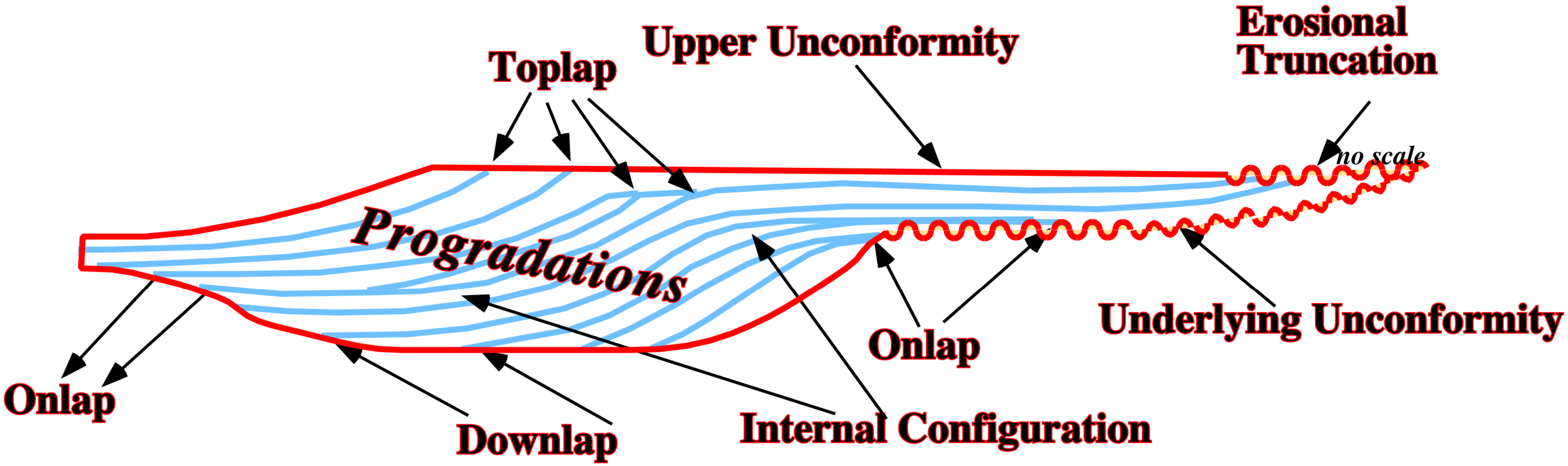
Volume II

Depositional Model
&
Geometrical Relationships

Onlap / Truncation / Downlap / Unconformities



Driving Concepts

1st Driving Concept

Time stratigraphy is established by physical stratal patterns of the rocks, on the ground, on electrical logs and on seismic lines.

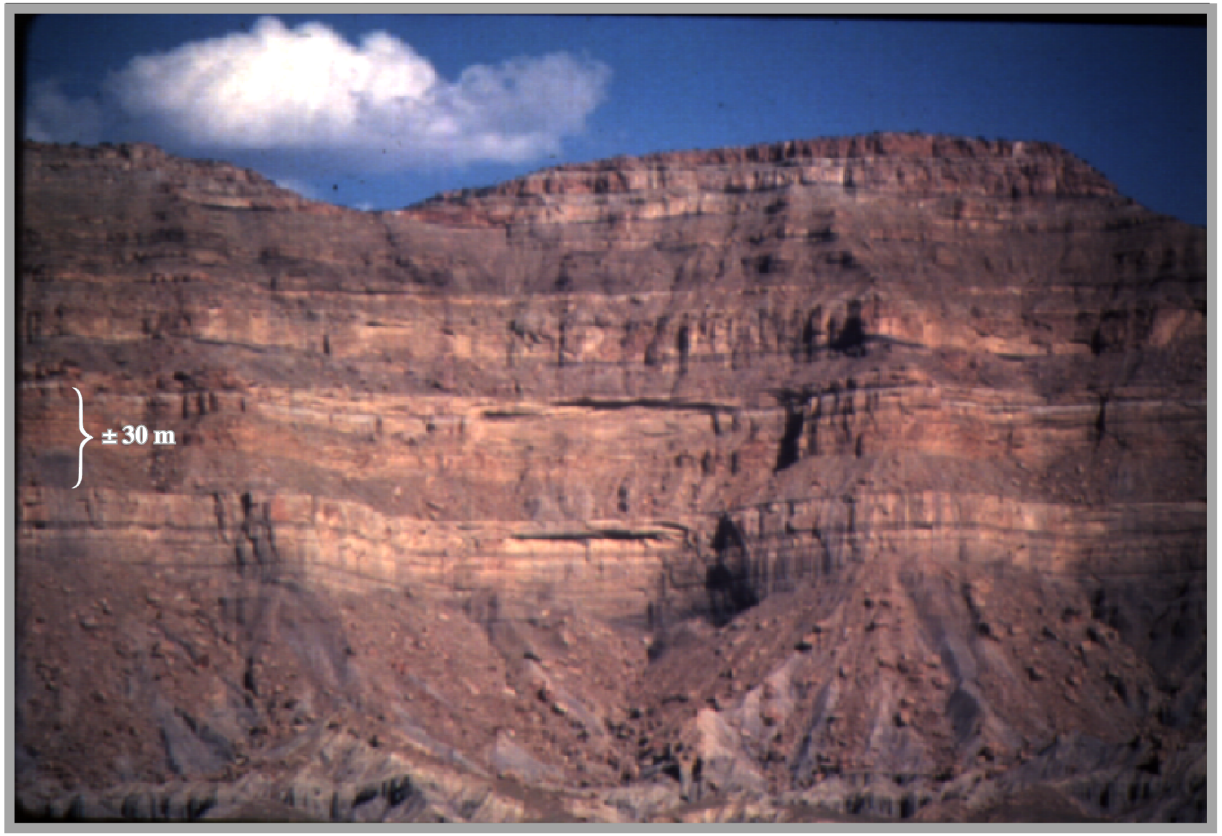
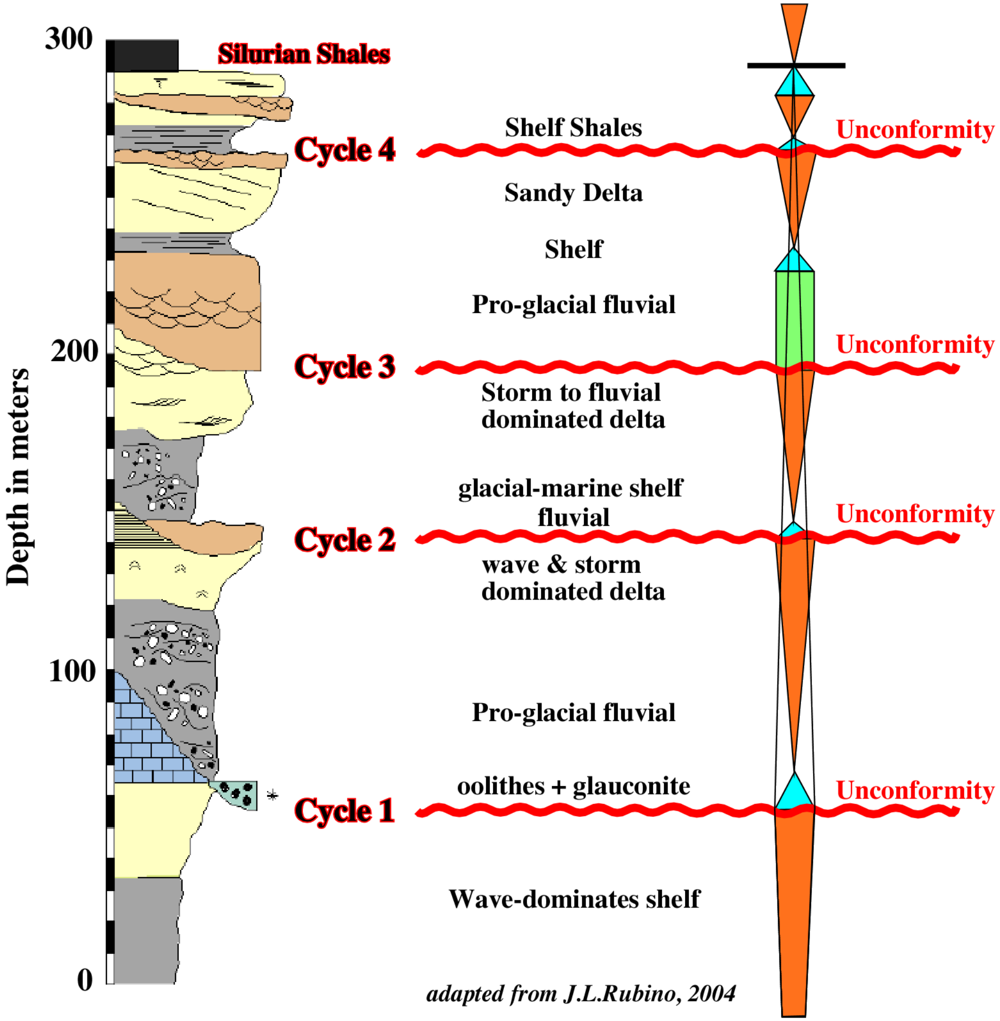


Fig. 1-As illustrated on this photograph, physical strata patterns strongly suggest depositional systems are cyclic. Actually, since the advent of Geology, as a natural science, geologists advanced several hypotheses to explain such cyclicity. However, eustacy (see glossary) has always been considered as the most likely cause of the cyclicity of depositional systems (de Maillet, Lavoisier, Lemoine, Burrolet and, recently, Exxon's geologists). Such hypothesis has been tested many times, but, so far, it has resisted quite well to the refutation tests. Admittedly, eustacy, that is to say, the global sea level changes can apply just to sediments deposited under marine influence. Nonmarine sediments, particularly those laid down landward of the bayline (see glossary) are out of the scope of eustacy.

1st Driving Concept

Time Stratigraphy



adapted from J.L.Rubino, 2004

Fig. 2- The cyclicity of the depositional systems recognized on the ground (fig. 1) is, naturally, depicted on stratigraphic cross-sections. However, the section illustrated on this figure comes from an Upper Ordovician glacial interval (Murzuq basin, Libya), that is to say, from an environment in which eustacy is meaningful. In spite of that, four stratigraphic cycles are pictured. They are bounded by erosional surfaces, which truncate the underlying strata putting in vertical abnormal superposition sediments with facies (lithology) and environments quite different. In addition, within each cycle, it is possible to identify a lower thinning and fining upward package, which is overlain by a coarsening and thickening upward package. Eustacy, in this particular example (glacial deposit), cannot be invoked as the main cause of the cyclicity. The landward and seaward movement of the glacier is probably the more likely cause of the observed cyclicity, with glacial erosion bounding the cycles. As we will see later, eustacy explains quite well the cyclicity observed in marine sediments. However, in turbidite depositional systems, deposition takes place when the space available for sedimentation (accommodation) increases (relative sea level rise).

1st Driving Concept

Time Stratigraphy

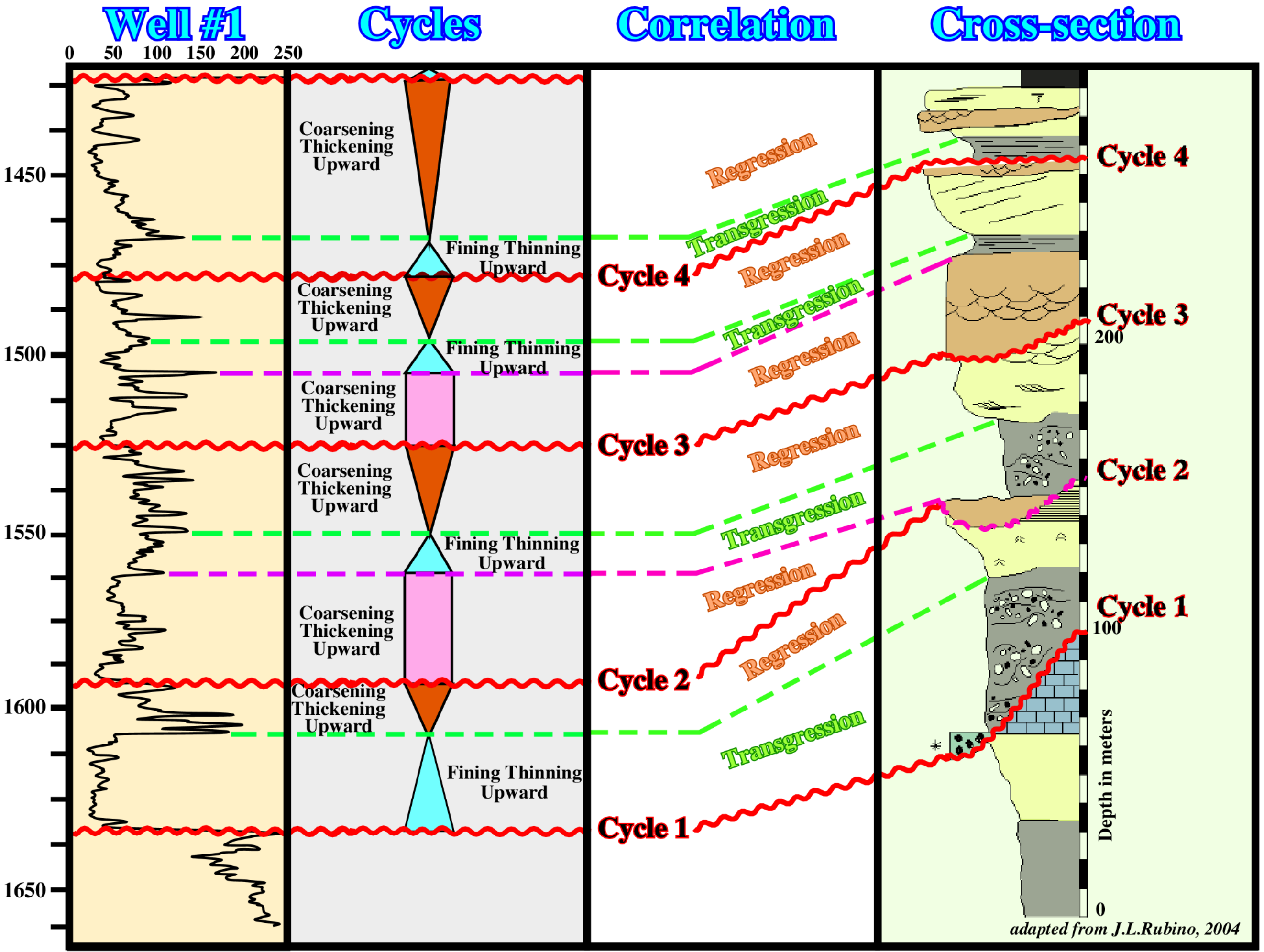


Fig. 3- Admittedly, the cyclicity and stratal patterns of marine sediments are readily recognized on all electric logs. Similarly, in glacial deposition, as illustrated above, the correlation between field stratigraphy and electric logs patterns are difficult to refute. Indeed, the four cycles, the glacial erosions, the fining and thinning upward (transgressive) and the coarsening and thickening upward (regressive) intervals, identified on the stratigraphic section (fig. 2), are easily recognized on the electric log. Despite such convincing regional correlations, it is quite astonishing that some geologists still hypothesize that eustasy was also active.

1st Driving Concept

Time Stratigraphy

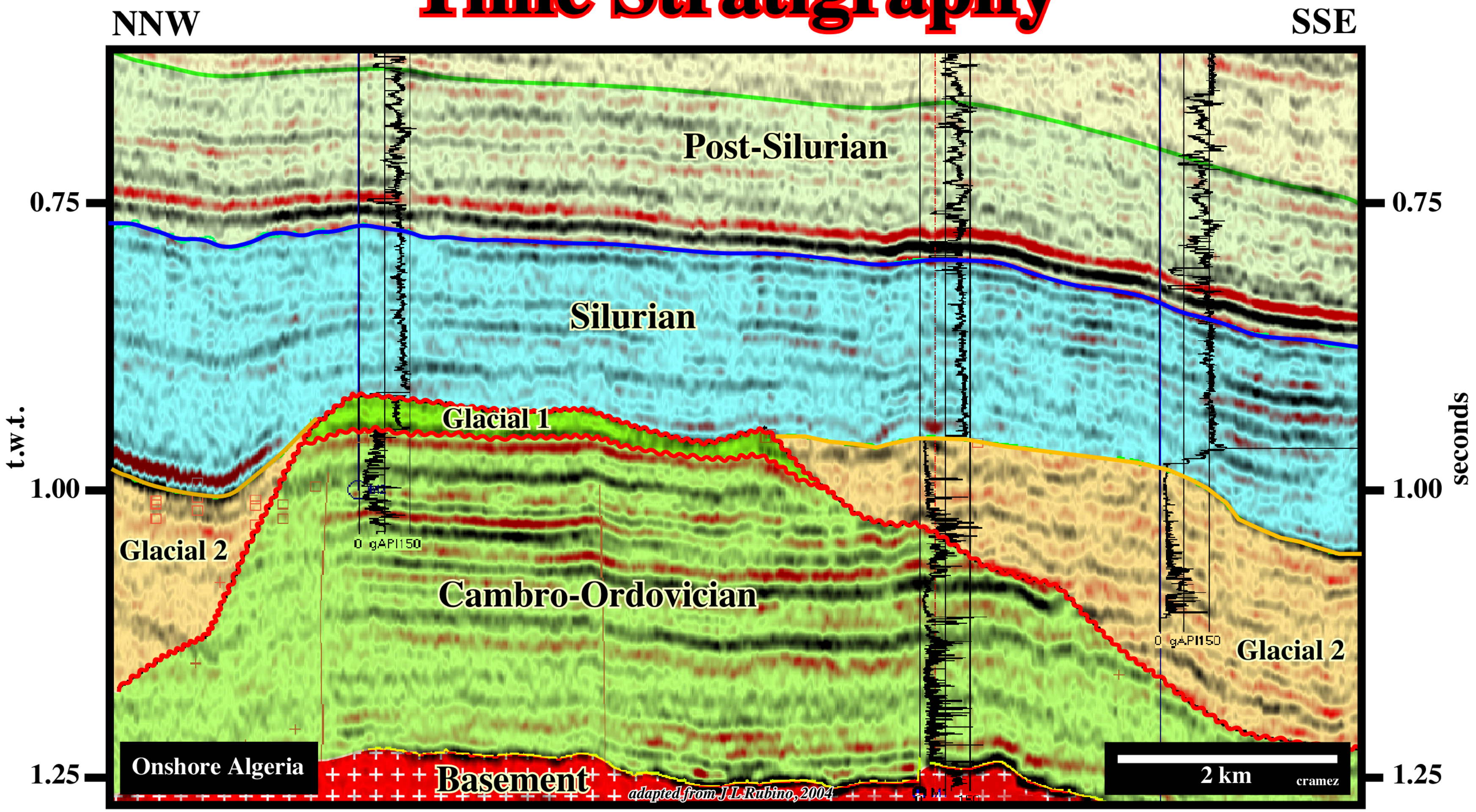


Fig. 4- This seismic line illustrates the time stratigraphy (seismic reflectors are chronostratigraphic lines) and cyclicity (eustasy) of the depositional systems of onshore Algeria (near the Libya boundary). Time stratigraphy and cyclicity can also be recognized on the electric logs of the wells drilled in the area. The glacial deposits (Upper Ordovician, glacial 1 & 2) depict quite different stratal patterns of the marine deposits (Cambro-Ordovician, Silurian and post-Silurian). Glacial erosional surfaces bounding glacial cycles look like angular unconformities, while the limits between marine geological packages look like eustatic unconformities. Internal configuration of glacial intervals is reflection free, while marine intervals have, roughly, a parallel internal configuration.

1st Driving Concept

Time Stratigraphy

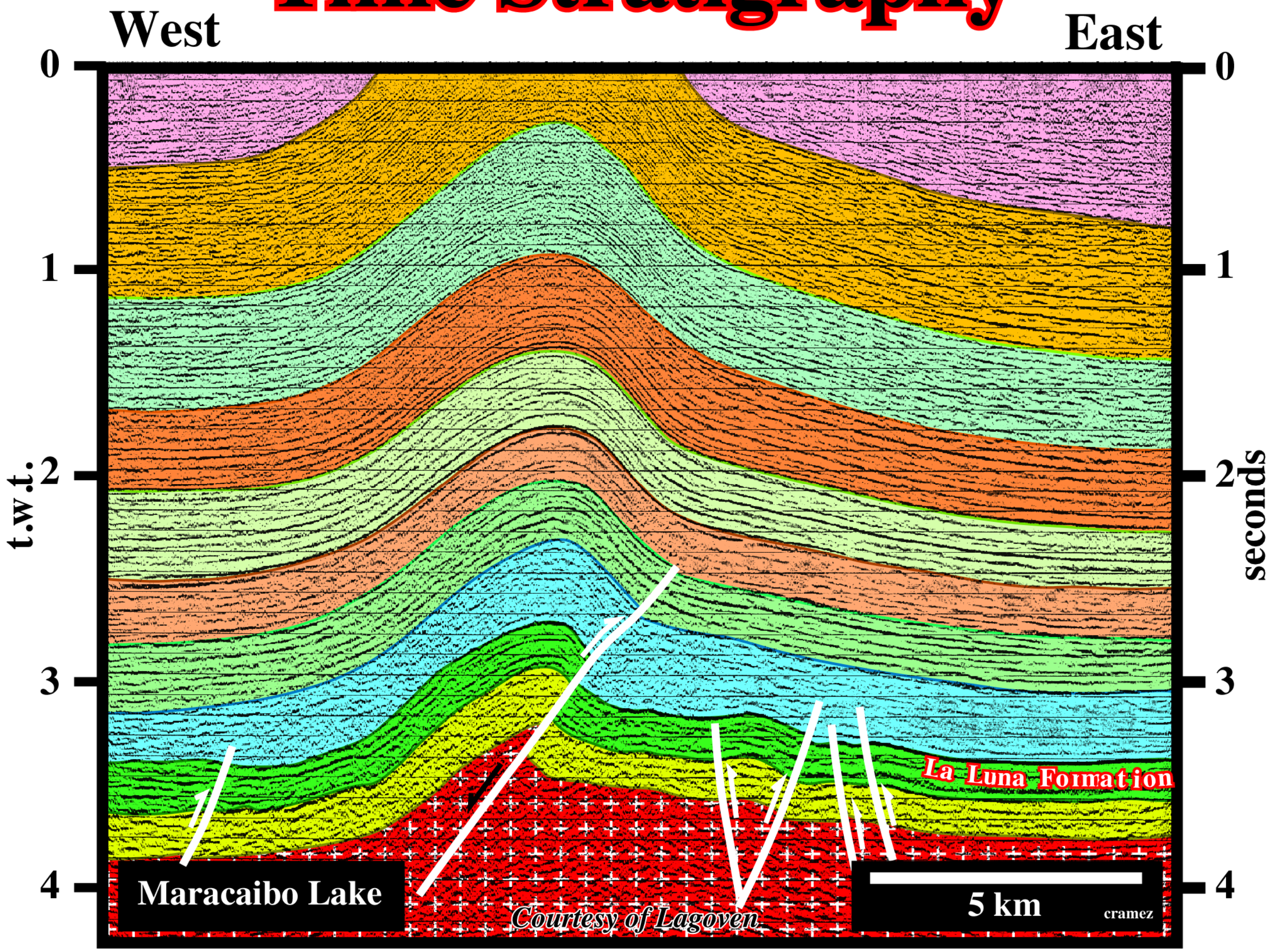


Fig. 5- On this seismic line, from the Maracaibo lake (Venezuela), seismic reflectors, which correspond to chronostratigraphic lines (interfaces between depositional surfaces), depict the time stratigraphy (not calibrated) and cyclicity of the depositional systems. The coloured seismic intervals correspond, roughly, to marine sedimentary packages (continental encroachment subcycles induced by 2^{sd} order eutastic cycles). The internal configuration of the seismic intervals look parallel, at least on this profile. However, it must be notice that this line is perpendicular to the structural trend and not parallel to the direction of sediment transportation along which geometrical relationships and reflections terminations are true and not apparent.

2nd Driving Concept

Seismic lines are a high resolution tool that can be used for determining chronostratigraphy: the time lines in rocks.

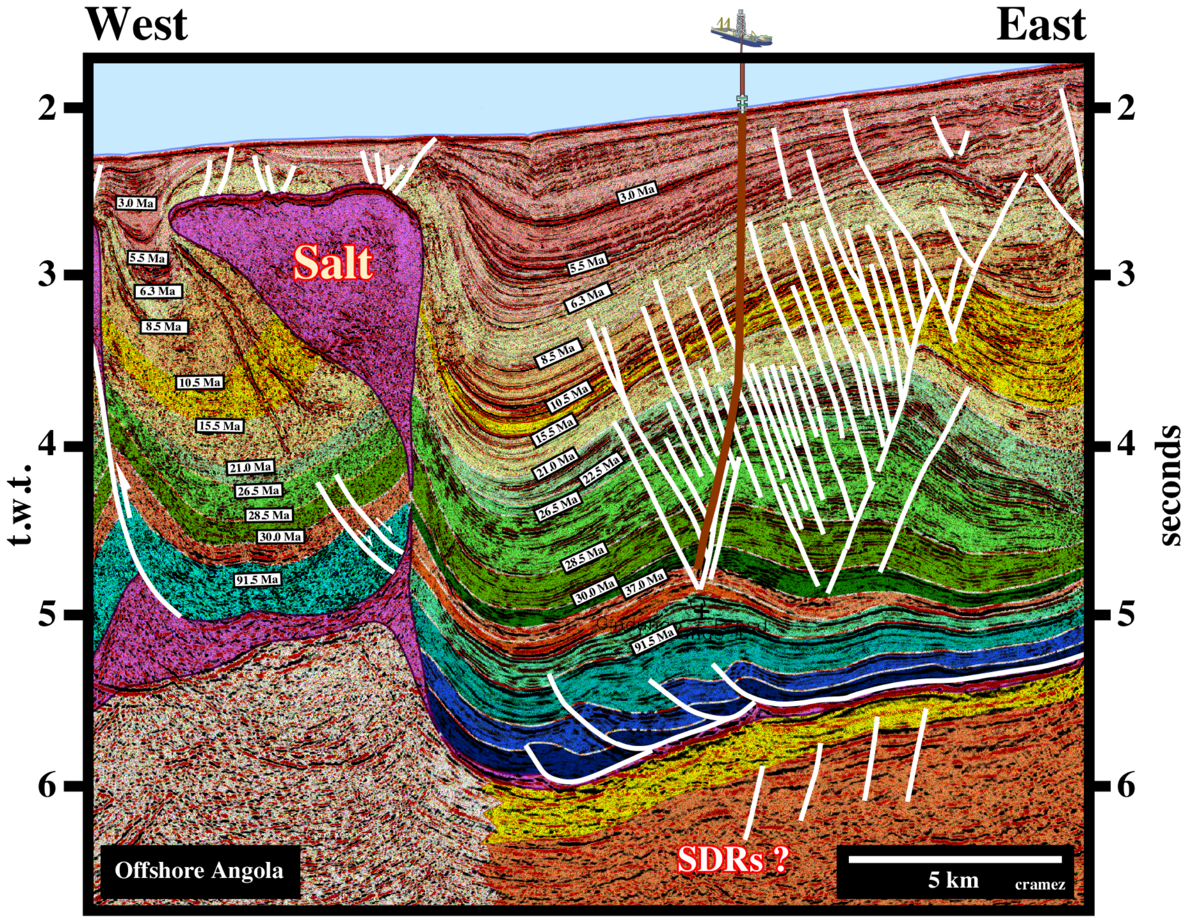


Fig. 6- The results of exploratory wells, or the knowledge of the stratigraphic signature of the area, allows explorationists, and mainly seismic interpreters, to calibrate seismic profiles in time stratigraphy. On this example, taken from deep offshore Angola (block 32), the major unconformities bounding the different seismic intervals, and downlap surfaces, are calibrated according the South Atlantic Margin basins signature. Notice, on the western part of the line, the pull-up of the bottom of the evaporitic layer induced by the high velocity (17500 feet/second) of the seismic waves in a salt layer.

2nd Driving Concept

Time Lines in Rocks

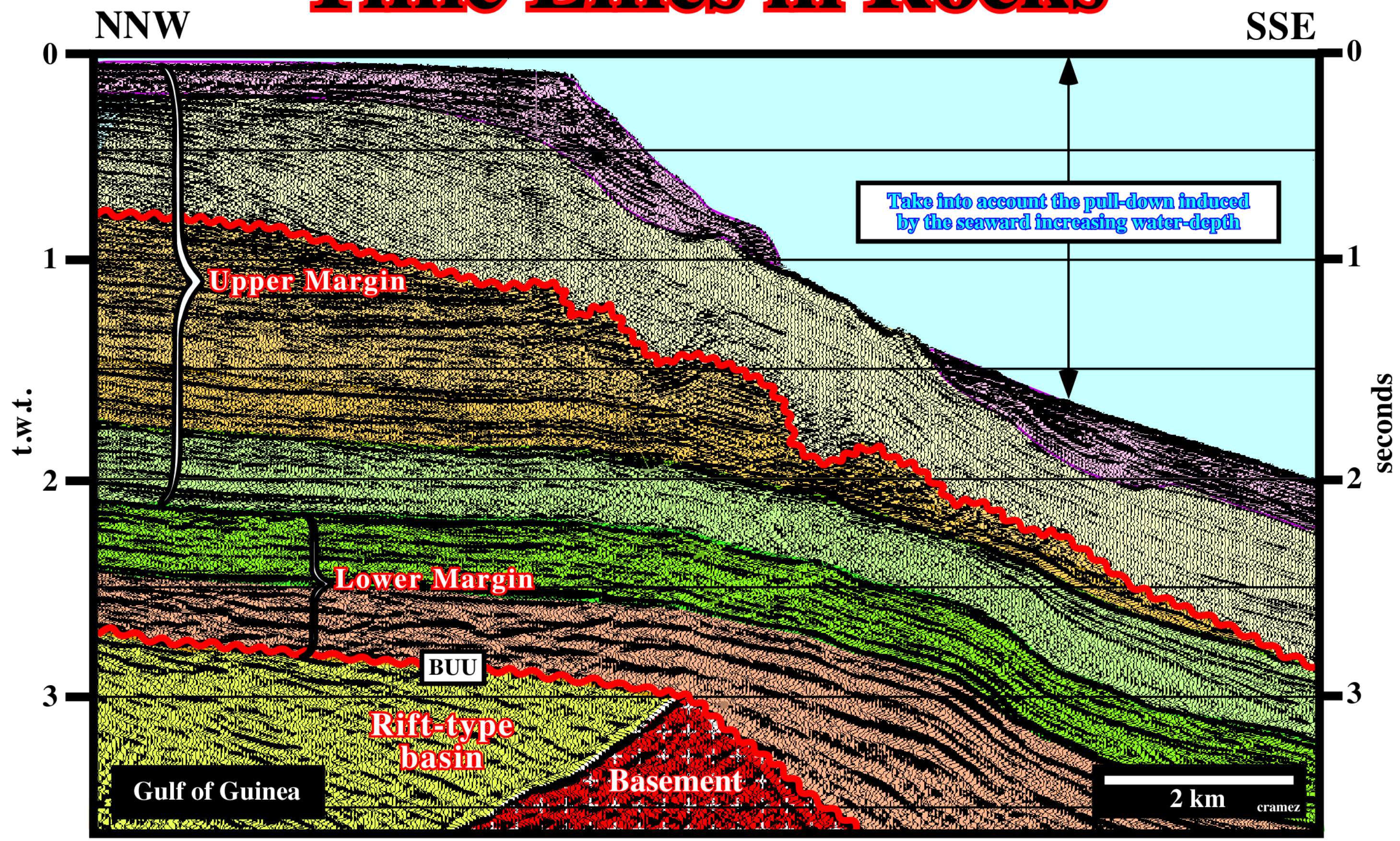


Fig. 7- Here again, it is easy to notice seismic reflectors follow chronostratigraphic lines. Therefore time stratigraphy can be performed using seismic data. On this seismic profile, coming from offshore Nigeria, different seismic packages can be recognized above a granite-gneiss basement. Rift-type basin sediments deposited during the lengthening of the lithosphere, that is to say, laid down before the break-up of Pangaea supercontinent, are separated from margin sediments by an angular unconformity (BUU). On the margin, different sedimentary packages can be recognized. However, in the upper part an erosional surface, probably induced by Upper Tertiary glaciations, eroded the sedimentary time surfaces creating typically truncated reflection terminations (see later). The lower margin sediments look transgressive, while the upper look regressive. A major non-depositional hiatus is likely between lower and upper margin.

2nd Driving Concept

Time Lines in Rocks

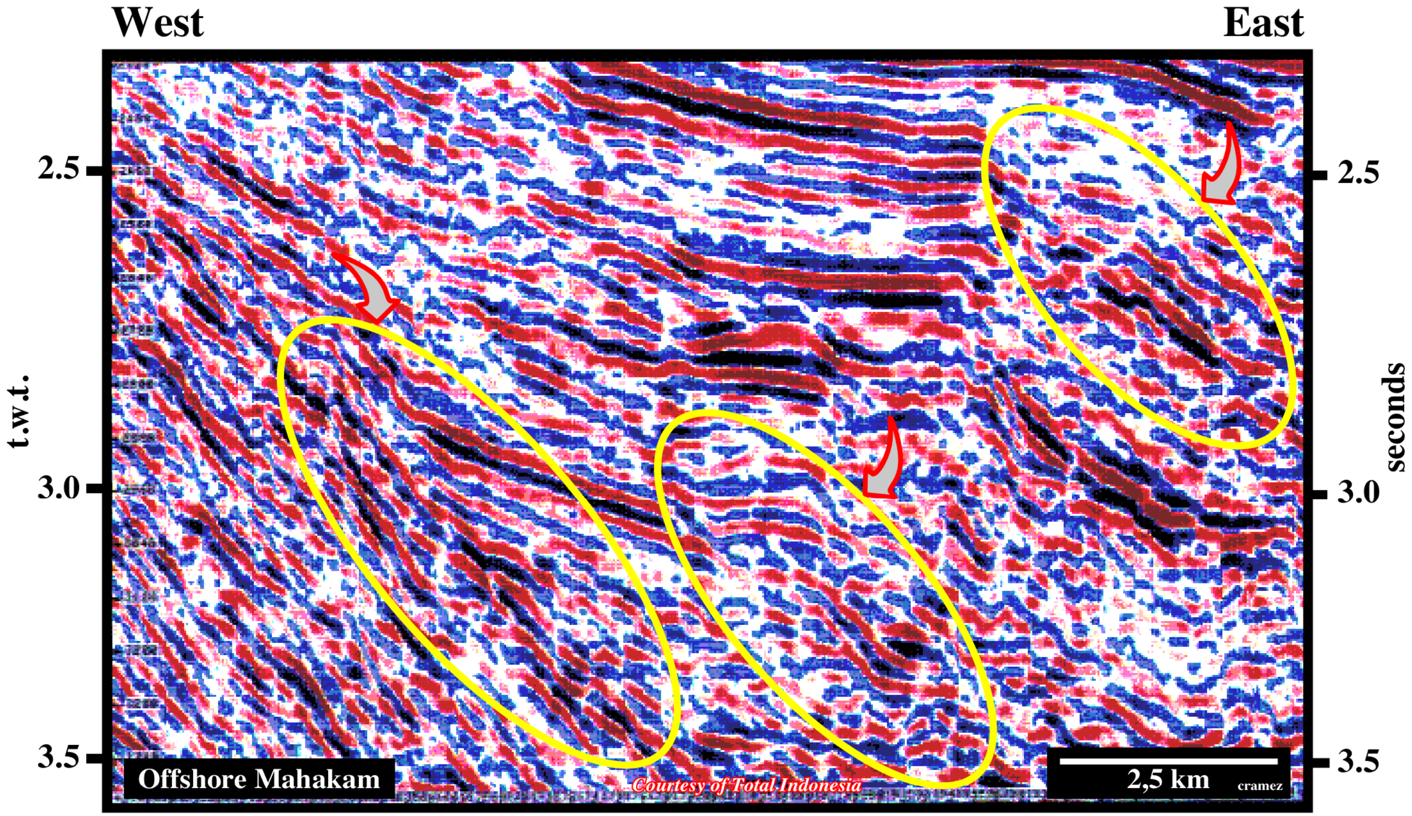


Fig. 8- When seismic data have good quality, and appropriate resolution, as illustrated on this seismic line from offshore Mahakam (East Borneo, Kalimantan, Indonesia), (i) the stratal patterns, (ii) geometrical relationships (between seismic markers) and (iii) seismic surfaces (hypothetical surfaces associated with reflection terminations) allow seismic interpreters to perform quite detailed time stratigraphy and depositional analysis. Indeed, on this line, for instance, it is utterly easy to see the theoretical disconformity surfaces separating the different seismic packages. Similarly, it is quite evident than certain depositional packages (seismic intervals) were laid down not in aggradation, that is to say, above the previous ones, but much lower on the seaward side. Such geometrical relationships, that we are going to describe and interpret very soon, correspond to a significant relative sea level fall, which displaces the depositional coastal systems basinward and downward.

3rd Driving Concept

Seismic depositional intervals follow the hierarchy of eustatic cycles. Higher hierarchic stratigraphic intervals as (i) **sequence cycles** (ii) **systems tracts** and (iii) **facies** (depositional systems), can be individualized in outcrop and, sometimes, on seismic data whenever conditions are favorable.

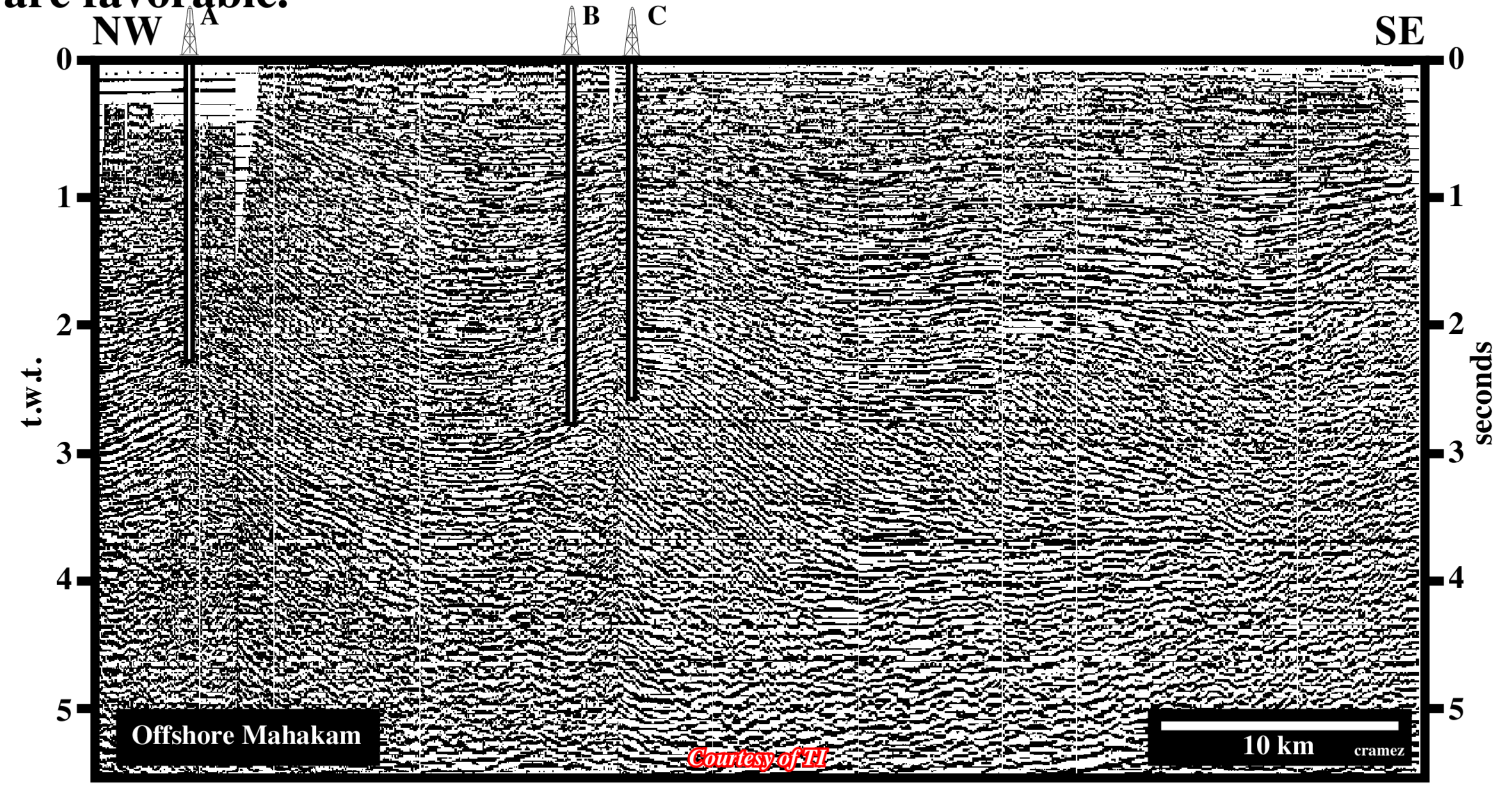


Fig. 9- Theoretically, seismic markers should underline significant contrast in acoustical impedance. In the 60's seismic interpreters, particularly Esso's geologists expected to recognize, on the seismic lines of Portuguese Guinea, the progradational delta front reservoirs, since their acoustical impedance is much higher than the landward costal silts and seaward prodelta shales. However, the well's results strongly indicated that the recognized seismic reflectors, follow time lines (depositional surfaces), and not facies lines (lithological changes). Indeed, as it will be shown later, lithological predictions using seismic data require a complete and exhaustive sequential stratigraphic interpretation. Seismic interpreter must pick and map lower hierarchic intervals (systems tract) in order to approach depositional systems, which are characterized by a lithology (facies) and an associated faunal assemblage.

3rd Driving Concept

System Tracts & Facies

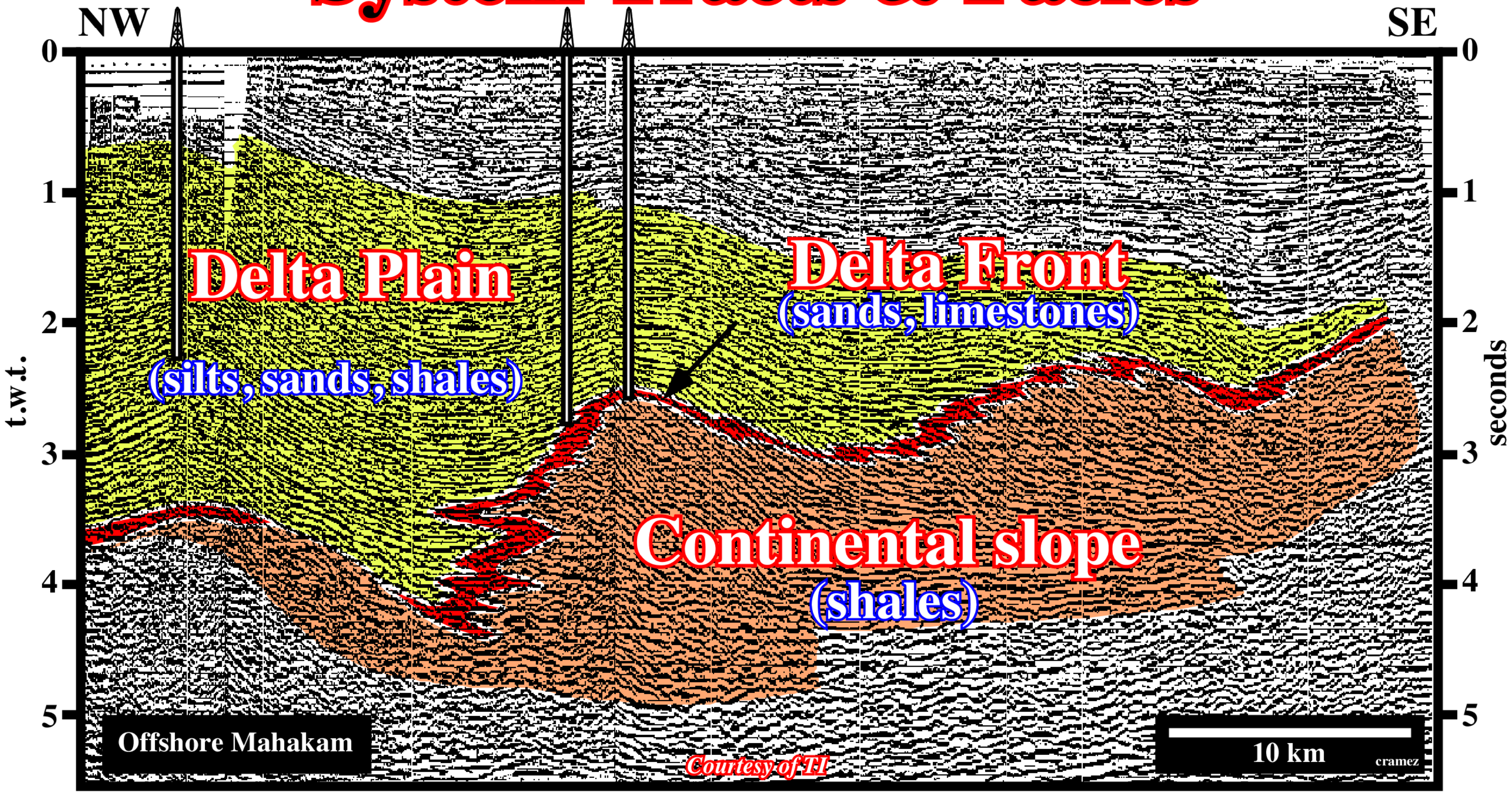


Fig. 10- This environmental interpretation of the seismic line illustrated on fig. 9, based on stratal patterns (seismic patterns) and calibrated by the well results, corroborates the hypothesis that seismic markers follow chronostratigraphic rather than facies lines. On this line, it is quite easy to follow the successive positions of the depositional coastal break (see glossary) that, in this particular instance (basin without continental shelf), coincide with the shelf break. So, one can say that near depositional coastal breaks, delta front sandstones and limestones were likely deposited, while landward, on the coastal plain, silts, sands and shales are predominant. Seaward of the depositional coastal break, on the continental and deltaic slope, slope shales are paramount. Taking into account the facies (lithology), the acoustical impedance contrast should theoretically follow the red interval, but as everyone can notice there is not an associated seismic marker. Therefore, lithological predictions, and mainly reservoir-rocks predictions, cannot be made by just looking at the seismic. They require, as we see later, a sophisticated method that certain explorations call the sequential seismic stratigraphic approach.

3rd Driving Concept

System Tracts & Facies

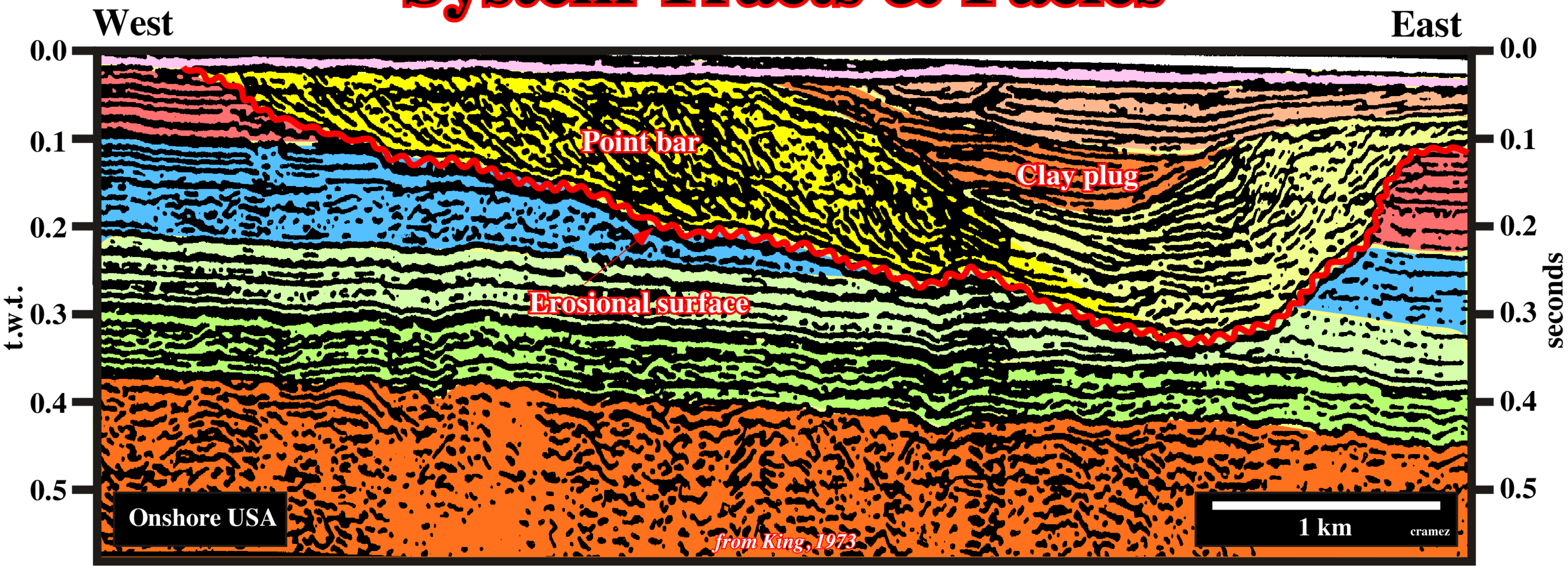


Fig. 11- When nonmarine depositional systems are suspected, or recognized on seismic lines, as illustrated above, lithological predictions, using seismic data, still are possible. This is particularly true when the nonmarine depositional systems are under the influence of relative sea level variations, that is to say, where eustasy is active. These types of nonmarine sediments are deposited landward of the depositional coastal break (see glossary), but seaward of the bayline. However, in order to make likely predictions, a full understanding of the depositional systems is required. So, on this line, assuming the erosional surface was induced by rupture of the equilibrium profile (see glossary) of a river, the stratal patterns of the filling intervals are easily interpreted, in lithological terms, by applying the meander belt and point bar geological models. Briefly speaking, seismic interpreters attemtinging advanced lithological prediction must imperatively know, à priori, the sedimentological models: Theory precedes Observation.

Depositional Model

Depositional Model

The sand-shale depositional model used in these notes is the one proposed by P. Vail and coauthors (1977), in which it is assumed that:

1) **Eustasy** is the main factor driving the cyclicity of the sedimentary deposits;

2) **Sedimentary Intervals** have high completness;

3) **Eustasy**, **Subsidence**, **Accommodation**, **Terrigeneous Influx** and **Climate** are the major geological parameters affecting stratal patterns:

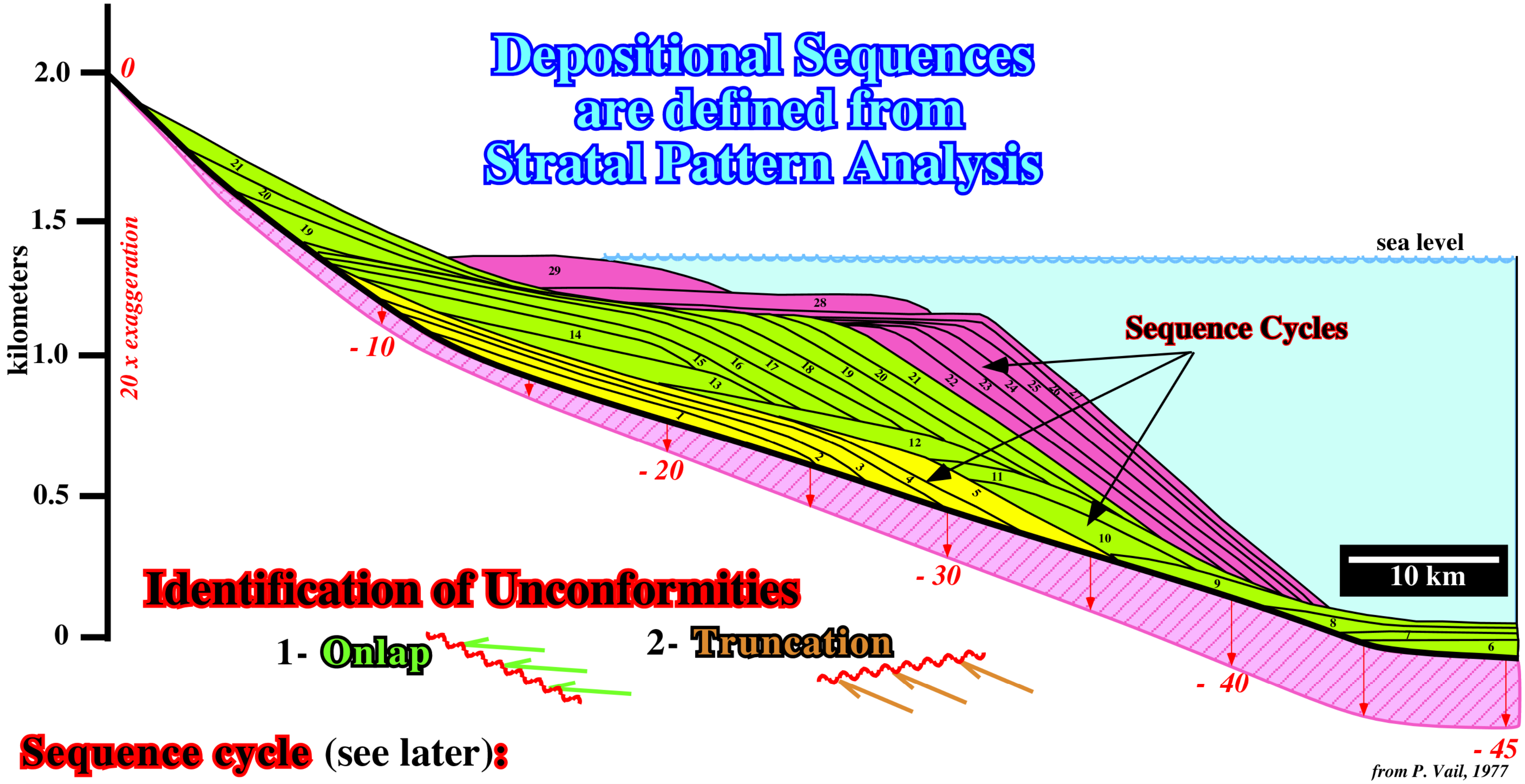
4) **Subsidence** and **Terrigeneous Influx** rates are smaller than sea level changes, that is to say, **Eustasy**;

5) **Terrigeneous Influx** is constant in time and space;

6) **Subsidence** increases gradually and linearly basinward;

7) The time interval between **each chronostratigraphic line** is 100 k years, that is to say, depositional events are **instantaneous** and **catastrophic** n geologic time.

Depositional Model



Depositional Sequences are defined from Stratal Pattern Analysis

Identification of Unconformities

1- **Onlap** 2- **Truncation**

from P. Vail, 1977

Sequence cycle (see later):

Fig. 12- On a seismic line, as we will see later, a sequence cycle is a succession of genetically related reflections bounded by unconformities or their correlative conformities associated with the strata deposited during a 3rd order cycle of sea level change between two consecutive relative falls of sea level (Mitchum et al., 1977).

Depositional Model

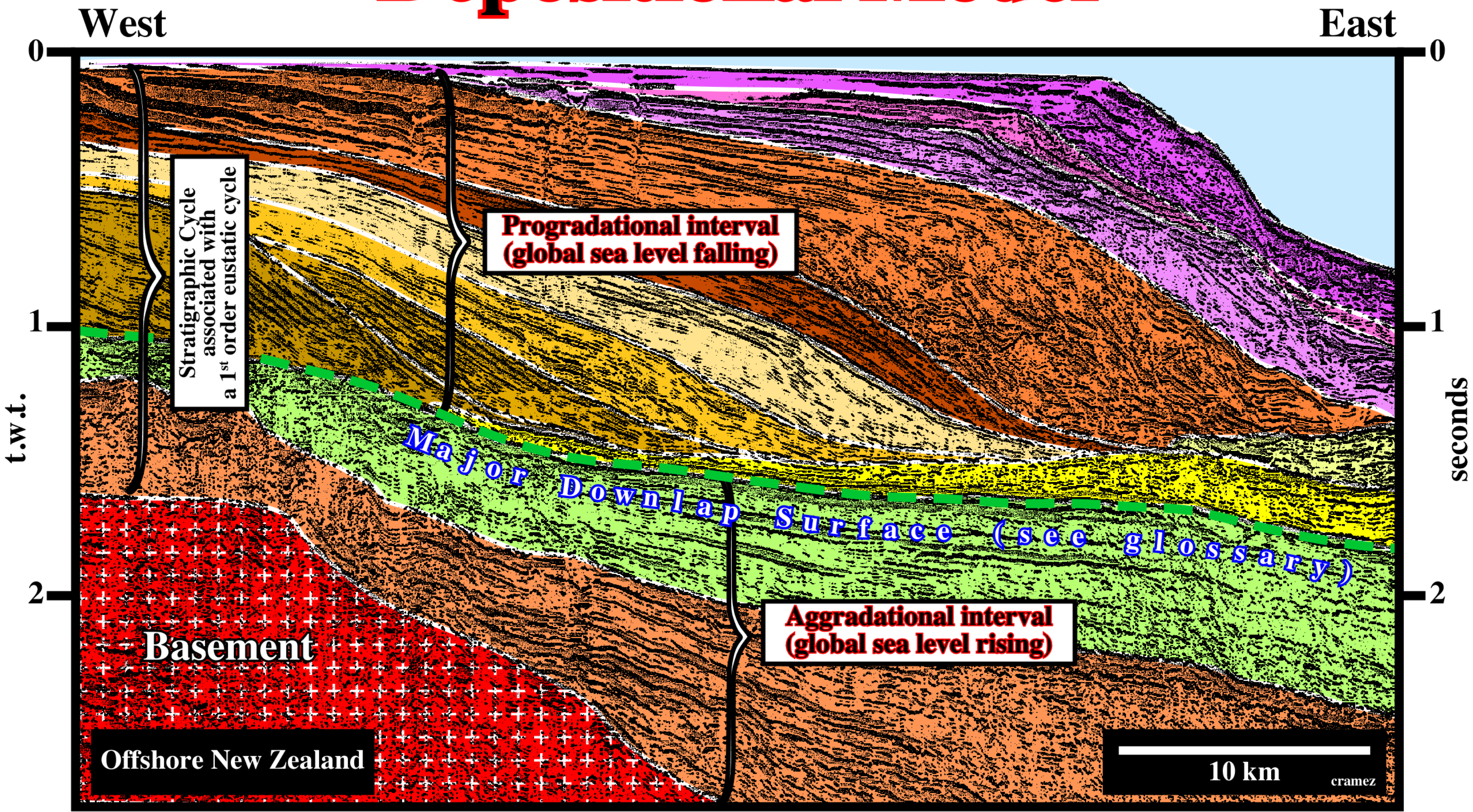


Fig. 13- Seismic lines, like this one, have confused a lot of seismic interpreters, who used mega and supersequences to advance lithological predictions. They erroneously considered mega and supersequences (see glossary) as big sequences. They assumed the presence of mega and super-turbidite intervals, as is the case in sequence cycles. The basic Exxon depositional model, is that, the building block of sequential stratigraphy is the stratigraphic cycle (sequence) deposited in association with a 3rd order eustatic cycle. Such a stratigraphic cycle being composed by depositional systems tracts allows lithological prediction, since each is characterized by a lithology and an associated typical fauna. Lithological predictions can be only advanced when seismic interpretation is performed at this high hierarchical level. Stratigraphic cycles associated with 2nd and 1st order eustatic cycles, as illustrated above, are composed by an aggradational (global sea level rising) and an progradational interval (global sea level falling), in which several higher hierarchical stratigraphic intervals can be recognized.

Stratigraphic Concepts

(P. Vail, 1989)

a) Clastic sediments are deposited in layers, called **strata or beds**. This layering results from the tendency of water or wind to spread similar sediment types in a relatively thin sheet over a broad are a during a period of **similar environmental conditions**. When environmental conditions change at the site of deposition, several things may happen:

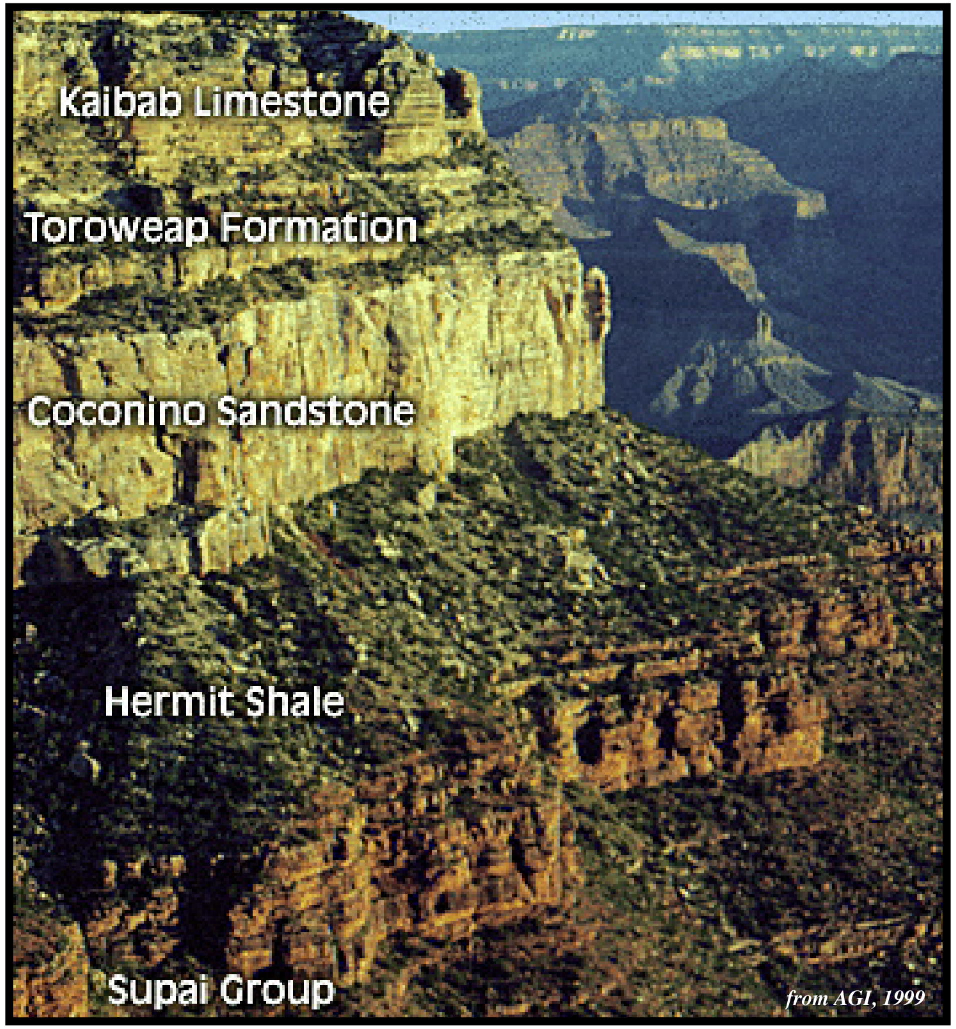
- different sediment types may be deposited on top of the previous layer,
- there may be a period where no sediments are deposited,
- the original layer may be eroded.

In any event, because of their common depositional environment, sediment types tend to be much more similar within layers than between layers.

b) Although sediments tend to be more similar within a layer than across layers, this **lateral continuity has finite limits.** A particular layer may be thin and pinch-out laterally, leaving no particular record of the time deposition in the pinched-out region. Or, the sediment types characterizing the layer may gradually grade laterally into other sediment types within the same layer, suggesting that depositional environments also change areally in a gradual fashion.

c) Certain combinations of depositional environments foster abrupt discontinuity of layers of **similar sediment types**. For instance, river laid sands and shales are commonly discontinuous because of repeated channeling and overbank flooding. Other environments lead to more continuous layers: pelagic shales in deep marine basins are a good example.

Bedded



from AGI, 1999

Fig. 14- In stratigraphy, bedded means formed, arranged, or deposited in layers or beds, or made up of or occurring in the form of beds. On this photograph, beds are grouped in formations, which have similar rock-types.

Stratigraphic Concepts

(P. Vail, 1989)

d) We are left then with layers of similar sediments which are of variable lateral extent, but which almost universally **have greater lateral extent than vertical**, i.e., cross-layer, continuity. These relationships have useful applications.

e) At the practical scale of well logs and of seismic interpretation these layers can be correlated to define units of sediments deposited within a common span of time. Such correlations are called **chronostratigraphic**, or more simply time-stratigraphic to distinguish them from rock-stratigraphic correlations which define physical units of common rock type deposited under a common range of depositional environments independent of layering.

f) Well log correlation of chronostratigraphic layers is very dependent on the continuity of sediment types within strata. Seismic correlation, fortunately, gives a much better view of large scale chronostratigraphic layering in discontinuous sediments than do well logs, but **seismic resolution of individual layers is limited when compared to well logs.** Thus the two media should be used as mutually helpful tools for chronostratigraphic correlation. Detailed ties of individual thin layers from logs to seismic sections is a critical step in the use of the two media.

g) Stratal surfaces typically represent a relatively small-time-gap. If the time-gap is large, the surface is called an unconformity. Such a time-gap often receives the name of hiatus, indicating that it might have represented the time-gap.

Stratigraphic Concepts

(P. Vail, 1989)

h) All unconformities somewhere have a minimum time-gap, often at the slope portion of the basin. **It is this minimum gap-time which is the appropriated age designation for the unconformity**. An understanding of the chronostratiographic correlation sections (see later) are essential to understand the relationships of physical stratigraphiy in a framework of geologic time.

Stratal surfaces implications can be summarized as follows:

a) Stratal surfaces typically represent a relatively **small time-gap**.

b) If the time-gap (hiatus) is large, the surface is called an **unconformity**.

c) Stratal surfaces may represent **different amounts of time** from place to place.

d) Stratal surfaces represent at least some small unit of time common to the surface over **its entire extent**.

e) The concept of stratal surfaces is completely dependent of the **time scale** and **rock** under consideration.

Stratigraphic Boundaries

Stratigraphic Boundaries Classification

(P. Vail, 1989)

Stratigraphic boundaries separate rocks of significantly different environments or lithology.

A) Stratigraphic Surface - Continuous Physical Boundary

(i) Stratal Surface

(ii) Discontinuity Surface

(iii) Diachronous Surface

B) Stratigraphic Boundaries

(iv) Synchronous: Parallels Stratal Surfaces

(v) Diachronous: Steps Across Strata Surfaces

Stratigraphic Boundaries

(P. Vail, 1989)

Stratigraphic boundaries separate different lithologies resulting from different depositional environments. They are of two types: continuous physical boundaries, called A) **physical stratigraphic surfaces**, and B) **lithofacies or biozone boundaries**. Physical stratigraphic surfaces are of three types: (i) stratal surfaces, (ii) stratal discontinuities and (iii)diachronous surfaces.

(i) Stratal surfaces are physical depositional surfaces that separate sedimentary rock layers. They bound laminae, bed and large stratal units and represent periods of non deposition or abrupt shifts in depositional environment. Stratal surfaces are easily recognized where they separate distinctly different rock types or environments, but the same stratal surfaces may be difficult to recognize where they bound layers of the same rock type. Stratal surfaces are the physical boundaries of sedimentary strata and form practical geologic time-horizons, consequently these are synchronous surfaces that represent (within the limitaions of practical subsurface technology) the same instant in geologic time over large areas.

(ii) Stratal discontinuities are physical surfaces caused by erosion or by non deposition. They include unconformities, disconformities and depositional hiatuses. Unconformity time-gaps may simply represent prolonged periods of subaerial exposure with minimal erosion, possibly with local valley or channel down-cutting, or they may represent periods of uplift and major subaerial erosion of strata, or they may represent submarine erosion by turbidites, slump or submarine currents.

Time-gaps (hiatuses)

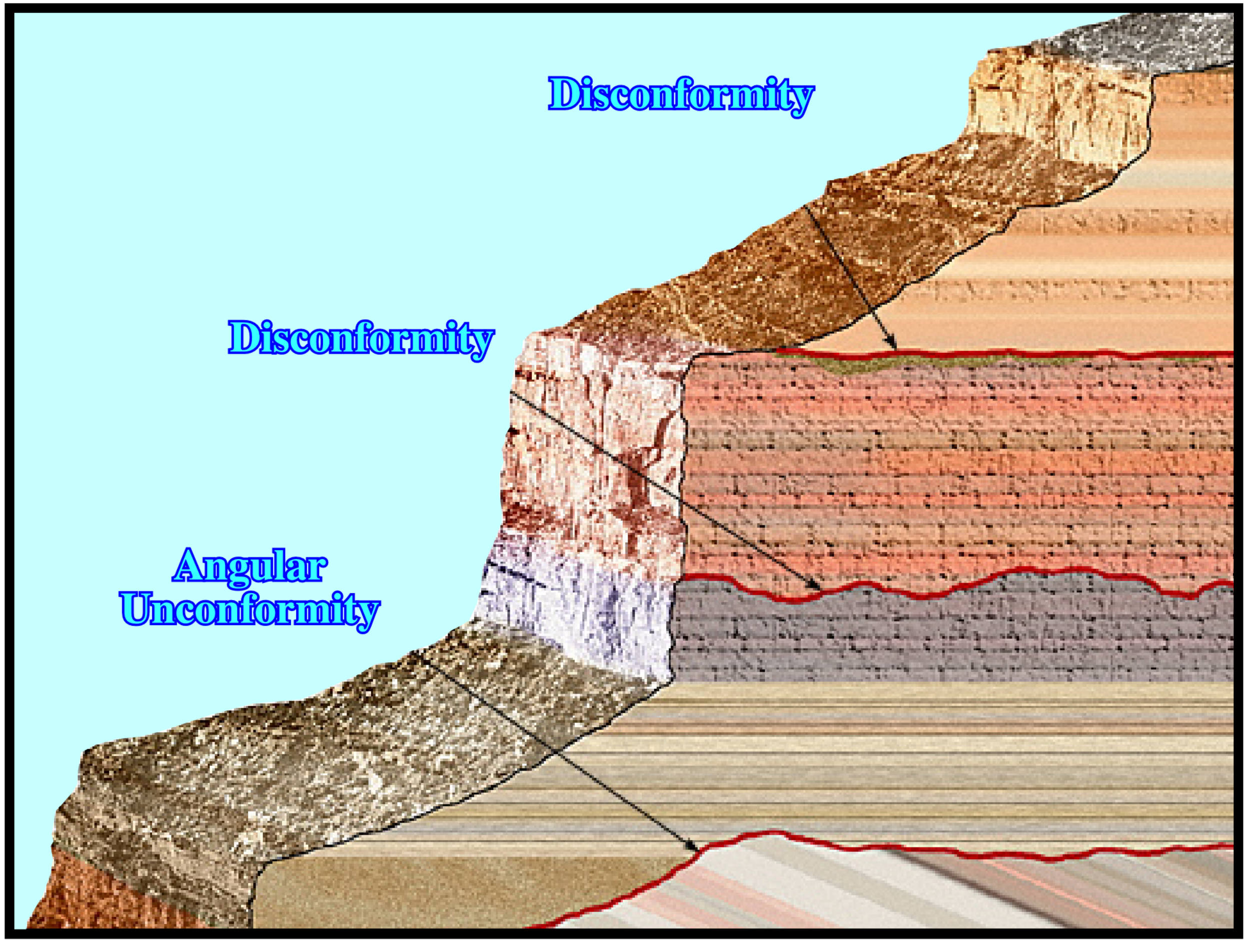


Fig. 15- Time-gap surfaces can be bedding planes, when the time-gap is small, and unconformities or disconformities when the time-gap is significant. As you will see later, unconformities can be tectonically enhanced (angular unconformities) or not. When they are not tectonically enhanced, unconformities are sometimes named disconformities as illustrated above. On these notes, the term unconformity will be used for all erosional surfaces induced by significant relative sea level falls.

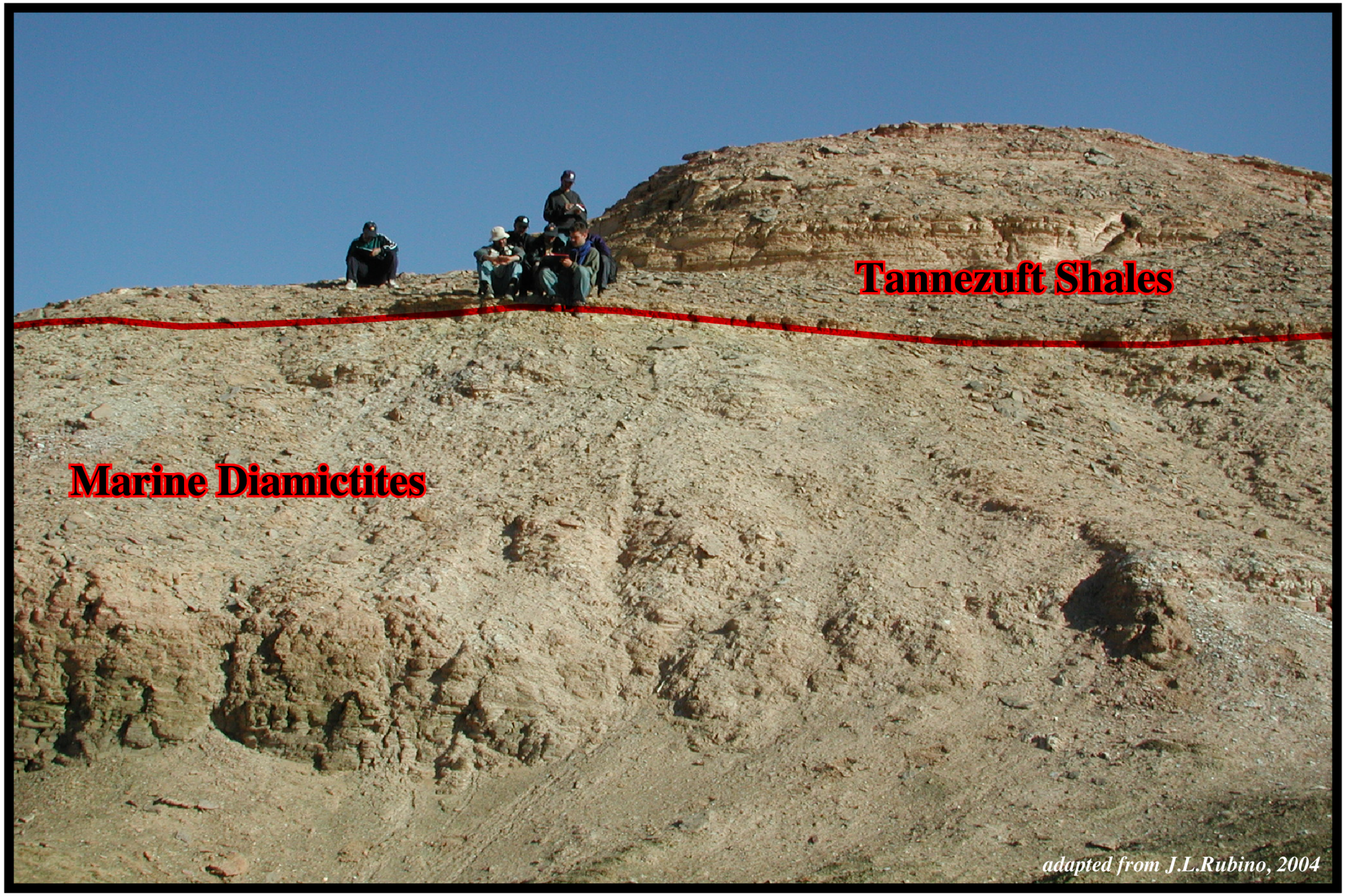
Stratigraphic Boundaries

(P. Vail, 1989)

Classical subaerial unconformities are of two major types: a) angular unconformities, with the discontinuity surface created by truncated strata beneath the boundary, and b) disconformities with beds parallel above and below the boundary. Disconformities do not show discontinuity patterns, consequently they are recognized either by paleontological evidence of a time-gap or by tracing regional discontinuity surfaces into the disconformity. These classic unconformity types remain significant, but we also find discontinuity patterns of onlap (marine, or lacustre, transgression of the old subaerially exposed and gently tilted surface) and toplap (rapid progradation of deltaic or bank-edge sediments into the basin from a common depositional surface) commonly associated with subaerial unconformities. **Submarine unconformities** have many of the same discontinuity patterns. Truncation is created by turbidite and gravity-slump erosion of submarine valleys and canyons. High energy submarine currents may also produce truncation patterns, although this is usually local and rarely removes consolidated sediments. Subaqueous nondepositional discontinuities are time-gaps caused by nondepositional or very slow deposition.

Diachronous surfaces are continuous physical boundaries that cross and are essentially independent of stratal boundaries. These are generally not stratigraphic surfaces and are mentioned here because they are sometimes confused with stratal surfaces. **Lithofacies and biozone boundaries** may be synchronous, that is the particular lithofacies or biozone assembly is laterally continuous within synchronous stratigraphic surfaces. It may also be diachronous, that is it may step across stratal surfaces in a transgressive or regressive pattern.

Angular Unconformity



adapted from J.L.Rubino, 2004

Fig. 16- The stratal relationships (reflection termination on seismic lines), between the Marine diamictites and the Tannezuft shales characterize an erosional surface, which created a large time-gap or hiatus, that is to say an unconformity between the sedimentary intervals. In addition, as we will see in next chapter (Geometrical relationships) the stratal relationships are those associated with an angular unconformity.

Geometrical Relationships

Geometrical Relationships

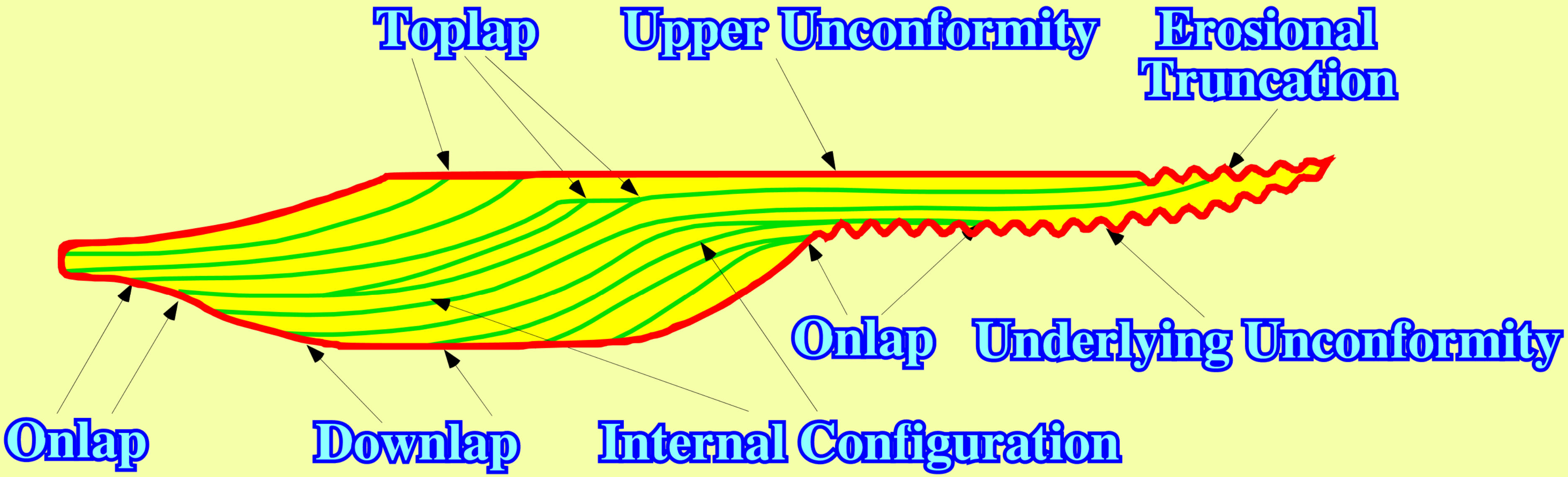


Fig. 17- In the next pages, we will review the geometrical relationships (reflection terminations) associated with sequence stratigraphic cycles, that is to say, stratigraphic cycles induced by 3rd order eustatic cycles or the building block of sequential stratigraphy. Each geometrical relationship will be defined and illustrated on a regional seismic line and we will try to explain its meaning in geological terms.

Onlap

A base-discordant relation in which initially (deposition time) horizontal strata terminate progressively against an initially inclined surface, or in which initially inclined strata terminate progressively up-dip against a surface of greater initial inclination.

Varieties of Onlap are:

(i) Proximal onlap;
(ii) Distal onlap;
(iii) Coastal onlap;
(iv) Marine onlap;
(v) Apparent onlap;
(vi) Non Marine Onlap;
(vii) True Onlap;
(viii) Tilted Onlap (Apparent downlap).

Onlap

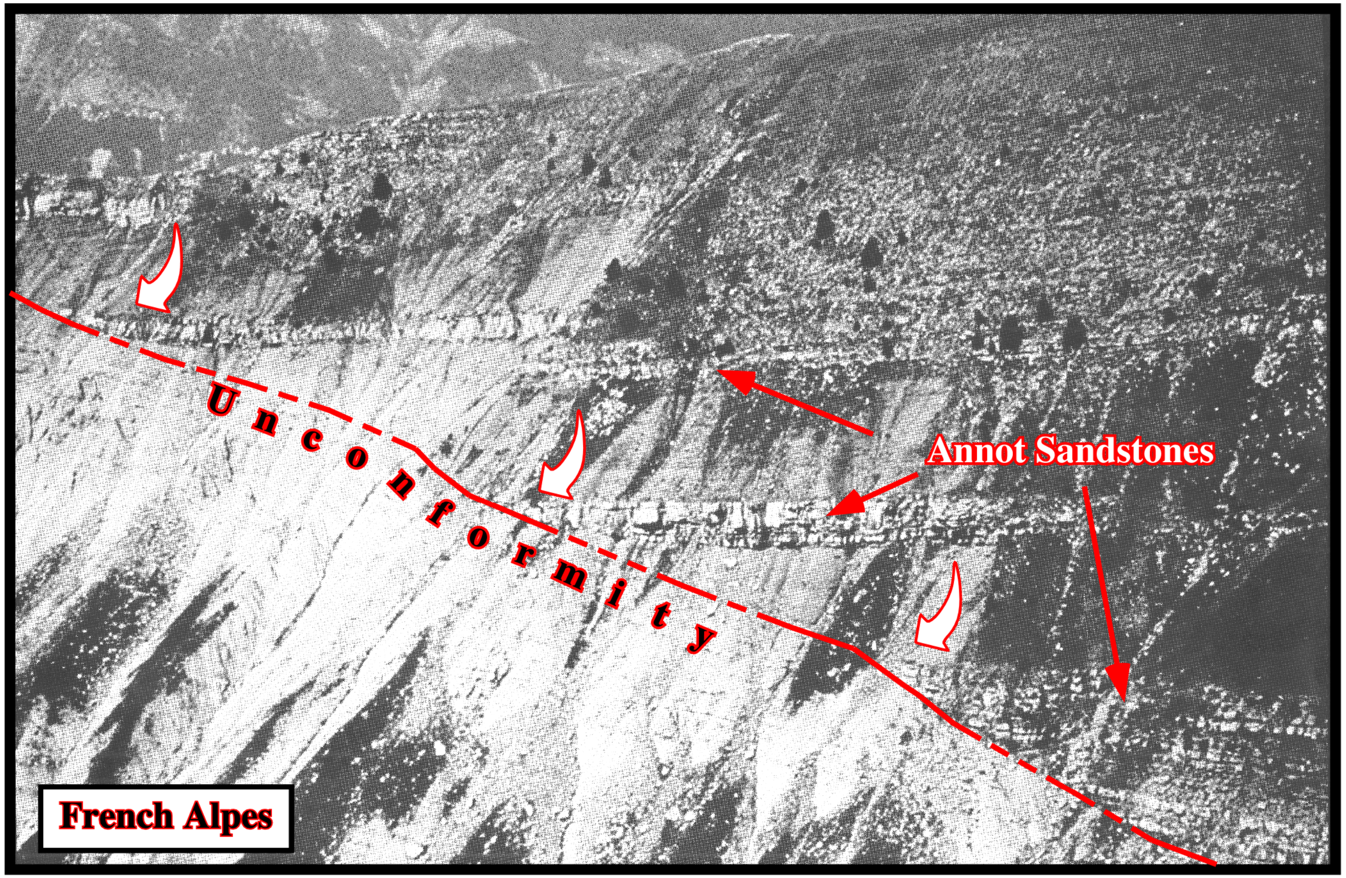


Fig. 18- The Annot sandstones are deep-water turbiditic lobes, which onlap against a major unconformity. As illustrated, one can say, the unconformity (in this case a marine erosional surface) is fossilized by the onlap of turbidite depositional systems. As we will see later, in this particular instance (turbiditic deposition), the onlap relations do not correspond to a relative sea level rise, but to the stacking of successive turbidite lobes induced by gravity currents, which generally developed during lowstand (see glossary) geological situations.

Example of Onlap

(sensu lato)

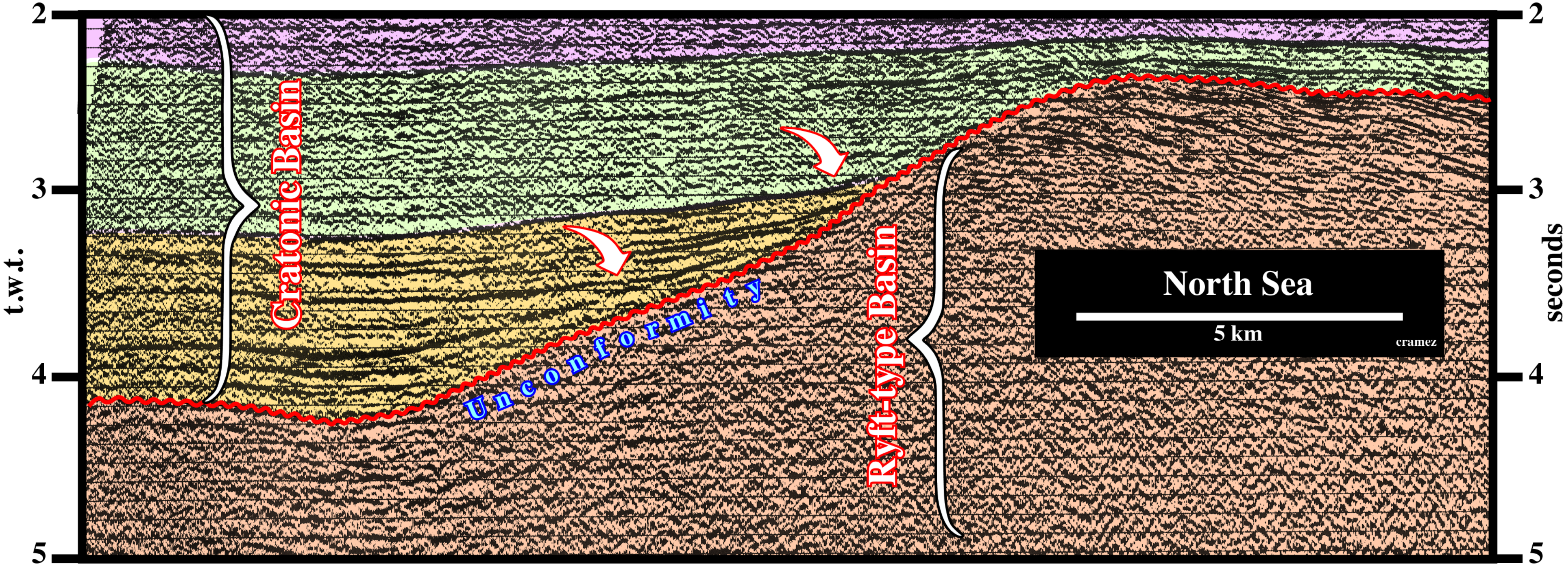


Fig. 19- The North Sea is composed of three different sedimentary basins that are stacked together. From bottom to top geologists generally have no major difficulties recognizing a Palaeozoic fold belt (not illustrated on this line), often considered as a petroleum basement, a Mesozoic rift-type basin and a Cainozoic cratonic basin. On this seismic line, it is easy to recognize that cratonic Cainozoic sediments onlap the Mesozoic rift-type basin sediments. Geologists, and particularly seismic interpreters, using reflection terminations of the Cainozoic sediments, consider that an onlap seismic surface (not emphasized by seismic reflectors) exists between the Mesozoic and Cainozoic intervals. Generally, onlap represents a marine (or lacustrine) transgression of the old sediments, that is to say a relative sea level rise. Different types of onlap can be recognized either on the ground or on seismic lines.

Example of Onlap

(sensu lato)

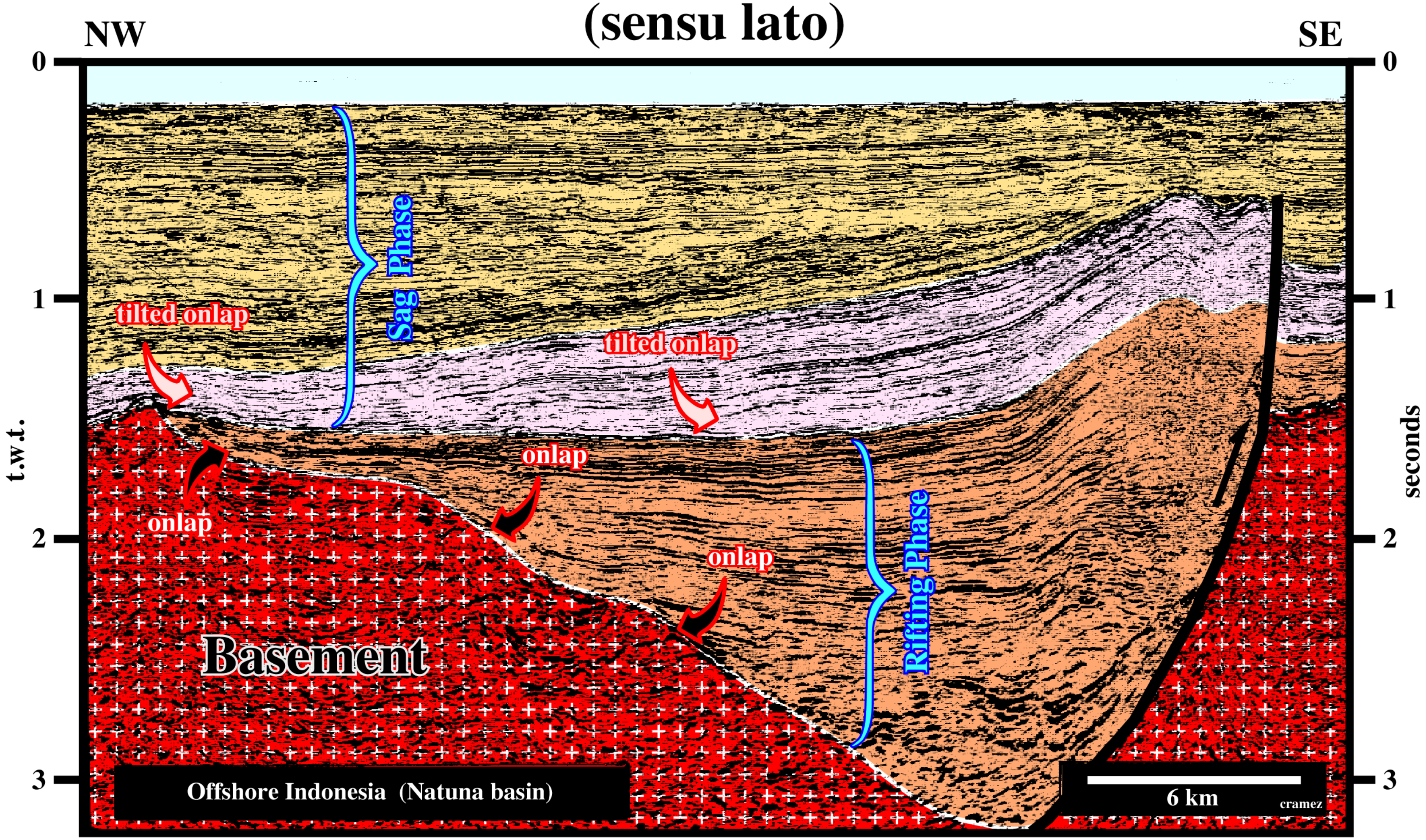


Fig. 20- The pristine geometrical relationships (deposition time) are often deformed by later tectonic regimes, as illustrated on this seismic line from a SE Asia back-arc basin. Indeed, it is quite easy to infer that a compressional tectonic regime took place after the rifting phase. The old normal faults of the rift-type basin were reactivated as reverse faults tilting the original geometrical relationships between the seismic markers. When the tilting is large enough, onlap can apparently become another geometrical relationship, as it is the case in the pink seismic interval.

Proximal Onlap

Proximal onlap is onlap in the direction of the source of clastic supply.

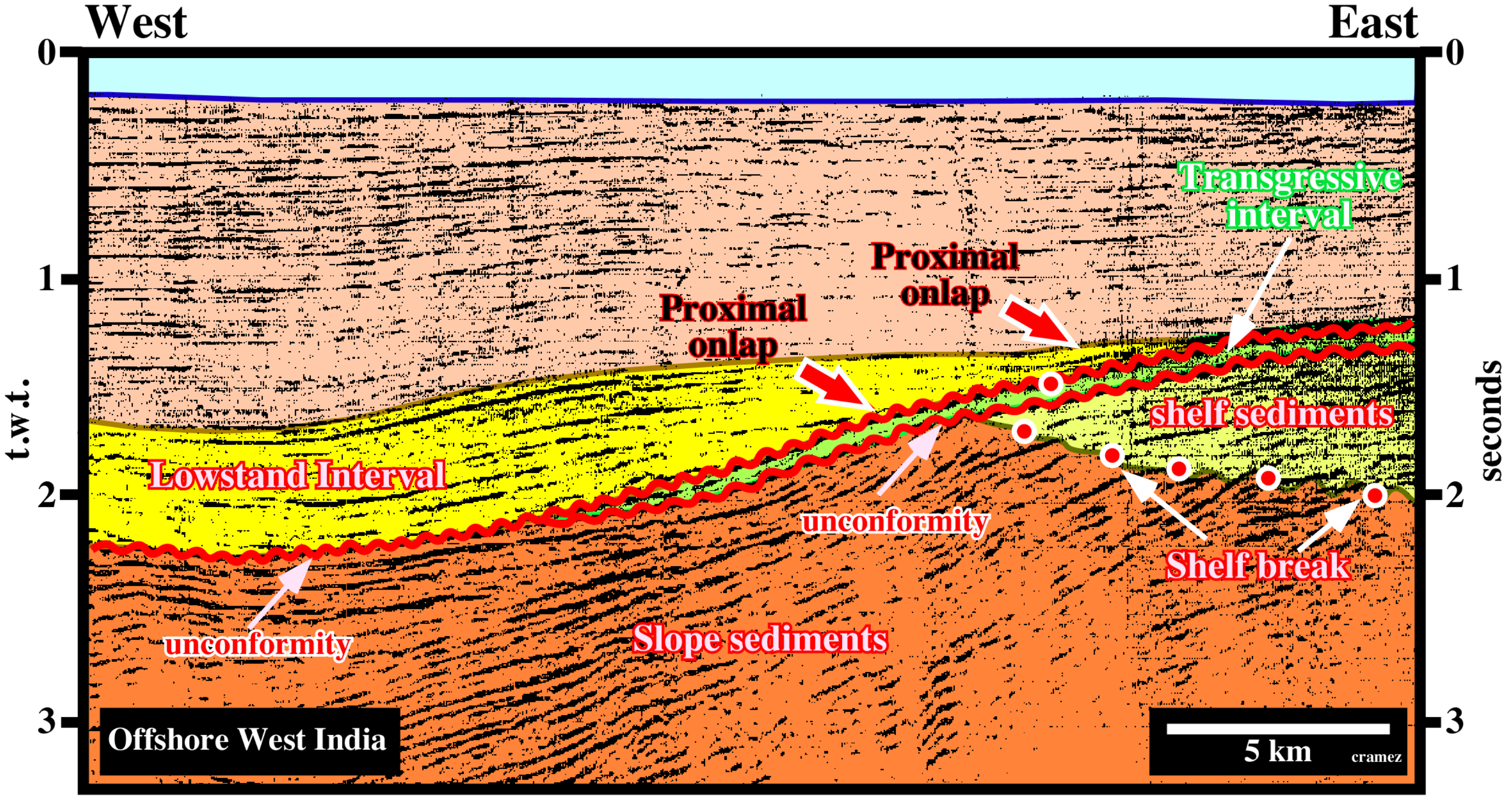


Fig. 21- As the source of clastic supply is located eastward, the red arrows underlie proximal onlaps, which can be coastal or marine, depending whether it is associated with marine sediments (seaward of the shelf break) or shallow marine (depositional coastal break). In this line, coming from offshore West India (Atlantic-type divergent margin), the onlaps are coastal. They are associated with the aggradation of a lowstand regressive interval (see glossary). They fossilize an unconformity (seismic onlap surface) induced by a relative sea level fall, which took place between the transgressive interval (green) and the regressive lowstand interval (yellow).

Proximal Onlap

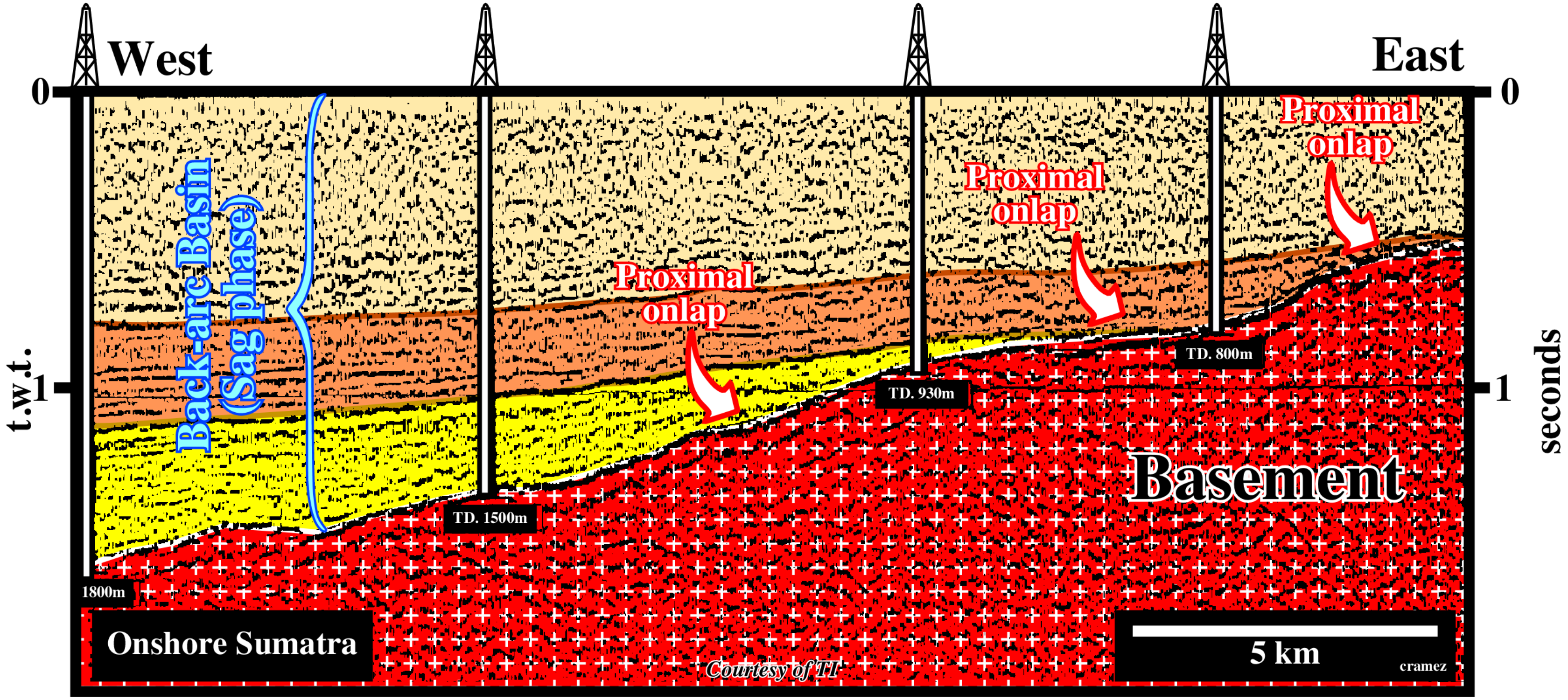


Fig. 22- On this seismic line from onshore Sumatra, that is to say, from a Cainozoic back-arc basin induced by a Benioff (or B-type) subduction zone, the proximal onlaps of the seismic reflectors (upper seismic packages of the sag phase) are easily recognized. Actually, taking into account the proposed geological interpretation, it is quite evident that the more likely source of clastic sediments is the basement, which outcrops few kilometres eastward. Theoretically, the onlap seismic surface, between the sag sediment terminations and the basement (granito-gneiss or Palaeozoic fold belt), is created by the coastal aggradation (see glossary) of the regressive intervals of the back-arc basin (sag phase). Coastal aggradational (relative sea level rise) takes places not only during the deposition of transgressive, but regressive intervals as well. But, deep-water turbidite depositional systems are deposited during relative sea level falls, generally in lowstand geological situations (see glossary).

Distal Onlap

Distal onlap is onlap in the direction away from the source of clastic supply.

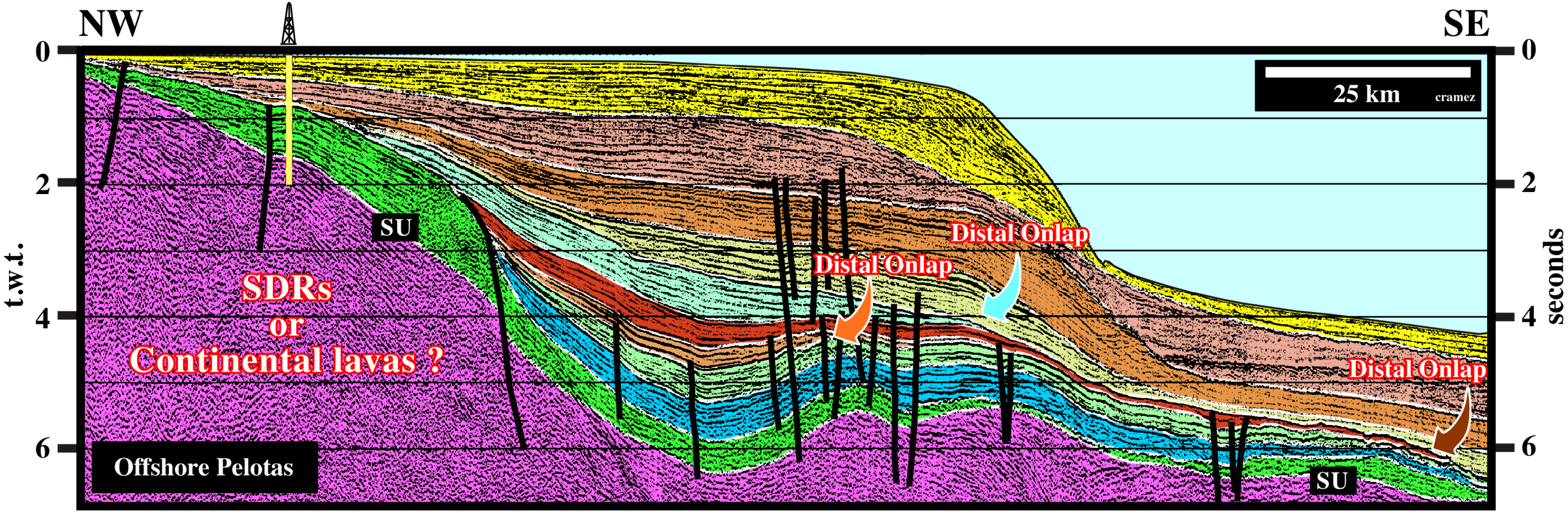


Fig. 23- Distal onlaps are easily recognized on this regional seismic line of an offshore Brazil basin (post-Pangaea Atlantic-type divergent margin). In this margin, the petroleum basement is mainly composed by Mesozoic subaerial lava flows, which locally can overly Precambrian and Palaeozoic sediments. The most likely source of clastic sediments are the rocks of the infrastructure (Precambrian or Palaeozoic rocks) and the post breakup lava flows. Both outcrop westward. Subsequently, distal onlaps of the Atlantic-type margin, as stressed above, are the reflection terminations in the direction away from the source of clastic supply (southeastward terminations). The unconformity (SU), on the top of the lava flows (seaward dipping reflectors), is not the breakup unconformity. Actually, it is around 10 My younger than the breakup unconformity (BUU), which is not illustrated on this line. The SU unconformity emphasizes the time-gap between the emplacement of the younger lava flows and their fossilization by the margin sediments. Readers should not forget to take into account the pitfall induced by the sharp change in water depth.

Distal Onlap

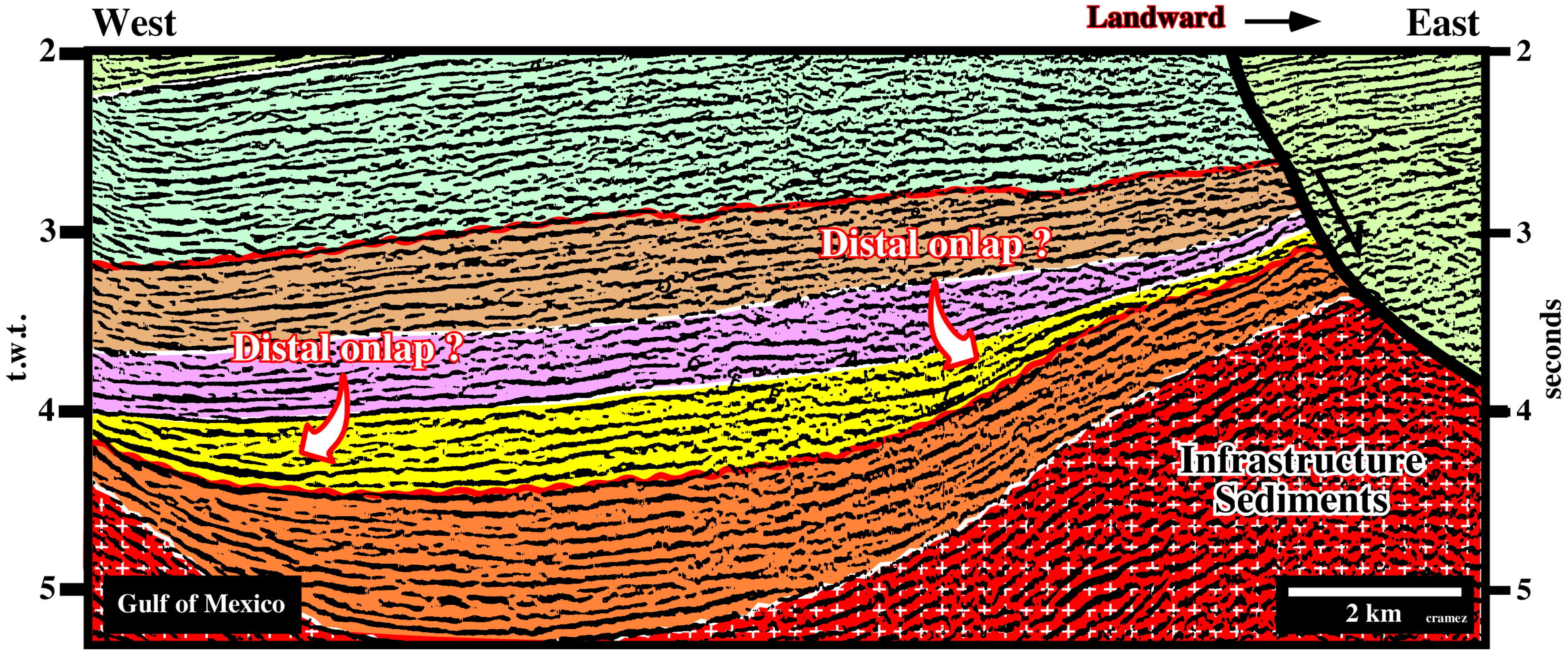


Fig. 24- This seismic line comes from the deep-water Gulf of Mexico (Cainozoic Mediterranean-type basin overlying a Mesozoic Pannonian basin). Reflection terminations and seismic surfaces are quite easy to recognize. However, in spite of the fact that the source of clastic sediments is located eastward (landward), is quite difficult to differentiate proximal from distal onlap. Indeed, due to salt flowage (halokinesis) and particularly due to salt evacuation, salt expulsion basins (minibasins) control the movement of gravity currents, which can take fancy trajectories. Subsequently, in a salt minibasin, a distal onlap does not necessarily mean that the onlap is in the direction of the major source of clastic supply. In other words, the direction of the source of clastic supply does not necessary corresponds to the direction of the sediment transportation, particularly in deep-water minibasin environments.

Proximal & Distal Onlap

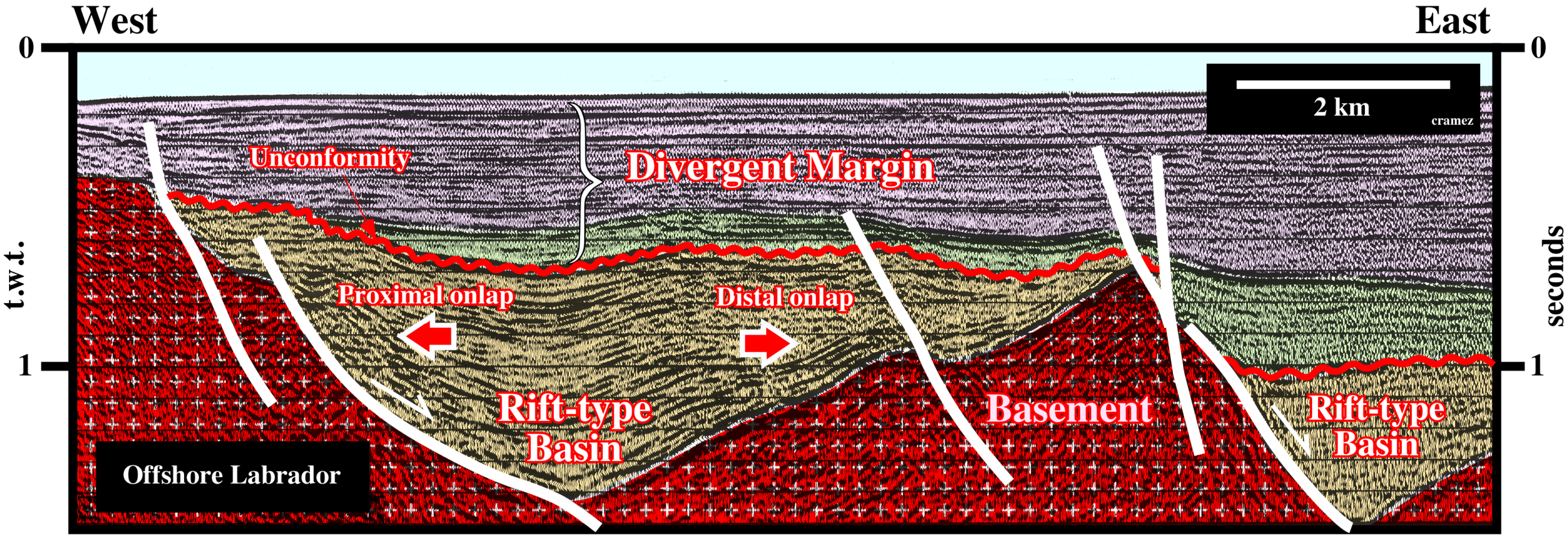


Fig. 25- On this line from the Labrador offshore, the geometry of the rift-type basin, as illustrated above, is often that of a half-graben. The filling sediments thick landward toward the normal fault planes (the subsidence is differential). This strongly suggests that the direction of the source of clastic supply is west to east. Subsequently, proximal onlaps look westward (landward), while distal onlaps look eastward (seaward). However, it must be noted that the onlap are non-marine. The predominant geological environments in rift-type basins are alluvial and fluvial. In addition, under certain climate and geological conditions, lacustrine environments can develop, and so organic rich lacustrine shale can be deposited (potential source-rocks).

Coastal Onlap

Coastal onlap is the progressive landward onlap of the coastal deposits in a given stratigraphic unit.

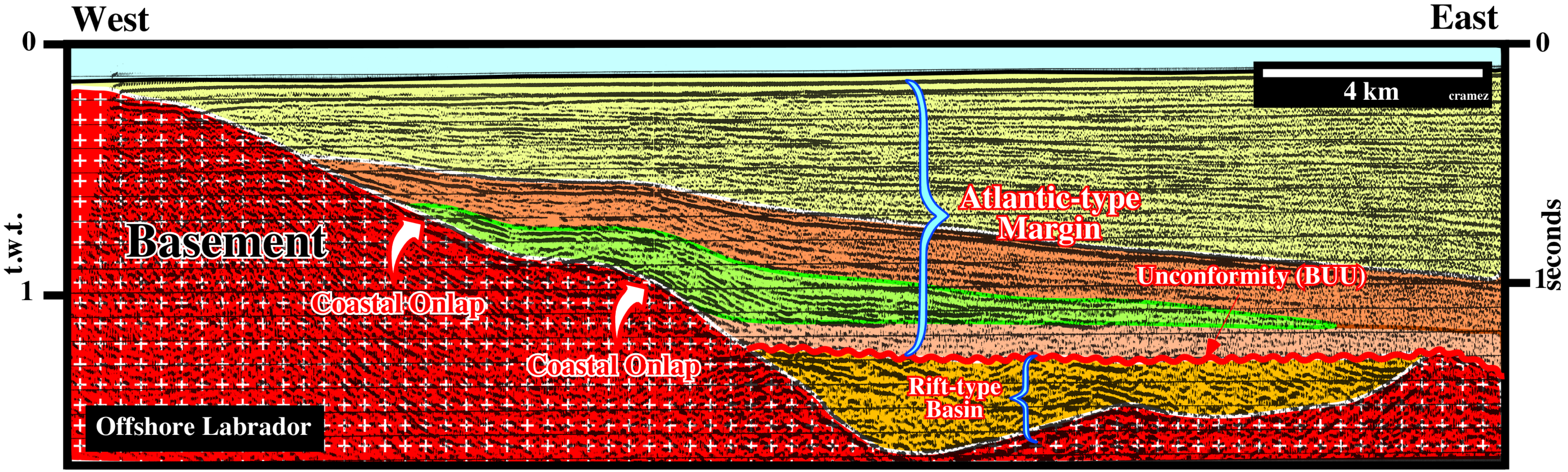


Fig. 26- The offshore of Labrador corresponds to a Cainozoic Atlantic-type divergent margin, which overlies Mesozoic rift-type basins, i.e., half-grabens which lengthened the lithosphere during the rifting phase (before breakup and subsequently oceanization). The green interval represents a transgressive sedimentary package of the margin developed during a relative sea level rise. In this interval, the coastal onlaps are quite evident. So, one can say, the coastal aggradation (vertical component of coastal onlap) of this transgressive interval is around 400 milliseconds and coastal encroachment (horizontal component of the coastal onlap) is roughly 4000 meters. For a given stratigraphic unit, the knowledge of the coastal aggradation and coastal encroachment allows prediction of the most likely topography of the underlying unconformity on which the unit transgressed. The breakup unconformity (BUU) between the rift-type basins and margin corresponds to a sharp change in environmental conditions (see unconformity BUU, in red).

Coastal Onlap

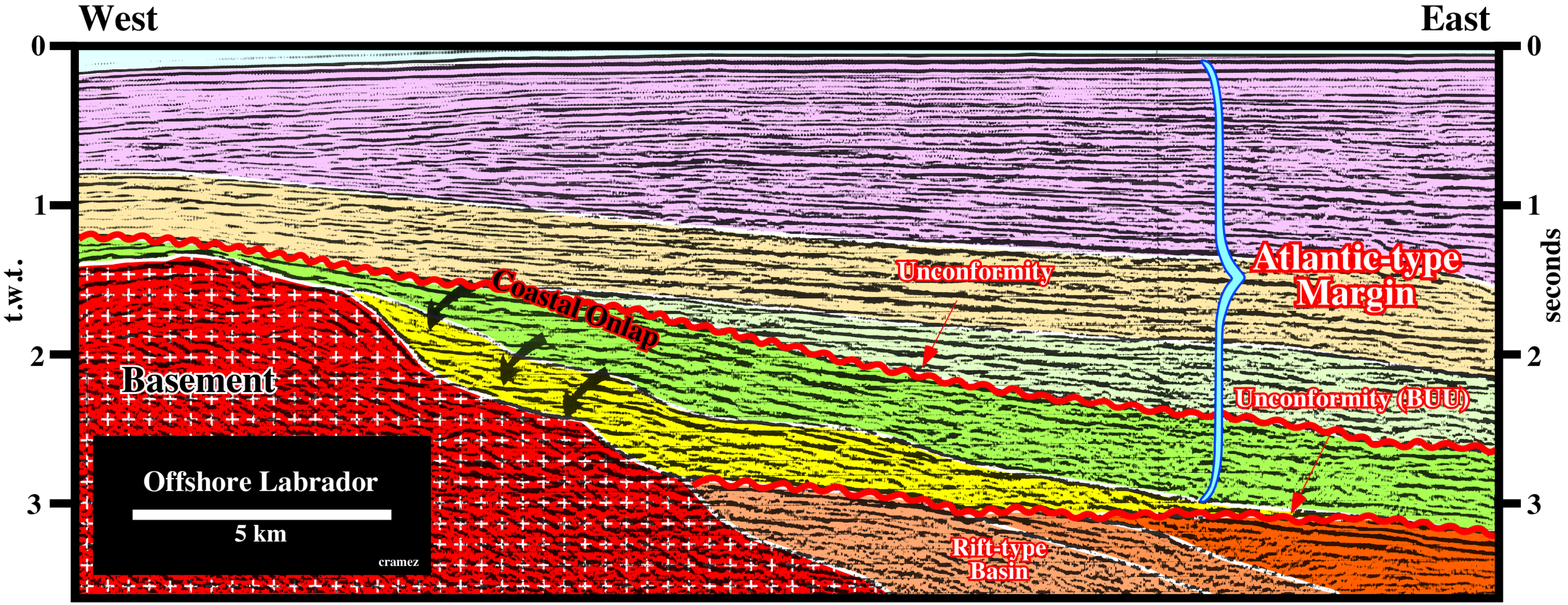


Fig. 27- This seismic line is located not very far from the line illustrated on the previous figure (fig. 25). It illustrates coastal onlaps in a transgressive interval, which is easily recognized by its backstepping geometry (see glossary). At each relative sea level rise, the depositional coastal break is displaced landward. Then, during a more or less stillstand of sea level, the depositional coastal break is progressively displaced seaward as sedimentation takes place. However, it never reaches the position of the last depositional coastal break of the previous parasequence (see glossary). A new relative sea level rise, again, displaces the depositional coastal break landward, and so on. This depositional mechanism is responsible of the backstepping geometry of the transgressive deposits, which, in fact correspond to a set of less and less regressive deposits. In other words, each parasequence in a transgressive interval has a progradational (forestepping) or regressive geometry as indicated by progressive landward onlap.

Coastal Onlap

Coastal Aggradation & Coastal Encroachment

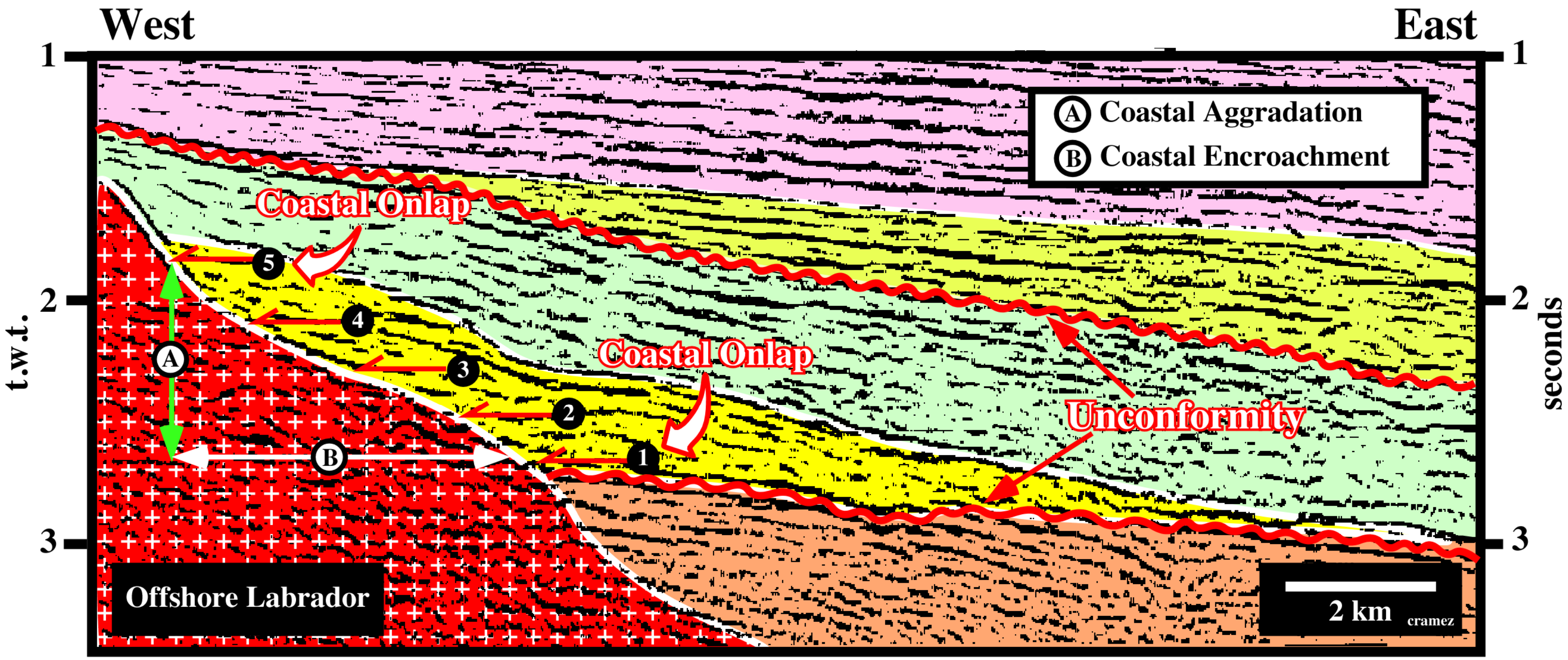


Fig. 28- This line illustrates coastal aggradation (A), that is to say, the vertical component of the coastal onlap of a regressive interval (green) and coastal encroachment (B), i.e., the horizontal component. Coastal encroachment is measured in kilometers, while the coastal aggradation is measured in milliseconds (two way time). A quickly time / depth conversion of the coastal aggradation, as we will see later, gives the total relative sea level rise. On the other hand, knowing the coastal aggradation (in meters, or kilometers) and coastal encroachment, it is possible to get an idea of the morphology of the basement over which the sediments transgressed. A high coastal encroachment coupled with an high aggradation characterizes a flat morphology of the underlying unconformity (eventually basement), while a small aggradation and a small encroachment characterizes a steep morphology.

Marine Onlap

Marine onlap is the onlap of marine strata, primarily deep marine (deposited seaward of the shelf break0 in nature.

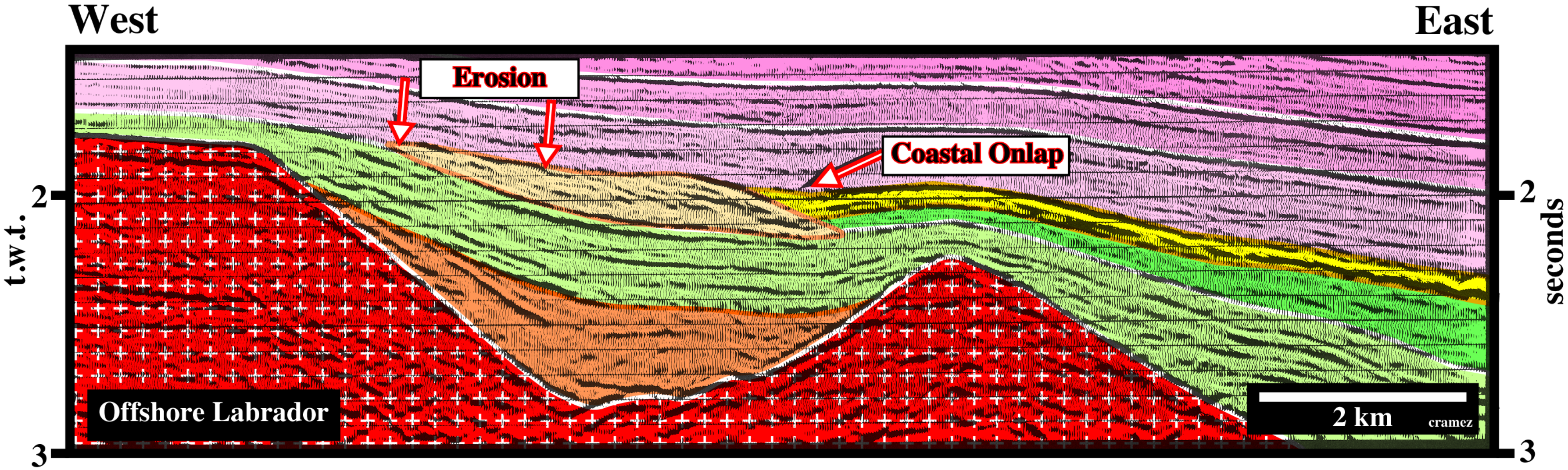


Fig. 29- On this line, geologists have considered the onlap of the orange marker as a marine onlap. I thing it is rather coastal onlap than marine onlap. Indeed, in the central part of the line, it is easy to recognize a lowstand regressive interval, bounded above by an erosional surface. The upper parts of the progradations, forming the regressive interval, were partially eroded. So, at the time of erosion, that is to say, at the end of the regressive interval, the basin did not have a shelf. The depositional costal break was coincident with the shelf break. Subsequently, following a small relative sea level fall, the coastal deposits were slightly shifted seaward and basinward, and so, the onlap of the yellow interval must be considered as a coastal onlap. Marine onlaps, as illustrated on the next plate, occur when the basin has a shelf (coastal break and shelf break not coincident) or when the relative sea level fall is big enough to create a change of environment of the depositional systems.

Marine Onlap

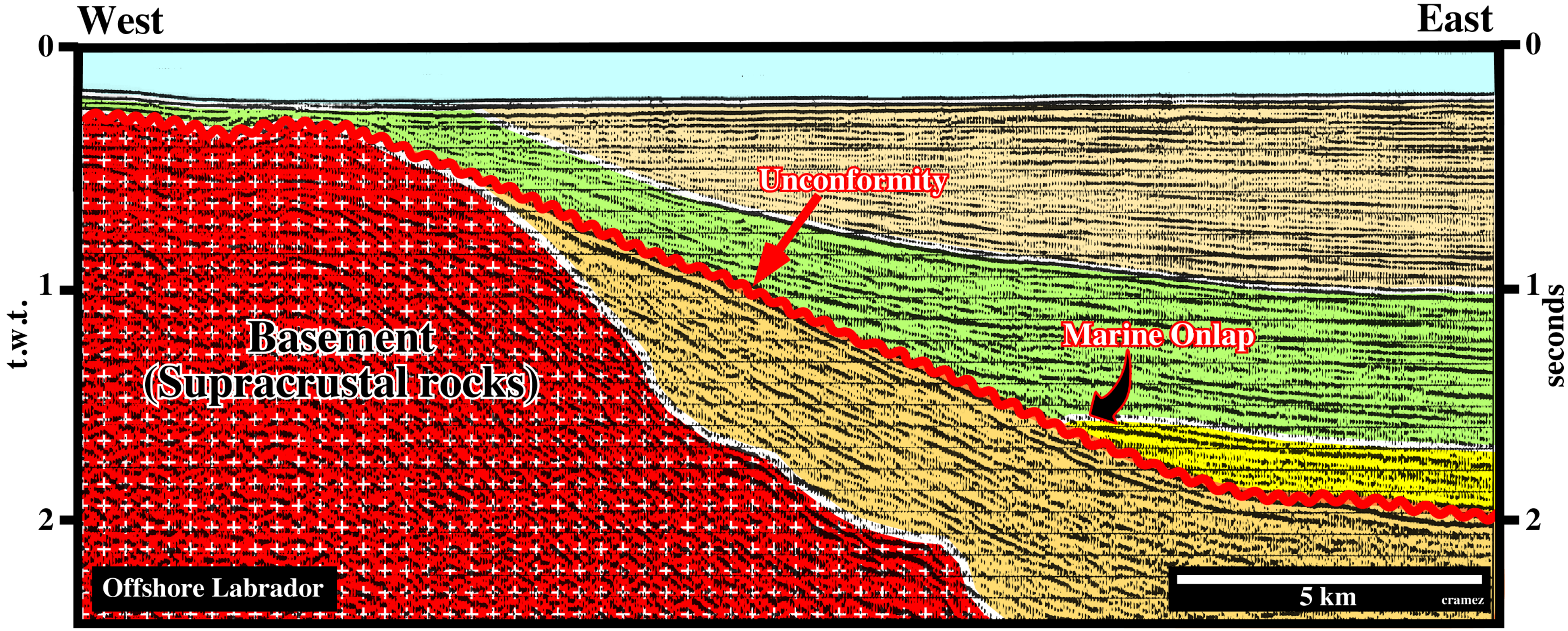


Fig. 30- On this line from offshore Labrador (parallel to the direction of the source of clastic supply), the turbidite depositional systems of a basin floor fan interval (yellow package) onlaps (marine onlap) on a major unconformity (in red), which seems to have been induced by an eastward tilting of the basin. As with coastal deposits one could speak of marine aggradation and marine encroachment. However, traditionally, geologists keep aggradation and encroachment to express the vertical and horizontal components of coastal onlap. Marine onlap implies a significant depositional water depth. In coastal onlap, the water depth is practically zero. In spite of the fact the basement is mainly composed by Precambrian supracrustal rocks, the majority of the reflectors visible in the basement are seismic artefacts, mainly peg-legs.

Marine or Coastal Onlap?

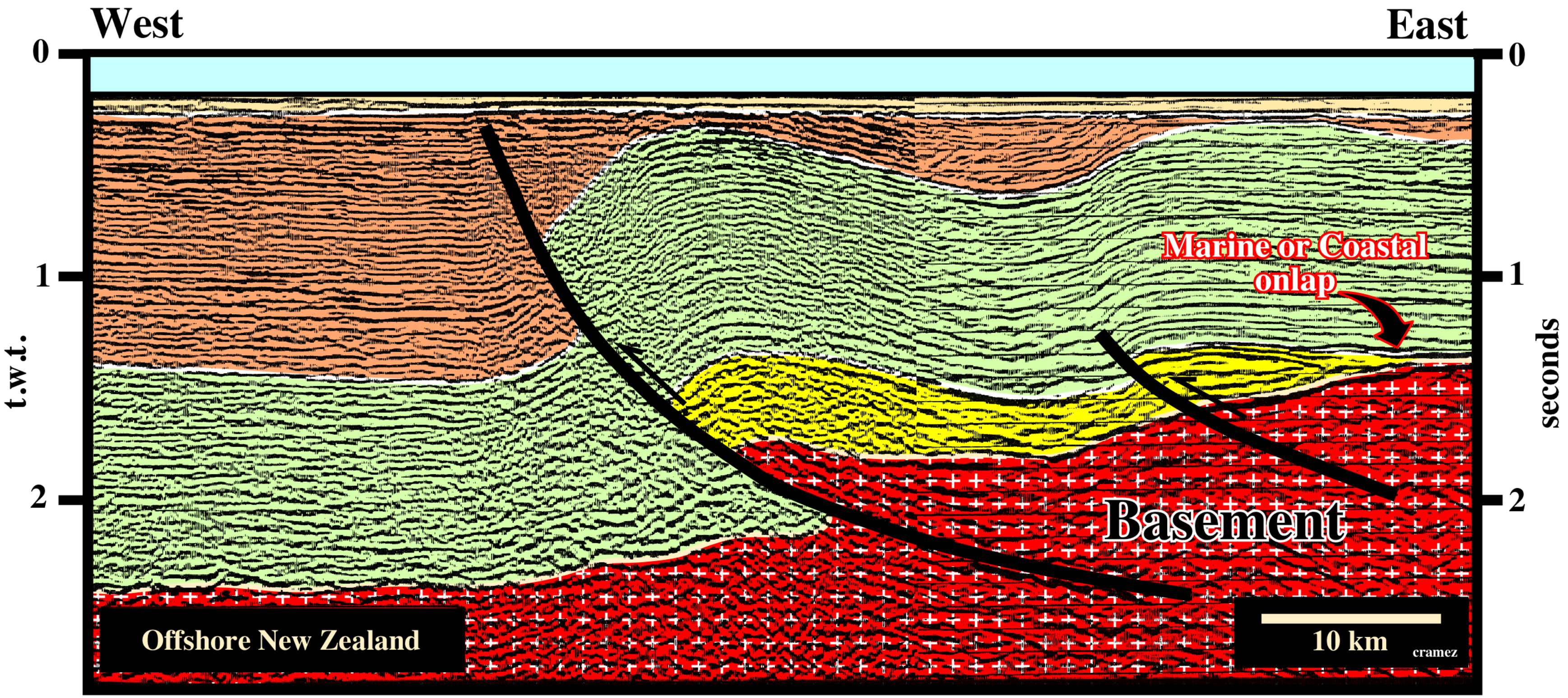


Fig. 31- On this line, from offshore New Zealand, compressional structures are paramount. These structures seem to have been developed by a significant tectonic inversion. Indeed, it is quite possible that the old normal faults, developed during the rifting phase (extensional phase), were later, during a compressional tectonic regime, reactivated as reverse faults. If such a tectonic interpretation is not refuted by additional data, the onlap recognized on the yellow seismic interval is coastal (or nonmarine) rather than marine. Actually, in this tectonic interpretation, the yellow interval is interpreted as the fill of a rift-type basin, which are generally filled by non marine sediments. However, this line can be interpreted in a differently way , as illustrated on the plate.

Marine or Coastal Onlap?

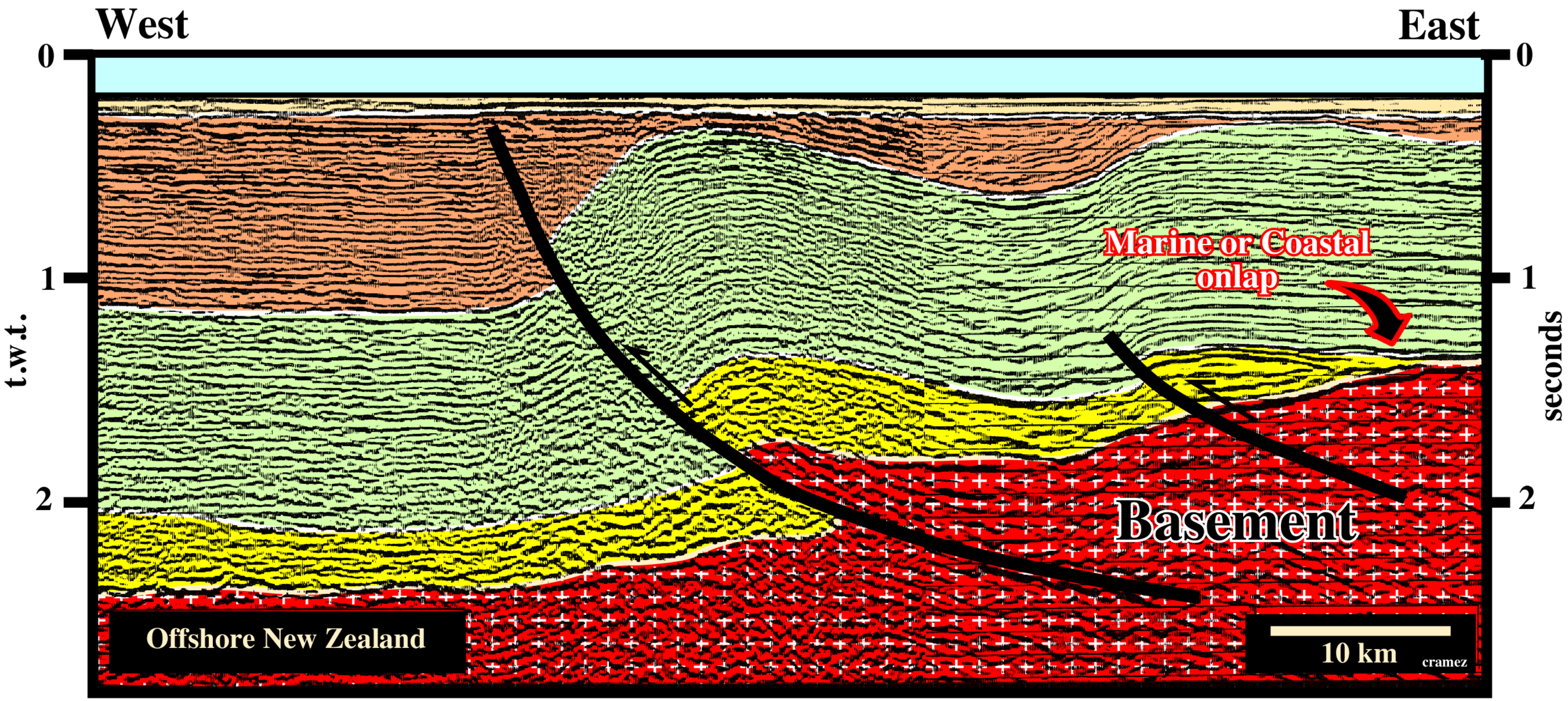


Fig. 32- On this interpretation, the yellow interval is interpreted no as a rift-type basin (see fig. 30), but as a marine interval, likely a deep-water turbidite package deposited over a basement. If such a hypothesis is not refuted, the geometrical relationships between the yellow strata and the basement must be interpreted as marine onlap. This example clearly indicates that seismic interpretation cannot be done in isolation. It is strongly dependent of the regional and global geological settings. On the other hand, geologists, and particularly seismic interpreters, should never forget that there are not any true interpretations. All seismic interpretations will be, sooner or later, refuted by new geological data. Strictly speaking, a seismic interpretation can never be verified. It can only be validated or corroborated.

Apparent Onlap

Apparent onlap is the onlap observed in any randomly oriented vertical section, which may or may not be oriented parallel to depositional dip.

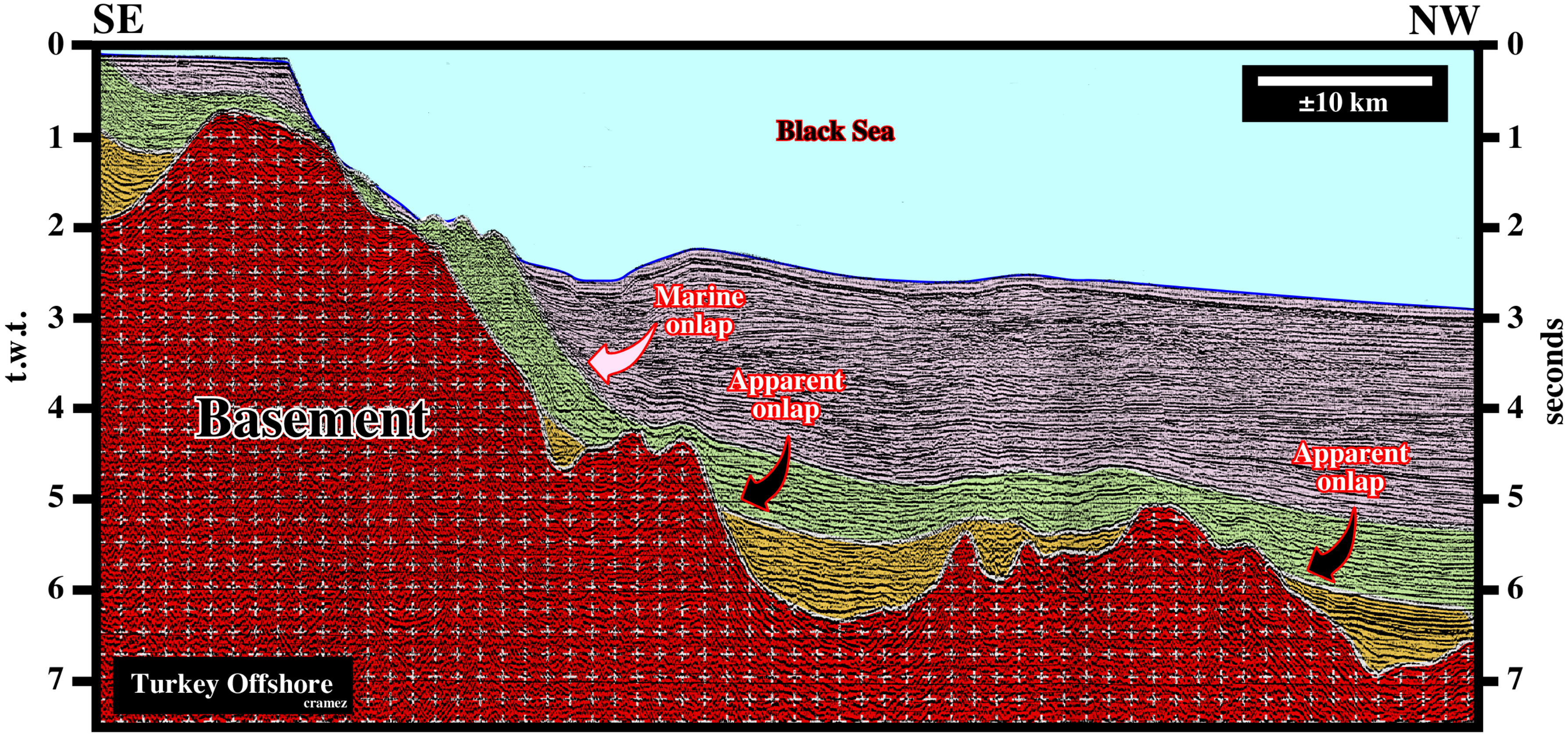


Fig. 33- The onlaps in the lower most sedimentary intervals (yellow and light green) are apparent onlaps. Indeed, this seismic line is oblique to the depositional dip of the lower intervals. On the contrary, in relation to the depositional dip of the upper interval, the line is roughly parallel, so the associated onlaps are marine.

Apparent Onlap

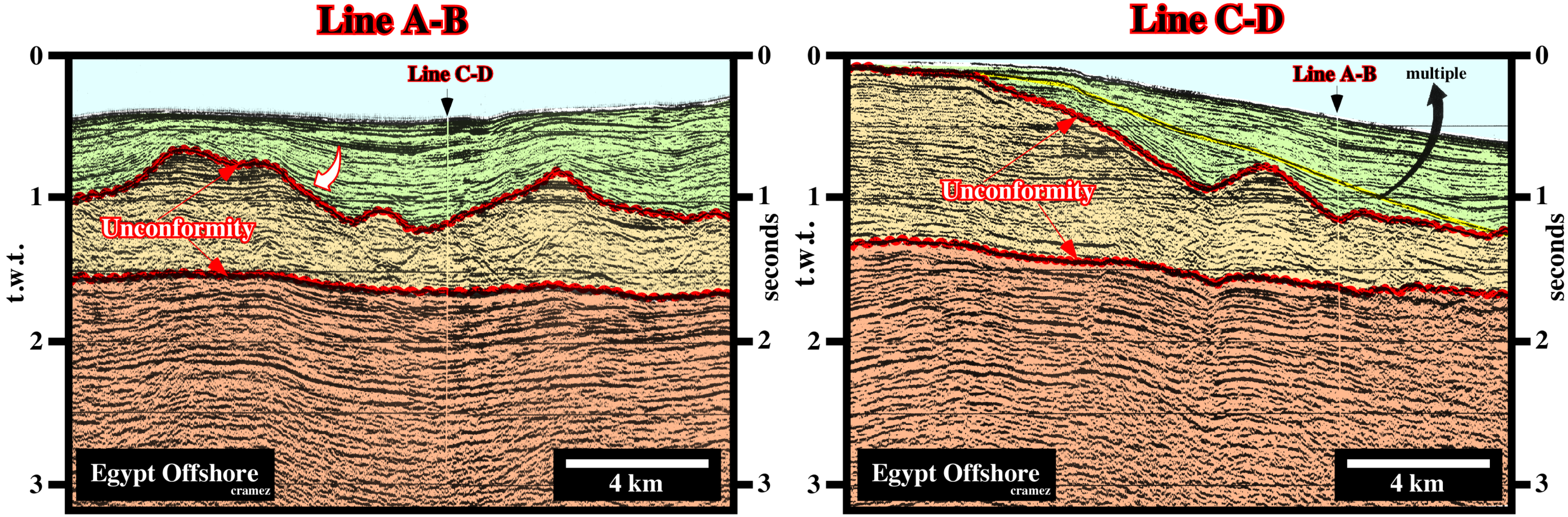


Fig. 34- On line A-B, the geometrical relationships of the uppermost interval are apparent onlaps. The seismic line is not parallel to the depositional dip of the rocks composing the concerned interval. On line C-D, which is orthogonal to the A-B line and parallel to the depositional dip of the sedimentary rocks composing the uppermost interval, it is easily to recognize that the geometrical relationships of the strata are not onlap, but downlap (see later). Briefly speaking, on seismic data, the real geometrical relationships are only recognized on an undeformed seismic line parallel to the depositional dip. However, it must be noted, that on a seismic line, the strike of the depositional dip can change from one seismic interval to another.

Non-Marine Onlap

Non-Marine onlap is the onlap observed in non-marine environments, that is to say, landward of the depositional coastal break.

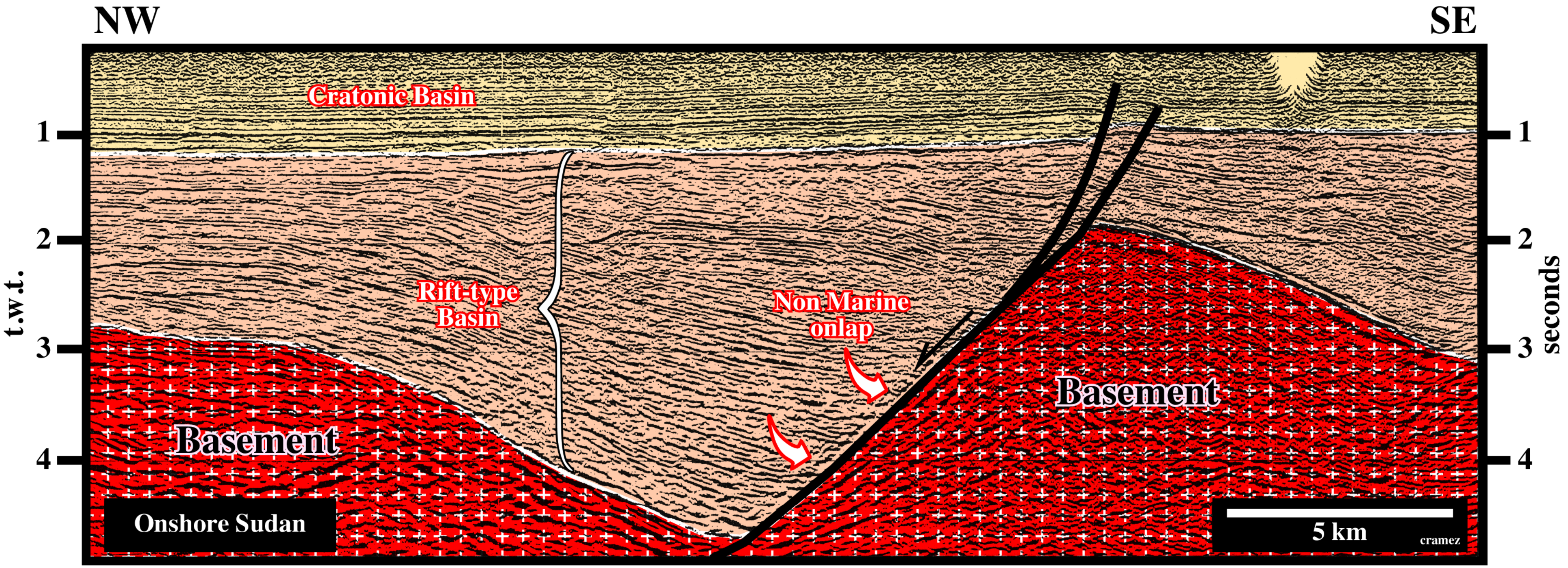


Fig. 35- This seismic line comes from onshore Sudan, in which rift-type basins, as the one illustrated above, are overlain by a quite large, but relatively shallow, cratonic basin. An unconformity, which locally can be tectonically enhanced (angular unconformity), individualizes the rift-type basin from the cratonic basin. In rift-type basins that are developed in non-marine environments, the onlap of the strata against the basement is non-marine. Actually, on this line, the onlap can even be considered as lacustrine onlap. Indeed, organic rich lacustrine shales (source-rocks) have been recognized by drilling (the giant Unity oil field, is located on the left end of the line).

Non-Marine Onlap

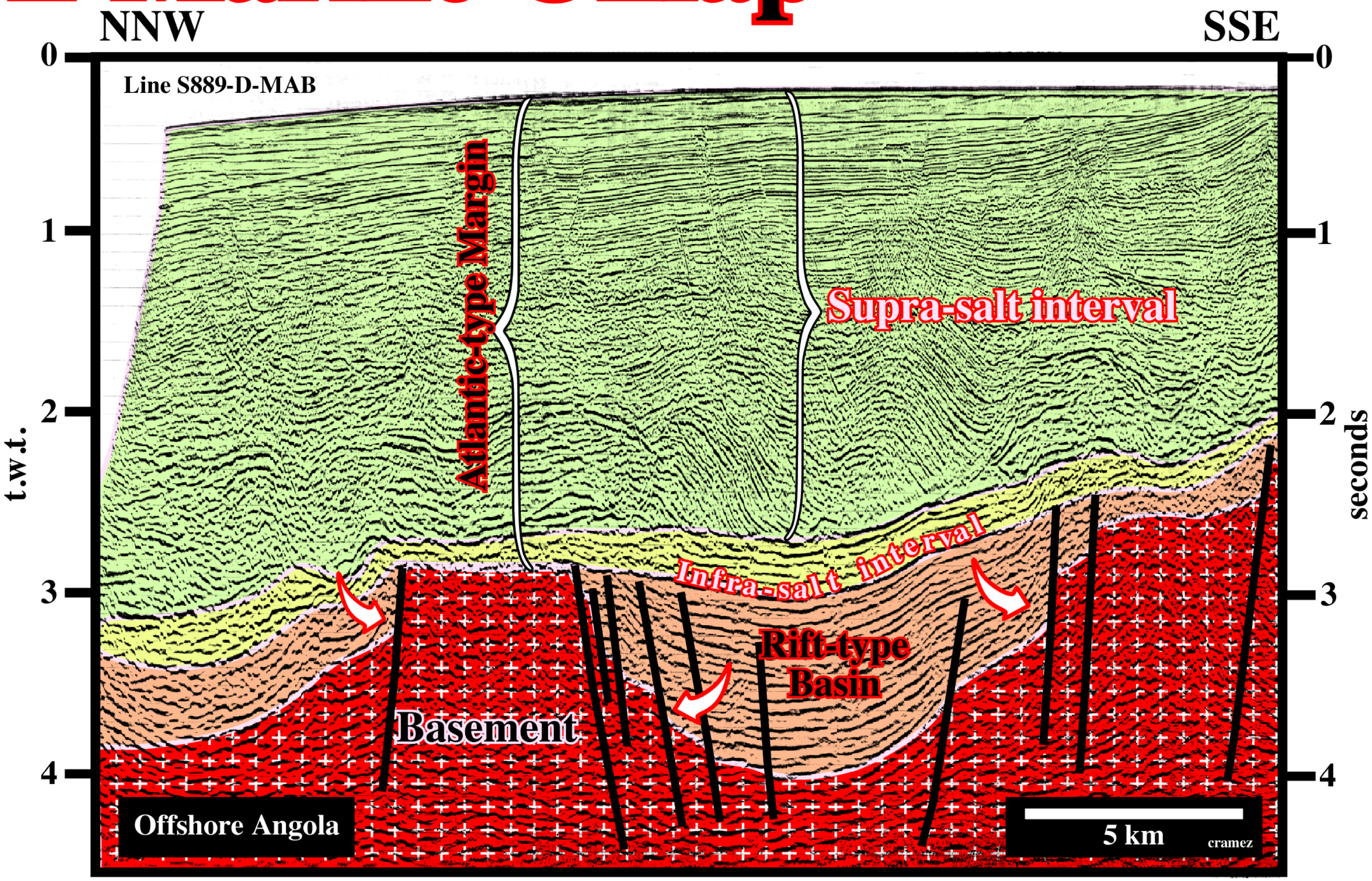


Fig. 36- Offshore Angola, both the Kwanza and Congo basins are composed of three sedimentary basins stacked together. On this line, from bottom to top, it is easy to recognize a Palaeozoic fold belt (or a granite-gneiss basement), two Upper Jurassic to Lower Cretaceous rift-type basins, which are covered by a Meso-Cainozoic Atlantic-type divergent margin. The onlapping recognized on the rift-type basins is non-marine. Rift-type basins are developed within the Pangaea supercontinent, where non-marine environments are paramount.

Non-Marine Onlap

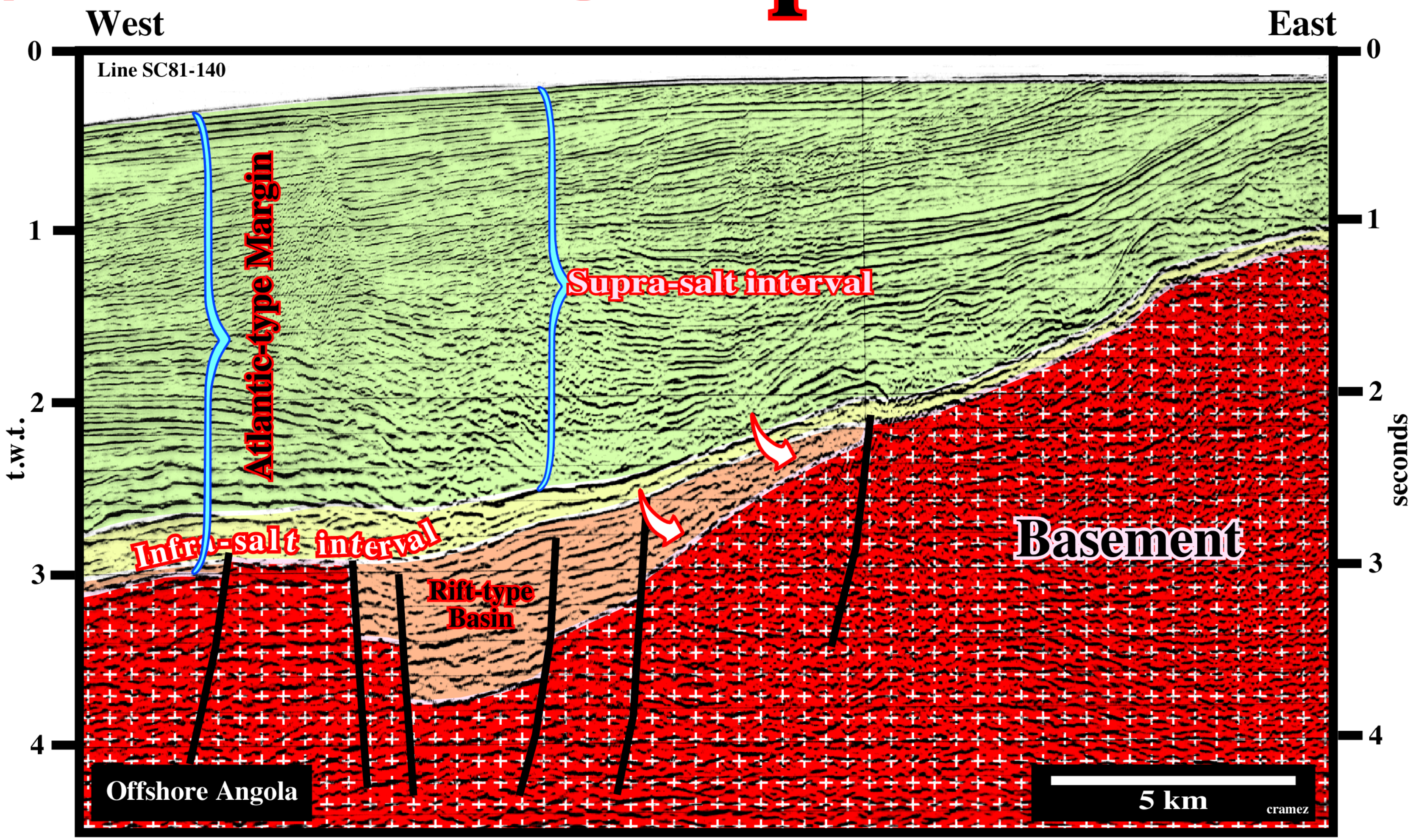


Fig. 37- On this line from offshore Angola, the onlap recognized in the rift-type basin is non-marine onlap. The predominant depositional environment of the South Atlantic rift-type basin is non-marine. However, in certain rift-type basins, such as the North Sea, the uppermost stratigraphic levels can show a marine influence (Kimmeridgian shales).

True Onlap

When two apparent onlaps are observed in two sections intersecting at right angles, the true onlap is likely in the section parallel to the depositional dip.

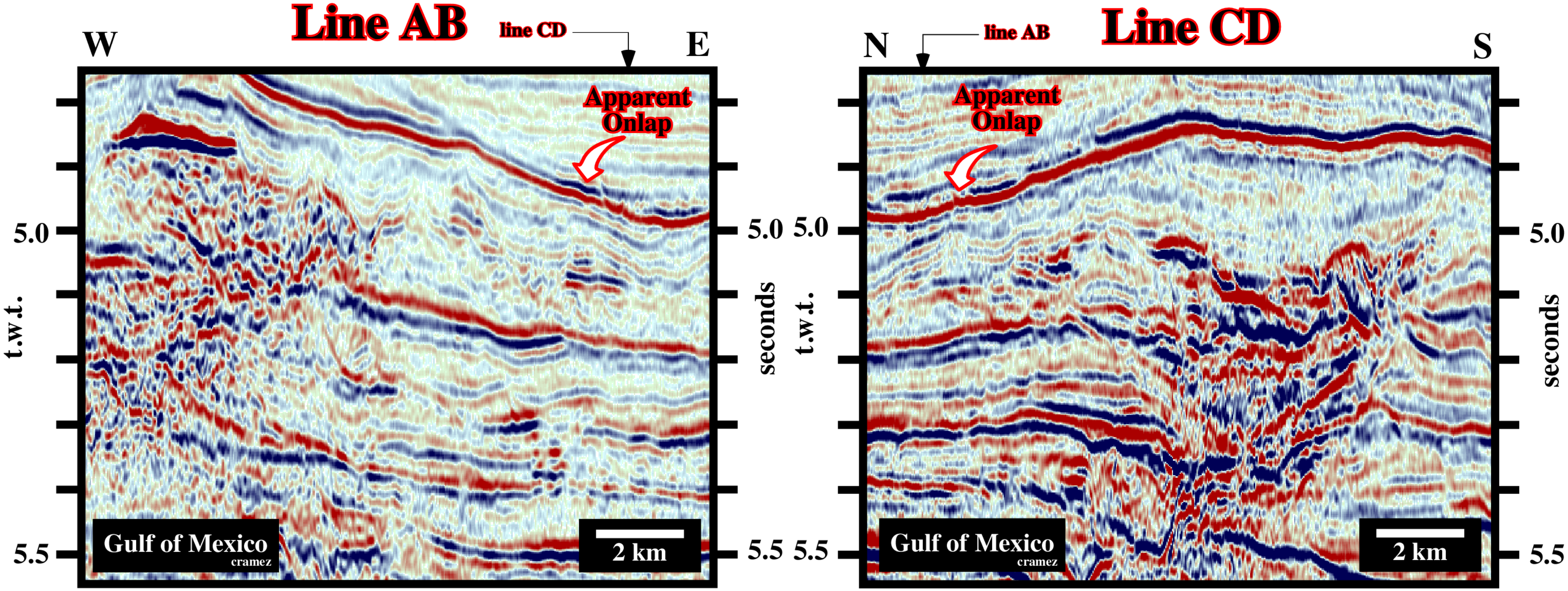


Fig. 38- On these orthogonal seismic lines, located in the Gulf of Mexico, two apparent onlaps can be recognized. So, it is likely that a true onlap will be recognized on the line shot parallel to depositional dip (parallel to clastic sediment supply). These lines illustrate deep-water environments, characterized by turbiditic channel-levee complexes, where onlap geometrical relationships are quite rare. Onlap occurs mainly in the overlying intervals as illustrated above.

Tilted Onlap

A tilted onlap is an apparent geometrical relationship, that looks like a downlap. Generally, it is induced by tilting, by compensatory subsidence or by salt or shale flowage.

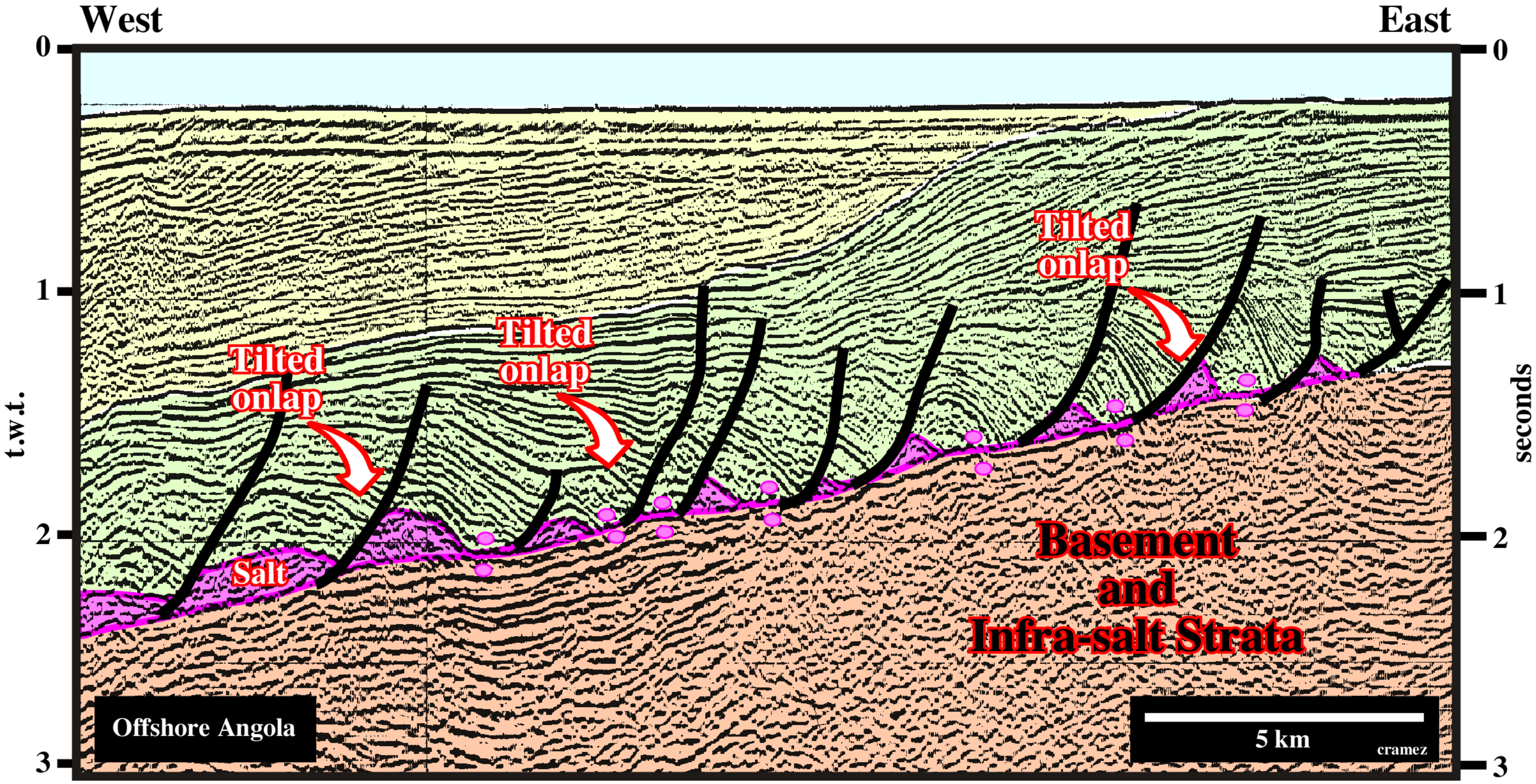


Fig. 39- On this line, in which lateral and vertical salt flowage are paramount, salt induces tectonic inversions took place. The original onlap geometrical strata relationships were tiled thus becoming similar in geometry to progradational reflectors (downlap). It is important to remember that onlap is a synsedimentary geometrical relationship, which can be more or less deformed by regional or local postdepositional tectonic regimes.

Tilted Onlap

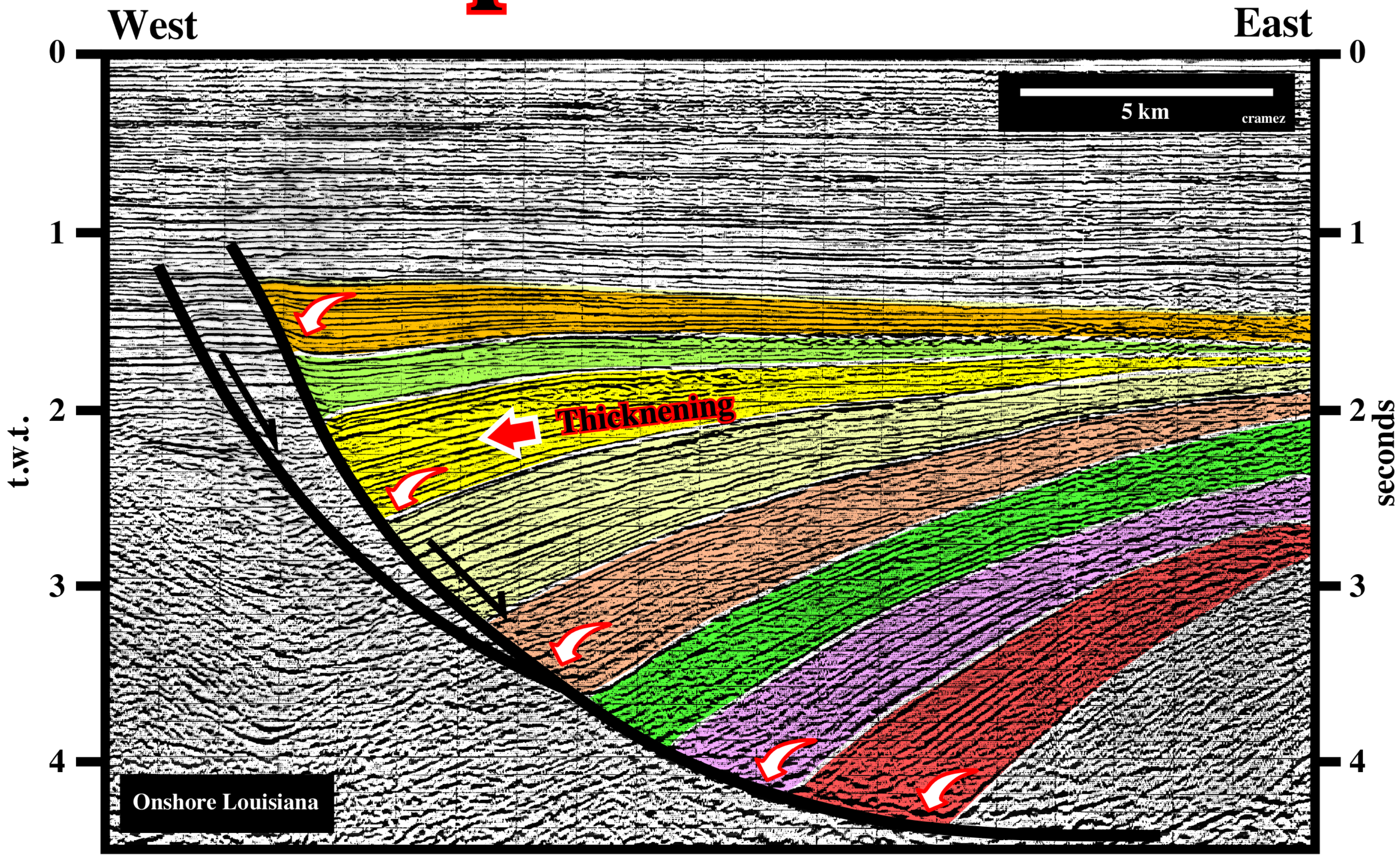


Fig. 40- On this seismic line, from onshore Louisiana, sediments thicken landward towards the fault plane of a large growth fault. The original onlap geometrical relationships were progressively rotated seaward. Subsequently, the seismic surface, defined by reflection terminations against the fault plane, is not an onlap surface, but rather a "tilted" onlap surface. Such tilted reflection terminations should not be confused with downlap. In a downlap geometrical relationship sediments thin (converge) downdip.

Tilted Onlap

adapted from J.L.Rubino, 2004

Fig. 41- On this outcrop (Murzuq basin, onshore Libya), tilted onlap can be recognized in association with a normal growth fault (in red). The hinge point is also easily recognized. It corresponds to a change in subsidence. Strata thicken toward the fault plane. Tilted onlaps against a fault plane have roughly the same geological meaning as a true onlap. In terms of relative sea level changes, they correspond to a relative sea level rise.

Tilted Onlap

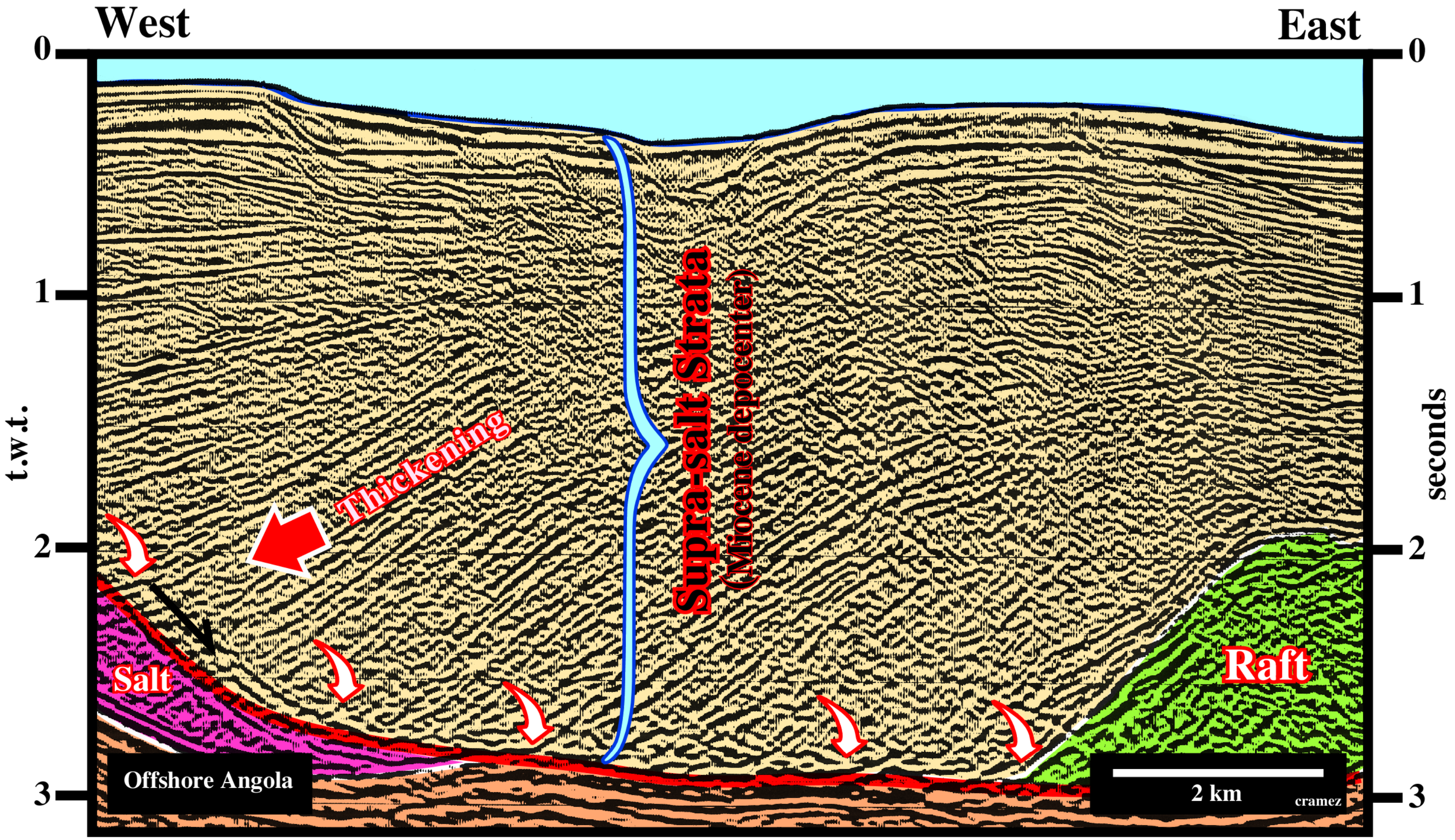


Fig. 42- On this seismic line, a synsedimentary salt flowage tilted the pristine onlap geometrical relationships. Presently, they look like progradational strata. However, as they thicken toward the fault plane, along which they glided downward, they should not be confused with progradational strata. Progradational strata thin, that is to say converge basinward, so the stratigraphic units (and the equivalent seismic interval) become condensed seaward.

Tilted Onlap

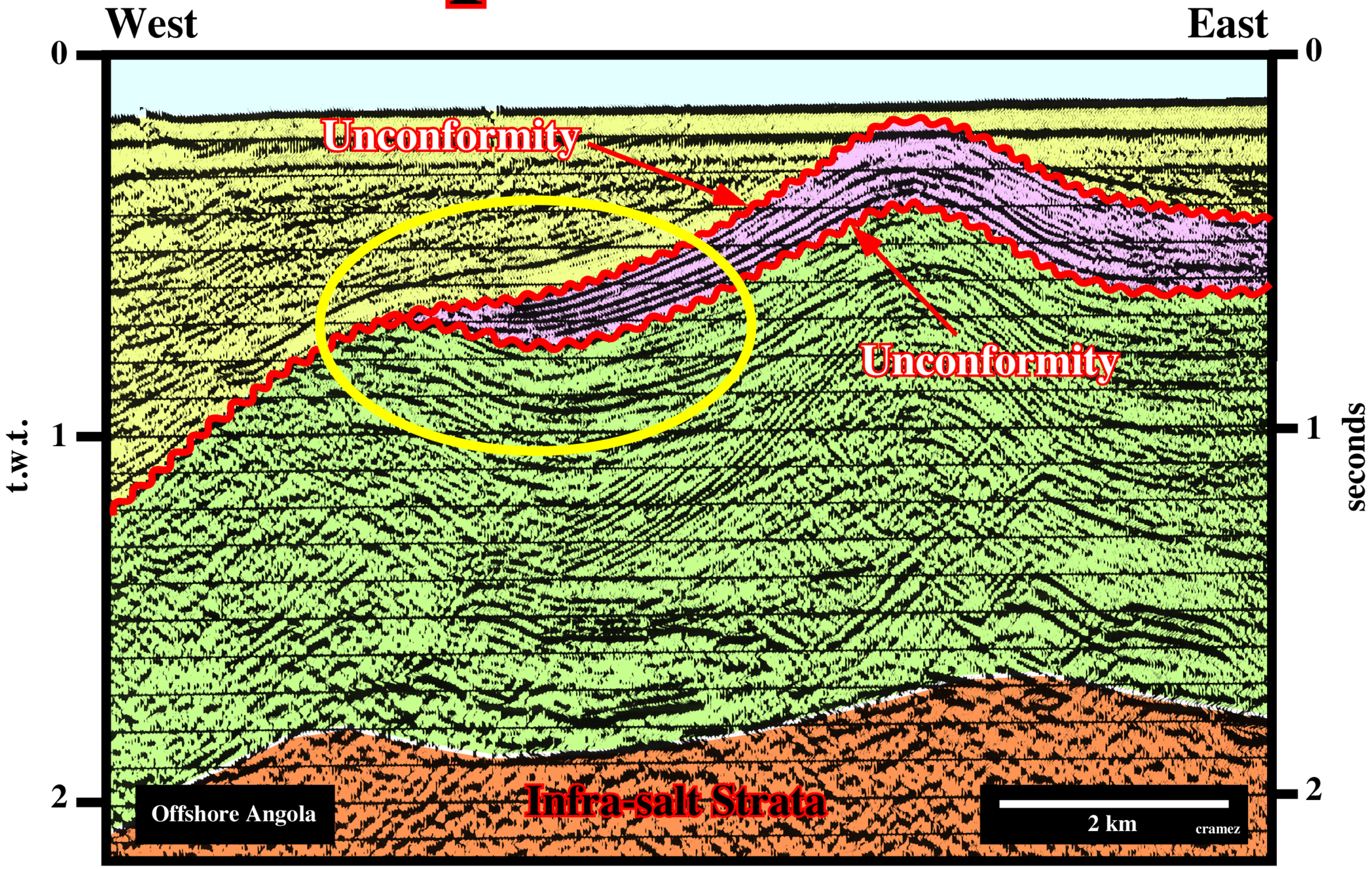


Fig. 43- As illustrated on this line, in salt basins, such as the Kwanza basin, halokinesis (extension) and reactivation of fracture zones (compression) can deform the original geometrical relationships between strata. Here, between two unconformities (relative sea level falls), the original onlaps (distal onlaps) were deformed. Presently, they look like downlaps (see next). However, it is quite evident that they correspond to an aggradational rather than a progradational unit.

Downlap

A downlap is a discordant relation, in which initially inclined strata terminate downdip against an initially horizontal or inclined surface.

Several different kinds of downlap can be considered:

a) Distal downlap

b) False downlap

c) Shelf downlap

d) Basin downlap

e) Opposite (local) downlap

f) Apparent downlap

Downlap

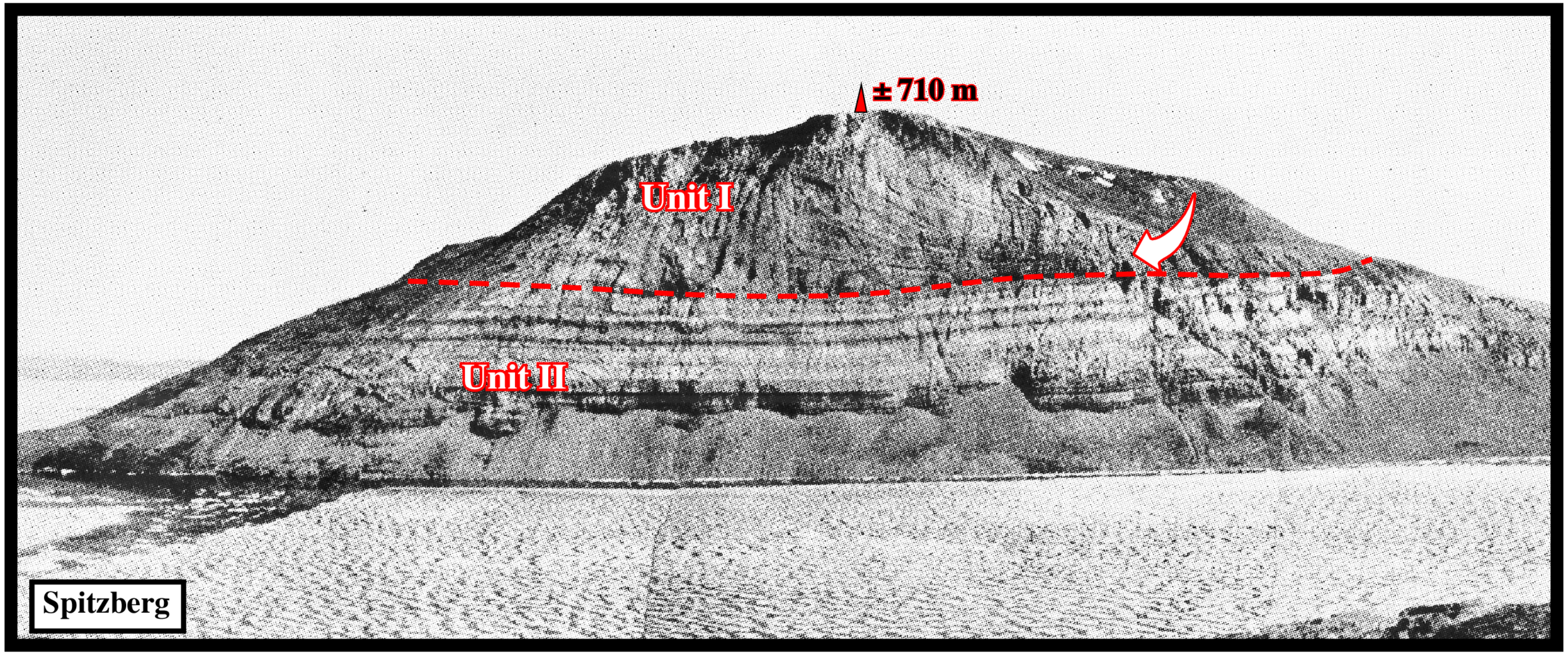


Fig. 44 - On this photograph, it is easy to recognize that a calcareous inclined strata (Unit I) terminates on much less inclined strata (Unit II). This geometrical relationship is called downlap. Therefore, one can say that a downlap surface, characterized by stratal, or seismic reflection terminations, exits between Unit I and II. Downlap surfaces are not unconformities (erosional surfaces), since they correspond mainly to a non-depositional time-gap. However, in the deep parts of a basin, downlap surfaces associated with the downdip terminations of the continental slope progradations (see glossary) can correspond with paraconformities, which are correlable updip with unconformities. In other words, in deep water environments, downlap surfaces can coincide with surfaces limiting stratigraphic cycles.

Downlap

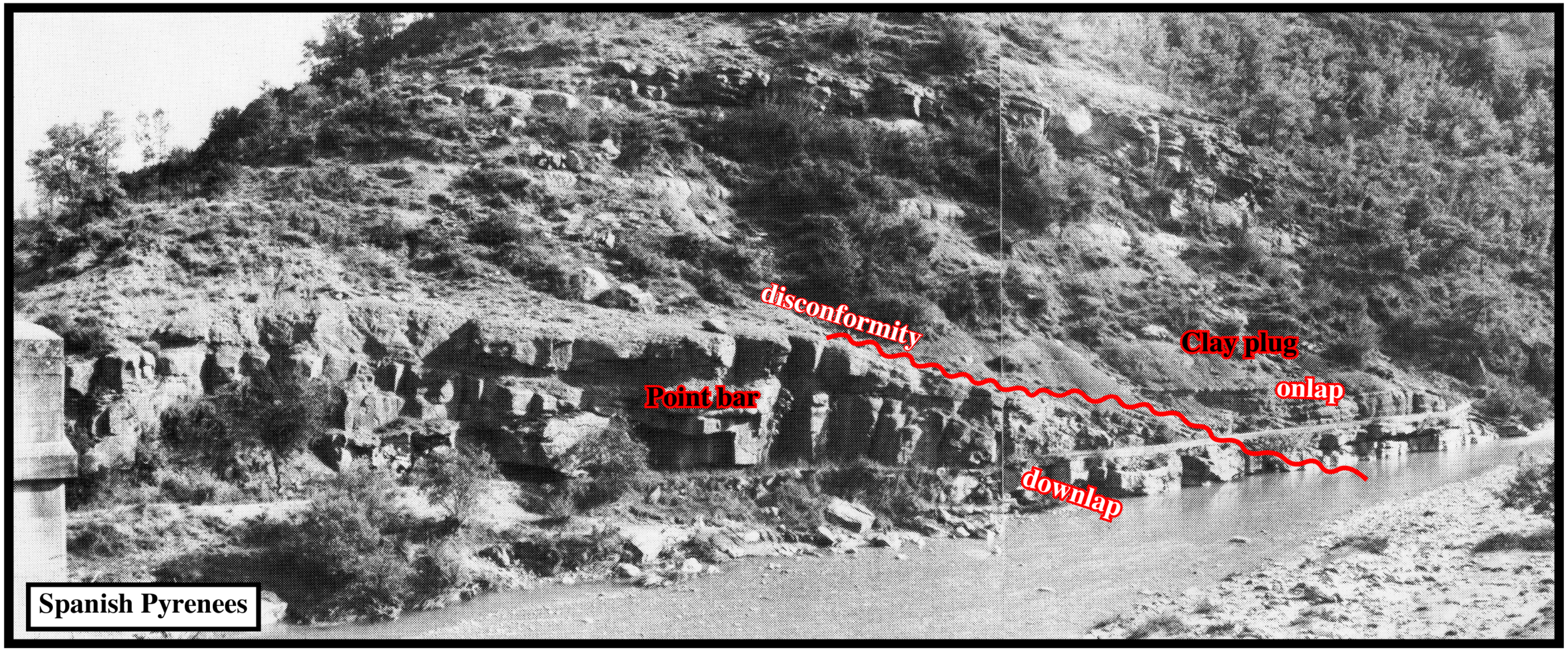


Fig. 45 - Downlap geometric relationships exist also in non-marine sediments, particularly in fluvial environments, as illustrated by the point bar illustrated above. Indeed, the inclined strata of the pointbar terminate downdip against a fluvial erosional surface (not visible). A local disconformity (in red), created probably by a neck-cutoff of the stream, was fossilized by a clay plug. The shales of the clay-plug are onlapping the disconformity limiting the point-bar. Notice that in this kind of environment, in which erosion and deposition are synchronous, the term disconformity fits better than unconformity (see glossary).

Example of Downlap

(sensu lato)

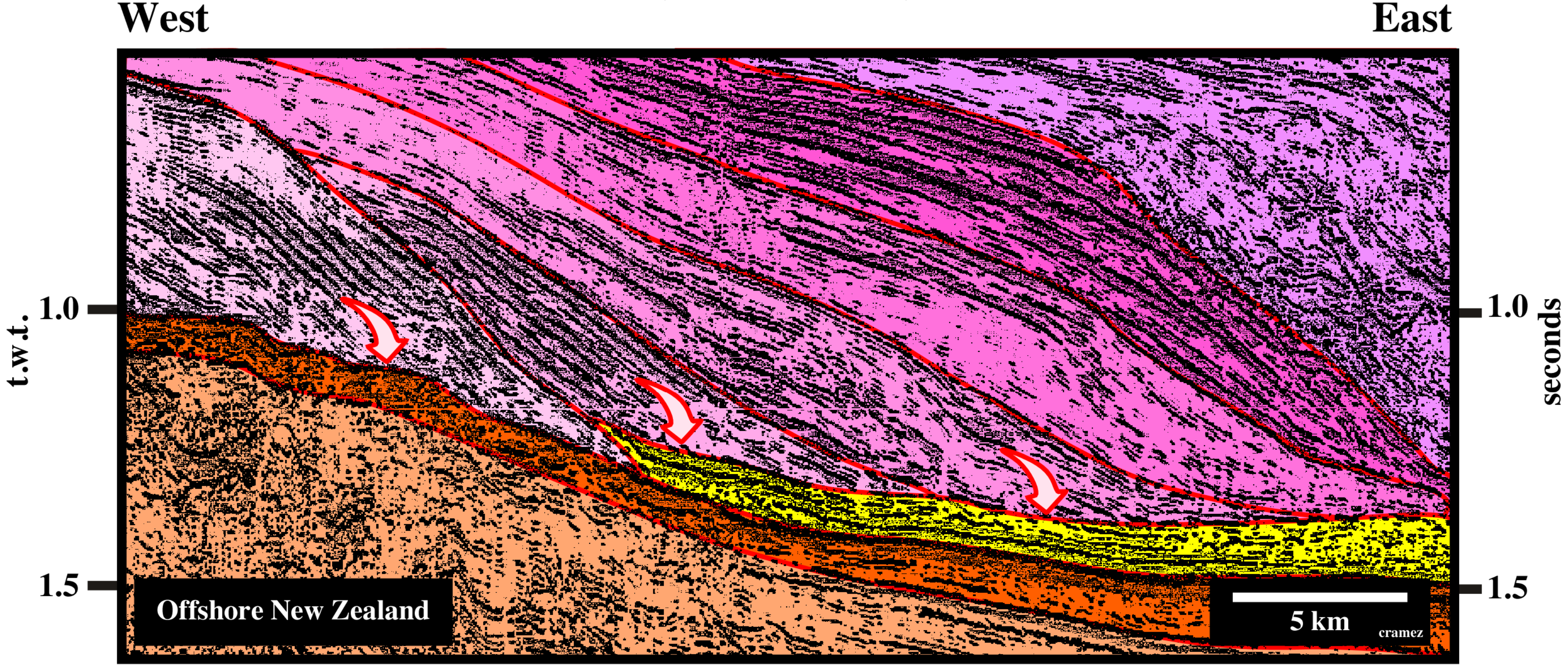


Fig. 46- On this line, downlap geometrical relationships are paramount on the progradational units. Indeed, the seaward inclined seismic reflections (chronostratigraphic lines) terminate against subhorizontal strata. Taking into account the vertical (t.w.t.) and horizontal scales, the pristine inclined reflections correspond to continental slopes. Therefore, one can say, they express roughly the direction away from the source for clastic supply. Briefly speaking, downlaps indicate the seaward direction.

Example of Downlap

(sensu lato)

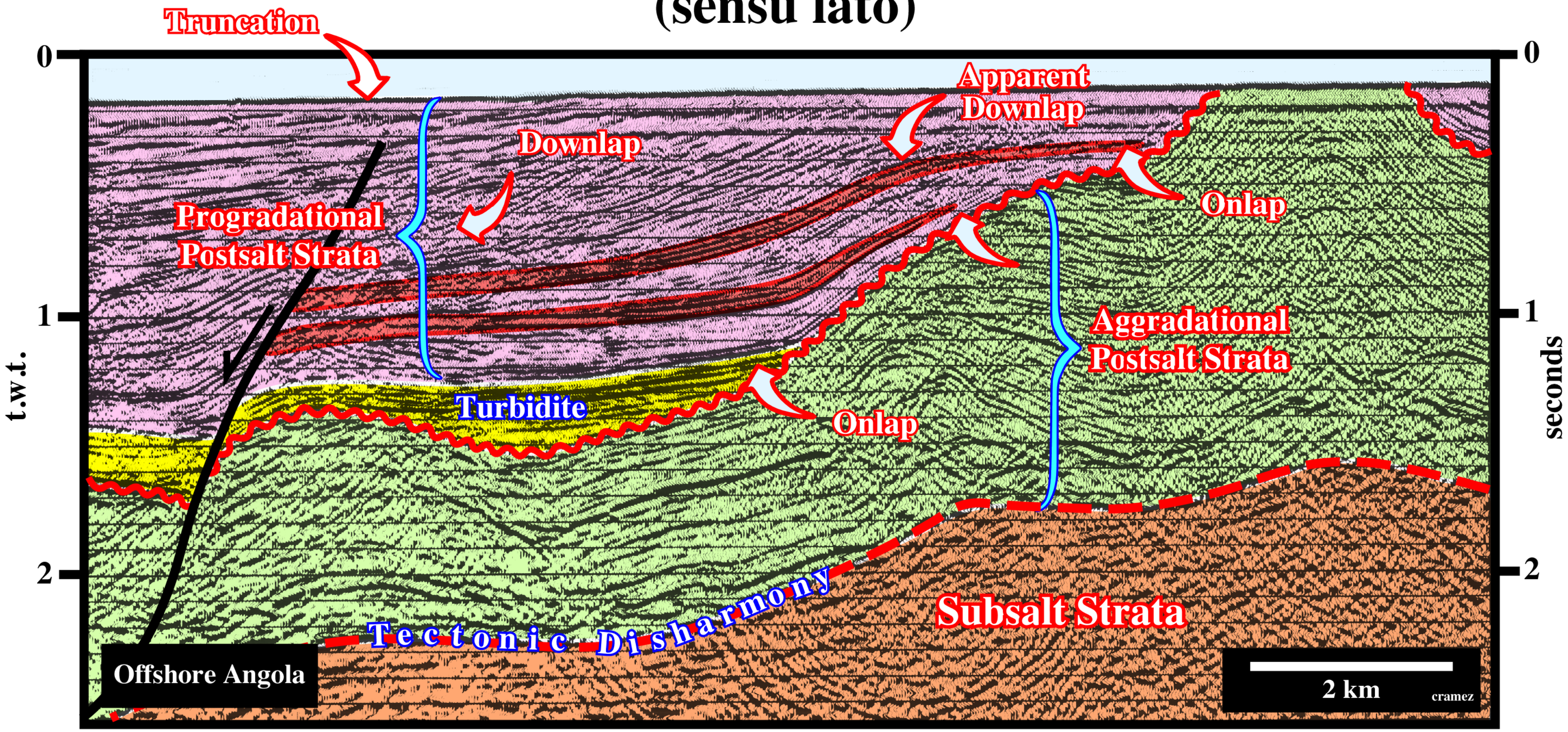


Fig. 47- 0n this line from offshore Angola, three principal sedimentary packages are recognized: (i) subsalt strata, (ii) aggradational and (iii) progradational postsalt strata. In the upper package, several types of reflection terminations can be identified. Onlaps are associated with the turbidite unit (onlap against the major unconformity). Downlaps are associated with the downdip terminations of some progradational reflections, while onlaps characterize the updip terminations. Two apparent downlaps (see later), with downdip tangential terminations (in orange), as well as truncations along the uppermost unconformity (seafloor), are also easily perceived.

Distal Downlap

A distal downlap is a downlap in the direction away from the source of clastic supply. The majority of downlaps are distal downlaps.

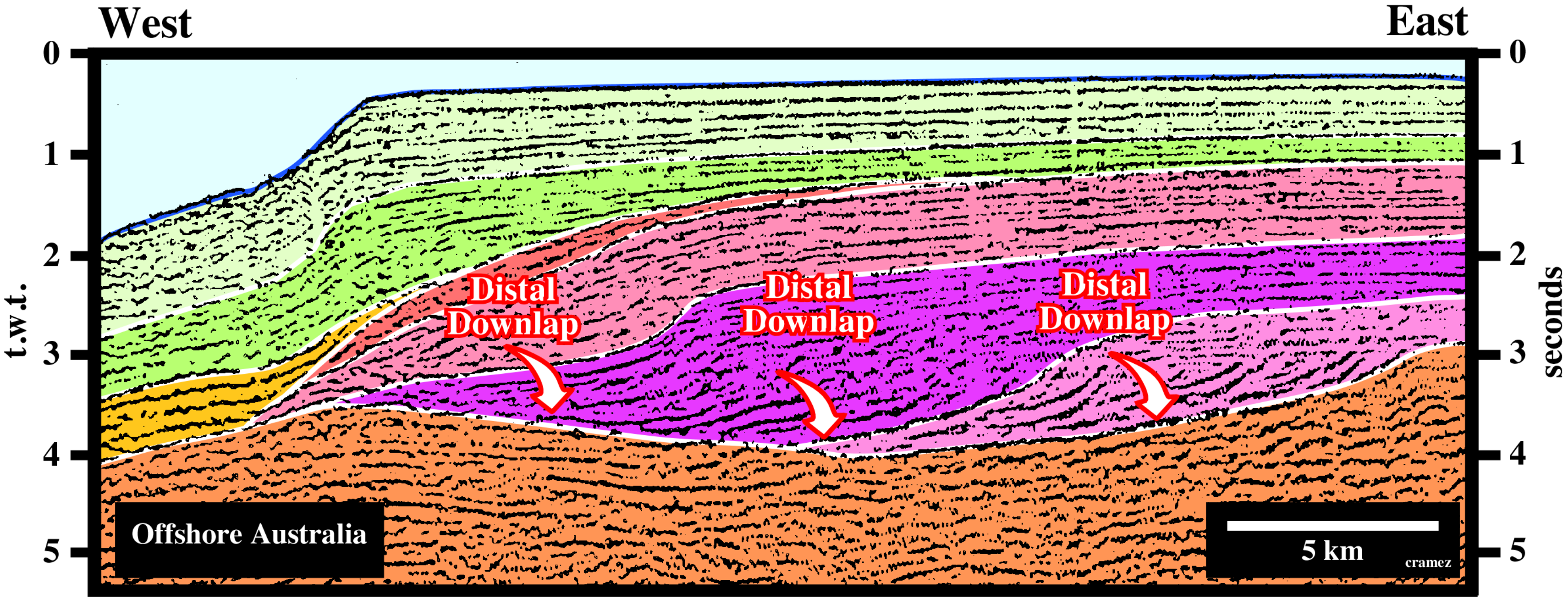


Fig. 48- In the upper stratigraphic levels of post-Pangaea Atlantic-type divergent margins, progradational intervals are very commom, as illustrated above. Such intervals have a forestepping geometry and distal downlaps, that is to say downlaps parallel to the clastic supply. Progradational intervals are generally associated with a falling global (eustatic) sea level . However, progradational sedimentatary intervals takes place during decreasing relative sea level rises, which globally form the eustatic falling. Indeed, when 10 m of relative sea level fall is followed by 7 m of relative sea level rise, then a fall of 12 m, a rise of 8 m, a fall of 15 m and a rise of 10, corresponds in total to a global falling of 12 m. So, forestepping units are deposited during successive decreasing relative sea level rises, in which coastal aggradation is progressively smaller and smaller.

Distal Downlap

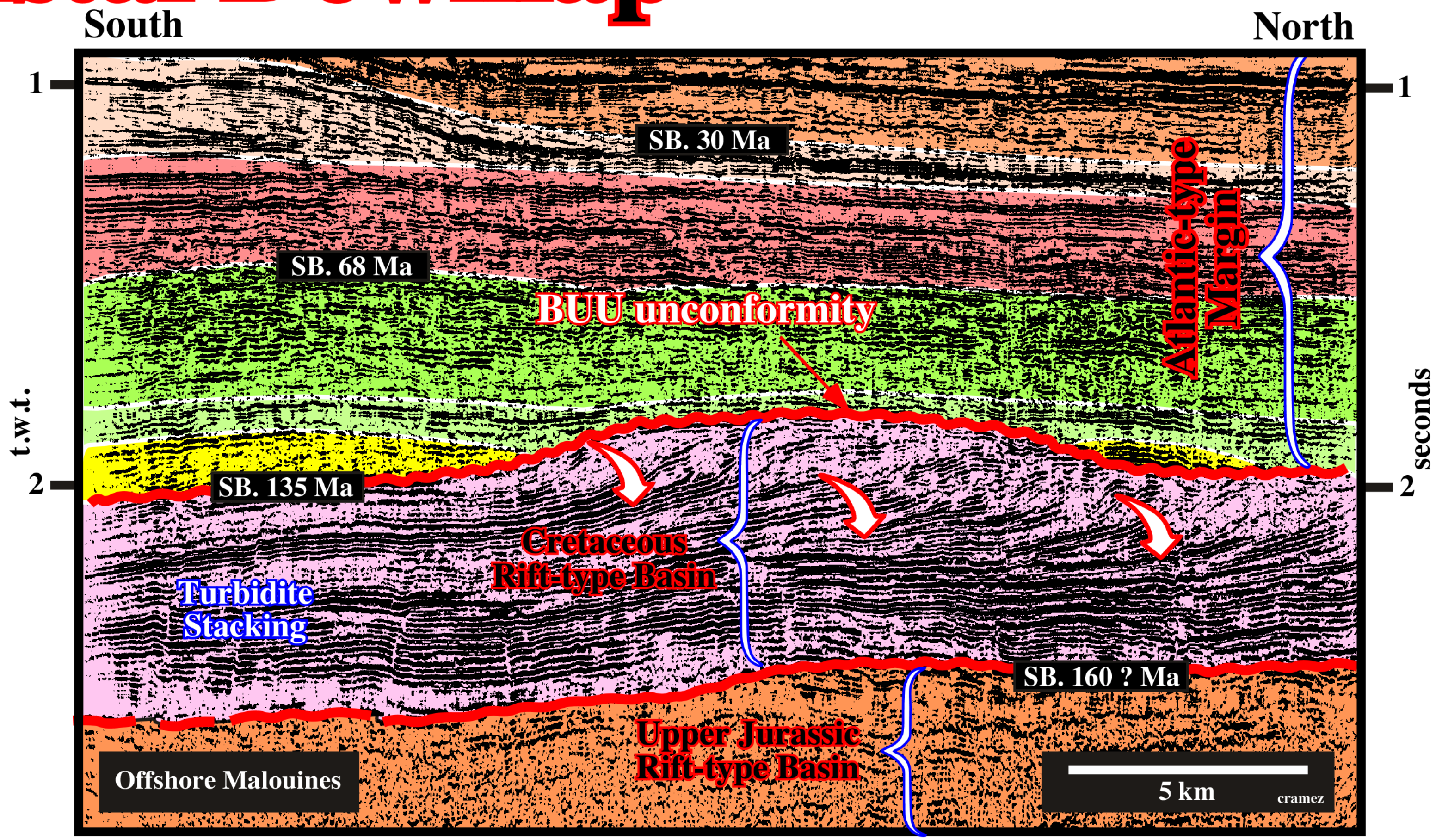


Fig. 49- Distal downlaps, i.e. downlaps in the direction away from the source of the clastic supply, often indicate the direction of terrigeneous supply, as illustrate above (Cretaceous rift-type basin). In this particular example, some distal downlaps look like apparent downlaps (see later). The inclined reflections seem to not terminate downdip, but flatten and continue seaward. Such a seaward continuity of the reflections can be apparent. It can be induced by low resolution of the seismic data. Indeed, geological speaking, there is a sharp facies change between the dipping reflectors (slope shales) and the flat reflectors (turbidite sandstones). The mounded sedimentological anomalies are sligthly disconnected from the toe of slope progradations (see glossary).

Distal Downlap

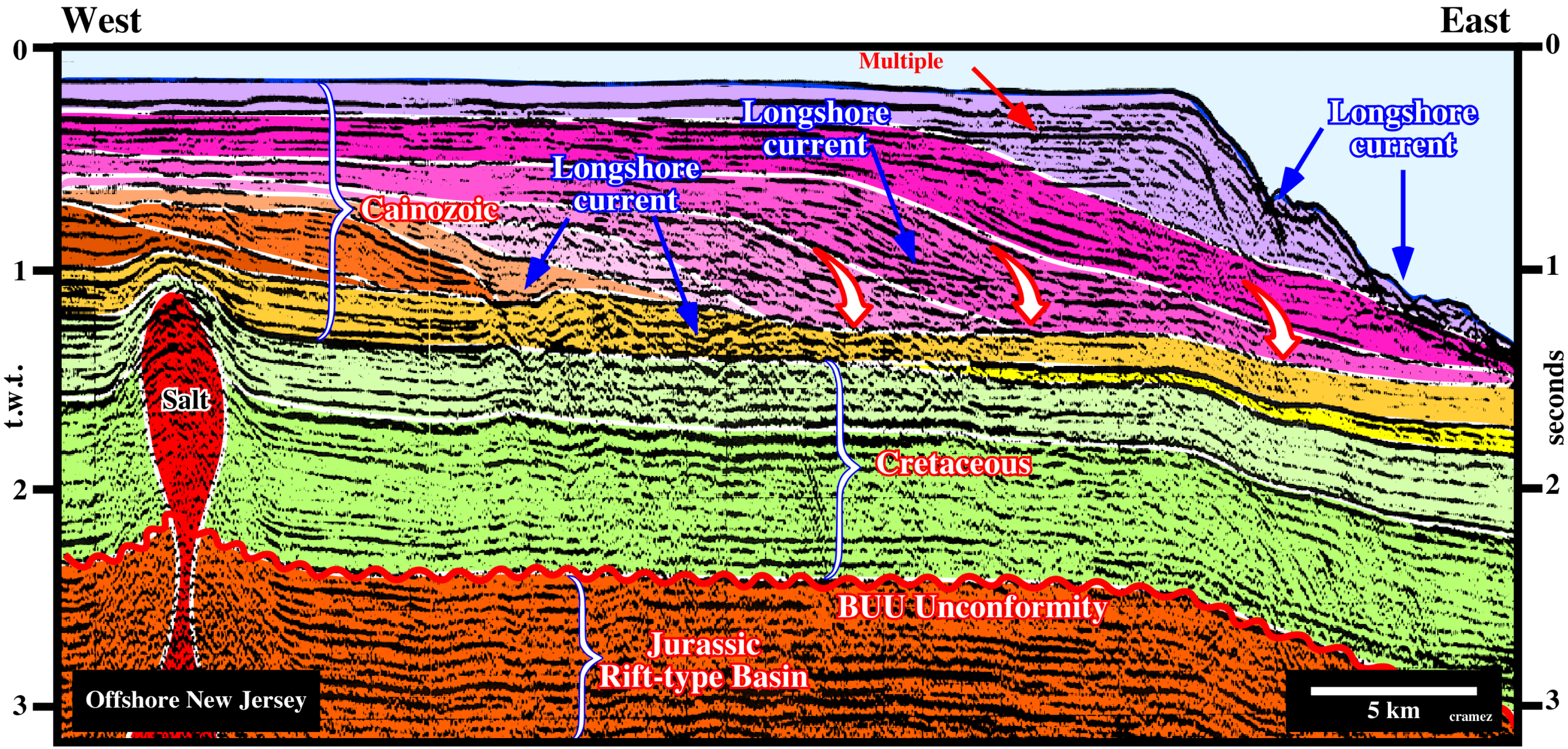


Fig. 50- On this line from Baltimore Canyon, distal onlaps are recognized in the Cainozoic progradational units, which genetically, are eustaticly induced. Indeed, during the Cainozoic, tectonic subsidence was negligible. In spite of the strong activity of longshore currents, these distal downlaps clearly indicate terrigeneous influx coming from the west. Longshore currents, which generally are limited to the surf zone and formed by waves approaching the coast at an angle, eroded the upper slope (basin without platform) creating channel-like depressions parallel to the coastline. Later, these depressions were filled by lateral terrigeneous influx. The facies of such filled-depressions (contourites for some geologists) is shale free and full of heavy minerals.

Distal Downlap

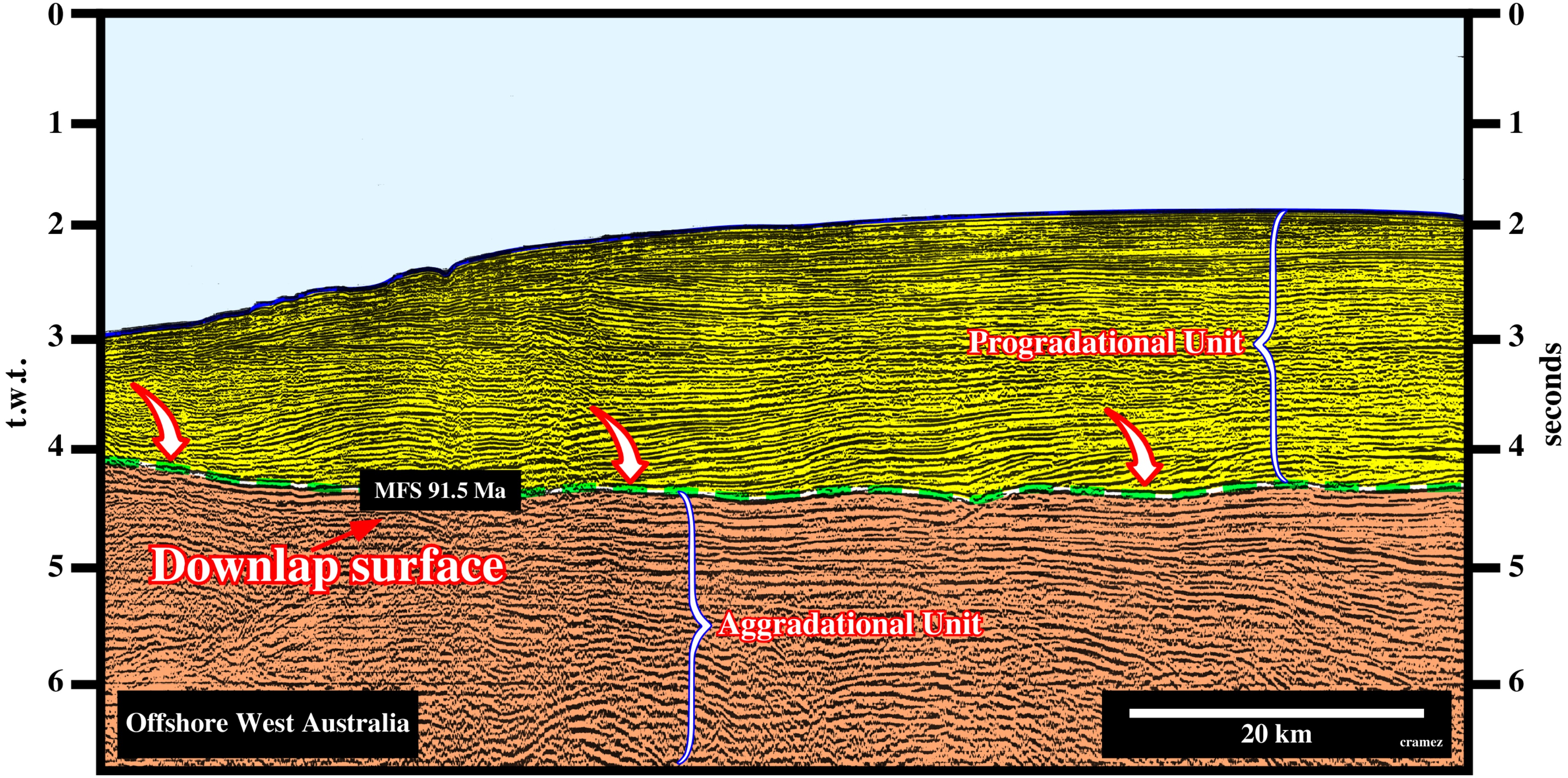


Fig. 51- Successive distal downlaps create a downlap seismic surface which is characterized by an increasing seaward time-gap (hiatus). Downlap surfaces are developed during eustatic highs, so they obey the same hierarchy as eustatic cycles. Downlap surfaces induced by 1st order eustatic cycles are often called major downlap surfaces. Since the Phanerozoic, there are two major downlap surfaces. Both separate the transgressive (backstepping) and regressive (forestepping) phases of the continental encroachment cycles (Palaeozoic and Meso-Cainozoic cycles).

Distal Downlap

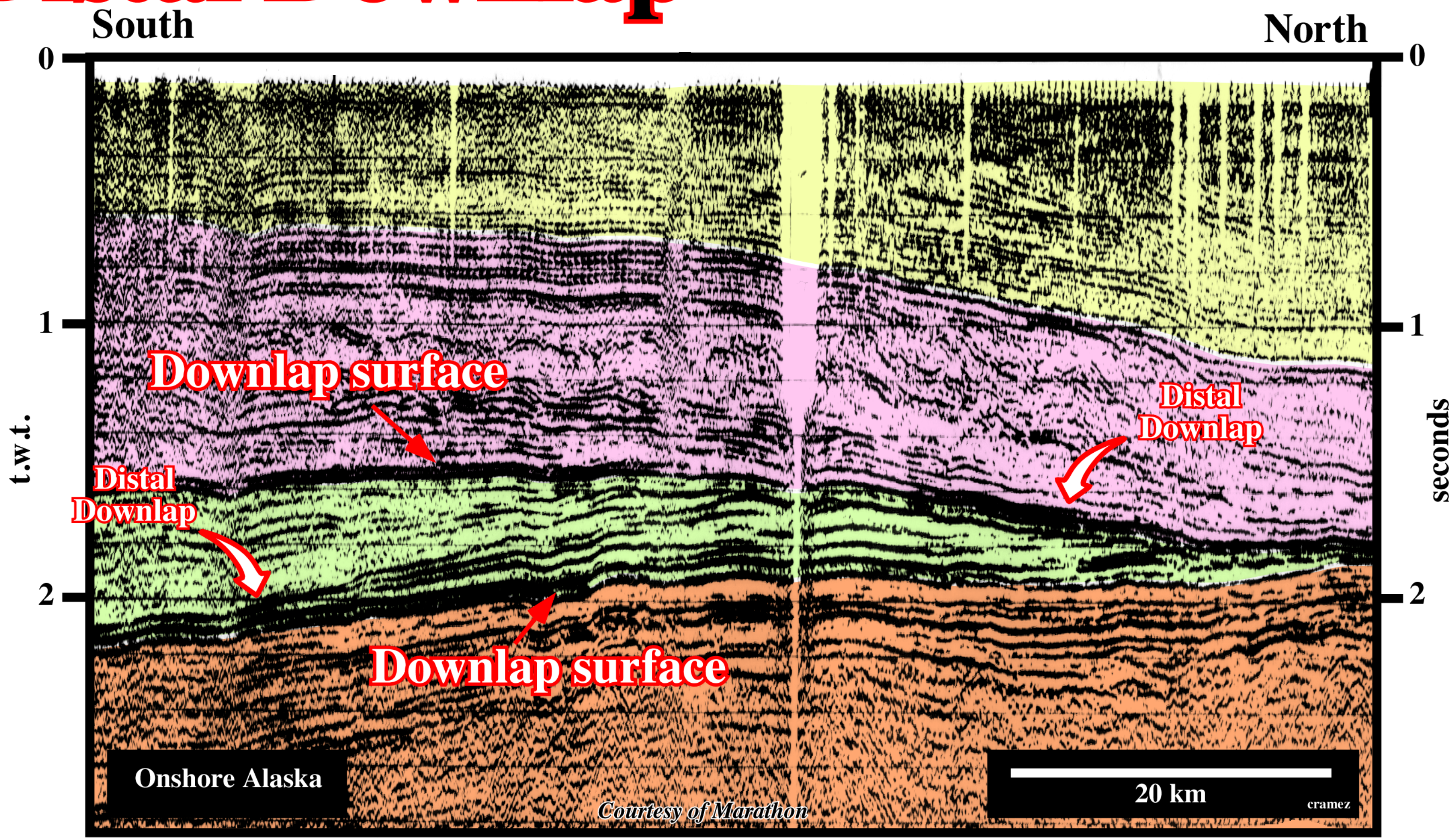


Fig. 52- On this seismic line, distal downlaps with opposite vergences define two significant downlap surfaces, which represent the closure of a sea, that is to say, the collision between two continents. The lower downlap surface, along which distal onlaps look southward, suggests a continent to the North, and a sea to the South. Contrariwise, the upper downlap surface suggests a sea, to the North and a continent to the South south. Subsequently, according to the Plate Tectonics paradigm, it is logical to hypothesize the closure of a sea as the continents collided.

False Downlap

False downlap is a downdip tangential stratal termination. Strata flatten and continue as units, which, often, are so thin that they fall below the seismic resolution.

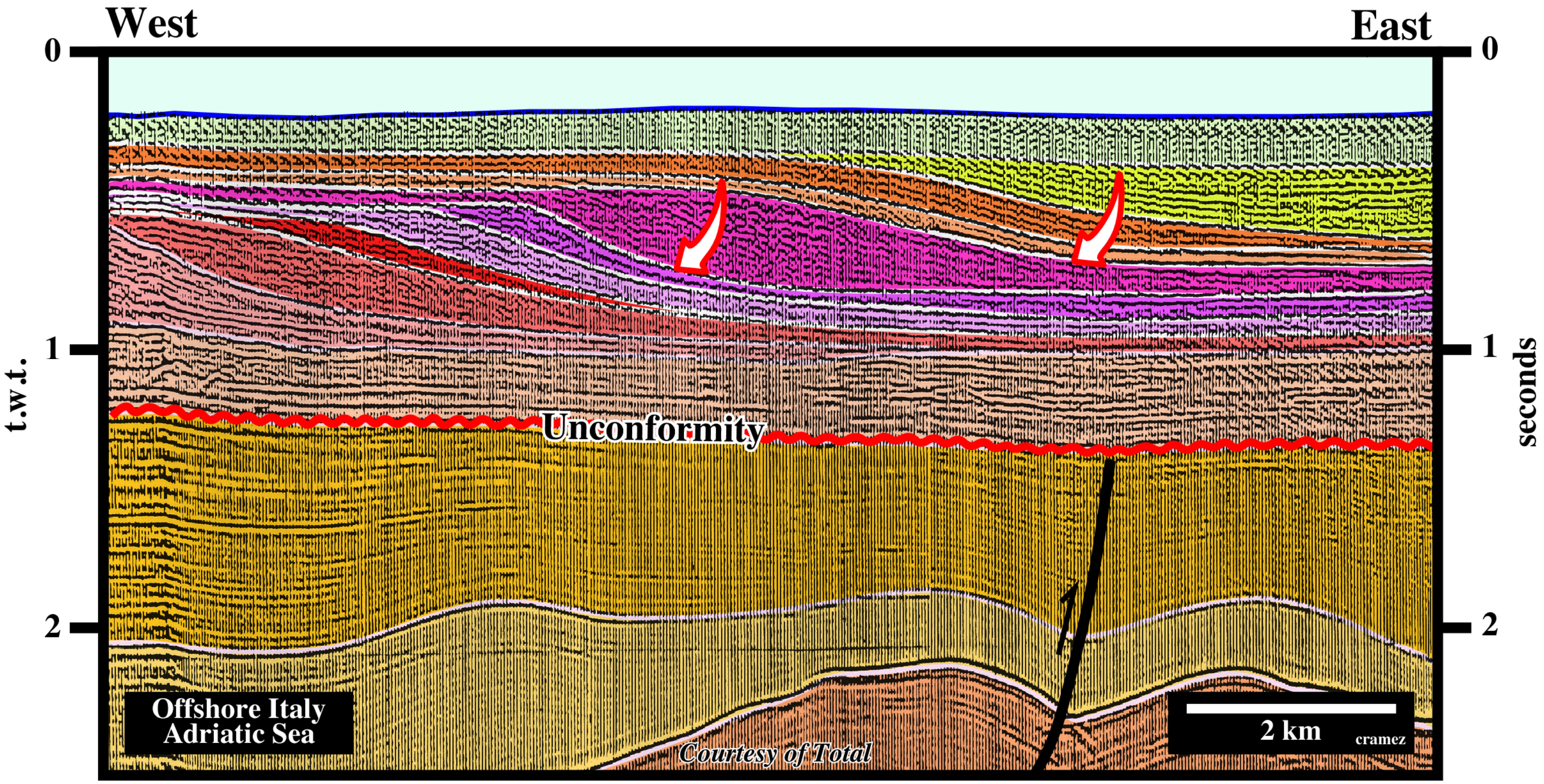


Fig. 53- As illustrated on this seismic line, in false downlap, the depositional oblique reflectors flatten downdip and continue seaward as sedimentary units, where their thickness can increase slightly. Before considering a downlap as a false downlap, interpreters must be sure that the tangential termination is not a consequence of low seismic resolution. If there is a sharp facies change between the oblique (shale) and subhorizontal (sand) segments, there is a downdip strata termination, and so it must be considered as a downlap.

Shelf Downlap

A shelf downlap is a downlap recognizd in the shelf. Often, it underlies the slope of a depositional coastal break; the water depth must be less than 200 meters (prodelta).

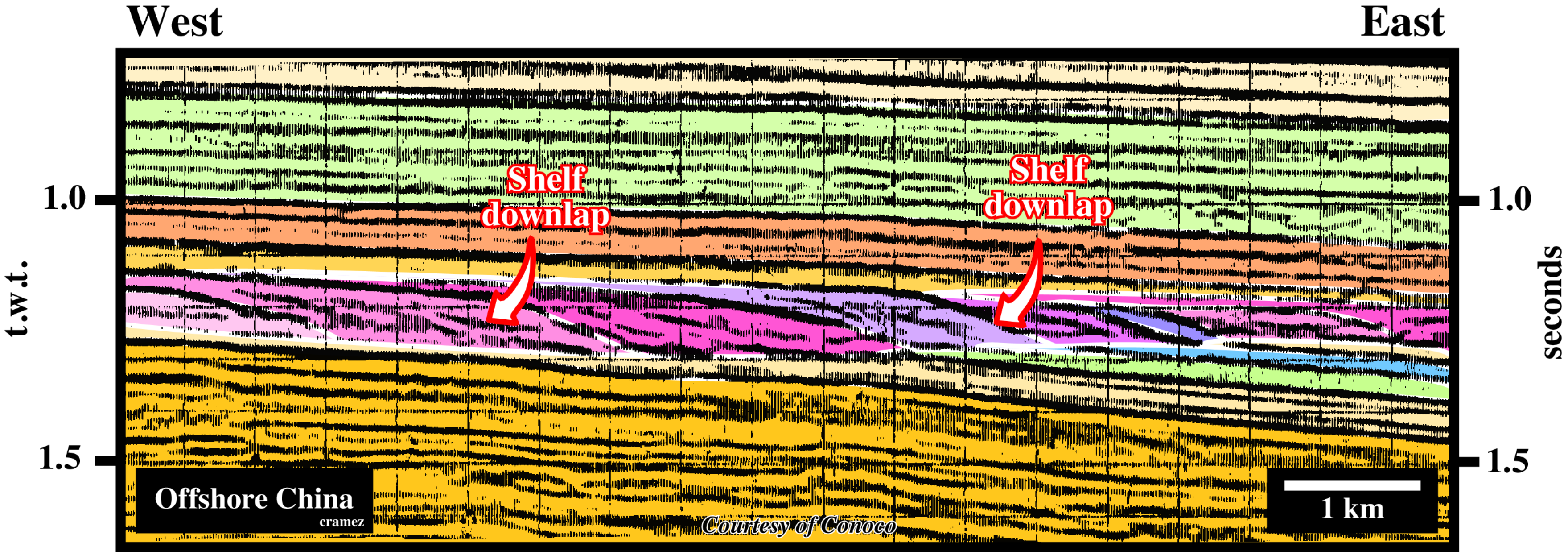


Fig. 54- Taking into account the vertical scale, it is evident that inclined seaward reflectors likely correspond to a deltaic slope. Indeed the time difference between the updip and downdip terminations is less than 200 milliseconds (two way time). Therefore, their downdip terminations can be considered as shelf downlap. Notice that within the progradational interval (deltaic environment), the relative sea level falls and/or the lateral shift of the deltaic lobes are denoted by subtle onlap surfaces.

Slope Downlap

A slope downlap is a downlap associated with a continental slope; the water depth must be higher than 200 meters.

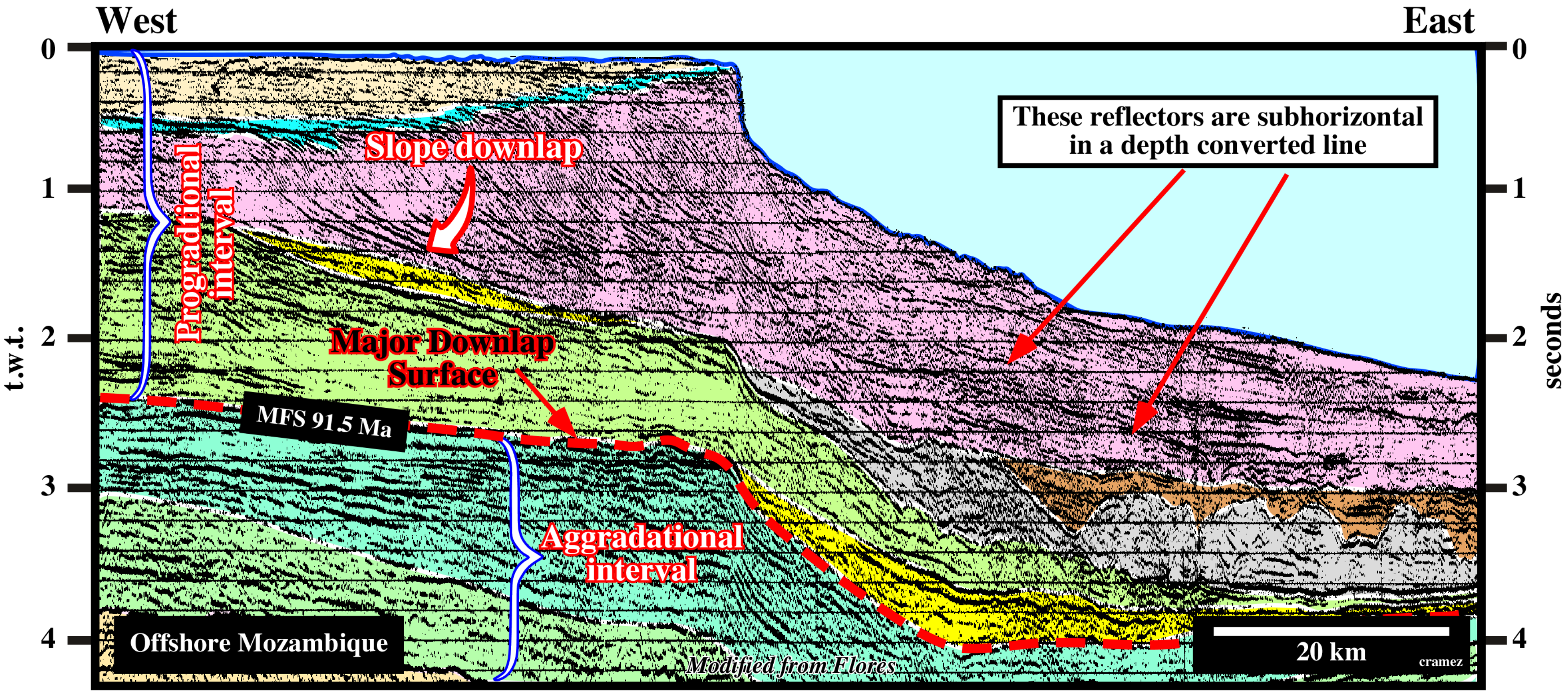
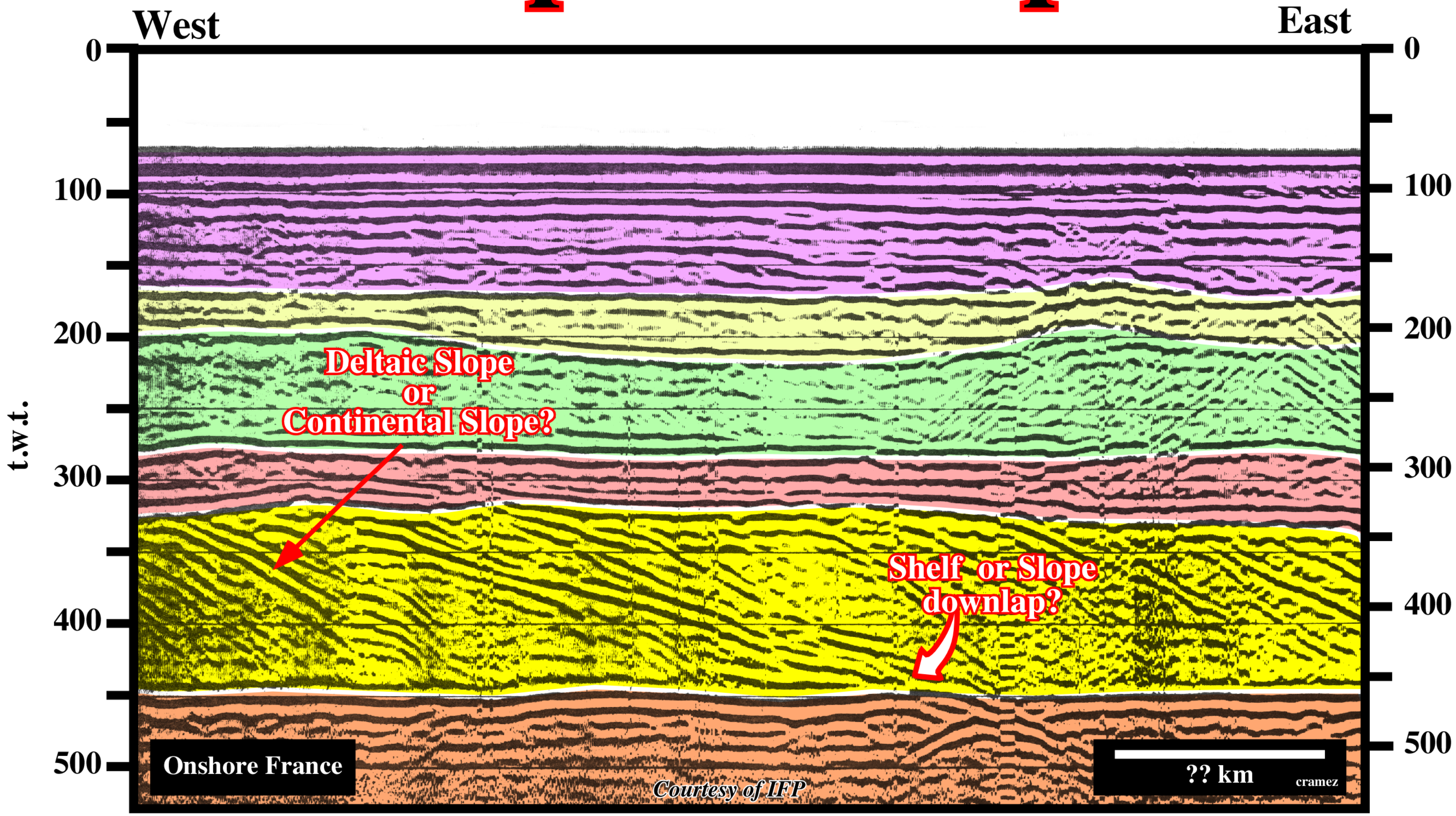


Fig. 55- Contrariwise to shelf downlaps (fig. 52), on this seismic line, the downlaps are slope downlaps, that is to say, the depositional inclined reflectors illustrate the successive morphologies of the continental slope. Readers must take into account the pitfall induced by the abrupt change in the water depth. Indeed, in a depth converted line, the reflectors seaward of the present-day shelf break are subhorizontal or gently dipping seaward.

Shelf or Slope Downlap ?



Courtesy of IFP

Fig. 56- On the two previous seismic lines, we could differentiate shelf downlaps associated with deltaic slopes, from slope downlaps associated with continental slopes, using the vertical and horizontal scales of the seismic lines. In other words, Geology is scale dependent and so seismic interpretation can only be performed knowing the scales of the seismic data. For instance, interpreters will be unable to interpret the depositional inclined reflector illustrated above. The reader is supposed to make a guess: shelf or slope downlaps?

Shelf or Slope Downlap ?

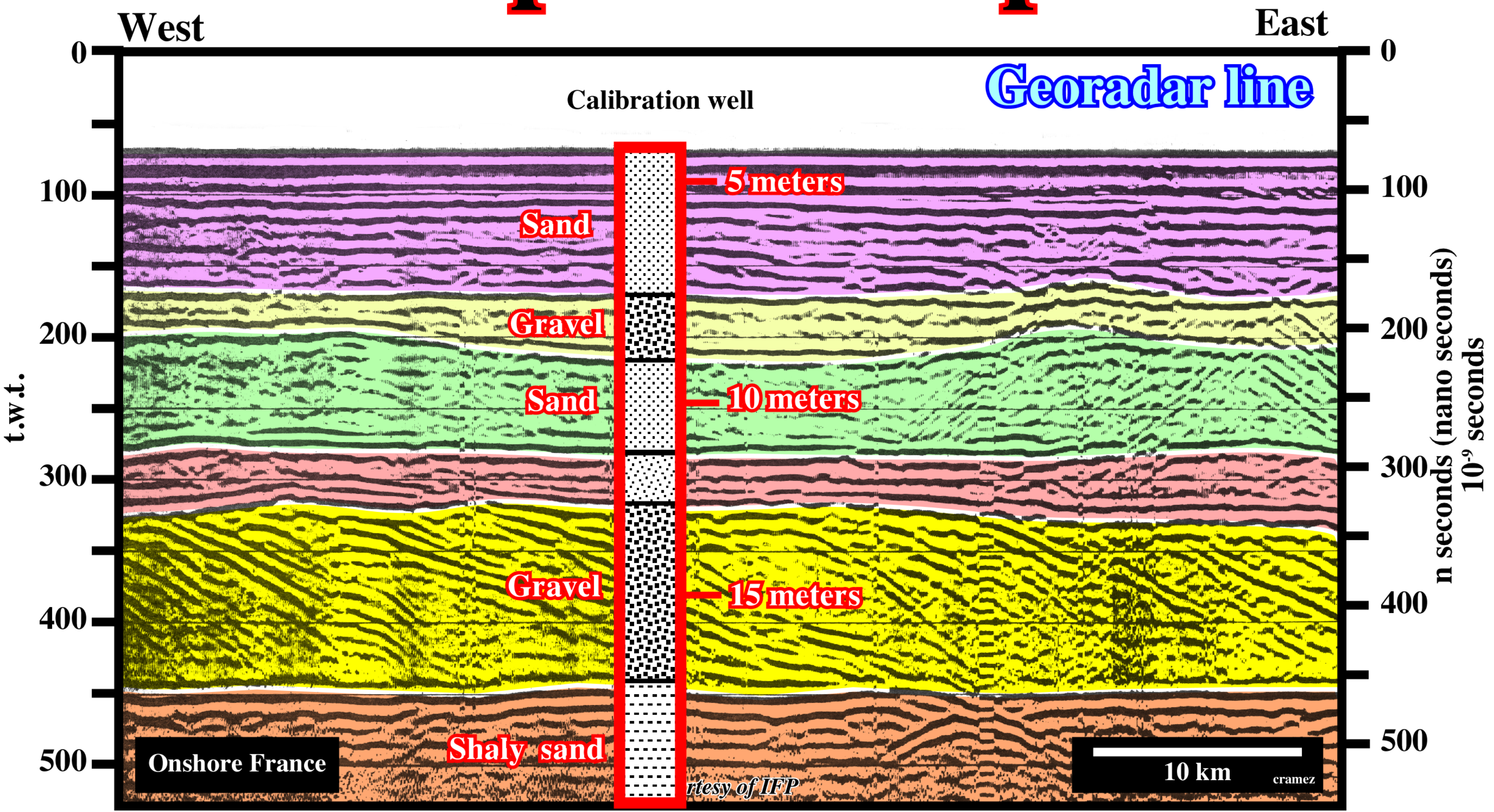


Fig. 57- The vertical scale of the previous line is in nanoseconds, that is to say, 10^{-9} seconds. In other words, the previous line is a georadar line, which was shot in onshore France (Pin Sec). The proposed interpretation is based in a calibration well in which georadar velocities range from 8 ns in the shaly sands, to 13 ns in the gravel. Velocities of 15 ns were found in the upper sand interval. Subsequently, the depositional inclined reflectors are not associated with a deltaic or continental slope, but are rather small oblique bedding planes.

Opposite Downlap

Opposite downlaps are characteristics of overbank deposits, whether associated with fluvial or turbiditic levees.

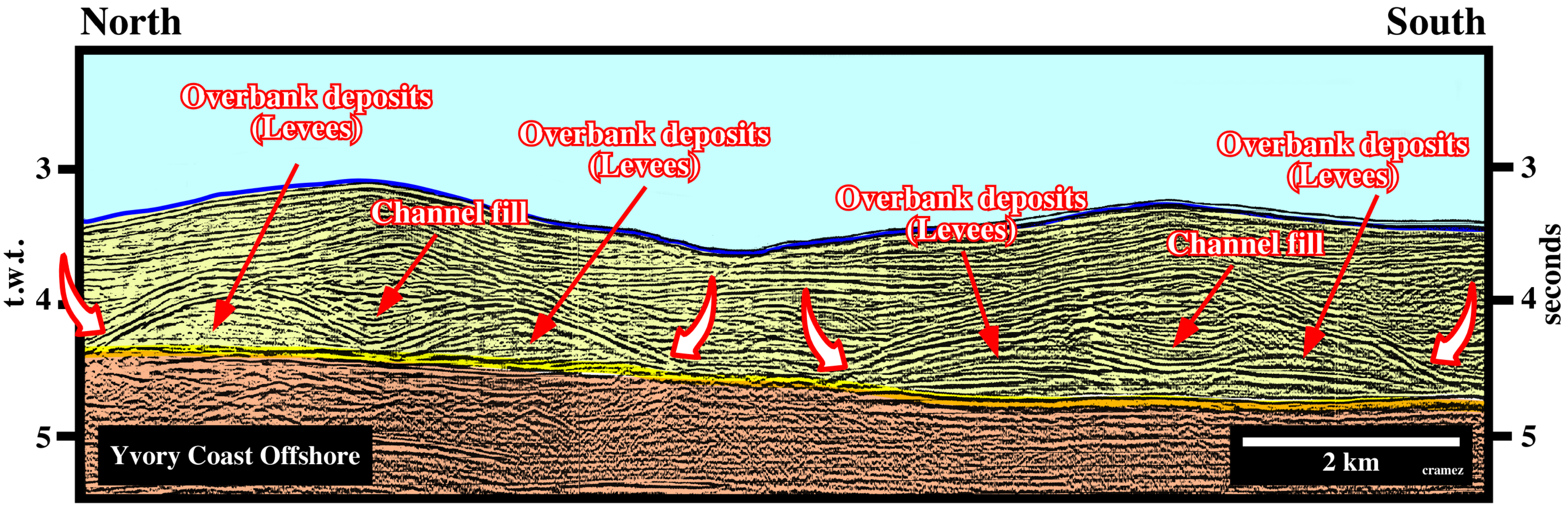


Fig. 58- On this line from the Ivory Coast deep-water, where turbidite channel-levees complexes ("gully wings" of P. Vail) are paramount, opposite downlaps are easily recognized in the overbank deposits. Evidently, these downlaps cannot be considered as distal, since they do not indicate the direction of the source of the clastic supply. On the contrary, they indicate the local direction of the overbank currents, that is to say, the local sediment transport-direction, which is away (roughly perpendicular) from the central troughs (often called "channels").

Opposite Downlap

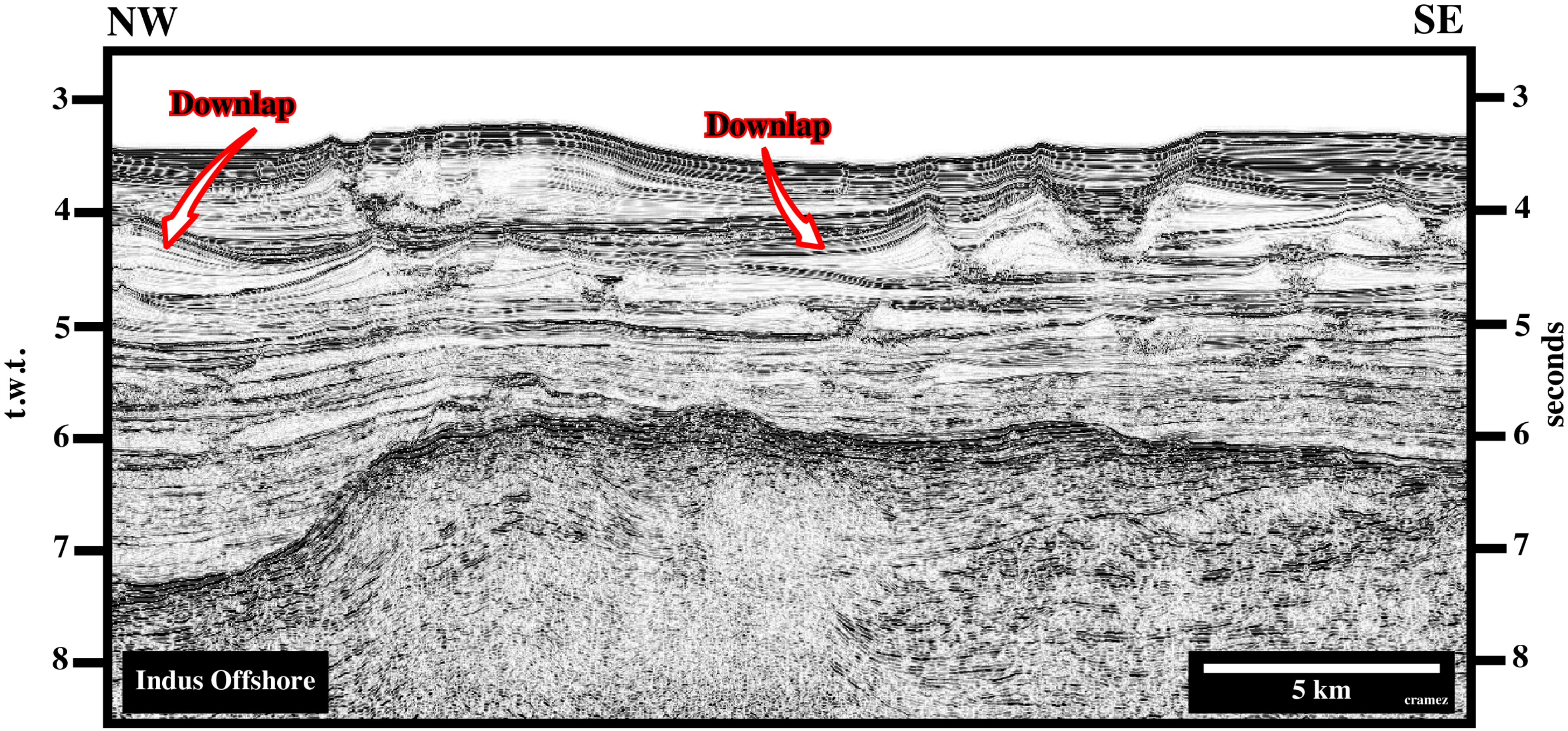


Fig. 59- In the seismic lines from Indus offshore, opposite downlaps are the preponderant reflection terminations. Admittedly, they are associated with turbidite slope depositional systems, particularly with channel-levees complexes, in association with the overbank deposits (turbiditic levees). As illustrated on this line, the seismic reflections can only be depositional. In other words, the observed dips are depositional and not tectonic dips (post-depositional). Indeed, they cannot be explained by any known tectonic model. At present time, all geologists associate the “gully wings” of P. Vail with slope fan turbidites. However, in the 60's and 70's, the majority of exploration wells drilled for instance, in the Cameroun offshore (Matanda, Sulebaba, etc.), were supposed to test structural traps (four way dip closure), but, in fact, they tested mainly channel-levees complexes (“gully wings”), that is to say, the opposite downlaps were considered as structural dips.

Opposite Downlap

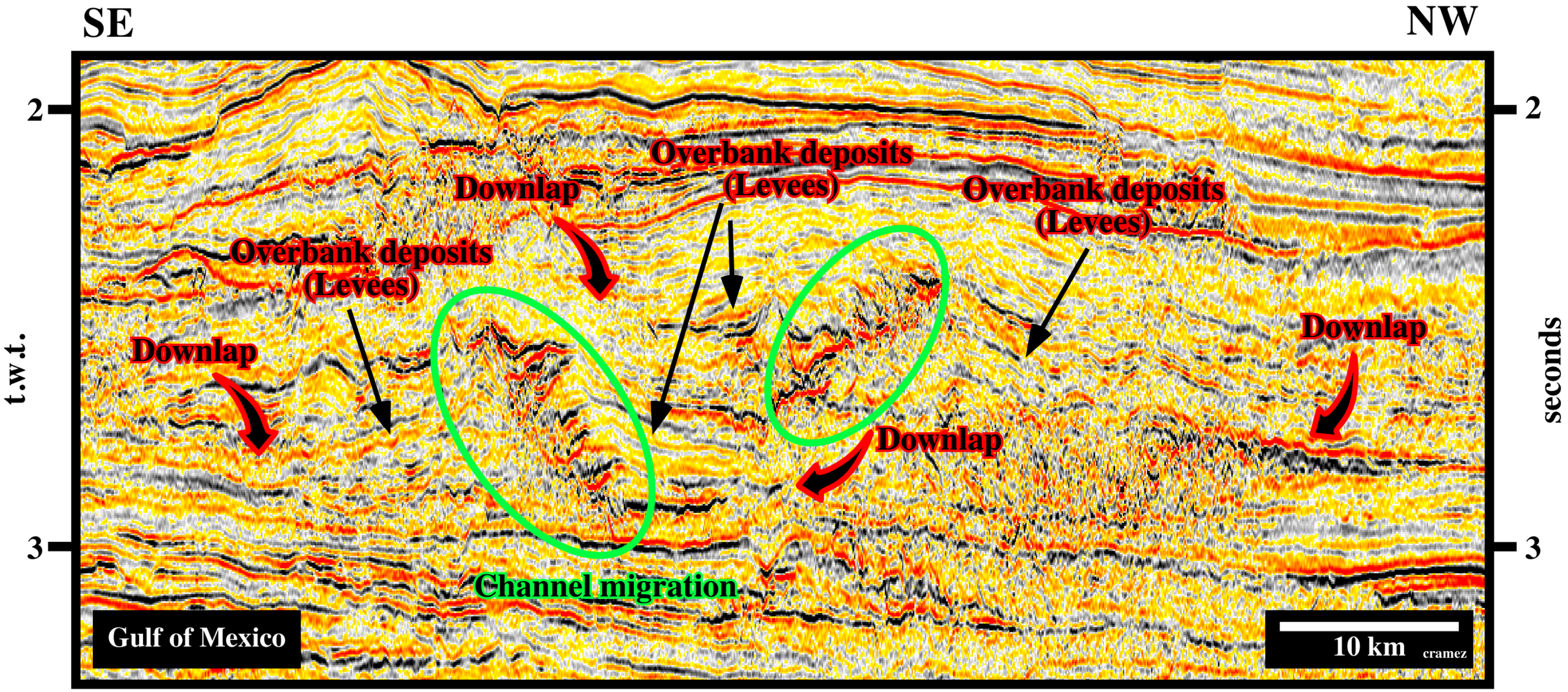


Fig. 60- Modern seismic lines, like this line from the Gulf of Mexico, show so many details that sometimes interpreters have difficulty recognizing the main characteristics of geological models. Indeed, on this line, the opposite downlaps associated with the deep-water turbidite channel-levees complexes are much more difficult to recognize than the migration of the turbidite channels. It is interesting to notice that, at least in this particular example, one cannot related the size (height) of the channel-levee complex with the height of the turbidite currents. Indeed, due to lateral and vertical migration of the channel, even a small gravity current canot be contained within the channel and so it overbanks.

Apparent Downlap

Original onlap terminations when deformed by tectonics or halokinesis (salt tectonics) can become apparent downlaps.

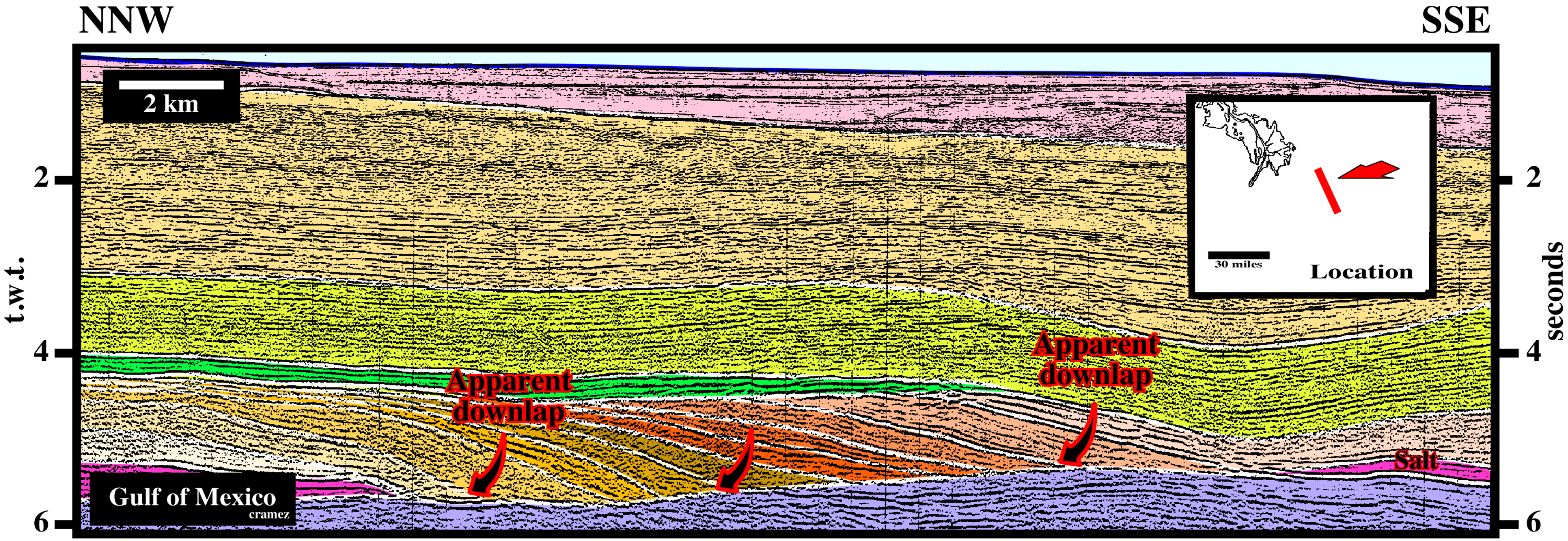


Fig. 61- The presence of autochthonous salt relics along the disconformity strongly suggests the reflexion terminations against it are apparent downlaps, that is to say, original onlaps tilted seaward as the salt flowed laterally. Actually, these oblique reflections cannot be interpreted as progradations, since they thick towards the décollement plane (salt-induced tectonic disharmony). It is interesting to point out that in 1986, arriving in Houston from Luanda (where halokinesis was well known), using this seismic line, I spent several hours explaining to the godfathers of Petroleum Geology that these reflectors should not be interpreted as Cretaceous continental slope progradations.

Toplap

A toplap is a termination of strata, or seismic marker, against an overlying surface mainly as a result of non-deposition (sedimentary bypassing) with perhaps only minor erosion.

Each unit of strata laps out in a landward direction at the top of the unit, and each successive termination lies progressively seaward.

Three different kinds of toplap can be considered:

a) Coastal toplap

b) Marine toplap

c) Non-marine toplap

Toplap

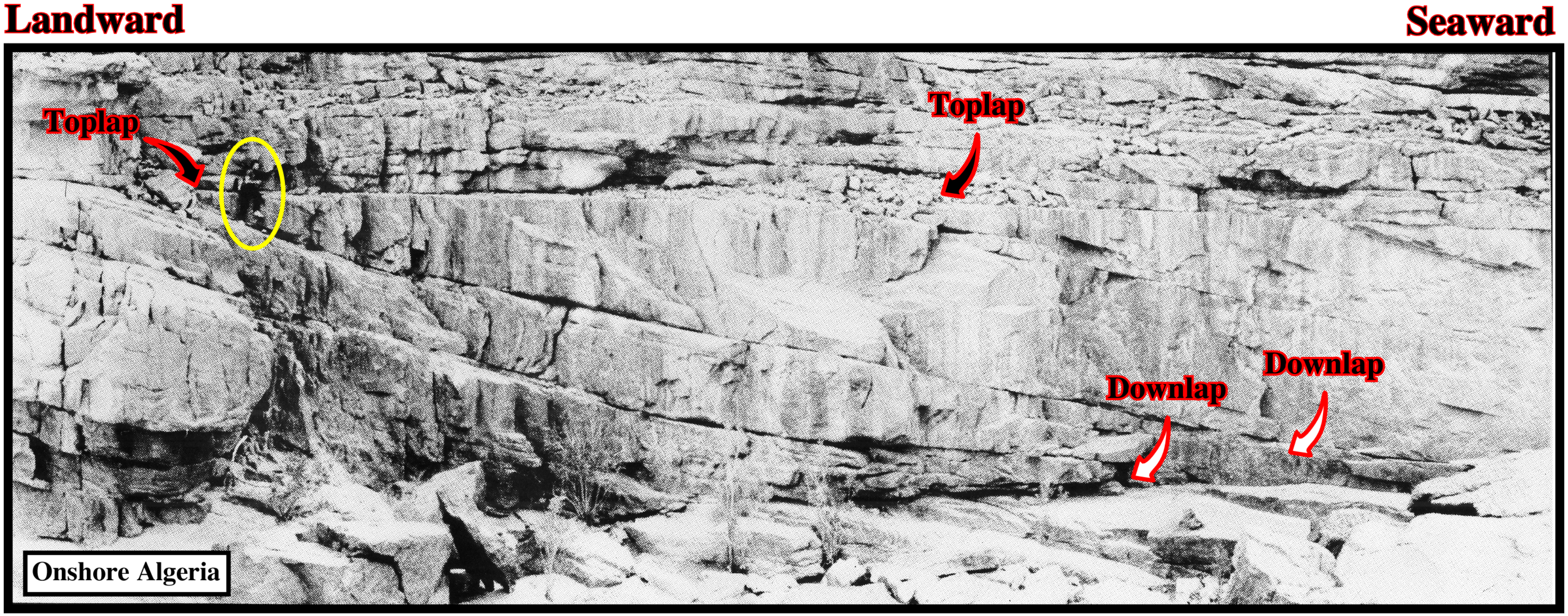


Fig. 62- First of all notice the scale of this photograph, since Geology is scale dependent. The scale is given by the geologist near the toplap termination (yellow ellipse). Indeed, toplap strata termination here are well illustrated. The strata laps out in the landward direction, but the successive termination lie progressively seaward. Notice that the downdip strata terminations are downlaps, and specially distal downlaps.

Toplap

from F. Ricci Lucchi, 1974

Fig. 63- Toplap should not be confused with cross-stratification. As illustrated above, cross-bedding occurs at a very small scale. Indeed, cross-strata thickness is measured in centimeters. Genetically, cross-bedding is produced by migration of bed forms, particularly ripples (which form small-scale cross-lamination) and dunes (which form medium- to large-sacle cross-lamination or cross-bedding).

Toplap

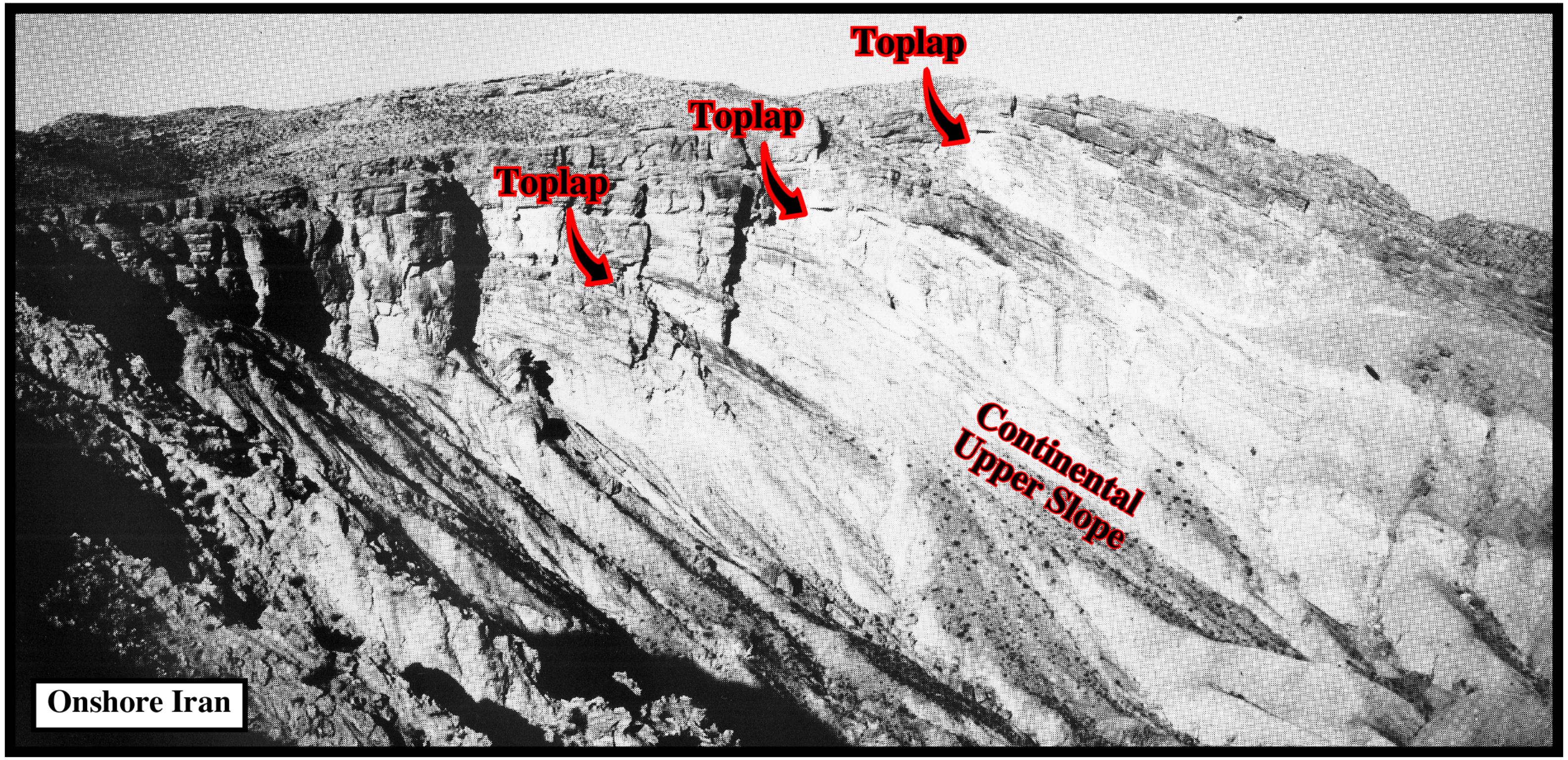


Fig. 64- Toplap is often associated with shelf breaks as illustrated at this outcropping. In this particular example some strata laps out in the landward direction but far away from the shelf break. Note, that toplap strata terminations implies an absence of erosion, that is to say, the geometry is mainly induced by non-depositional processes. As we will see later, when erosion is associated with the upper limit of stratigraphic cycles we will use the term truncation (erosional toplap for certain geologists).

Toplap

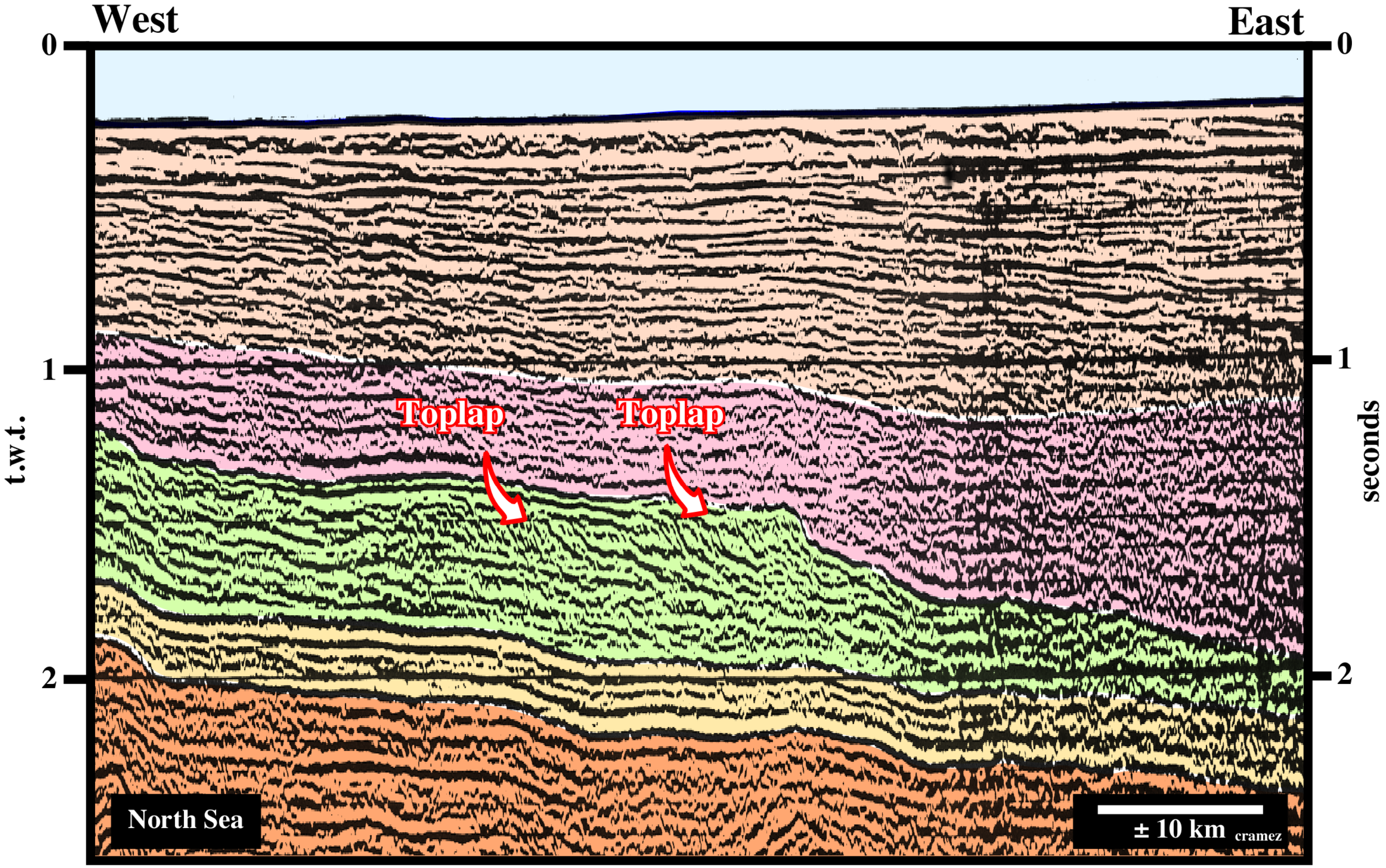


Fig. 65- Theoretically, toplap implies non-deposition, that is to say, sedimentation with minor erosion. However, on seismic lines, and particular on regional lines such as the one illustrated above, it is often difficult to recognize the magnitude of erosion in order to separate toplap from erosional truncation. As a guess, we hypothetize that on this line, the toplaps are associated with coastal deposits and so they should be considered as coastal toplaps.

Coastal Toplap

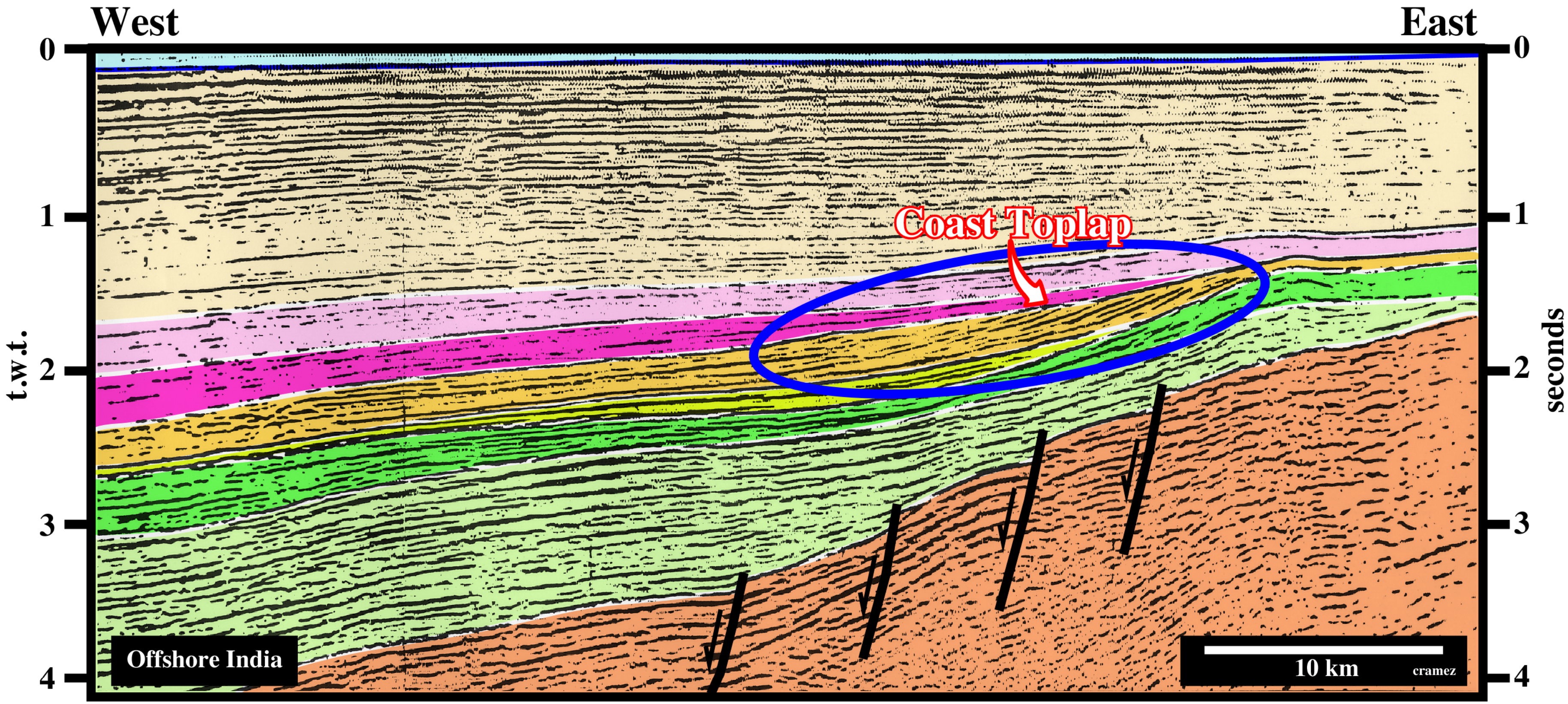


Fig. 66- On this line, the depositional inclined reflectors, probably associated with carbonate sediments, terminate updip by toplap geometrical relationships. In addition, taking into account that they occur in a likely shallow water environment, they can certainly be considered as coastal toplaps. On the other hand, they are clearly associated with an upper boundary of a stratigraphic cycle. Actually, as we will see later one can say they occur along the upper sequence boundary (a sequence is a stratigraphic cycle induced by a 3rd order eustatic cycle, see glossary).

Marine Toplap

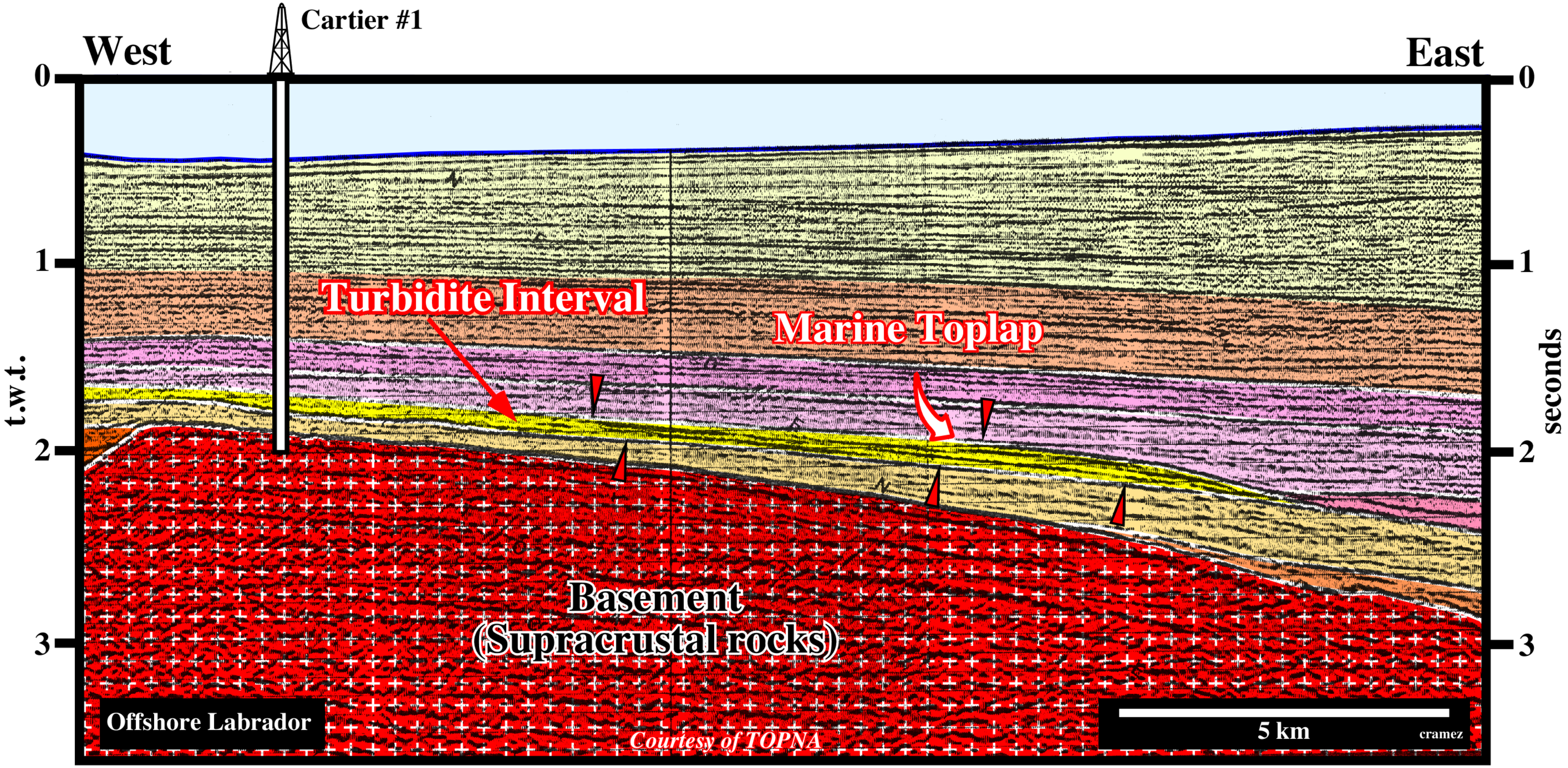


Fig. 67- Marine toplaps are here associated with a turbidite interval, which was corroborated by the results of Cartier well drilled by Total in the 70's. Indeed, it is easy to notice the internal geometry of the turbidite interval, and so the toplap terminations are inferred to be the result of lateral stacking of turbidite depositional lobes, which induces a progradational like geometry.

Toplap & Truncation

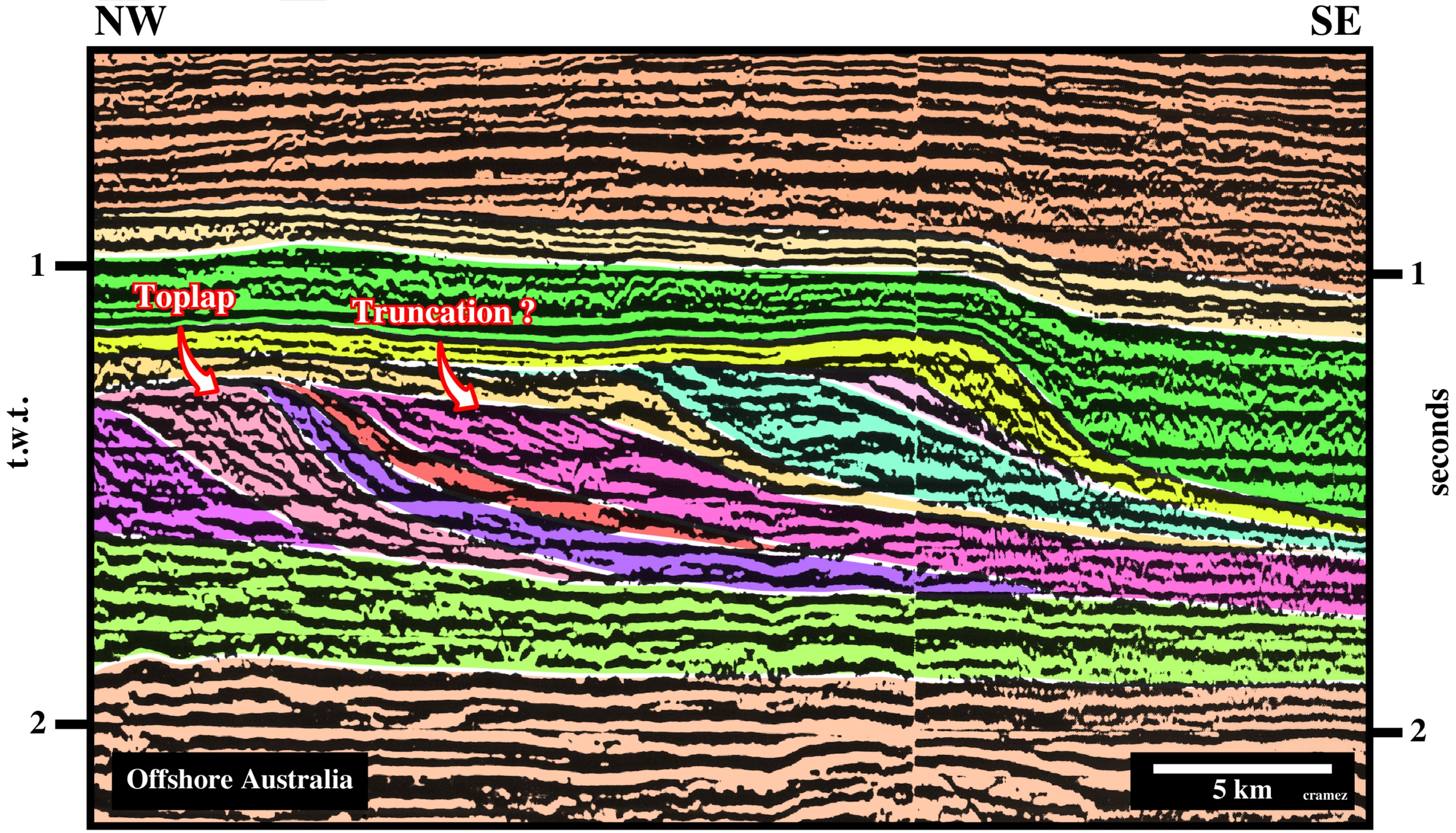


Fig. 68- On this seismic line, toplap and truncation seem to be side by side. As said previously, the differentiation between them is often so difficult that certain geologists use the term toplap to express all updip reflection terminations. However, when erosion is evident, they speak of toplap by erosion. Similarly, toplap by non-deposition is used when sedimentary bypassing is paramount.

Truncation

Truncation is a termination of strata or seismic reflections interpreted as strata along an unconformity surface due to post-depositional or structural effects.

Truncation occurs along the upper limit of stratigraphic cycles (sequences). Erosional truncation implies the deposition of strata and their subsequent removal along an unconformity surface.

Structural truncation is quite different from erosional truncation. Indeed a structural truncation is a lateral termination of a stratum by structural disruption, produced by faulting, gravity sliding, salt flowage, or igneous intrusion.

Truncation

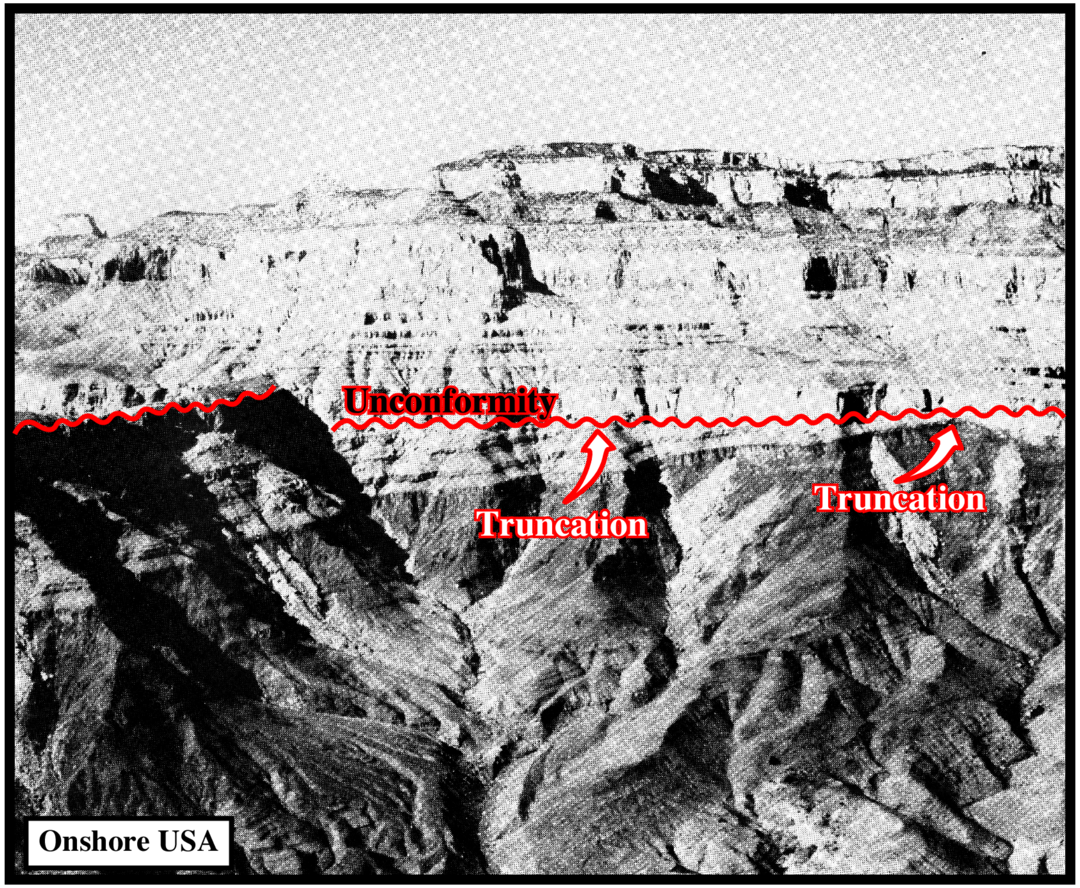


Fig. 69- Truncation of sediments, underlying an erosional surface (unconformity) is evident on this photograph taken of the Colorado Canyon. Subsequently, and according the terminology followed in these notes, the strata termination do not correspond to toplaps, but truncation.

Truncation

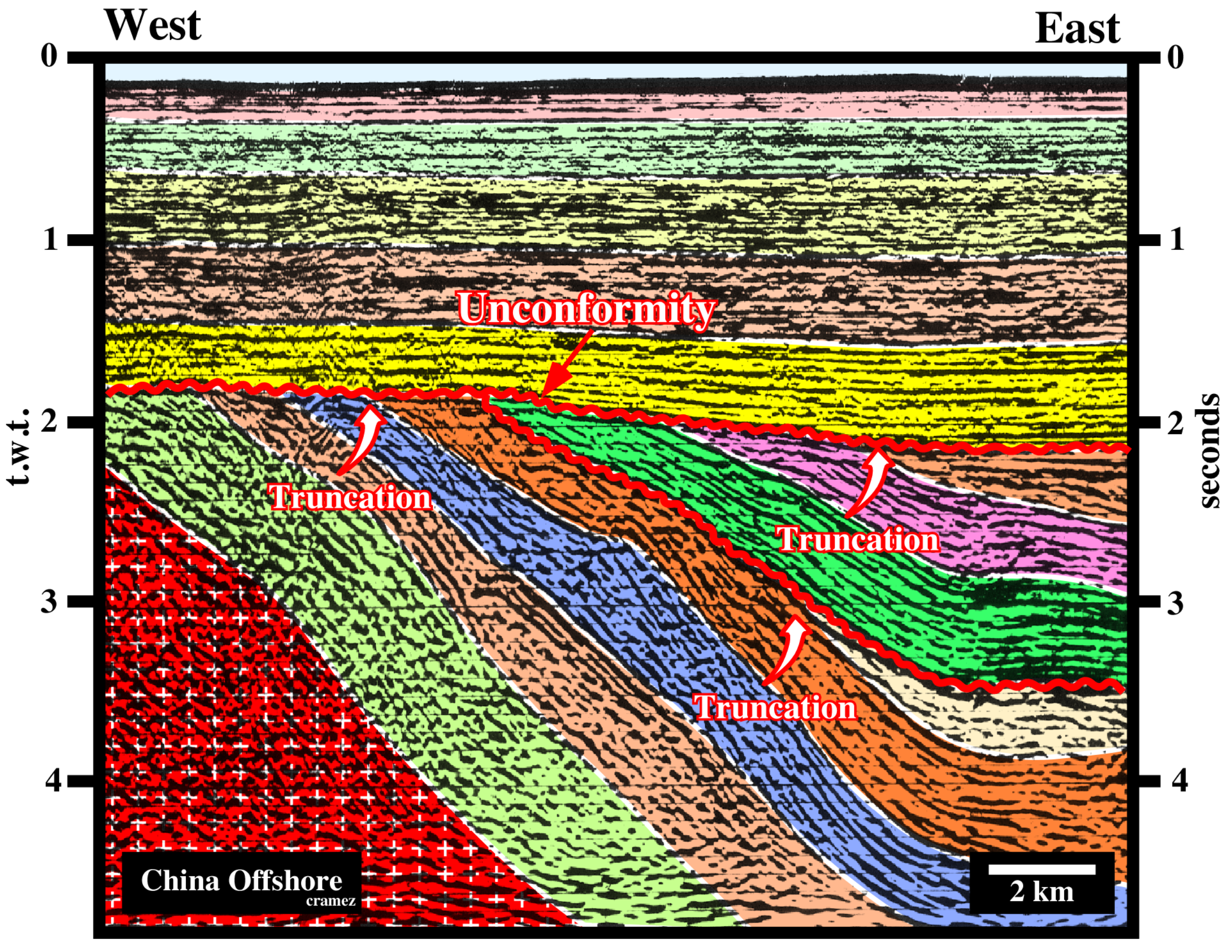


Fig. 70- Truncation reflection terminations are easily recognized on this seismic line from offshore China. As pictured, the erosional surfaces, that is to say, the unconformities cannot be picked in continuity. The associated interfaces change laterally quite a lot. So, interpreters will be obliged to jump from a peak to a trough or trough to peak depending on the impedance contrasts.

Truncation

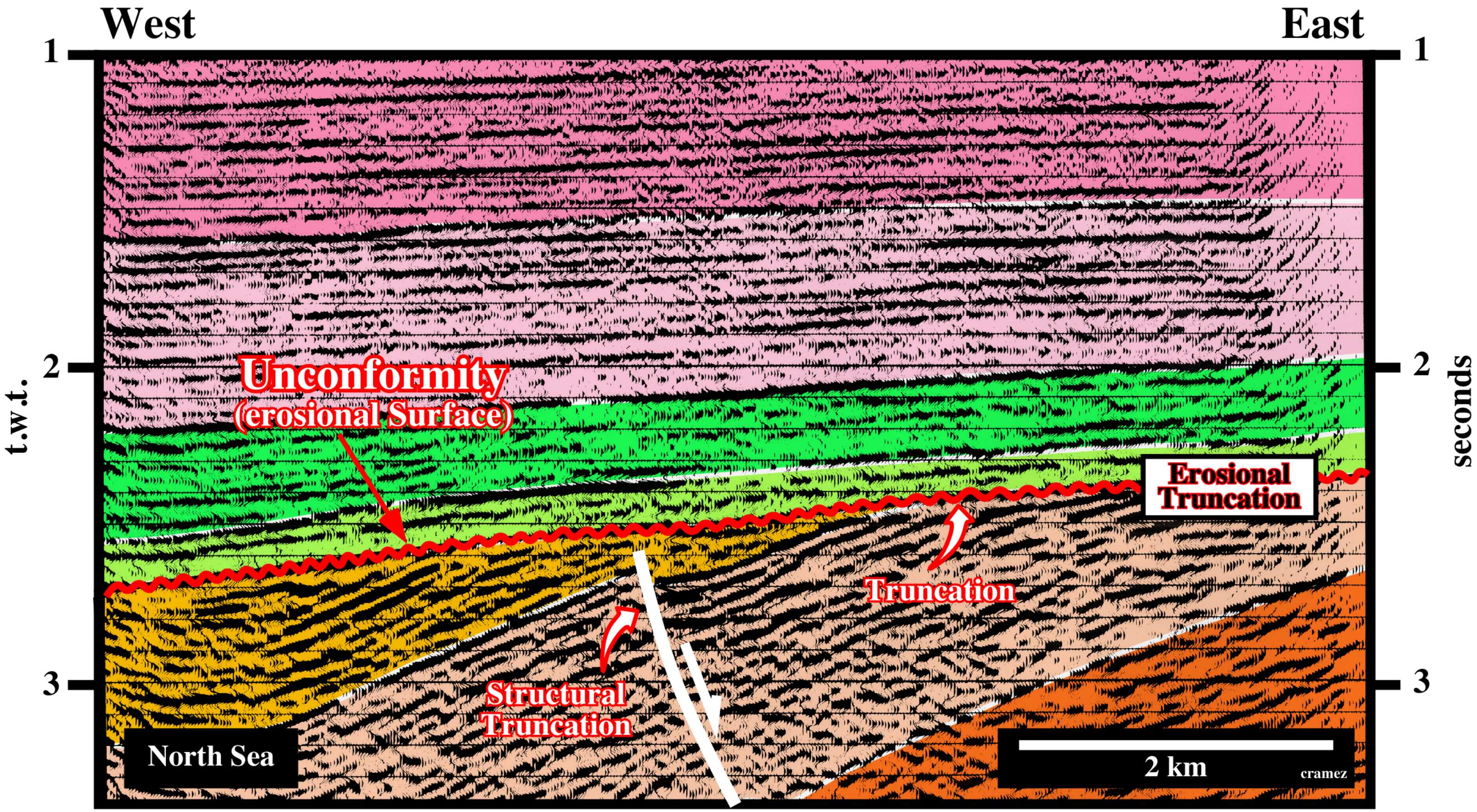


Fig. 71- On this seismic line from the North Sea, truncation reflection terminations are associated with the erosional surface between the Mesozoic Cretaceous rift-type basin and the Cainozoic cratonic sediments. On the rift-type sediments, in association with a normal fault, another type of truncation can be observed (structural truncation). However, on this subject, the next seismic line (fig. 70) is more significant.

Truncation

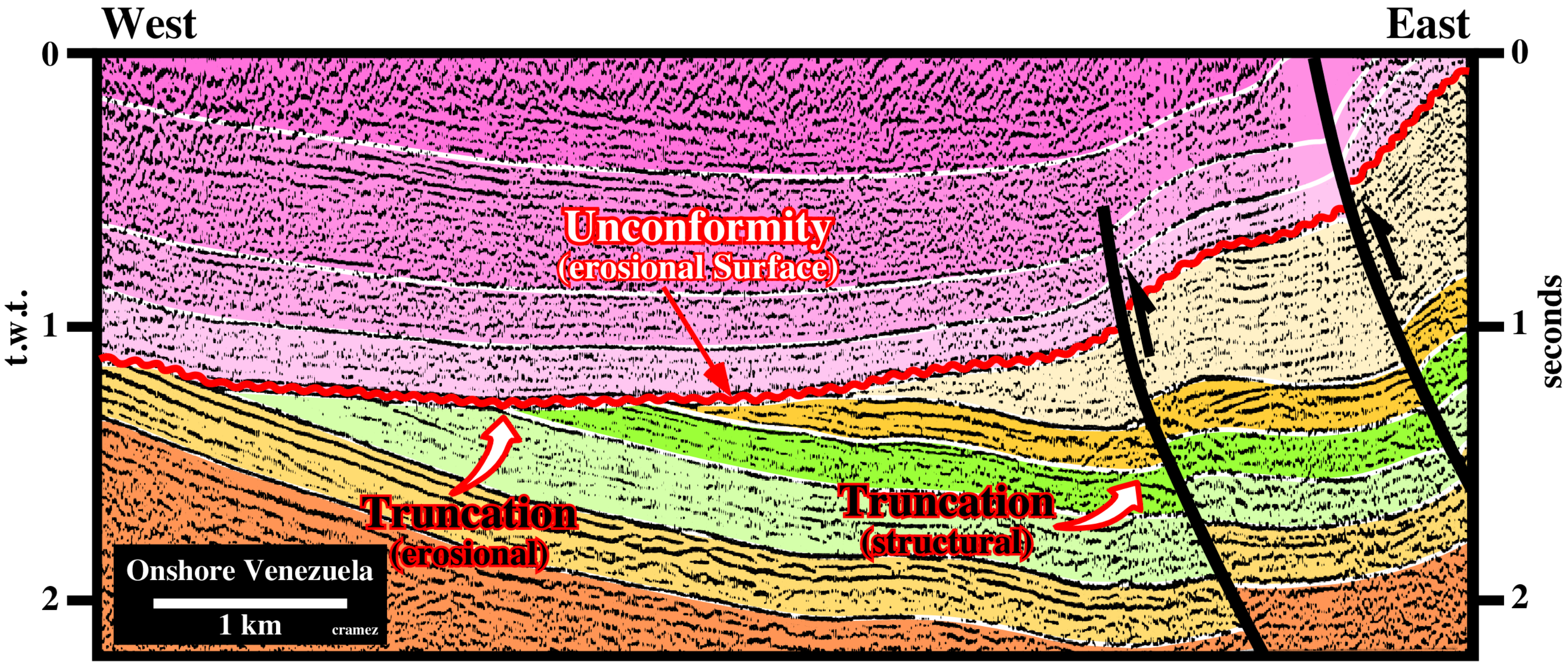
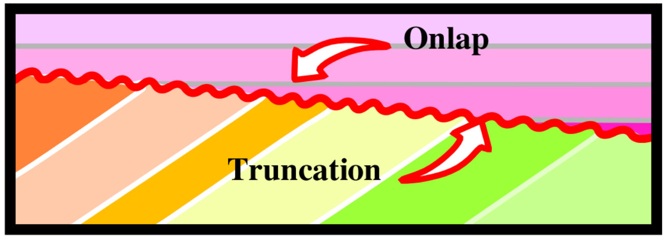


Fig. 72- This seismic line comes from onshore Venezuela, eastward of Maracaibo lake. The regional structural context of the area is compressional. Several compressional tectonic regimes took place, particularly during the Cainozoic. As picture above, the sediments were shortened and uplifted as tectonic inversions took place. Subsequently, an Upper Miocene unconformity truncated pre-Miocene sediments creating sharp truncation reflection terminations. Later, in Mio-Pliocene, another tectonic regime took place folding and faulting the sediments. So, in certain areas, where folding was not enough to accommodate the sediments, reverse faults developed to shorten the sediments to solve the volume problems. Subsequently, the sediments were broken and displaced along the reverse fault planes creating structural truncation terminations on the reflectors ending against the fault planes.

Discontinuity Surfaces

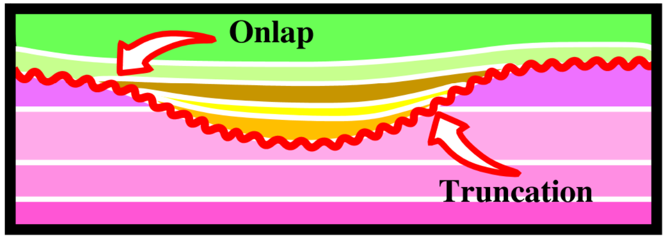
Discontinuity surfaces are surfaces caused by to erosion or depositional hiatus.

A) Unconformities



Uplift and Erosion

- Onlap
- Truncation



Valley or Channel

- Onlap
- Truncation