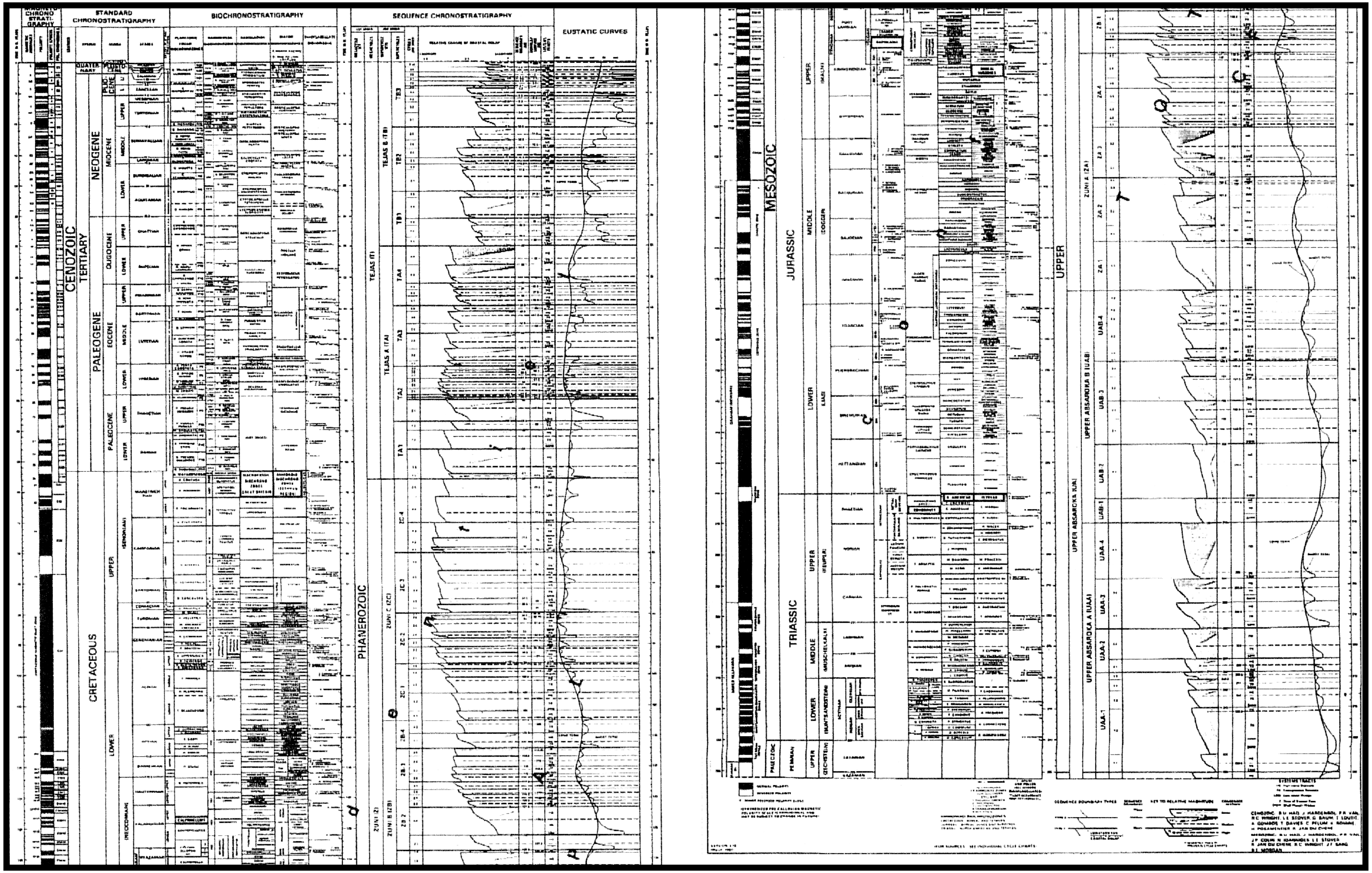
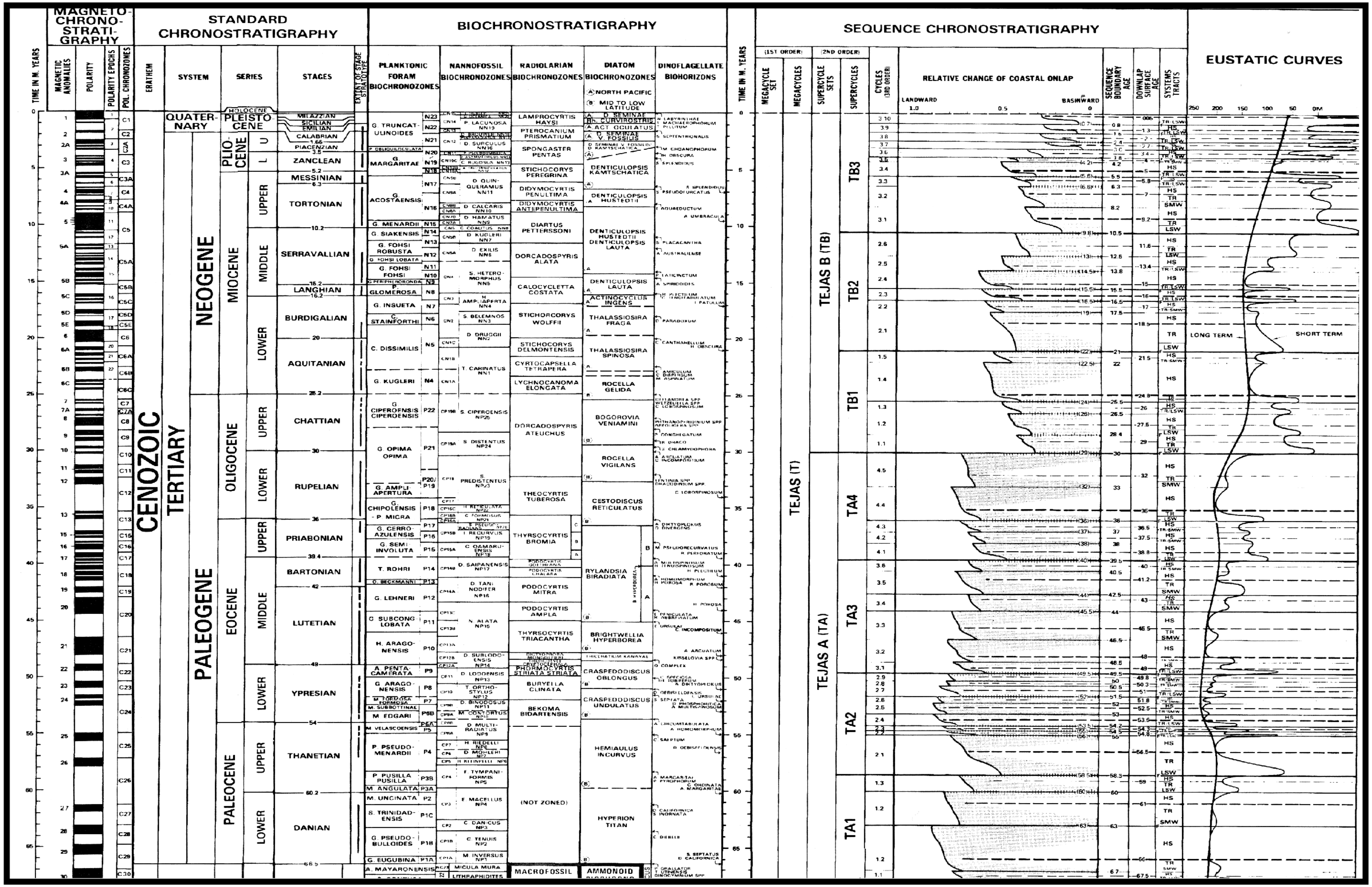


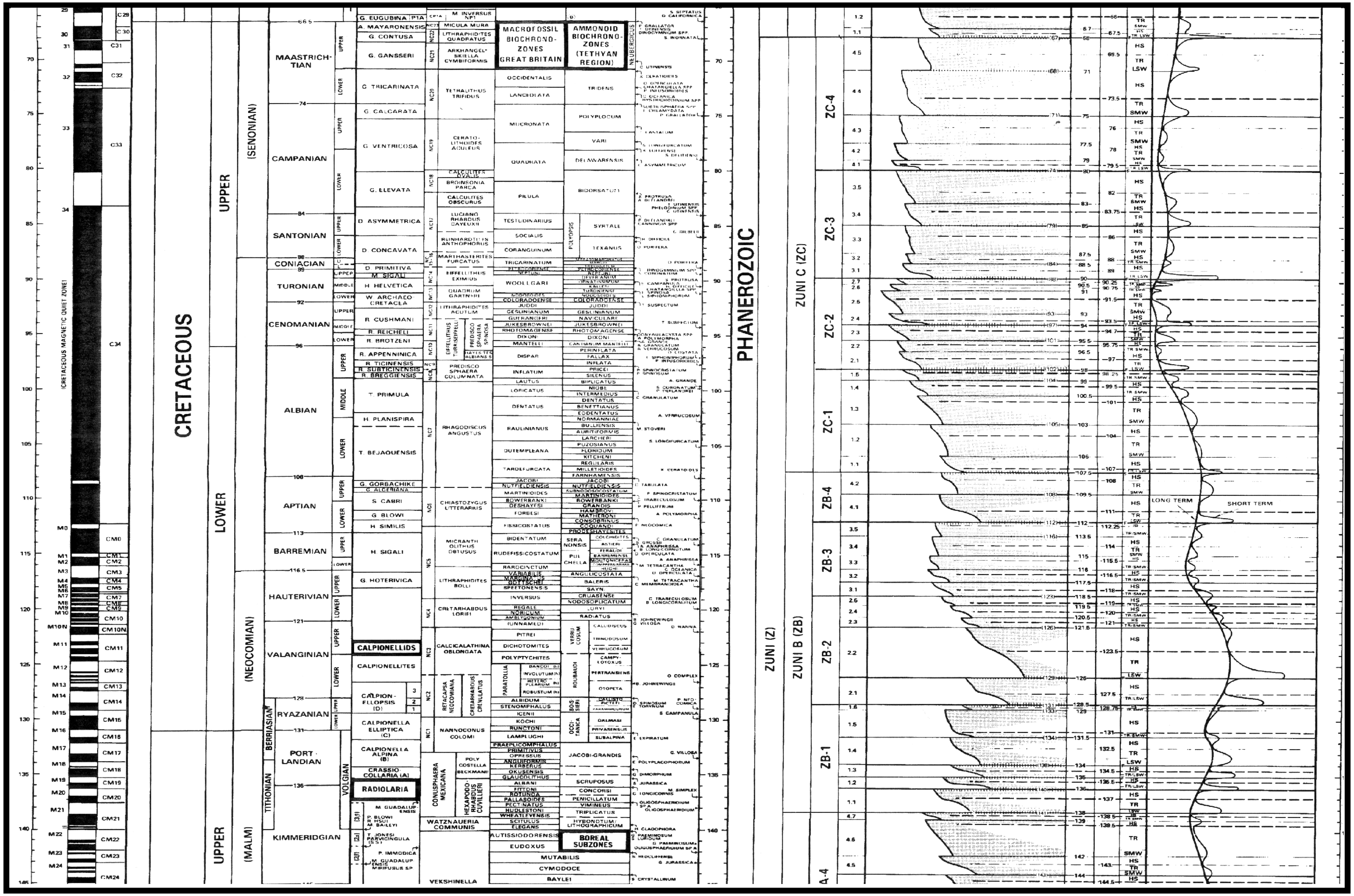
Fig. 146- On this close-up, a condensed stratigraphic section located in the slope, as indicated by the yellow arrow, suggests a decreasing rate of the relative sea level rise in a highstand geological setting with the depositional coastal break probably coincident with the shelf break.

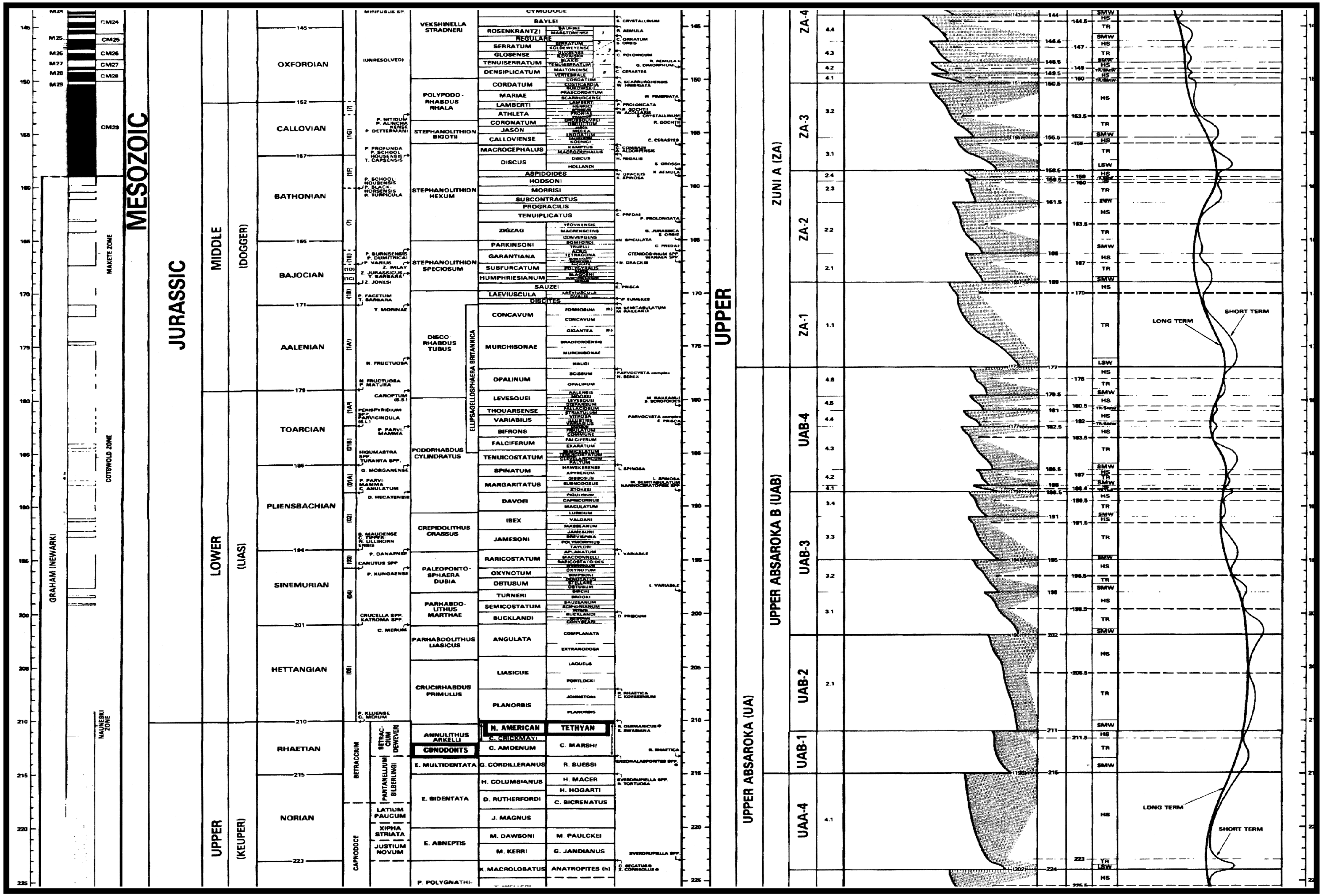
Meso - Cenozoic Cycle Chart

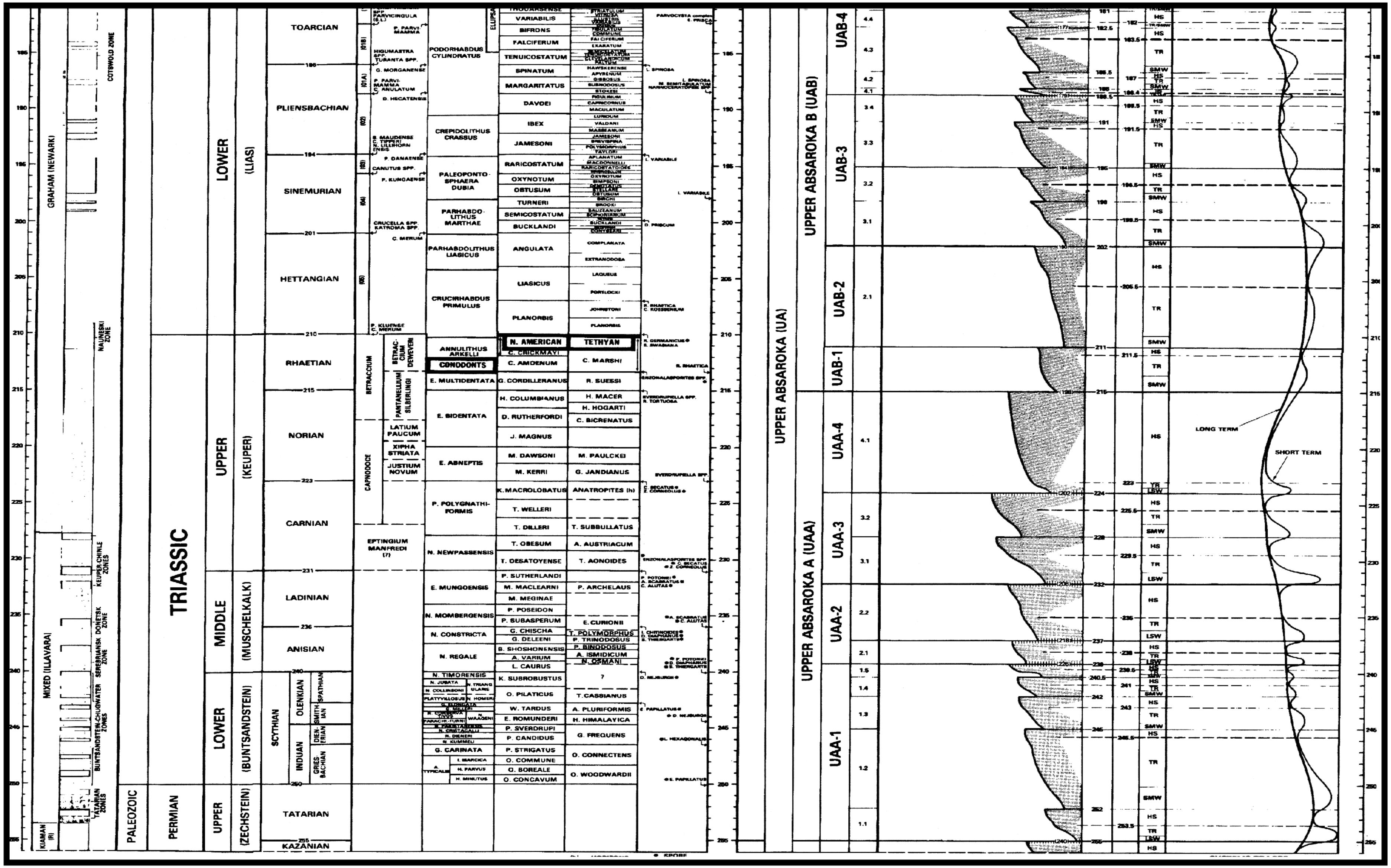
Mesozoic-Cenozoic Cycle Chart

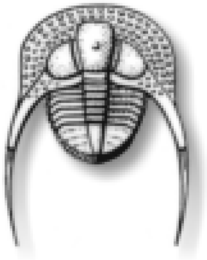



MAGNETO-CHRONO-STRATI-GRAPHY
STANDARD CHRONOSTRATIGRAPHY
BIOCHRONOSTRATIGRAPHY
SEQUENCE CHRONOSTRATIGRAPHY
EUSTATIC CURVES
TIME IN M. YEARS
MAGNETIC ANOMALIES
POLARITY
POLARITY EPOCHS
POL. CHRONOZONES
ERATHEM
SYSTEM
SERIES
STAGES
EXTENT OF STAGE STRATOTYPE
PLANKTONIC FORAM BIOCHRONOZONES
NANNOFOSSIL BIOCHRONOZONES
RADIOLARIAN BIOCHRONOZONES
DIATOM BIOCHRONOZONES
DINOFLAGELLATE BIOHORIZONS
MEGACYCLE SET
MEGACYCLES
SUPERCYCLE SETS
SUPERCYCLES
CYCLES
RELATIVE CHANGE OF COASTAL ONLAP
LANDWARD
BASINWARD
SEQUENCE BOUNDARY AGE
DOWNLAP SURFACE AGE
SYSTEMS TRACTS
LONG TERM
SHORT TERM
CENOZOIC
TERTIARY
QUATERNARY
NEOGENE
PALEOGENE
PLEISTOCENE
PLIOCENE
MIOCENE
OLIGOCENE
EOCENE
PALEOCENE
TORTONIAN
SERRAVALLIAN
LANGHIAN
BURDIGALIAN
AQUITANIAN
CHATTIAN
RUPELIAN
PRIABONIAN
BARTONIAN
LUTETIAN
YPRESIAN
THANETIAN
DANIAN
TEJAS (T)
TEJAS B (TB)
TEJAS A (TA)
TB3
TB2
TB1
TA4
TA3
TA2
TA1


(CRETACEOUS MAGNETIC QUIET ZONE)
CRETACEOUS
UPPER
LOWER
(SENONIAN)
(NEOCOMIAN)
(MALM)
MAASTRICHTIAN
CAMPANIAN
SANTONIAN
CONIACIAN
TURONIAN
CENOMANIAN
ALBIAN
APTIAN
BARREMIAN
HAUTERIVIAN
VALANGINIAN
BERRIASIAN
RYAZANIAN
PORTLANDIAN
TITHONIAN
VOLGIAN
KIMMERIDGIAN
CALPIONELLIDS
RADIOLARIA
MACROFOSSIL BIOCHRONOZONES GREAT BRITAIN
AMMONOID BIOCHRONOZONES (TETHYAN REGION)
BOREAL SUBZONES
NEUBERGICUS
PHANEROZOIC
ZUNI (Z)
ZUNI B (ZB)
ZUNI C (ZC)
ZC-4
ZC-3
ZC-2
ZC-1
ZB-4
ZB-3
ZB-2
ZB-1
A-4
LONG TERM
SHORT TERM


MESOZOIC
JURASSIC
UPPER
MIDDLE
(DOGGER)
LOWER
(LIAS)
(KEUPER)
OXFORDIAN
CALLOVIAN
BATHONIAN
BAJOCIAN
AALENIAN
TOARCIAN
PLIENSBACHIAN
SINEMURIAN
HETTANGIAN
RHAETIAN
NORIAN
GRAHAM (NEWARK)
COTSWOLD ZONE
MAKETE ZONE
NALIKEVSKI ZONE
CM24
CM25
CM26
CM27
CM28
CM29
M24
M25
M26
M27
M28
M29
N. AMERICAN
TETHYAN
CONODONTS
ELLIPSAGELLOSPHAERA BRITANNICA
ZUNI A (ZA)
UPPER ABSAROKA B (UAB)
UPPER ABSAROKA (UA)
ZA-4
ZA-3
ZA-2
ZA-1
UAB-4
UAB-3
UAB-2
UAB-1
UAA-4
LONG TERM
SHORT TERM
HS
TR
SMW
LSW


PALEOZOIC
PERMIAN
TRIASSIC
UPPER
LOWER
MIDDLE
(LIAS)
(KEUPER)
(MUSCHELKALK)
(BUNTSANDSTEIN)
(ZECHSTEIN)
SCYTHIAN
TOARCIAN
PLIENSBACHIAN
SINEMURIAN
HETTANGIAN
RHAETIAN
NORIAN
CARNIAN
LADINIAN
ANISIAN
OLENEKIAN
INDUAN
SPATHIAN
SMITHIAN
DIENERIAN
GRIESBACHIAN
TATARIAN
KAZANIAN
GRAHAM (NEWARK)
MIXED (ILLAVARA)
KIAMAN (R)
COTSWOLD ZONE
NAUNESKI ZONE
KEUPER-CHINLE ZONES
SEREBRIANSK DONETSK ZONE
BUNTSANDSTEIN-CHUGWATER ZONES
TATARIAN ZONES
CONODONTS
N. AMERICAN
TETHYAN
EPTINGIUM MANFREDI
UPPER ABSAROKA B (UAB)
UPPER ABSAROKA A (UAA)
UPPER ABSAROKA (UA)
UAB-4
UAB-3
UAB-2
UAB-1
UAA-4
UAA-3
UAA-2
UAA-1
HS
TR
SMW
LSW
LONG TERM
SHORT TERM



March, 2005