A) Unconformities

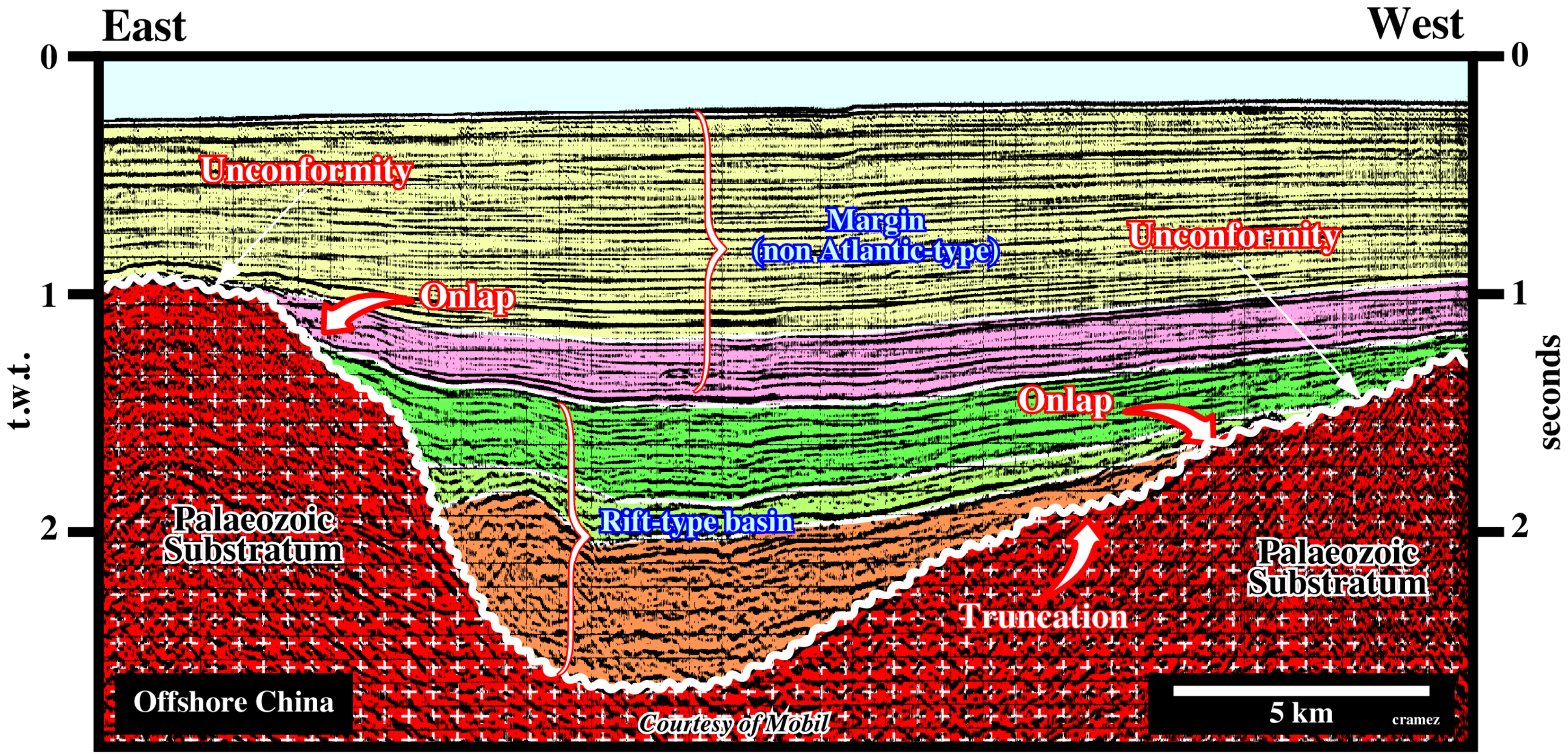


Fig. 77- On this line from offshore China, the major unconformity separating the Palaeozoic substratum from the Meso-Cenozoic sediments of the rift-type basin and non Atlantic-type margin (on the eastern part of the line) is underlined by onlap reflection terminations. Such reflection terminations are easily recognized in the lower seismic packages, which have a parallel internal configuration. In spite of the fact that in the rift-type basin non-marine environments are preponderant, the onlaps indicate successive relative sea level rises.

A) Unconformities

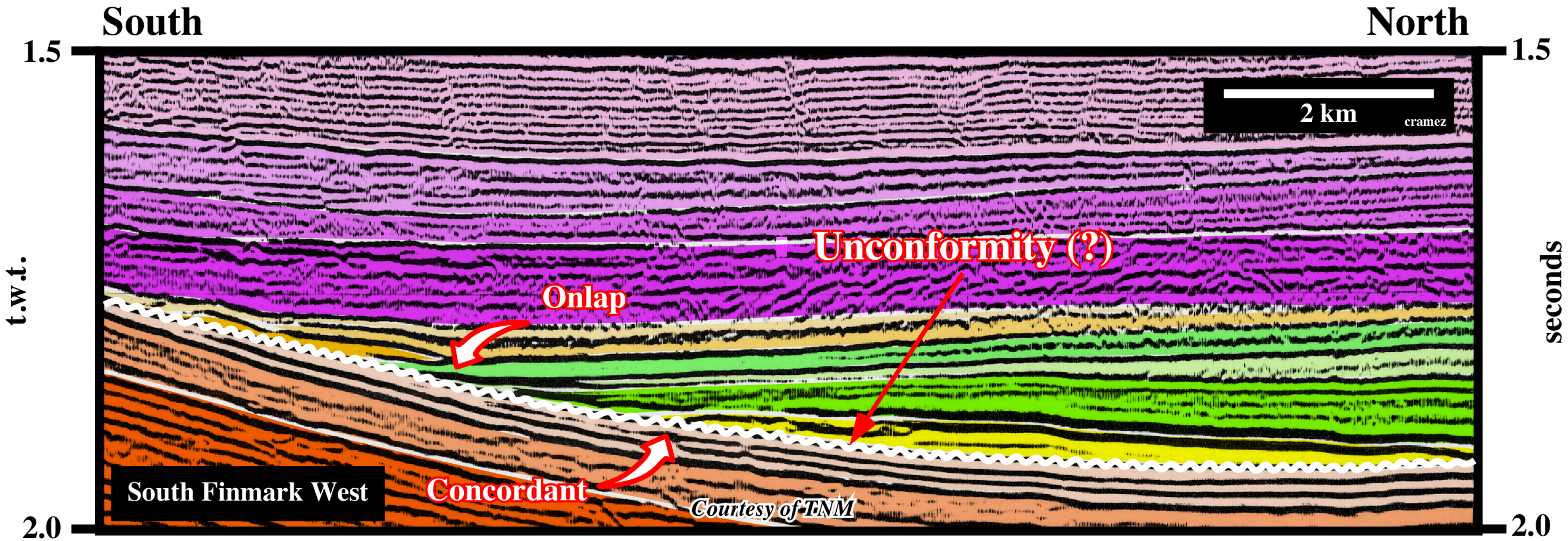


Fig. 78- The seismic surface illustrated on this seismic line, in white, is quite particular. Indeed, erosion is not evident as pictured by the concordance between it and the underlying sediments. The sediments overlying it are deep-water sediments (turbidite depositional systems) and the associated reflections terminate in onlap defining a classic onlap seismic surface. Strictly speaking, this onlap seismic surface is not an unconformity, but, as we will see later, it is correlable updip with an erosional surface, that is to say, with an unconformity. Summing up, such a deep-water onlap seismic surface, which locally can show evidence of submarine erosion, bounds stratigraphic cycles (sequence cycles) and is correlabe updip with a subaerial erosional surface (unconformity).

A) Unconformities

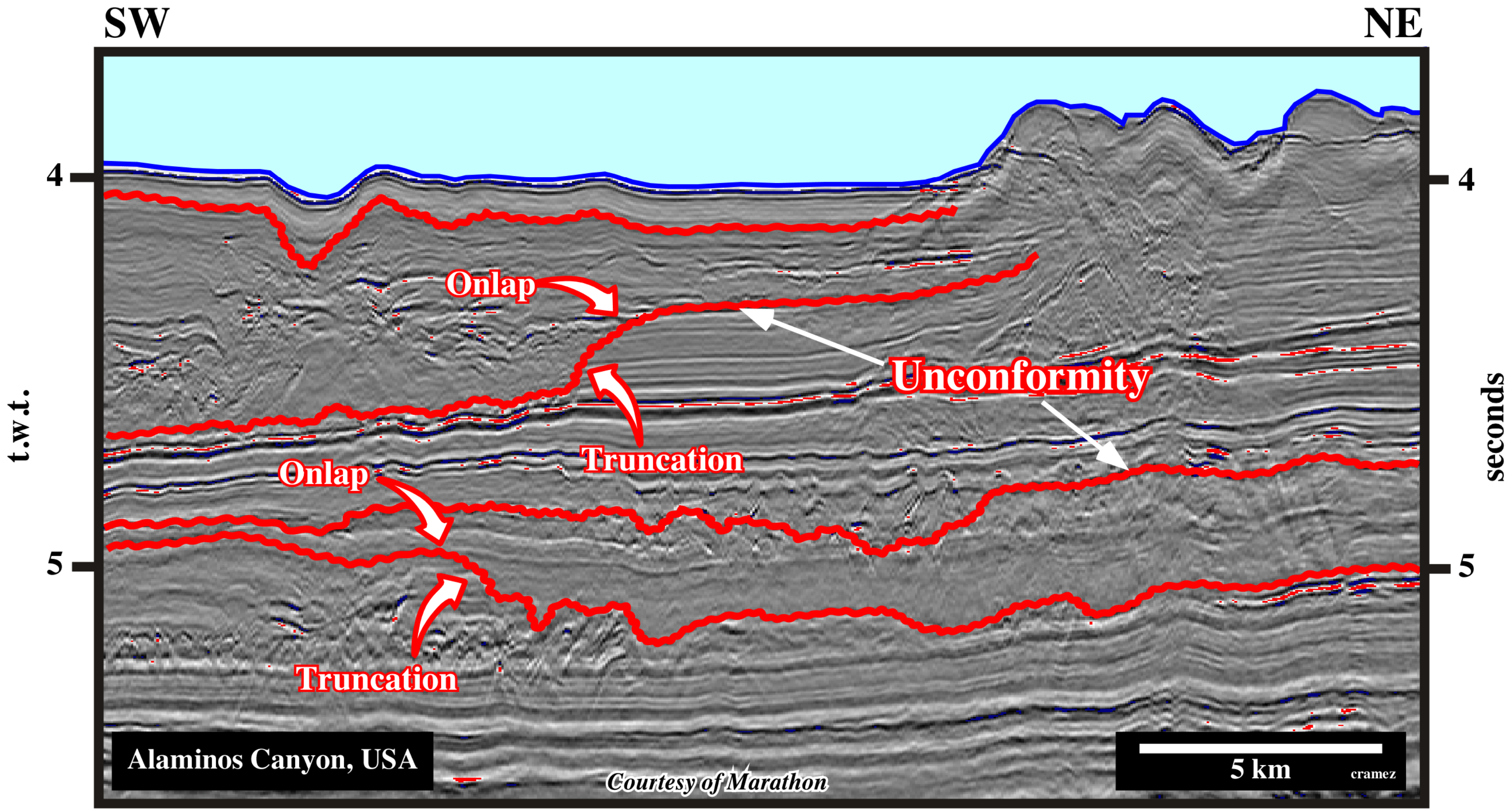
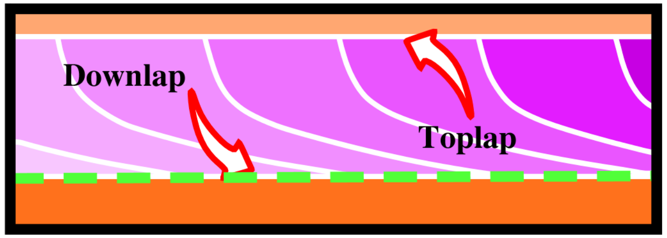


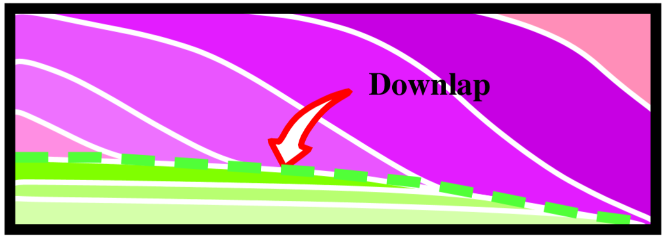
Fig. 79- When submarine deep-water erosion is paramount, as is the case in deep-water of Gulf of Mexico, the associated truncation seismic surfaces are, by definition, unconformities (see glossary). Deep-water unconformities are often fossilized by onlapping of slope or basin floor fan sediments, as illustrated above.

Discontinuity Surfaces

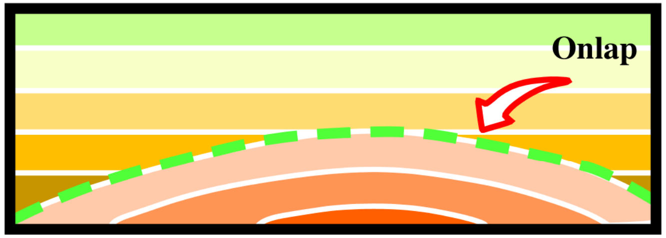
B) Depositional Hiatus



Toplap: *subaerial*
Downlap: *subaqueous*



Downlap: *subaqueous*
Apparent truncation: *subaqueous*



Onlap: *subaerial*
Conformable: *subaqueous*

B) Depositional Hiatus

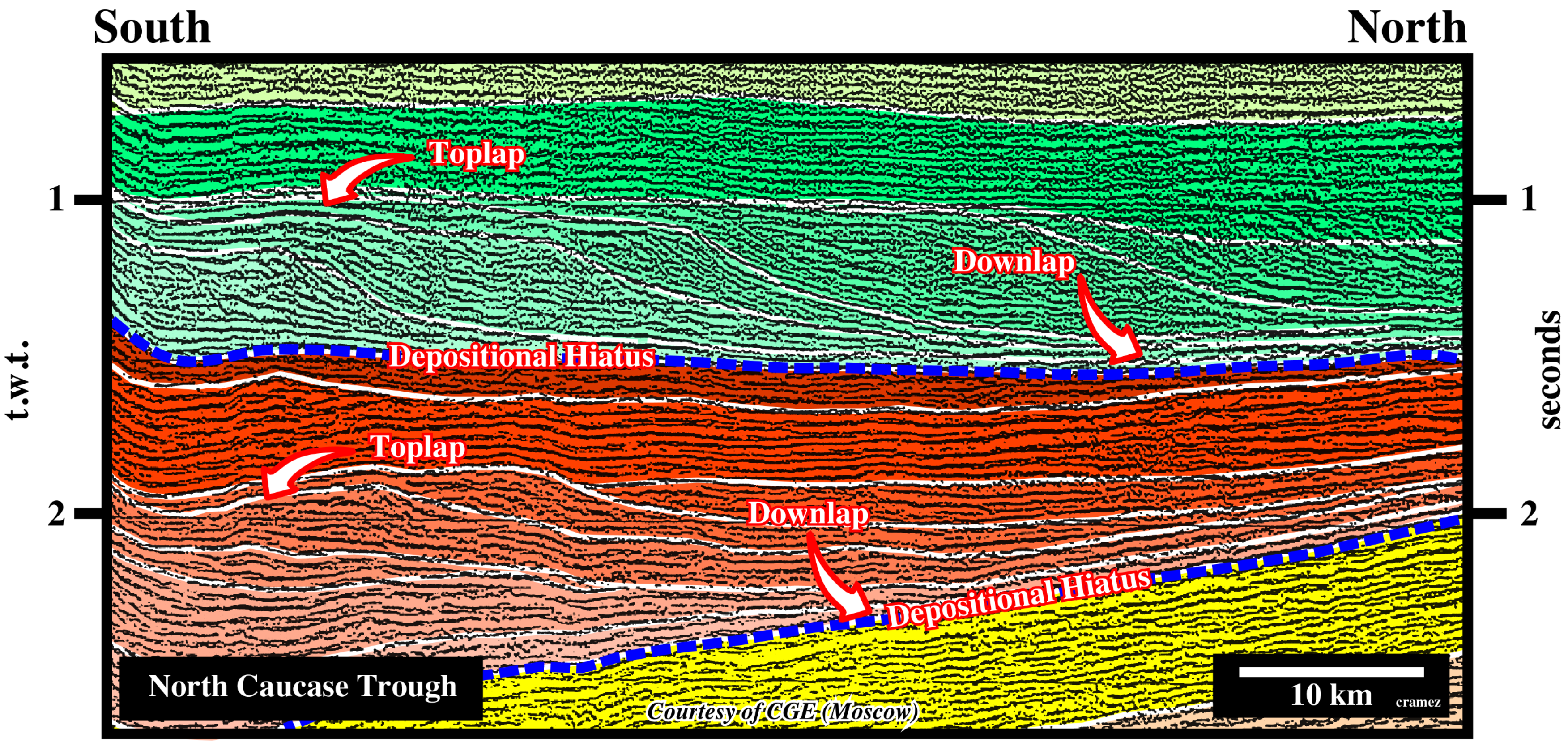


Fig. 80- Two major non-depositional hiatus surfaces (in blue) defined by downlap reflection terminations are quite evident on this seismic line from the North Caucase trough. These surfaces emphasize the geologic-time interval during which no strata was deposited at the depositional surface. The progradational (forestepping) geometry of the depositional systems implies a progressive fossilization of the depositional surface. Subsequently, the hiatus duration increases seaward, that is to say, in the direction of the downlap terminations.

B) Depositional Hiatus

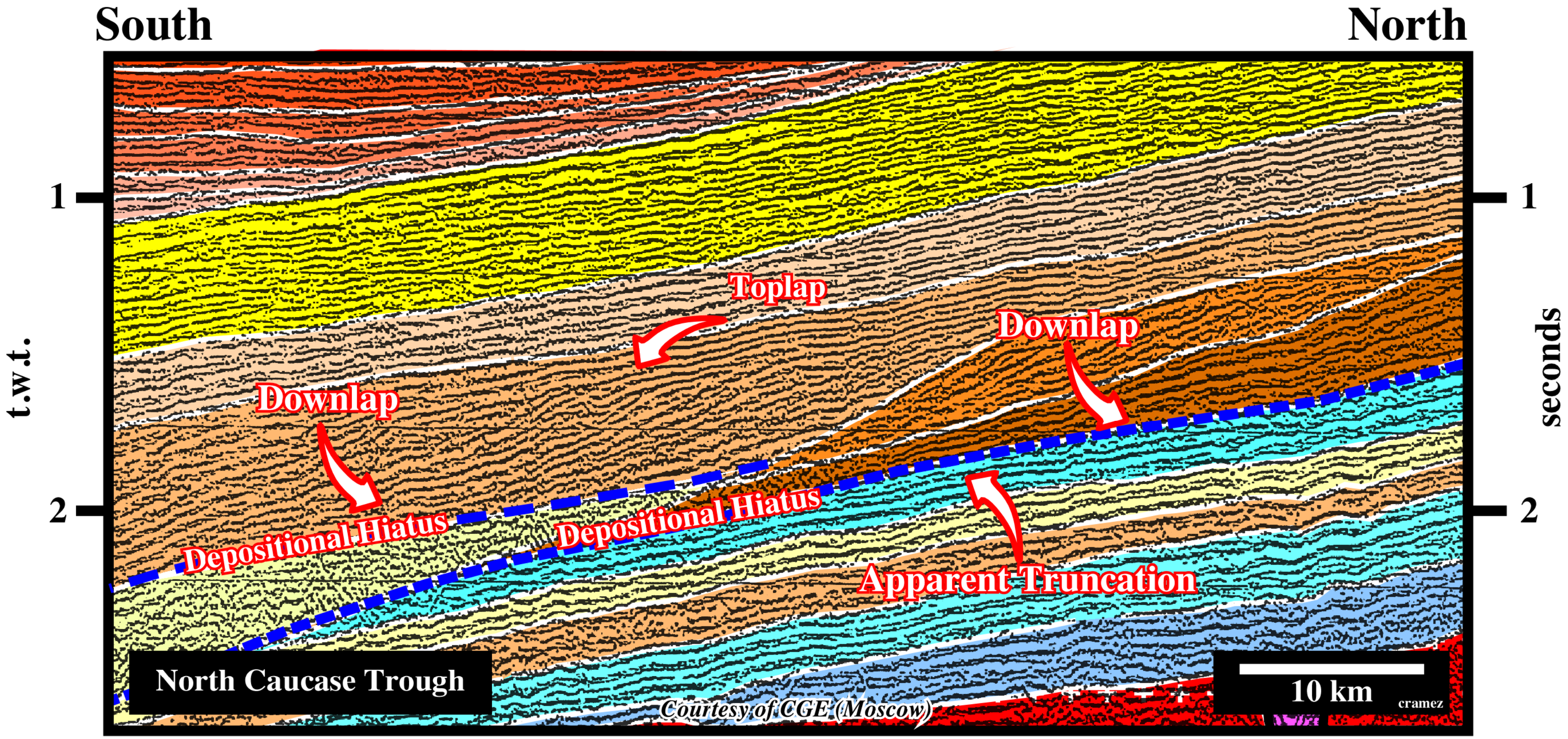


Fig. 75- The lower non-depositional hiatus surface illustrated on this seismic line is more complex than those illustrated on fig. 74. As an aggradational turbidite interval (in light yellow), probably basin floor fans, is recognized on the southern part of the line. The geologic-time during which no strata were deposited on the hiatus surface is more difficult to reckon, since the turbidite deposit can be disconnected from the downlap termination. On the other hand, immediately after the deposition of the turbidite interval, a depositional hiatus surface was developed on the top of the turbidites, which was later fossilized by downlap terminations.

B) Depositional Hiatus

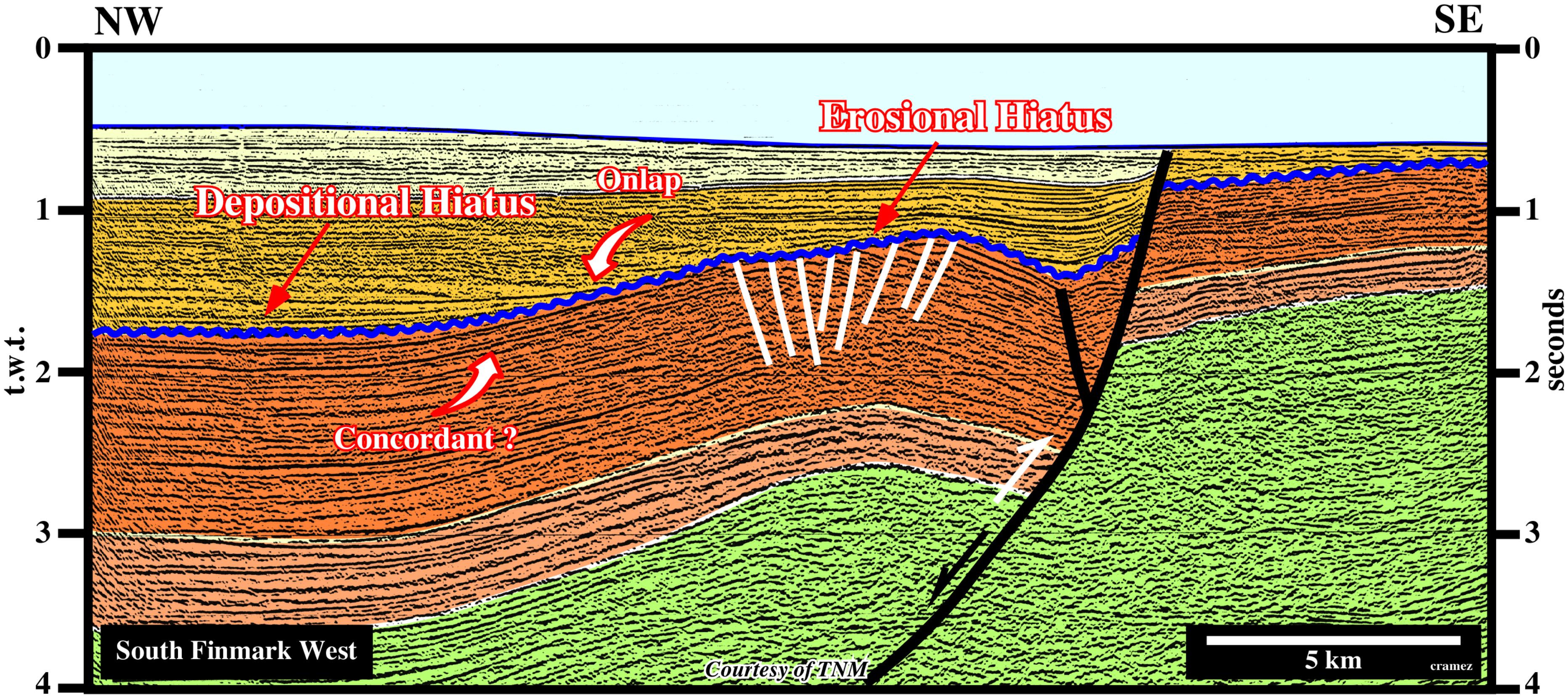


Fig. 76- Taking into account that erosion is only evident on the apex of the structure (enhanced unconformity), the unconformity on the northern flank can be considered as classic eustatic unconformity. Subsequently, on the northern flank, the hiatus can be considered as a non-depositional hiatus characterized by underlying subaquous concordant sediments and overlying subaerial (?) onlapping sediments. Contrariwise, on the apex of the structure, the hiatus is erosional and it refers to the geologic-time range of the strata which was removed by erosion and not the time at which erosion occurred. Please note the sedimentary shortening corresponds to a tectonic inversion, in which older normal faults were reactivated as reverse faults.

B) Depositional Hiatus

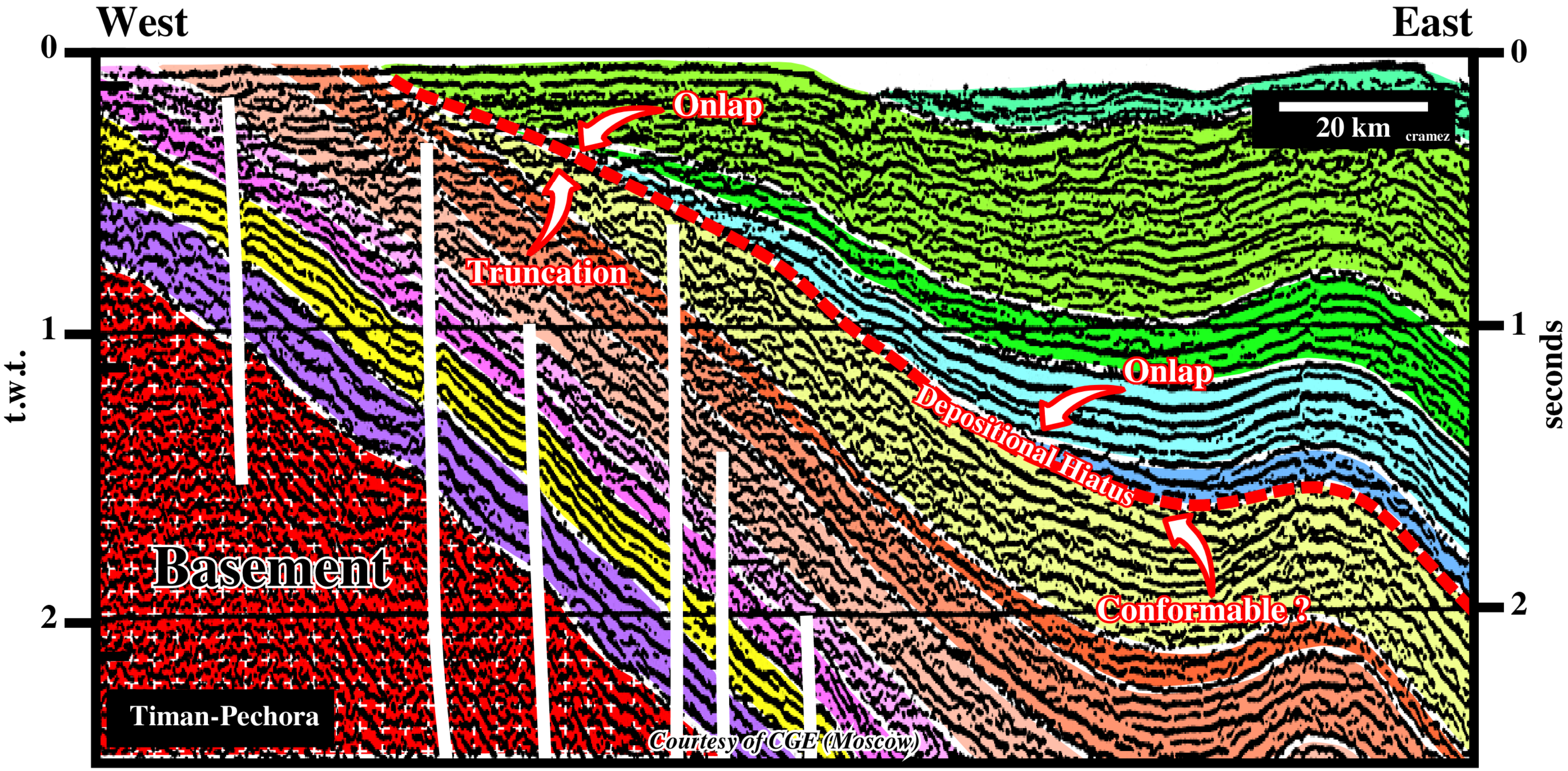


Fig. 77- The hiatus surface recognized on this line (eastern part) can be considered, at least partially, as a non-depositional hiatus surface. Erosion is meaningless. Actually, the depositional hiatus surface corresponds to an interface characterized by underlying conformable sediments and overlying onlapping sediments. The upper sediments underlying the depositional surface were significantly eroded. So, the hiatus surface, in this area, must be considered as erosional. In other words, such a surface can be considered as an unconformity or correlable with an unconformity, that is to say a stratigraphic cycle boundary (see later).

Unconformities

An unconformity is an erosional surface that separates younger strata from older rocks and represents a significant hiatus (at least a correlable part of a geochronologic unit is not represented by strata).

In very particular cases, an unconformity can corresponds to an non-depositional surface.

Periods of erosion and non deposition occur at each global fall of sea level producing interregional unconformities.

Although in some areas of continuous deposition, the hiatus may be too small to be detected paleontologically or seismically, and the surface is defined as a conformity.

Unconformities

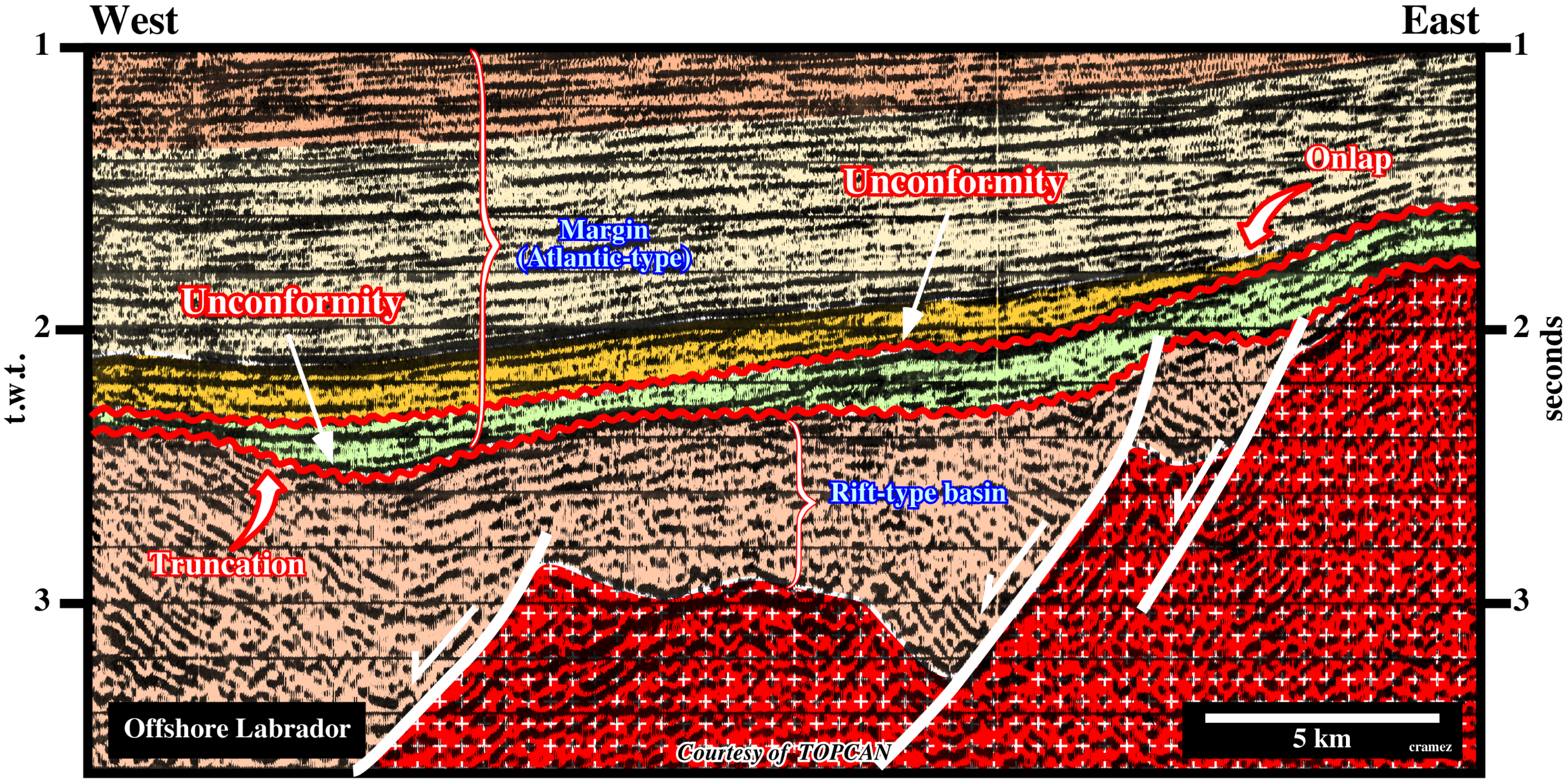


Fig. 78- Two major unconformities, that is to say, erosional surfaces characterized by truncation and onlap reflection terminations, are easily recognized on this line. The lower one is the breakup unconformity (BUU). It limits the rift-type sediments from the Atlantic-type margin sediments. The upper one separates the basal fluvio-deltaic sediments of the margin from marine and deep marine sediments. Both unconformities are induced by significant relative sea level changes.

Unconformities

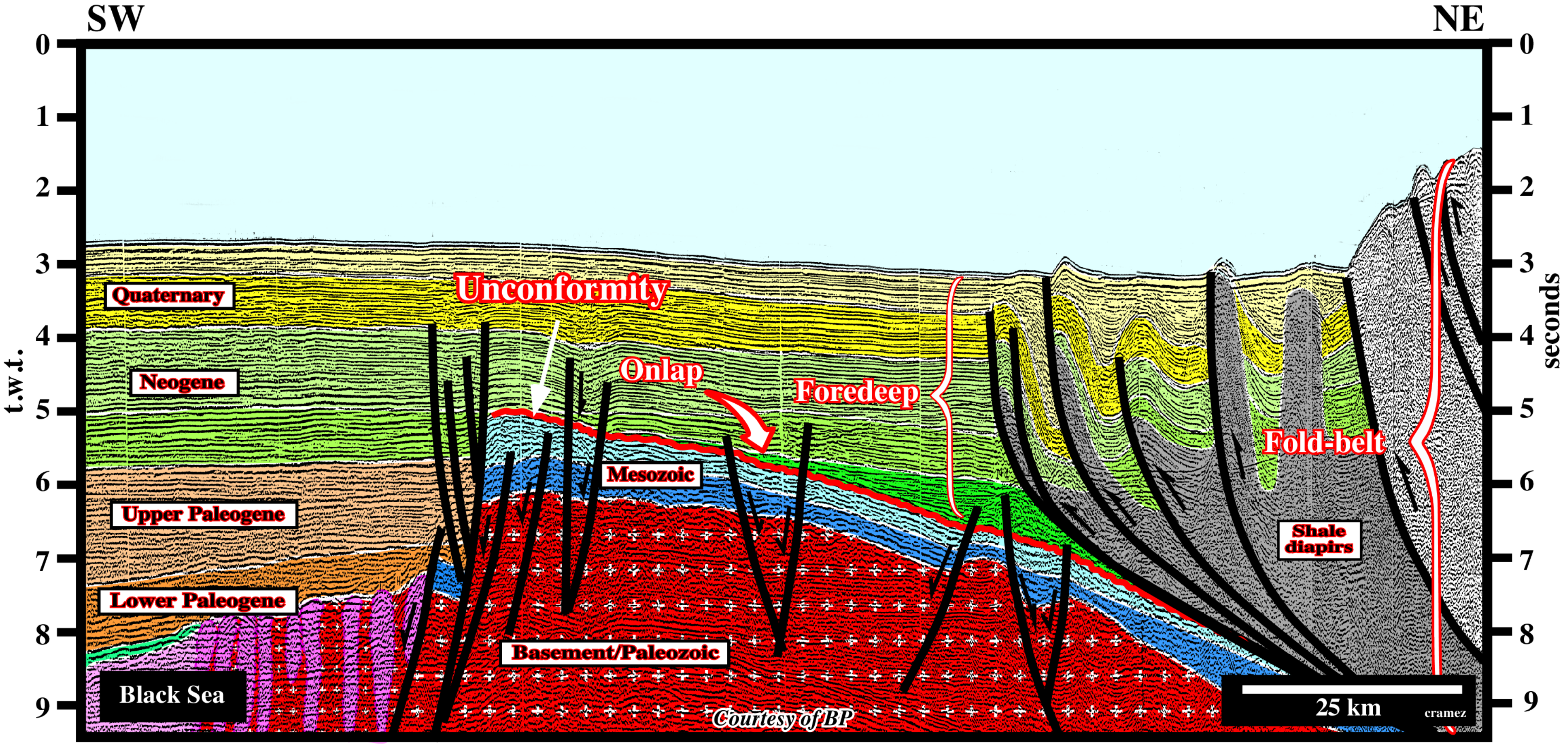


Fig. 79- On this seismic line from the Black Sea, the major unconformity (in red) is mainly tectonically induced. Indeed, the loading of the thrusts associated with the folded belt seems to be principally responsible for the unconformity (basal foredeep unconformity). In this particular instance, it is emphasized by the onlap reflection terminations of the foredeep sediments. The underlying sediments roughly conform with the unconformity.

Unconformities

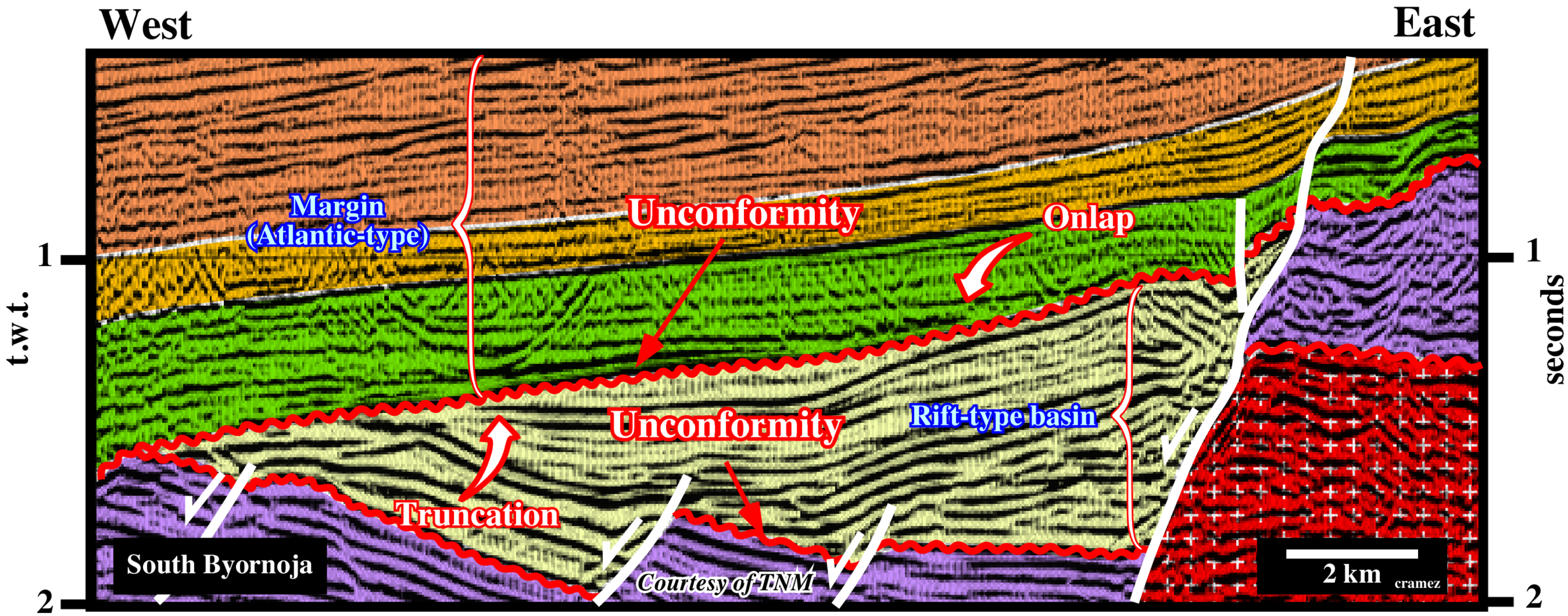


Fig. 80- On this line, the upper unconformity is often considered as the breakup unconformity, that is to say, the unconformity induced by the breakup of the lithosphere. However, some geologists think the unconformity associated with the breakup is the lower unconformity. In spite of the turbiditic nature of the interval bounded by the unconformities, I have a tendency to consider the upper unconformity as the BUU, since differential subsidence (extensional tectonic regime) is much more frequent in rift-type basins. As depicted, the upper erosional surface is underlined by truncation reflection terminations of the seismic reflectors. The margin sediments fossilized the erosional surface by onlapping induced by successive relative sea level rises created by seafloor spreading. The geometric relationships associated with the lower unconformity are more subtle.

Unconformities

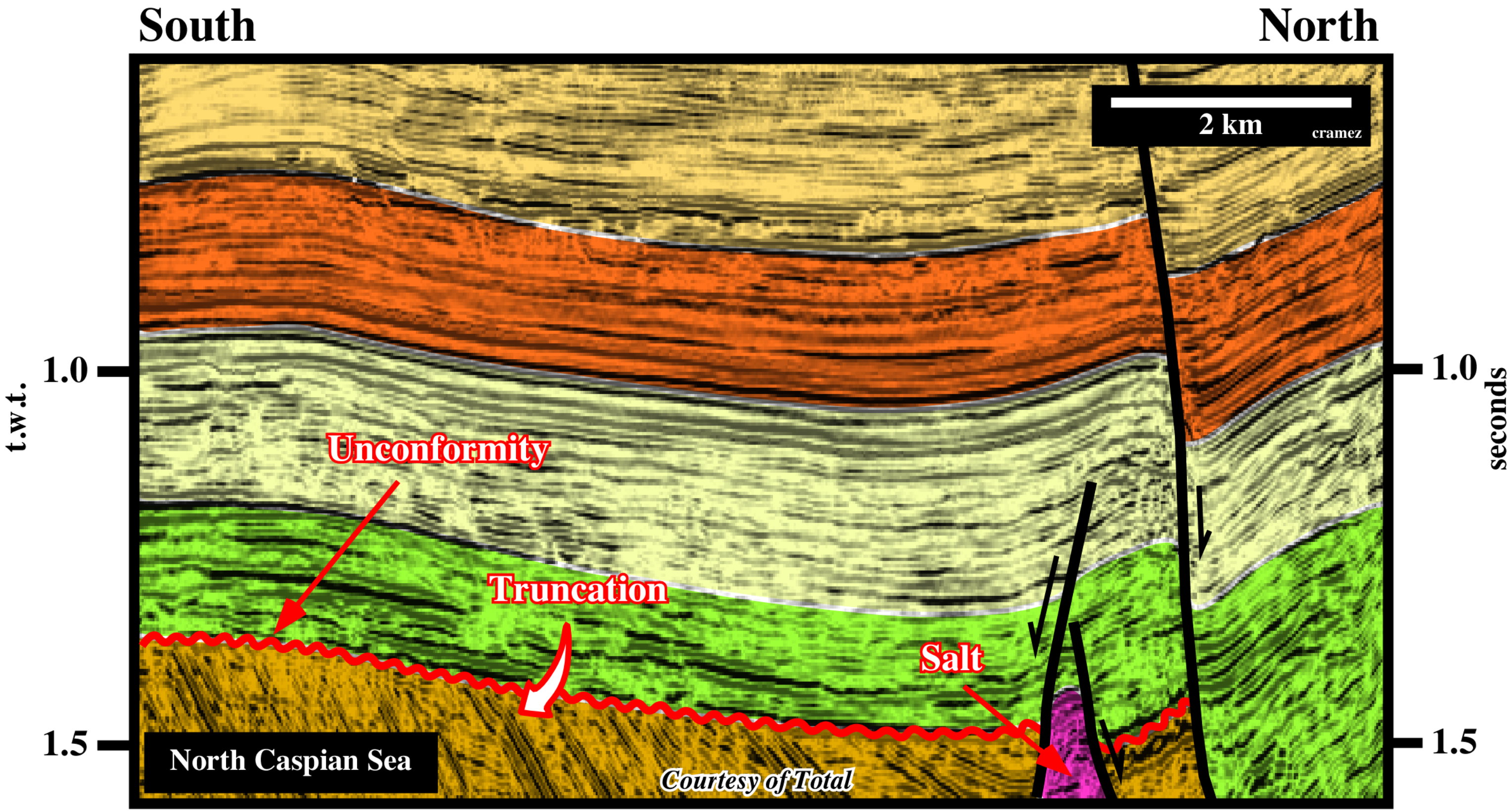
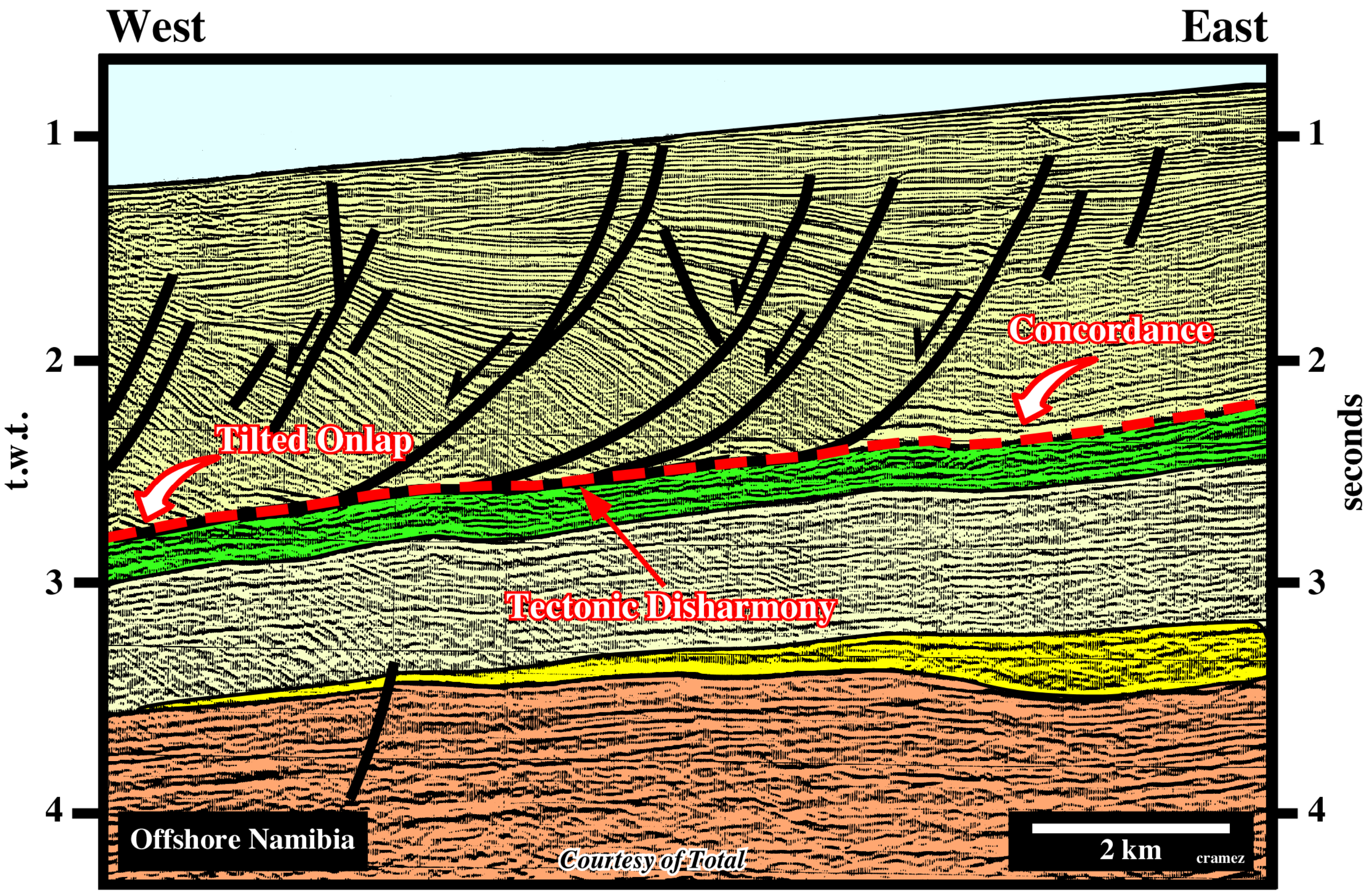


Fig. 81- As we will see in volume III, unconformities are mainly eustatically induced. However, they can be tectonically (halokinesis and shalokinesis included) enhanced. In such a hypothesis, the underlying associated reflection terminations are truncations and the unconformity is often labeled an angular unconformity. On this seismic line, it is quite evident that the picked unconformity was tectonically enhanced. Indeed, in the North Caspian Sea, and particularly in the area of the Kashagan oil field, halokinesis is paramount. The major geologic consequence of Permian salt (Kungurian salt) flowage was the deformation and uplift of Triassic sediments, which were partially eroded (truncation) before being covered by Jurassic marine sediments.

Unconformities



Courtesy of Total

Fig. 82- Interpreters must differentiate tectonic disharmonies from unconformities (erosional surfaces). Tectonic disharmonies, as depicted above, are décollement surfaces bounding two sedimentary intervals with quite different tectonic deformations. There is not significant erosion associated with tectonic disharmonies. On the contrary, as said previously, erosion is a distinguishing trait of unconformities. However, erosion is mainly subaerial. Submarine erosion is generally localized on the upper slope and associated with gravity currents.

Unconformities

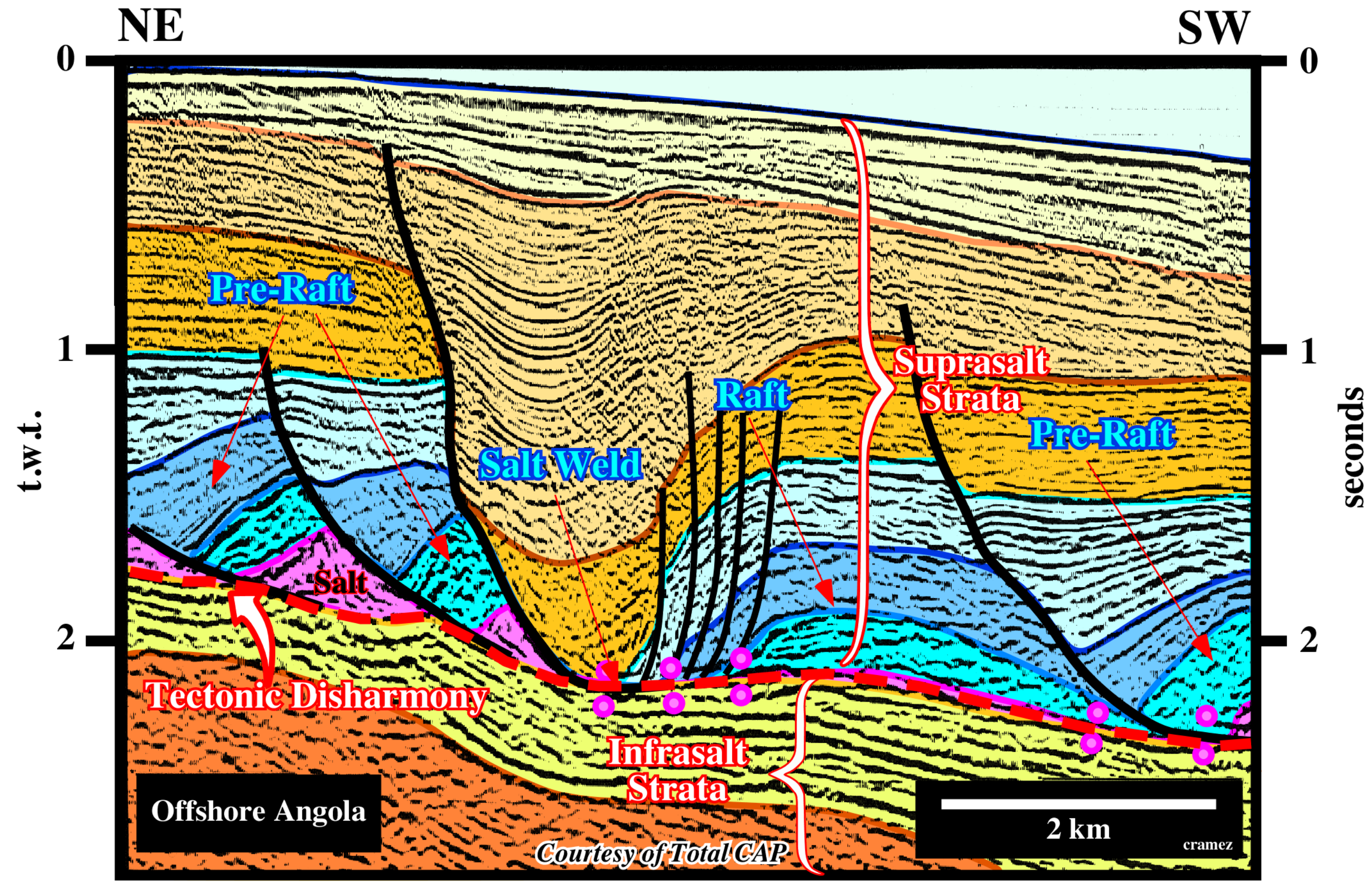


Fig. 83- In salt basins, the evacuation of salt often creates significant tectonic disharmonies. An example from the Kwanza basin (Angola) is illustrated above. This disharmony can be recognized on almost all seismic lines in the basin. As depicted above, due to salt flowage, the suprasalt strata is quite deformed, while the infrasalt stratais almost undeformed. So, the reflection terminations of the suprasalt strata are not pristine. They look like downlaps but actually they are tilted onlaps. It is important to notice that there is not erosion between the infra and suprasalt strata, so such an interface cannot be considered as an unconformity. Salt welds are developed where salt expulsion is total.

External Form
and
Internal Reflection
Configuration

The overall geometry of a stratigraphic, or seismic unit, consists of the external form and the internal reflection configuration of the unit. Both must be described to understand the geometric interrelation and depositional setting of the units.

Initial analysis always starts in the two-dimensional mode of a single seismic section, and these apparent configurations are later corroborated in a three-dimensional grid of seismic sections.

Single sections obviously may cut strata geometry at any angle. However, on these notes, diagrammatical sections illustrating reflections configuration, and seismic lines, are assumed to be parallel with sedimentary dip unless otherwise indicated.

Filling Patterns

Strata filling geologic negative features in the underlying sediments define characteristic reflection configurations. Underlying reflections may show either erosional truncation or concordance on the basal surface of the fill unit. Fill units may be classified by:

a) External Form

- Channel fill
- Trough fill
- Basin fill
- Front slope fill

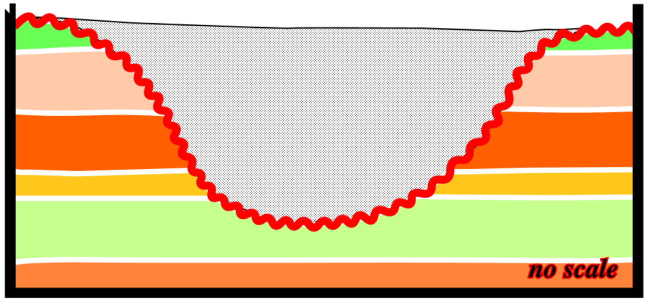
b) Internal Configuration

- Onlap
- Mounded onlap
- Divergent
- Prograding
- Complex
- Chaotic

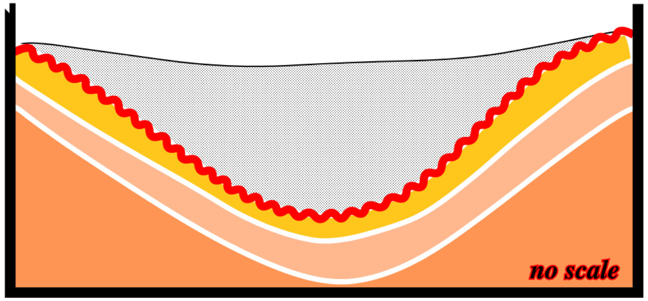
Filling Patterns

External Geometrical Patterns

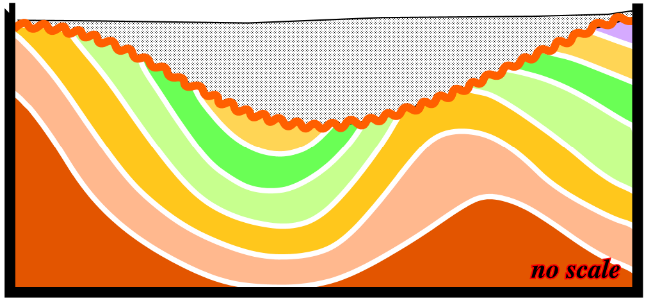
Channel Fill



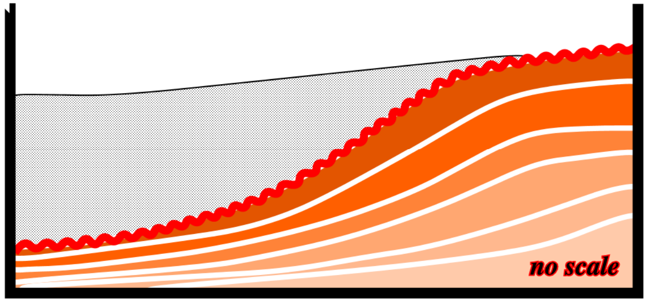
Trough Fill



Basin Fill

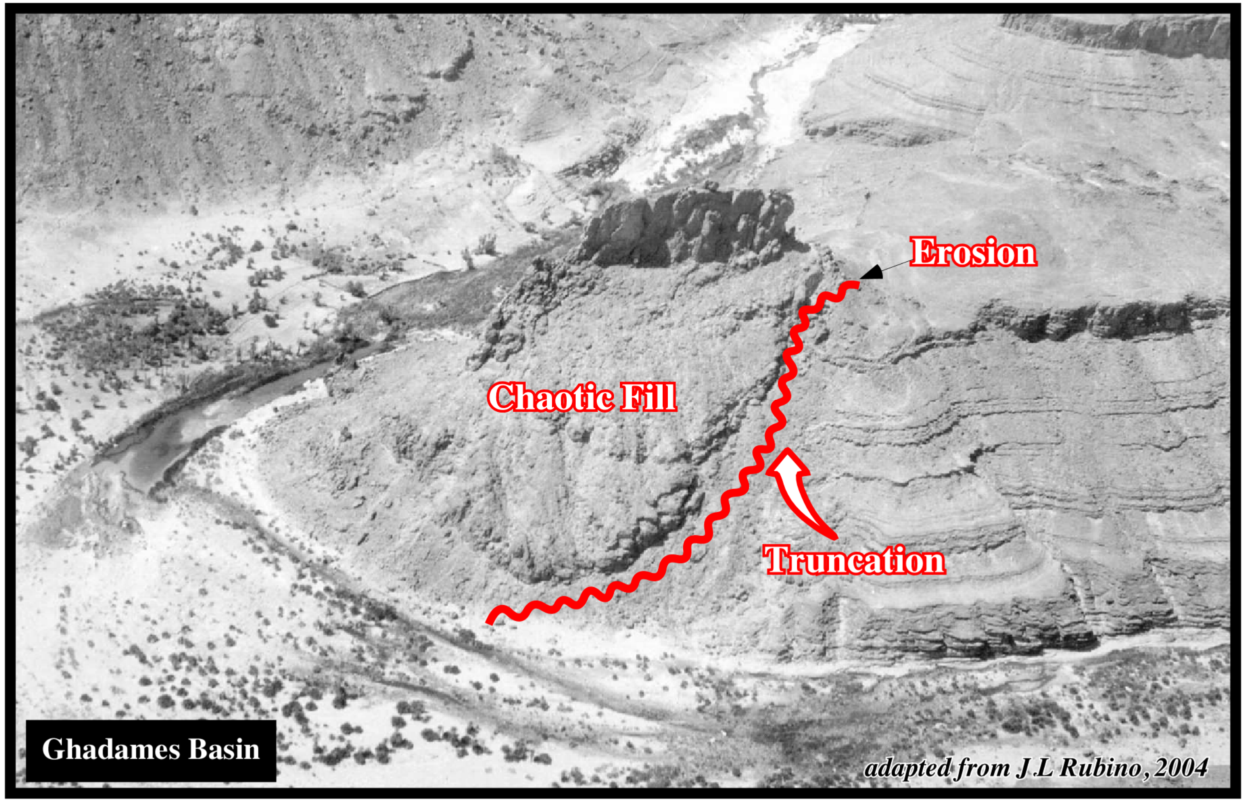


Front Slope Fill



Filling Patterns

Channel fill

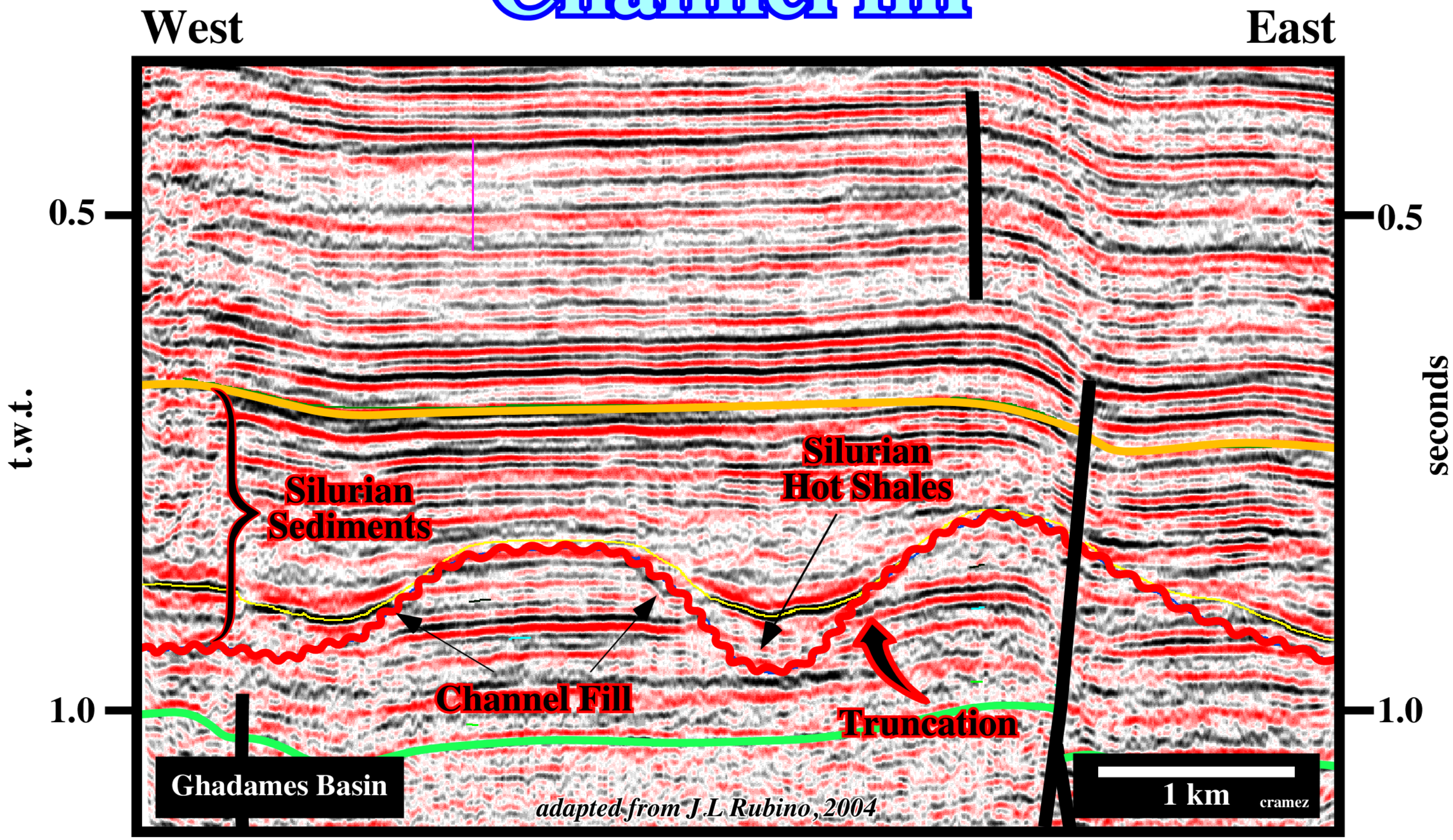


adapted from J.L Rubino, 2004

Fig. 84- On this photograph, taking into account the external geometric patterns (truncation), one can interpret in channel fill. Similarly, as we will see soon, the internal filling configuration is chaotic. It is relevant here to point out that the erosional surface as well as the filling are glacially controlled.

Filling Patterns

Channel fill



adapted from J.L Rubino, 2004

Fig. 85- On this seismic line, channel fill patterns are easily recognized by the obvious truncation reflection terminations of the Ordovician sediments. Similar to the previous slide, the erosion inducing the channel fill geometry is glacially controlled. Later, that is to say, during the Silurian transgression, these glacial channels were partially filled in onlap by Silurian hot shales, which are by far the best source-rock of the basin.

Filling Patterns

Channel fill

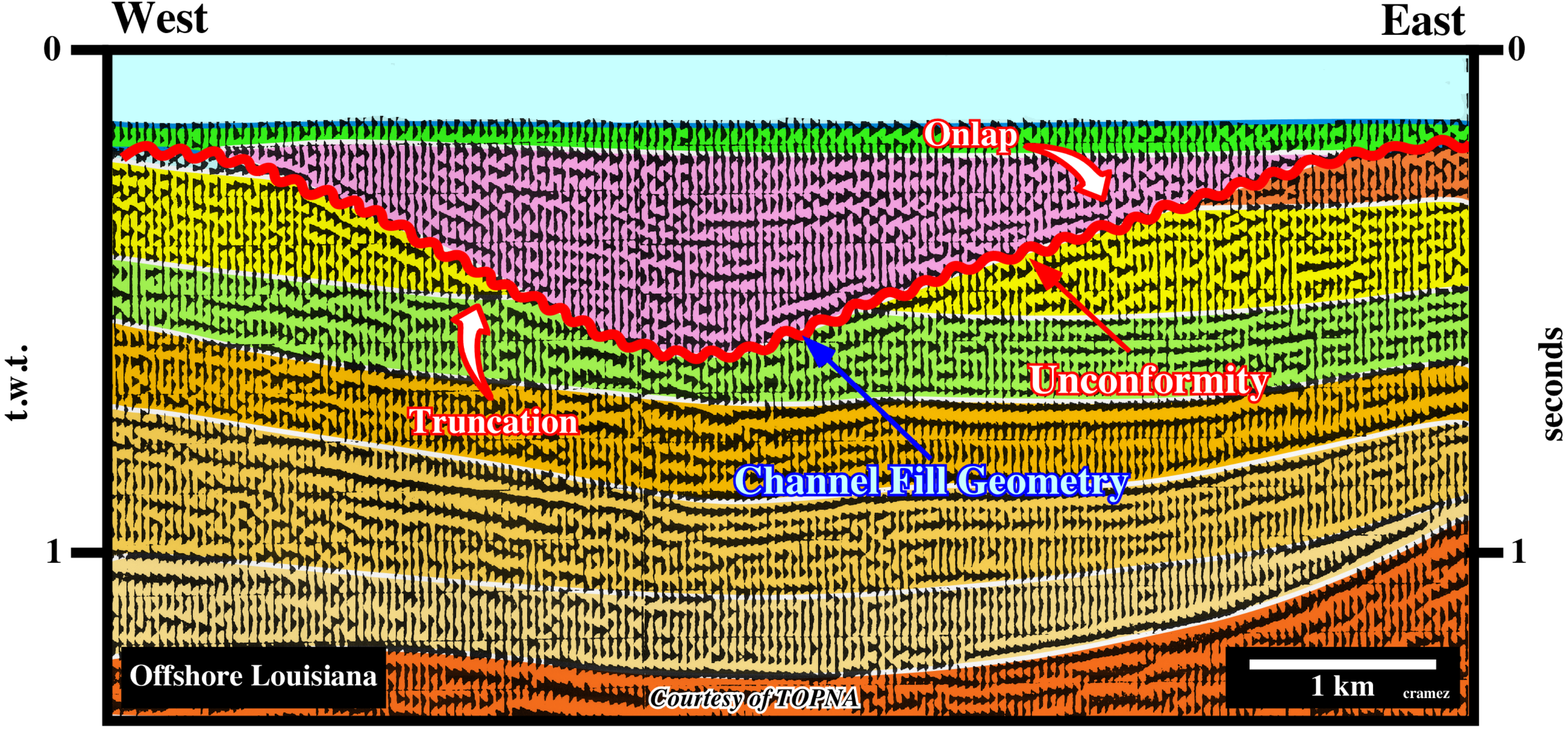


Fig. 86- On this line from offshore Louisiana, a relative sea level fall shifted the coastal onlaps basinward and downward. Subsequently, subaerial erosion took place on the outcropping shelf creating an erosional surface (unconformity) with a typical channel fill geometry. Later, when relative sea level rised, the negative morphologic anomalies (channel fill) were onlaped by a slightly divergent shaly interval.

Filling Patterns

Channel Fill

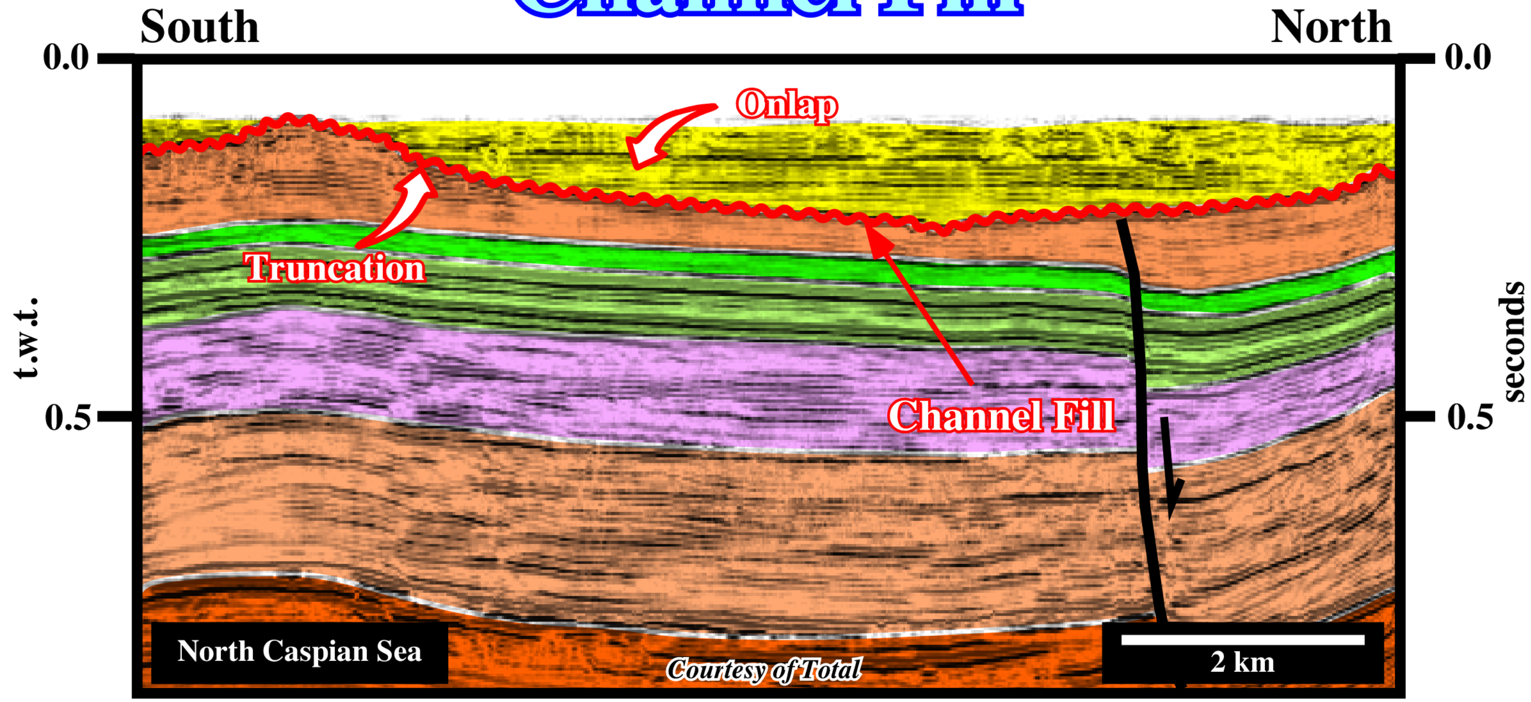


Fig. 87- On this seismic line, a relative sea level fall shifted the coastal onlaps basinward and downward developing a subaerial erosion in the outcroping shelf, which created an external channel fill morphology. Later, when relative sea level rose, the shelf was flooded and the channel fill anomalies were filled, in onlap, by shaly marine sediments. In such geological conditions, the erosional surface is quite regional and so, the channel fill corresponds to an unconformity.

Filling Patterns

Trough Fill

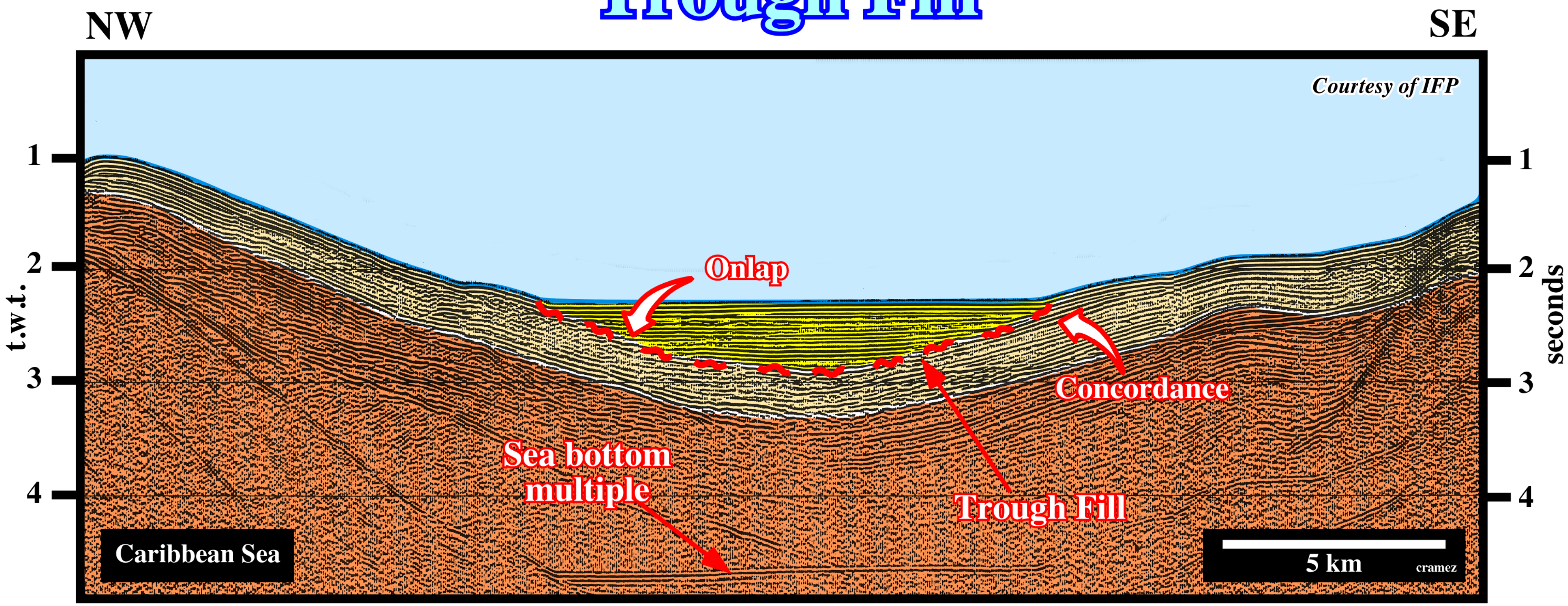


Fig. 88- An external geometry pattern is called trough fill when the depositional anomaly is structural, that is to say, when the depositional surface is not created by local or regional erosion. As illustrated on this seismic line, there is no significant erosion between the yellow and the light brown intervals, in spite of the depositional hiatus between them. In such geological conditions, the trough fill geometry does not correspond to an unconformity. The internal fill configuration of trough fills can vary considerably.

Filling Patterns

Basin fill

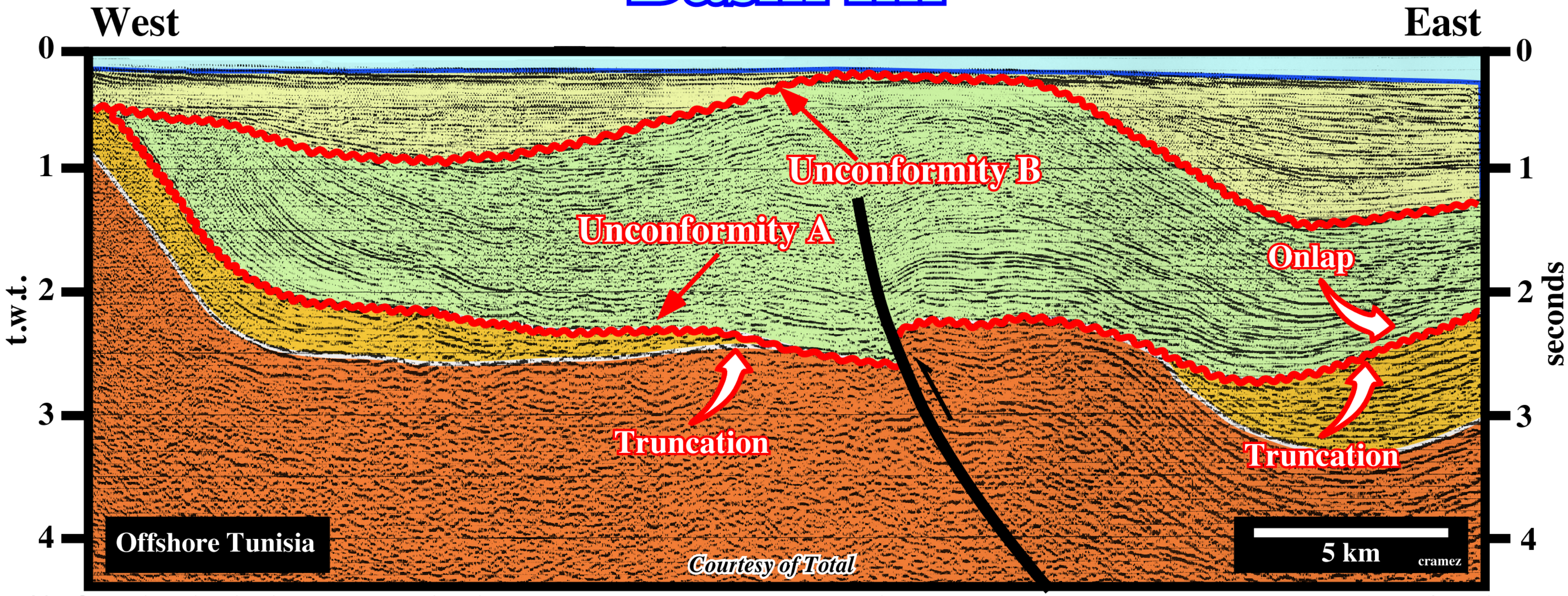


Fig. 89- On this seismic line, when taking into account the external geometrical pattern, one can say that the lower unconformity, at the base of the green interval, corresponds to an external basin fill. Actually, it is quite easy to recognize the underlying reflection terminations of the unconformity A, which are truncations, and the overlying terminations, which correspond to tilted or deformed onlap. On the other hand, at least two major compressional tectonic regimes can be put in evidence. The oldest predates the unconformity A, while the youngest postdates the unconformity B. Similarly unconformity B, in terms of external fill patterns can also be considered as a basin fill. Indeed, truncation (below) and onlap (above) are quite obvious.

Filling Patterns

Front Slope Fill

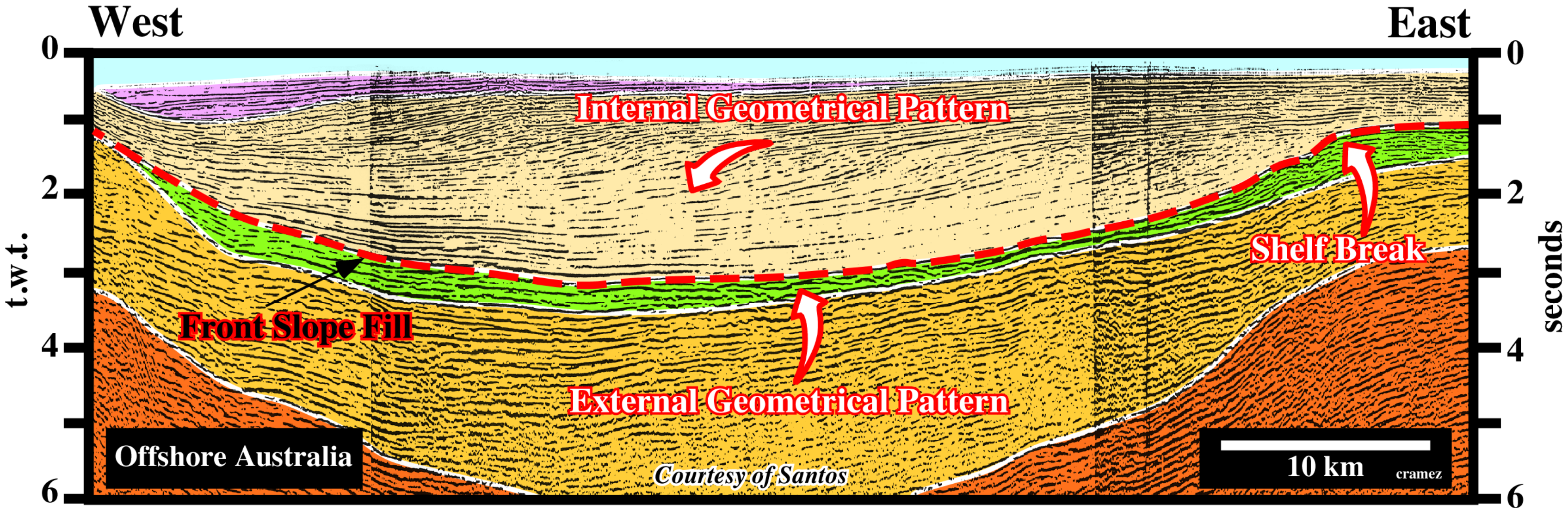
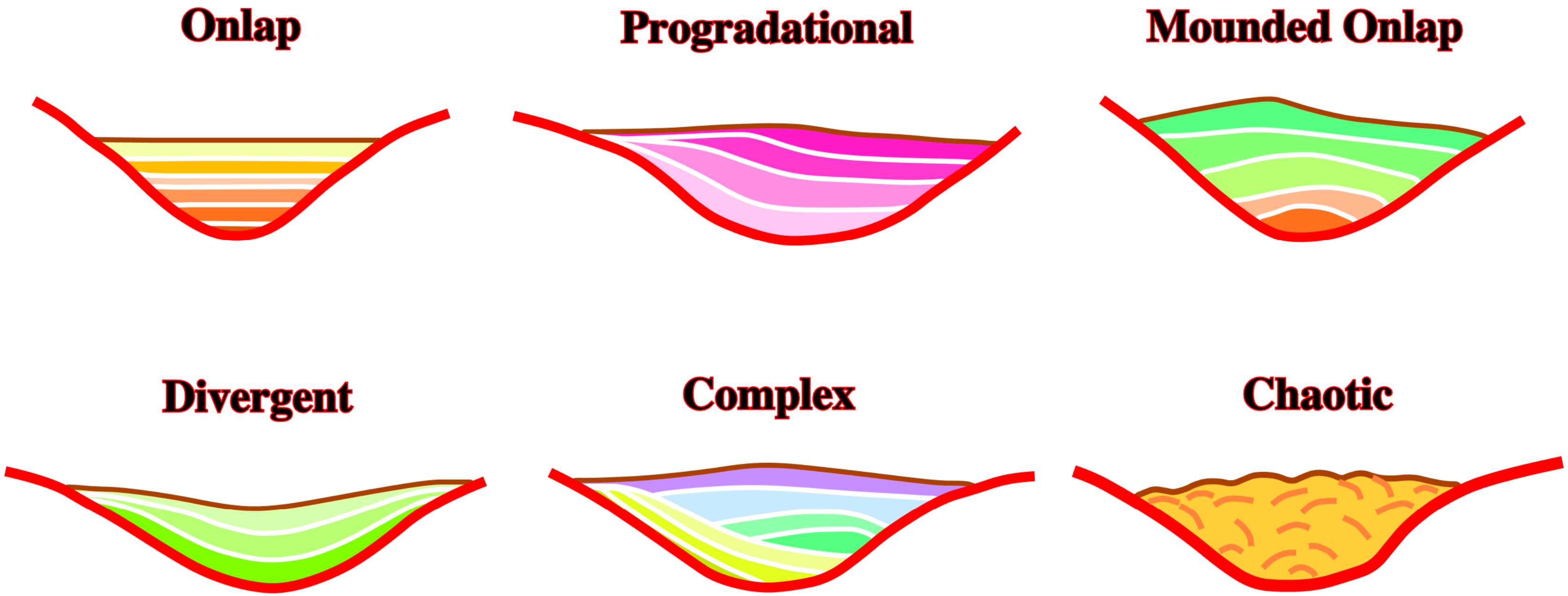


Fig. 90- On this line a front slope fill pattern is illustrated, which is composed by a progradational internal filling configuration. The green seismic interval underlying the front fill depositional surface, corresponds indeed to a front slope. Indeed, the shelf break, limiting the shelf from the continental slope, is easily recognized on the eastern part of the line. On the other hand, it is evident that there is no significant erosion associated with this front slope fill.

Filling Patterns

Internal Filling Configurations



no scale

Filling Patterns

Onlap Fill

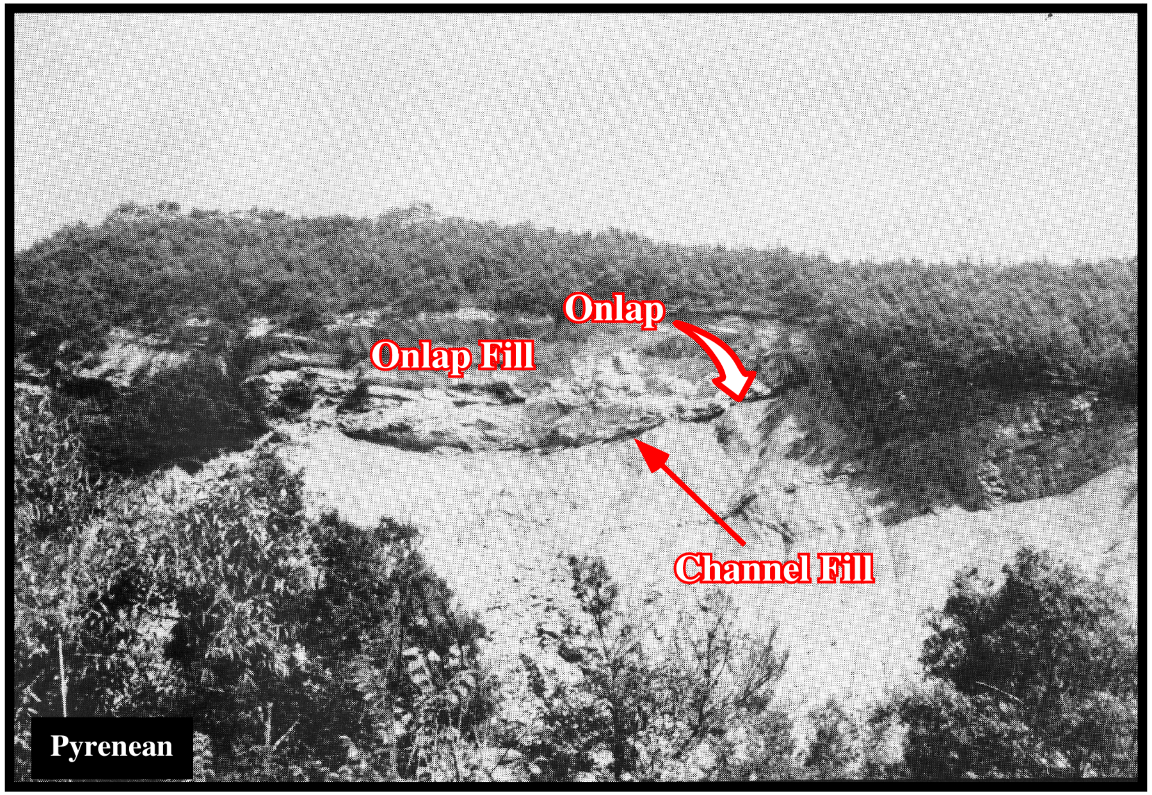


Fig. 91- The internal filling configuration is here clearly onlap. The external channel fill geometry seems to be created by the erosion of gravity currents (turbidite currents). The aggradational geometry filling underlines the stacking of turbidite deposits. In other words, in deep-water environments, onlap reflection terminations do not necessary correspond, as it is the case in shallow water deposits, to relative sea level rises. Indeed, as we will see later, turbidite depositional systems are most oftendeposited during relative sea level falls, that is to say, during lowstand geological condictions.

Filling Patterns

Onlap Fill

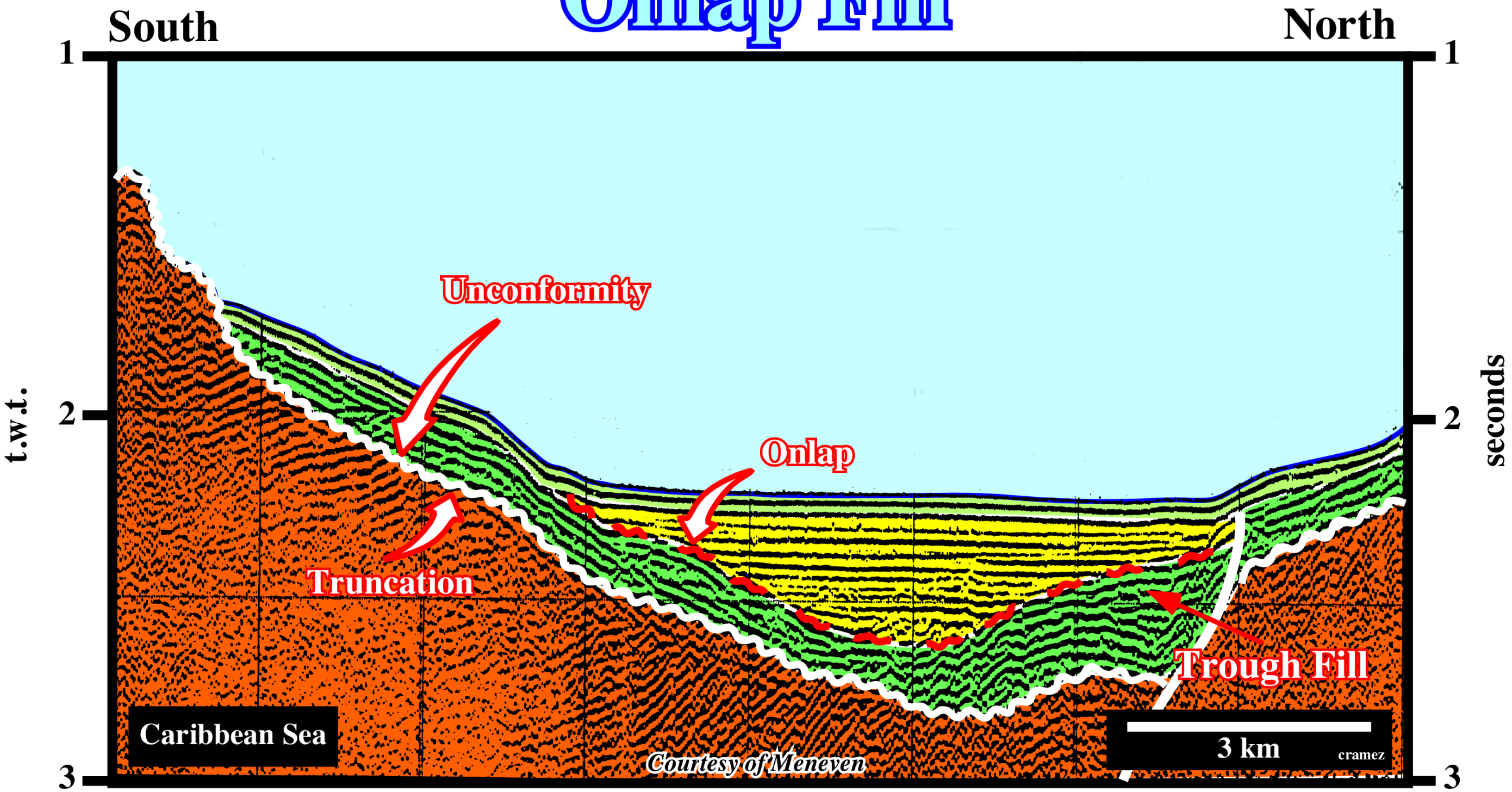


Fig. 92- This line illustrates the difference between an unconformity (erosional surface or the basinward conformity correlable with) and trough fill. Unconformities, as illustrated above, are characterized by underlying truncation reflection terminations. In a trough fill there are no underlying reflection terminations. In fact there is concordance. On this line, the structurally induced trough fill was fossilized by deep-water sediments with an internal onlap fill geometry (at least on the N-S direction).

Filling Patterns

Progradational Fill

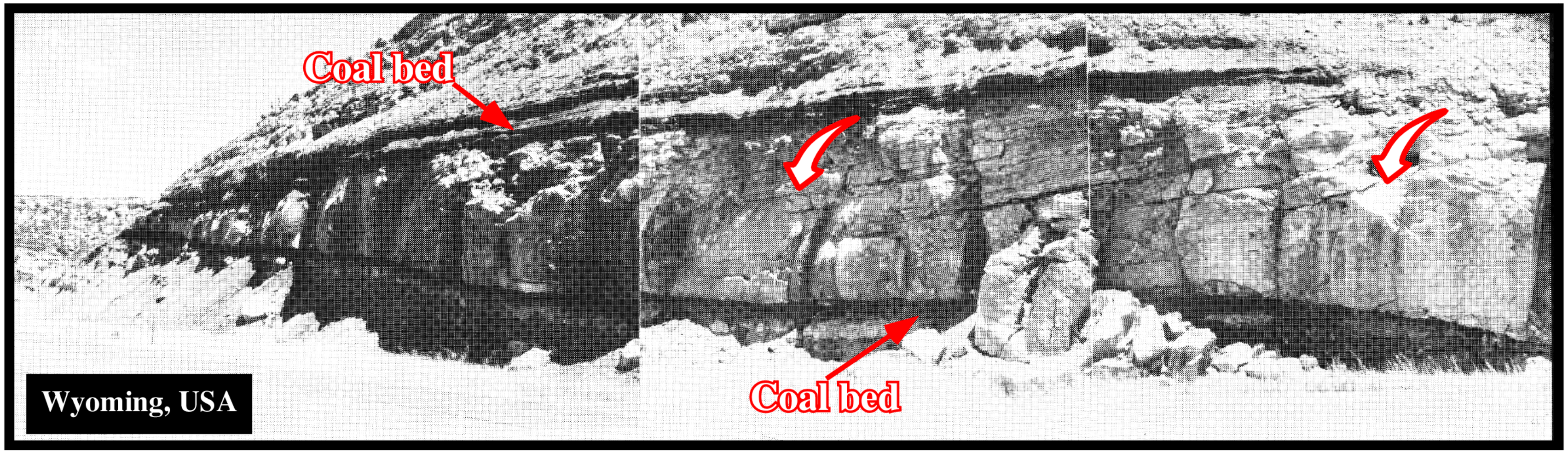


Fig. 93- Progradational reflection configuration, as illustrated on this photograph, can be interpreted as strata that was deposited due to lateral outbuilding or progradation. As we will see later, sigmoid, oblique, complex, shingled and hummocky progradational patterns form through progressive lateral development of gently sloping depositional surfaces, called clinoforms. Differences in prograding clinoforms result in large part from variations in the rate of deposition and water depth.

Filling Patterns

Progradational Fill

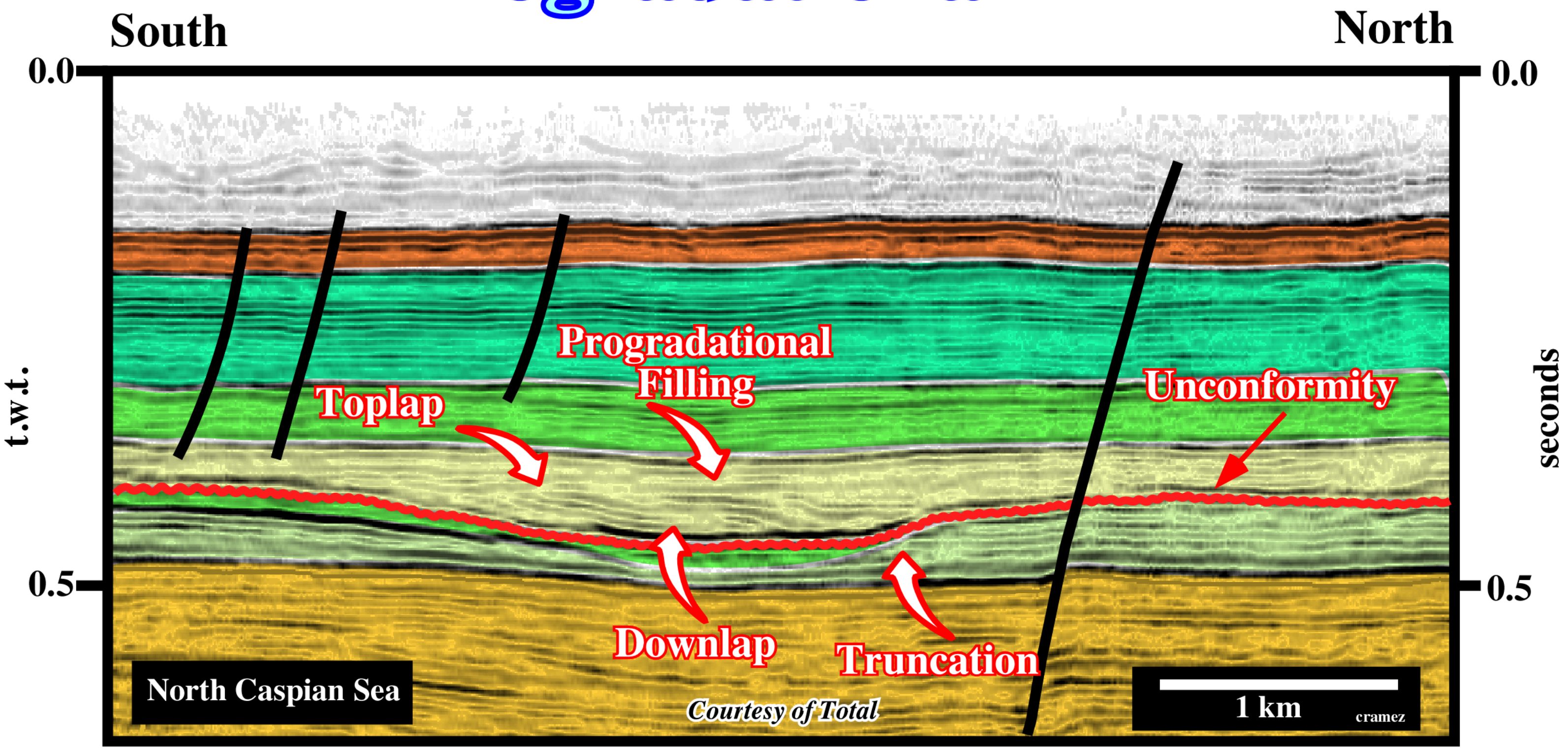


Fig. 94- On this line, an incised valley, created during a relative sea level fall, was later filled by progradational sediments as indicated by the downlap reflection terminations. On the other hand, the downlaps strongly suggest a terrigeneous influx coming from south. Notice that quite often the incised valley, particularly those located near the shelf break, are filled by transgressive sediments, which at a small scale can have a forestepping geometry. Indeed, the source of clastics sediments is the continent.

Filling Patterns

Mounded Configuration

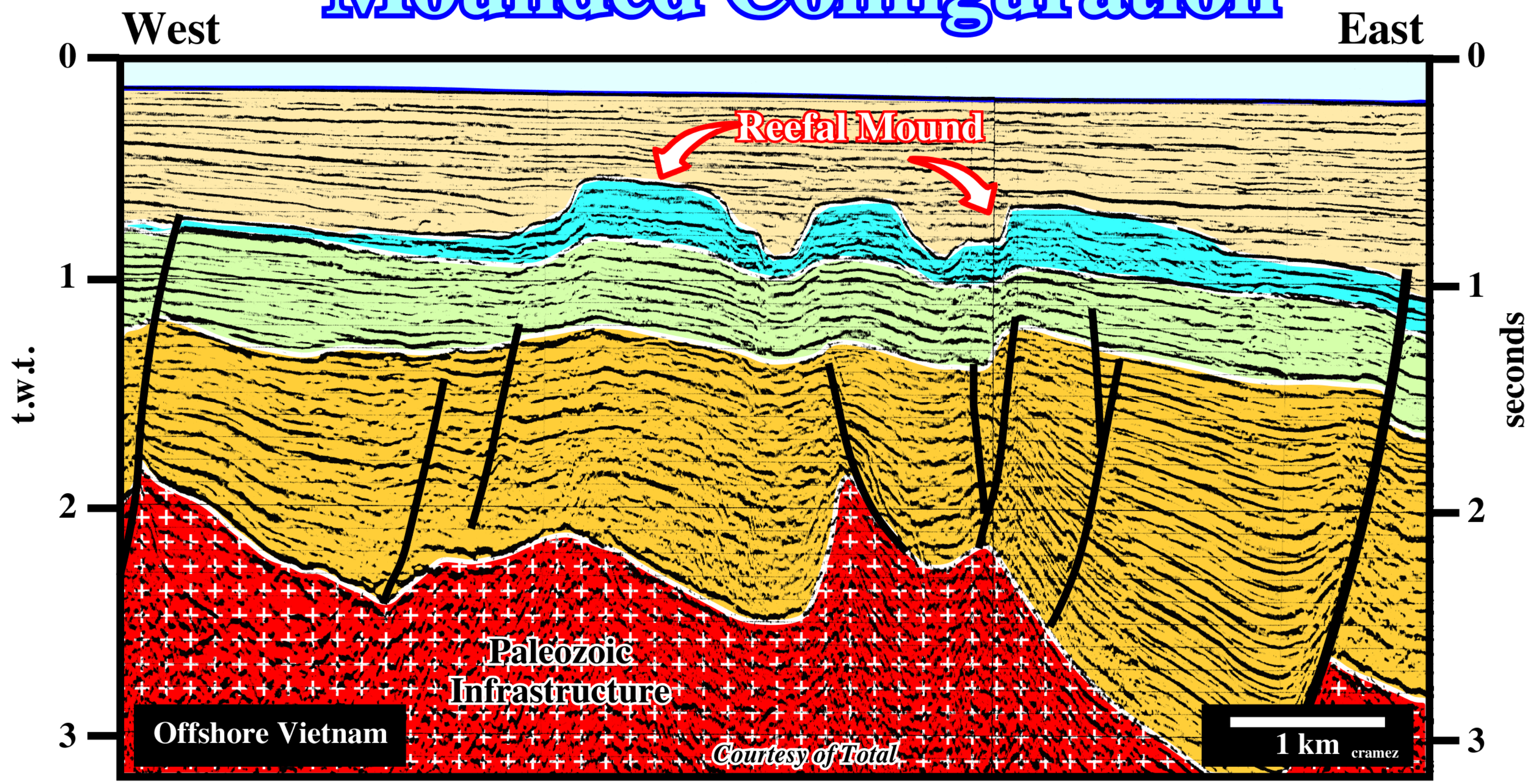


Fig. 95- Mounded reflection configurations are interpreted as strata-forming elevations or prominences, rising above the general level of the surrounding strata. Most mounds are topographic buildups resulting from either clastic or volcanic depositional processes, or organic growth. On this line from offshore Vietnam, the mounded configuration is obviously associated with reefal buildups.

Filling Patterns

Mound Configuration

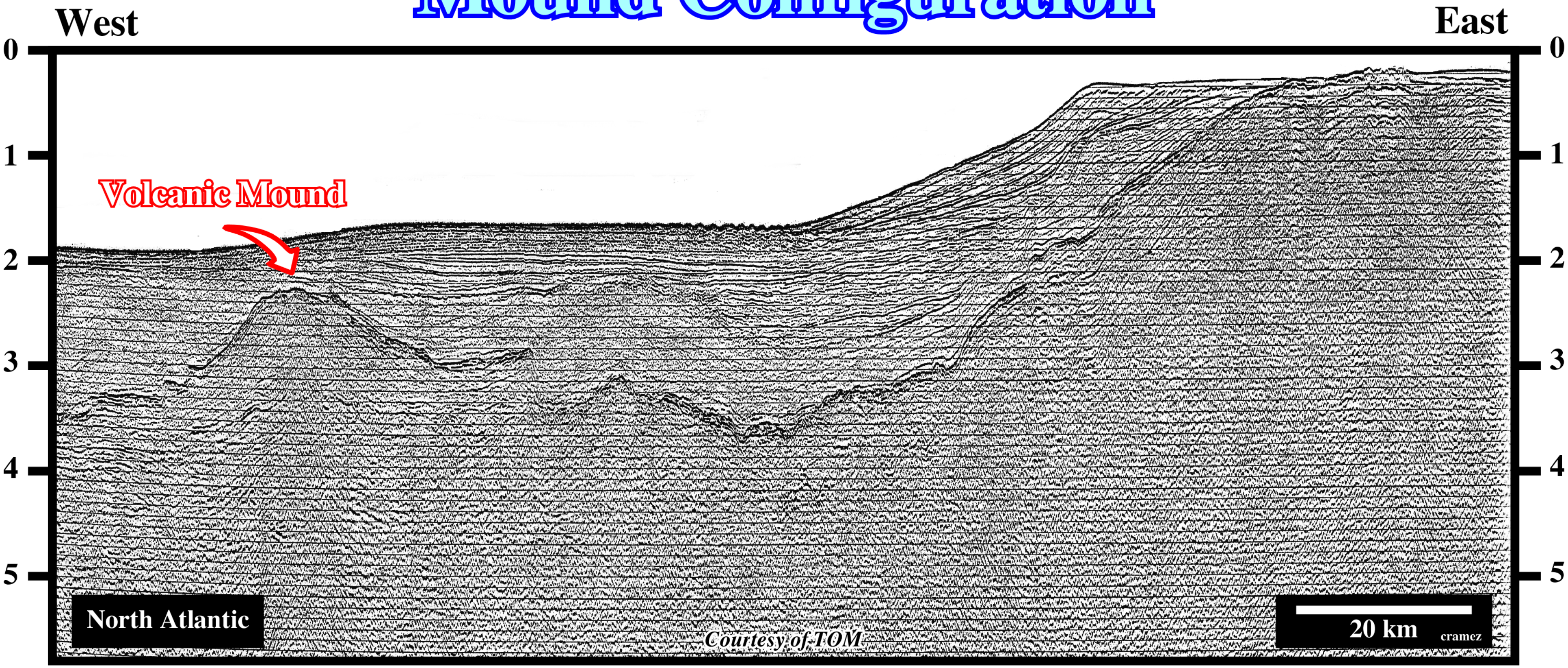


Fig. 96- Volcanic mounds are quite frequent, particular in the North Atlantic where this seismic line comes from. In this particular example, the volcanic mound corresponds to a seamount, with which lava deltas and sub-aerial lava flows (seaward dipping reflections) are often associated. On this subject, it important to point out that volcanic material cannot flow under water as it is quickly frozen. Indeed, the development of lava deltas is due to such behavior.

Filling Patterns

Onlap Mounded Fill

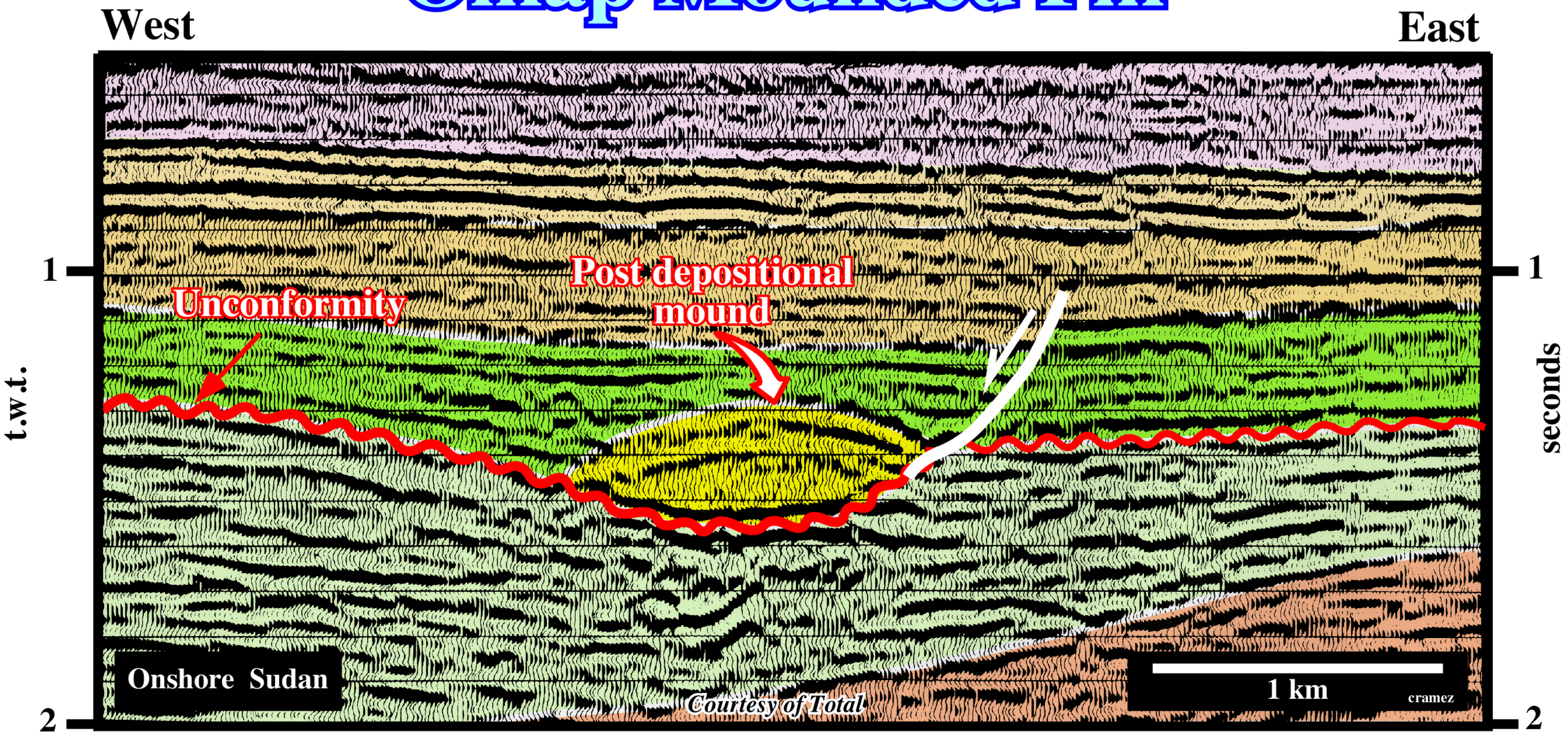


Fig. 97- Mounded geometries, and particularly onlap mounded reflection configurations can be postdepositional. Actually, as illustrated on this seismic line, which comes from onshore Sudan (Piber Post Basin), the onlap mound configuration was created due to differential compaction of the sediments. Indeed, the sandy facies filling the channel are less compacted than surrounding shale sediments. In fact, geologists often use compaction to predict if a channel is filled by sandstones (onlap mound) or clays (absence of onlap mound).

Filling Patterns

Divergent Fill

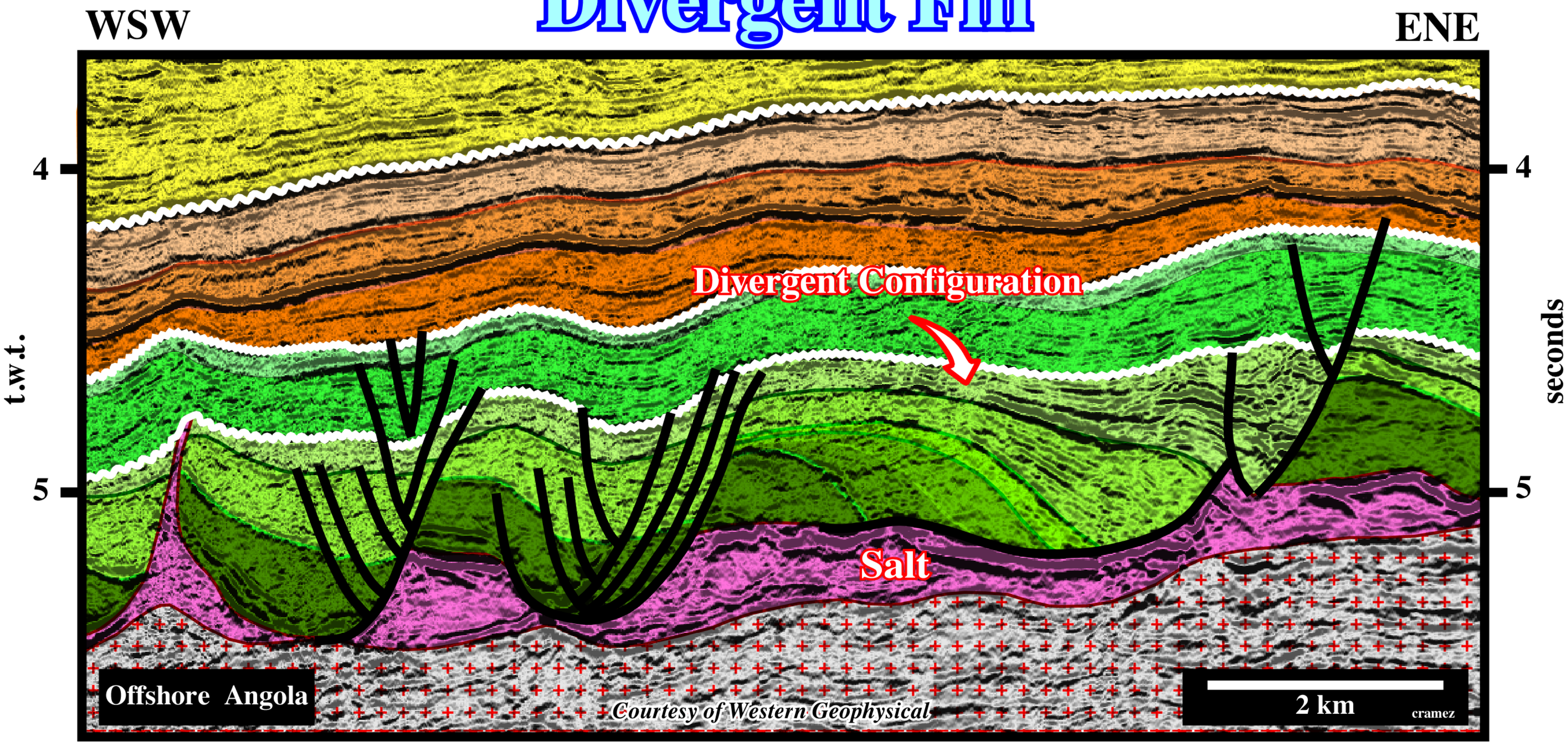


Fig. 98- Divergent fill or divergent reflection configuration is characterized by a wedge-shaped unit in which most of the lateral thickening is accomplished by thickening of individual reflection cycles within the unit, rather than by onlap, toplap or erosion at the base or at the top of the stratigraphic cycle. Divergent configurations suggest lateral variations in the rate of deposition, or progressive tilting of the depositional surface as illustrated on this line from the offshore Angola.

Filling Patterns

Divergent Fill

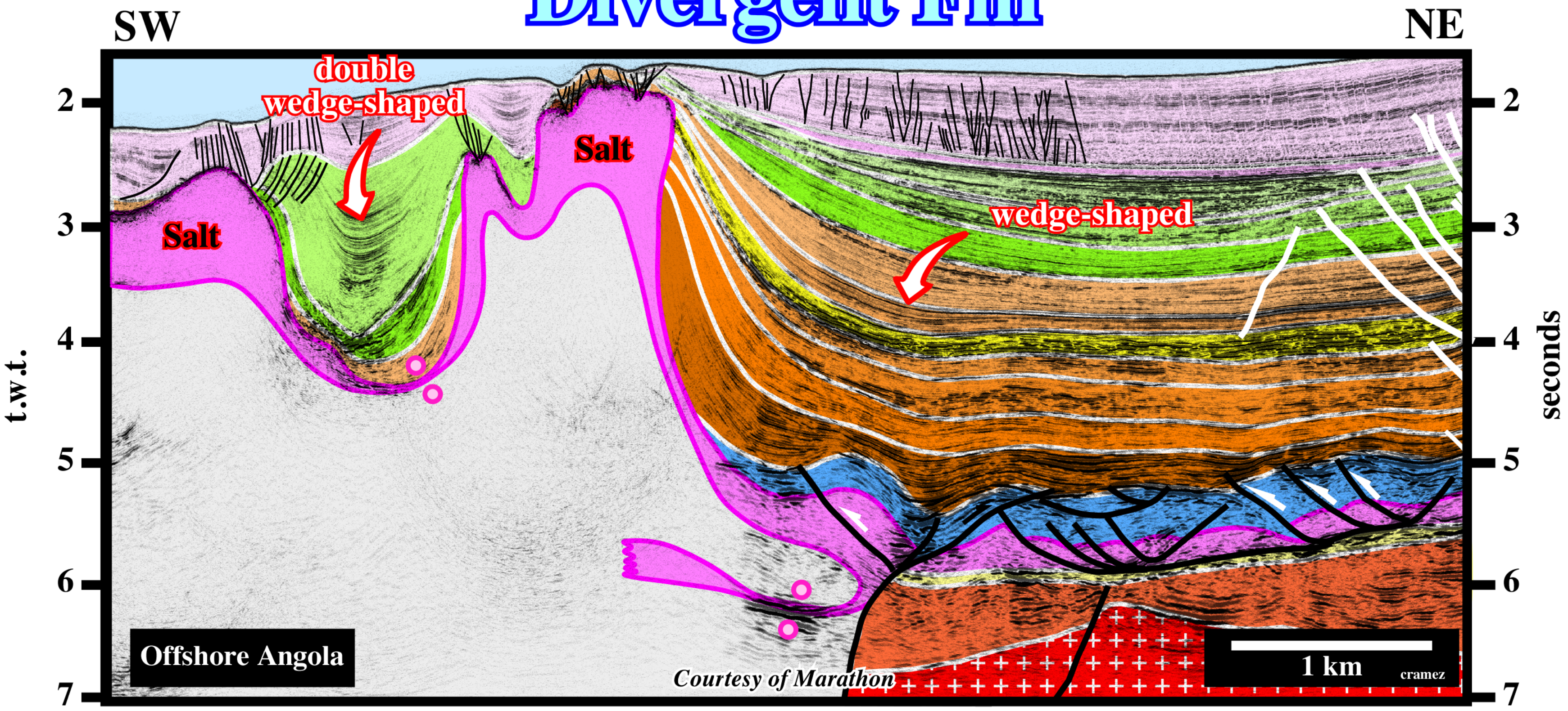


Fig. 99- On this line from deep-water Angola, divergent wedge-shaped configurations are mainly associated with compensatory subsidence induced by salt flowage. However, in association with allochthonous salt layers, salt expulsion basins (minibasins) are almost always filled by double wedge-shaped divergent sediments. Such a divergent configuration suggests a convergent increasing of compensatory subsidence toward the center of the basin.

Filling Patterns

Divergent Fill

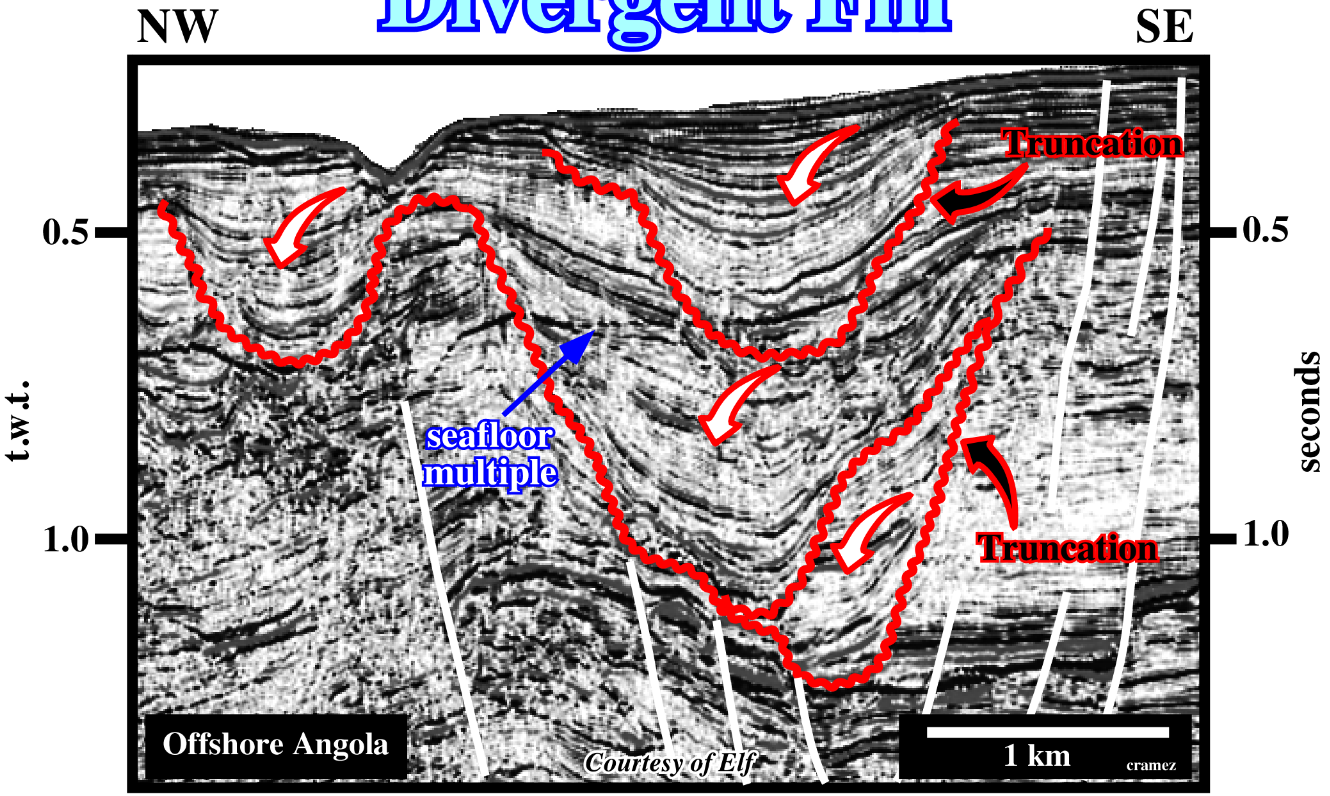


Fig. 100- In the offshore Angola, near the mouth of the Congo River, external channel fill patterns were filled by deep-water sediments, which, on NW-SE seismic lines, exhibit a double divergent configuration. Such a reflection configuration is not observed in a SE-NW seismic line. Subsequently, one cannot say that this double divergent configuration is induced by a subsidence change. Actually, in dip seismic lines, roughly parallel to the sediment transportation along the submarine valleys, one can notice the filling is retrogradational, that is to say, it backsteps toward the shelf break. Briefly speaking, as for the reflection terminations, external and internal patterns must be defined on seismic lines parallel to sediment transportation.

Filling Patterns

Divergent Fill

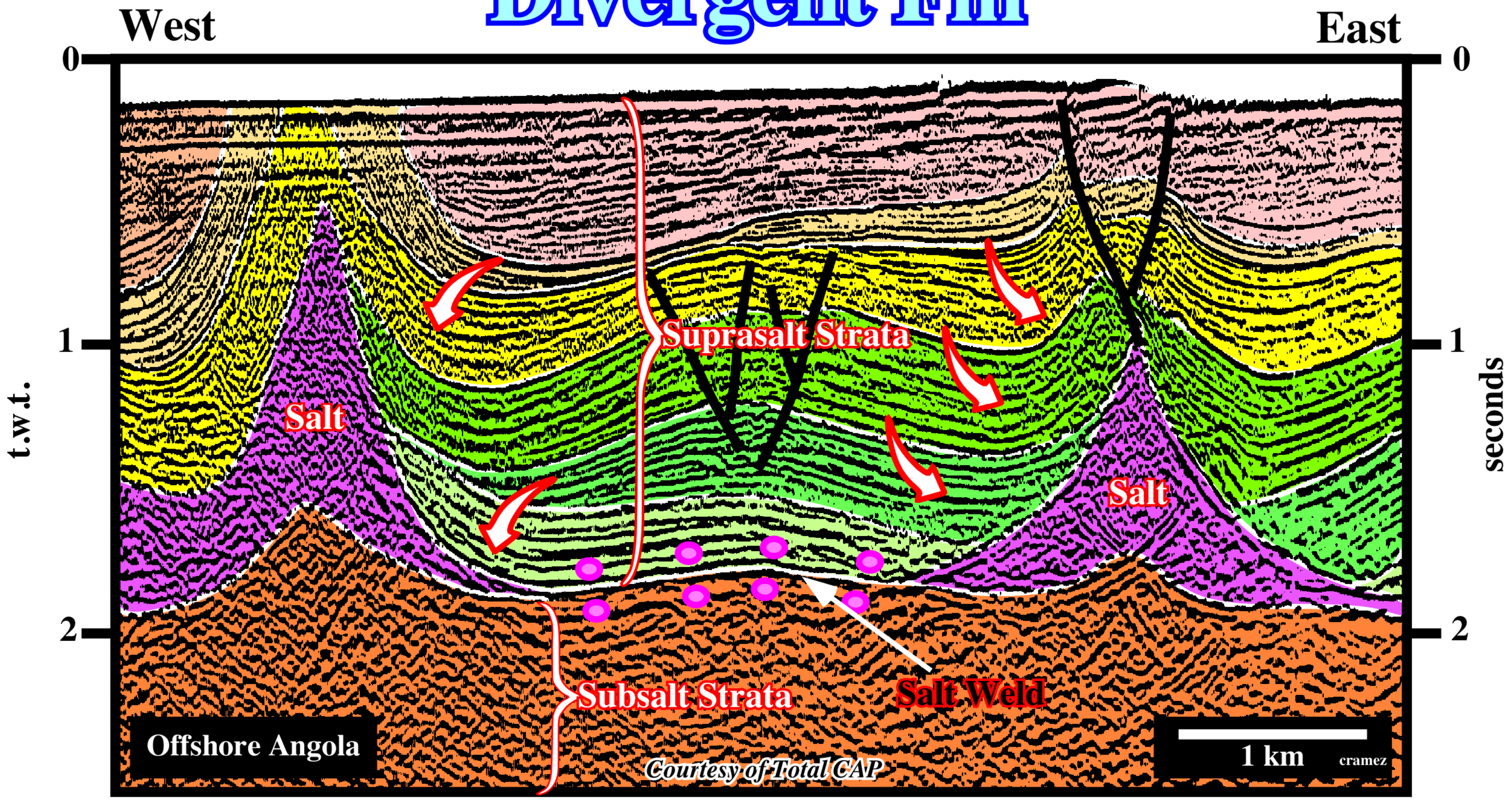


Fig. 101- In association with halokinesis, compensatory subsidence can induce seismic intervals with divergent configurations striking in different directions. As illustrated on this seismic line, the development of turtle-back structure (salt induced tectonic inversion), created a stratigraphic interval with quite different divergent configurations. The vergence of the divergent intervals strongly suggests the maximum of compensatory subsidence, that is to say, the maximum of salt evacuation.

Filling Patterns

Complex Fill

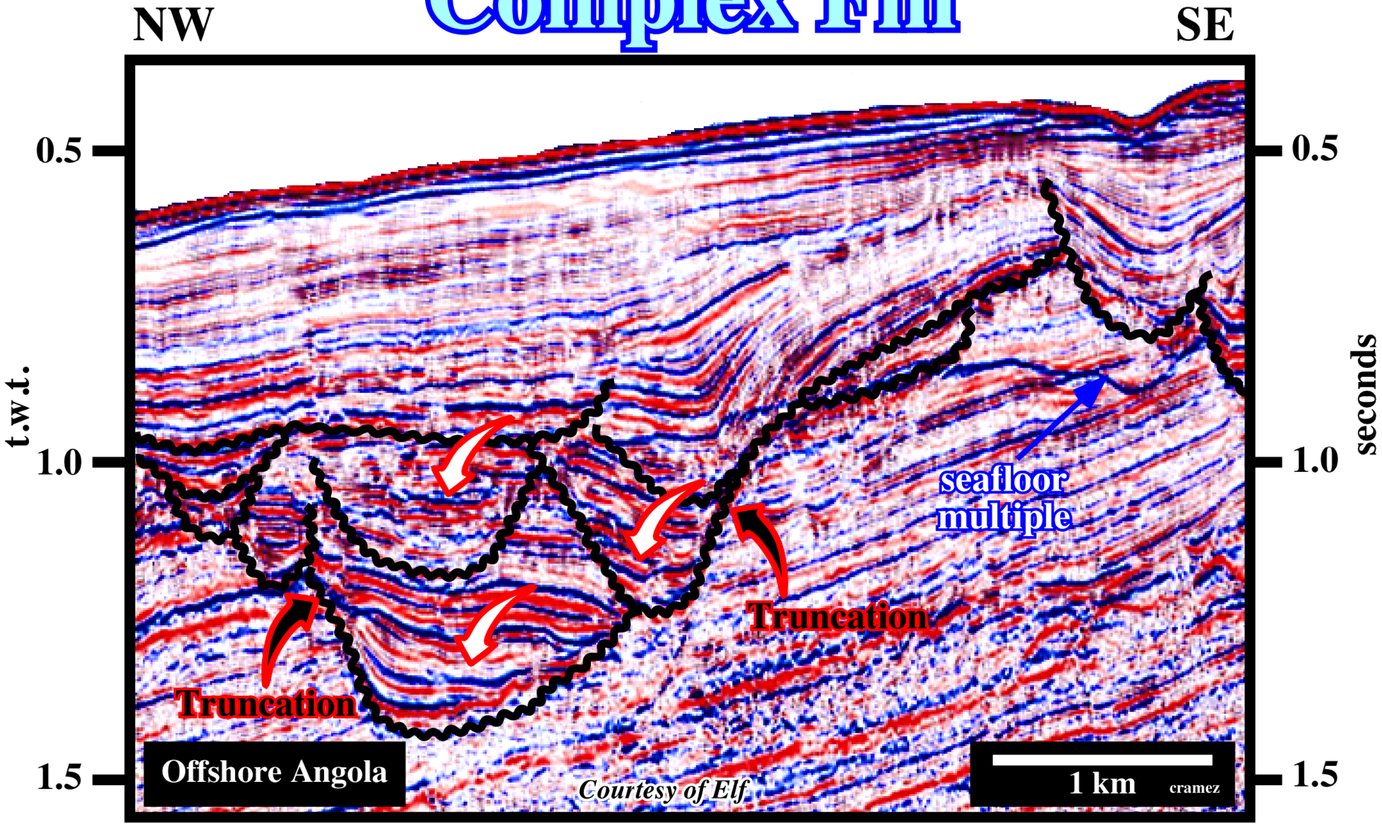
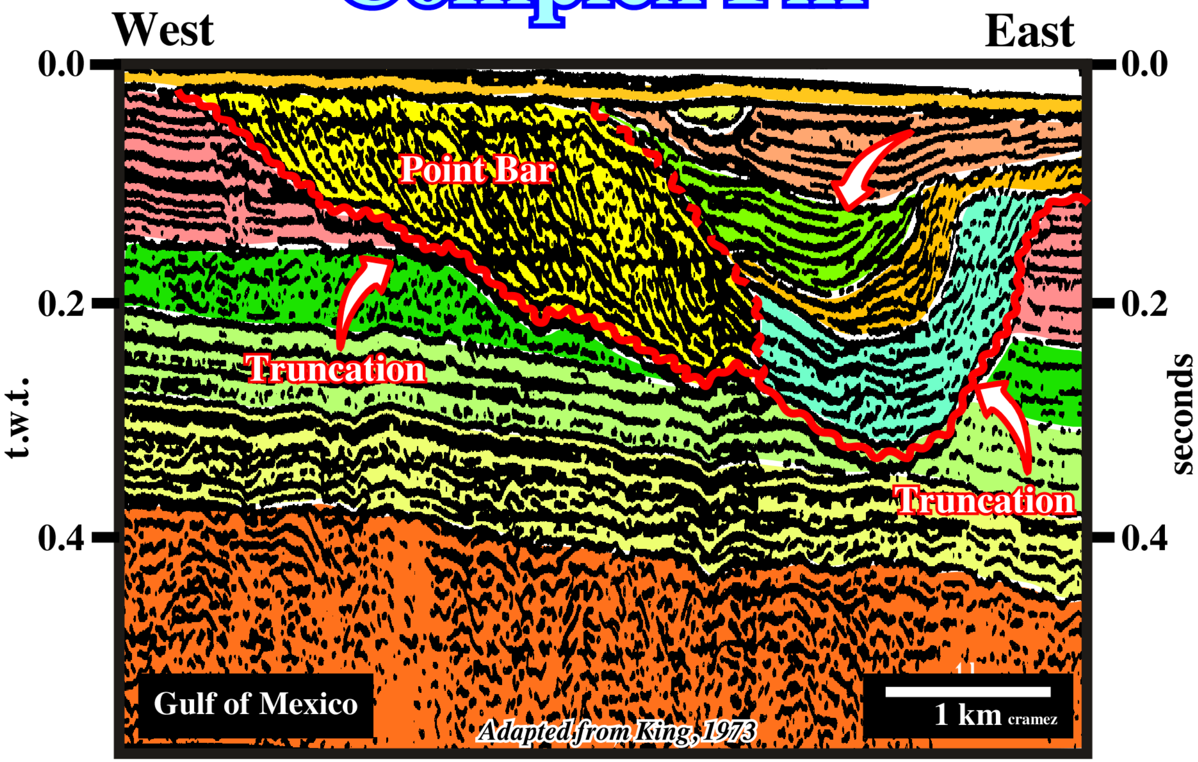


Fig. 102- In the upper slope of northern offshore Angola, near the mouth of the Congo river, several submarine valleys characterized by channel fill external patterns, show a complex filling. As usual, the designaties complex expresses mainly a mixture of all possible types of internal configurations. Subsequently, it is quite difficult to hypothesize the main filling mechanism.

Filling Patterns

Complex Fill

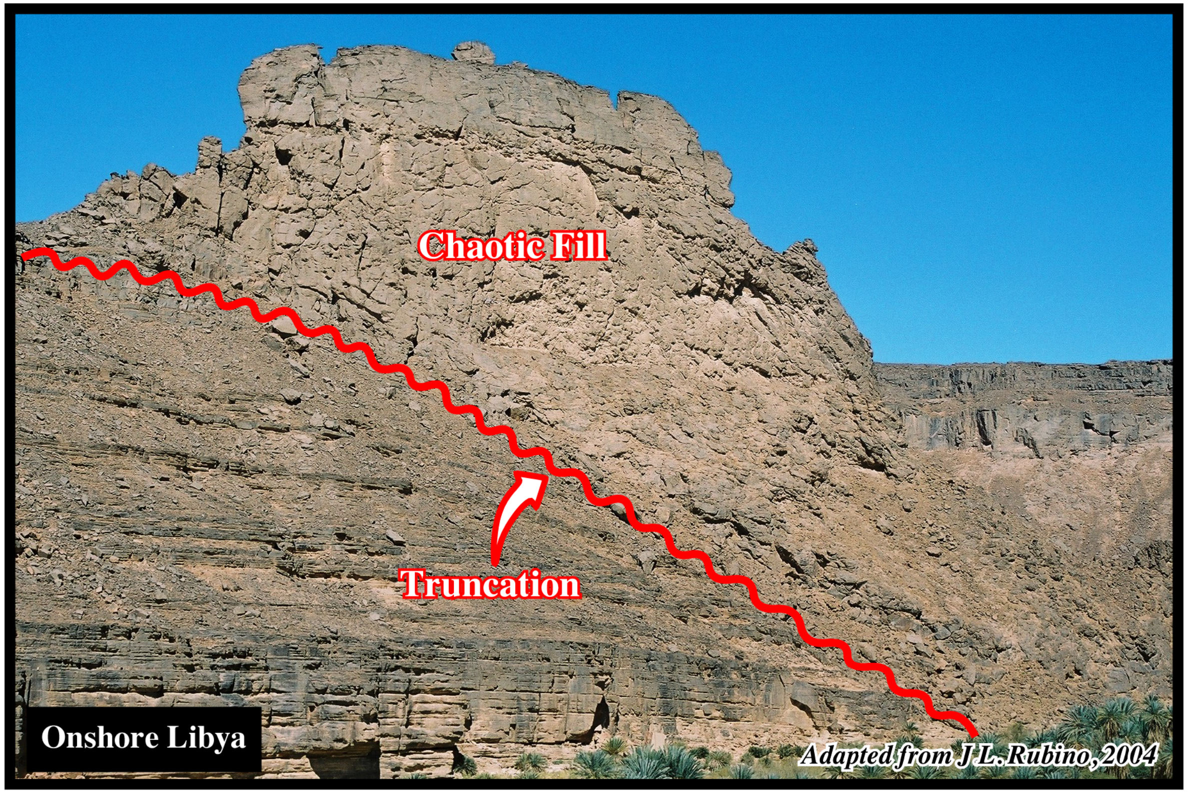


Adapted from King, 1973

Fig. 103- Meander belts are often taken as instances of internal complex filling configuration. As illustrated on this seismic line, the external channel fill pattern is obvious. Contrariwise, with exception for the point bar, the internal filling configuration is quite diverse and complex. Indeed, in such fluvial depositional systems, sedimentation and erosion are interrelated, which creates complicated patterns.

Filling Patterns

Chaotic Fill



Adapted from J.L.Rubino, 2004

Fig. 104- Chaotic filling configurations are often found in association with glacial deposits, such as the one illustrated on this photograph. Indeed, the clearness of the external channel fill pattern strongly contrasts with the disorder of the internal filling.

Filling Patterns

Chaotic Fill

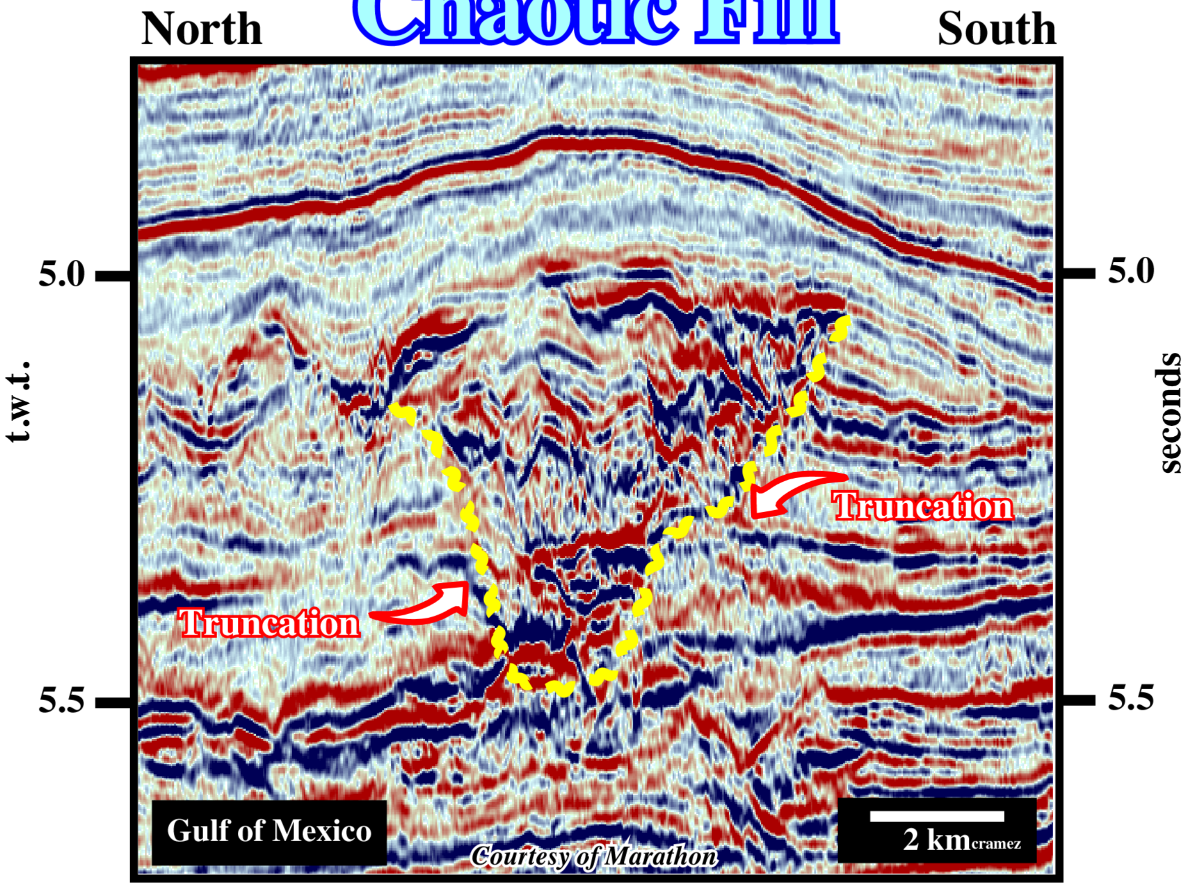


Fig. 105- On this seismic line, from the deep-water Gulf of Mexico, the filling of a submarine valley located between overbank deposits (turbidite levees), can unequivocally be considered as chaotic. Indeed, it is quite difficult to interpret any kind of filling pattern. Notice that in spite of the sharpness of the reflection terminations (truncation), some geologists do not believe that the truncation seismic surface corresponds to an erosional surface (see later).

Filling Patterns

Chaotic Fill

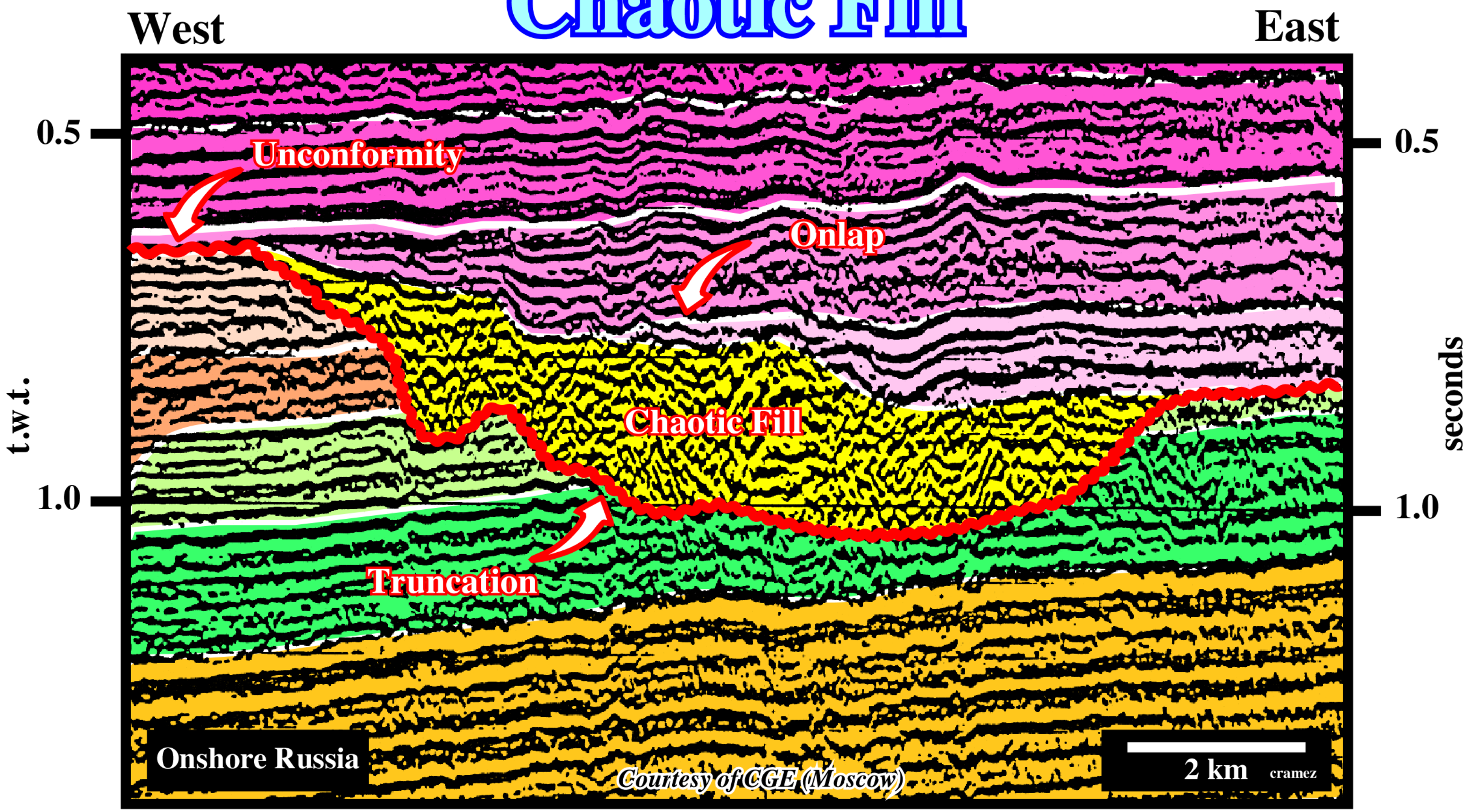
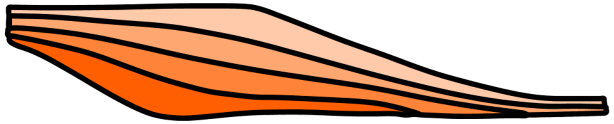


Fig. 106- On this line, an incised valley was filled by non-marine sediments creating an external channel fill pattern. No pattern is discernible in the filling interval (chaotic filling). The erosion responsible for the channel fill pattern was induced by a relative sea level fall, which, at the same time, destroyes the equilibrium profile of the rivers, causing them to incise their beds. The filling of the incised valleys started a new stratigraphic cycle, which continues with the onlap deposition, of transgressive marine sediments.

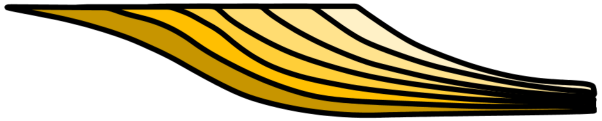
Prograding Patterns

Prograding patterns are interpreted as strata that was deposited due to lateral outbuilding or prograding of gently sloping depositional surfaces, called clinoforms.

Sigmoid

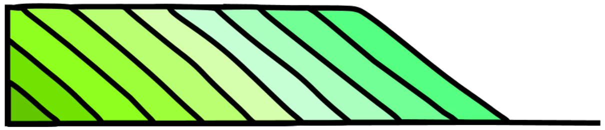


Oblique



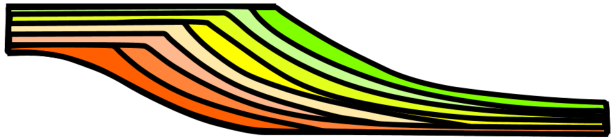
Oblique Tangential

Oblique



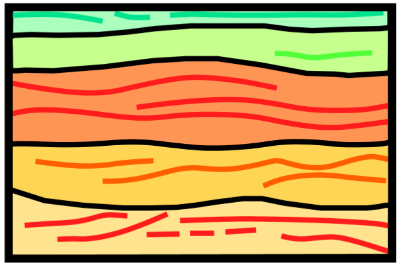
Oblique Parallel

Complex Sigmoid-Oblique



Shingled

Hummocky Clinoforms



Prograding Patterns

Sigmoid Pattern

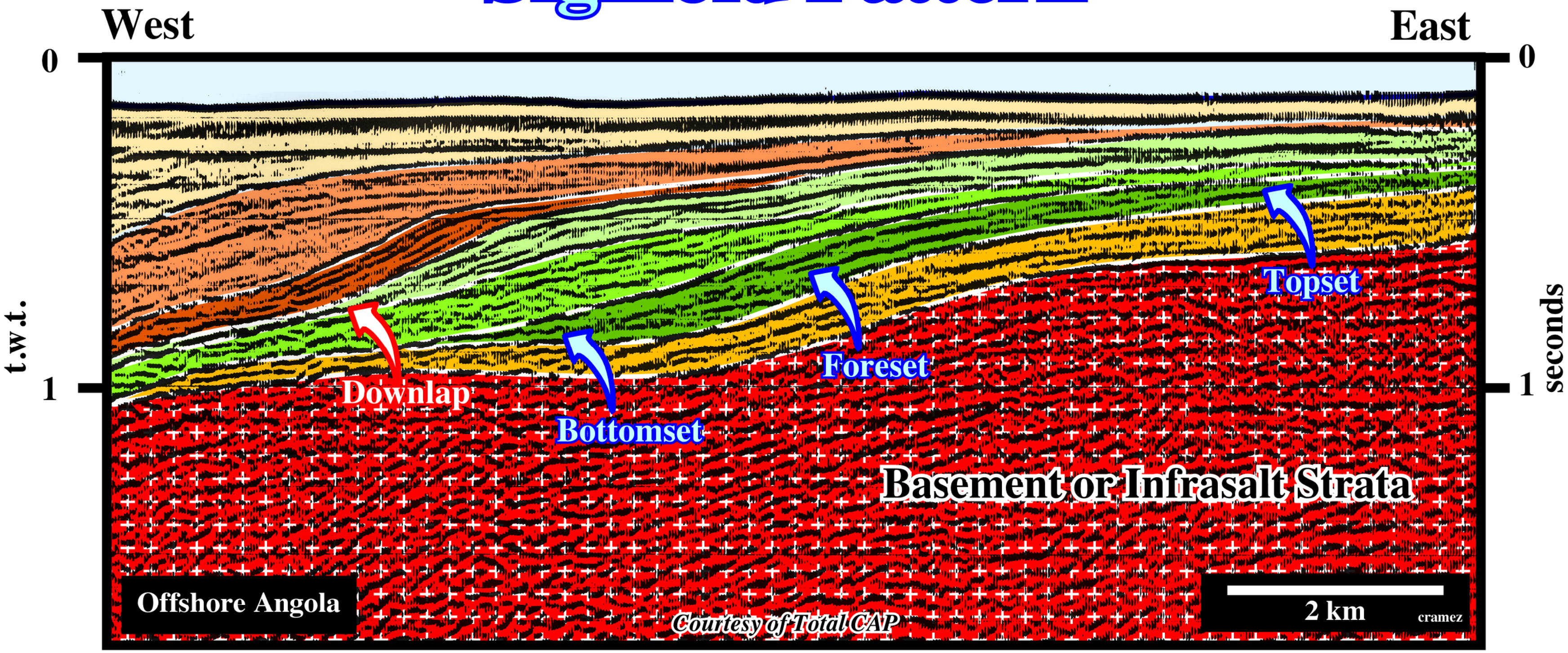


Fig. 107- As illustrated on this seismic line from the conventional offshore Angola, a sigmoid progradational configuration is a prograding clinoform pattern formed by a superposed sigmoid (S-shaped) reflection interpreted as strata with thin, gently, dipping upper and lower segments, and thicker, more steeply dipping middle segment. The upper (topset) segments of the strata have horizontal or very low angles of dip and are concordant with the upper surface of the facies unit. The thicker middle (foreset) segments form lenses superposed to allow successively younger lenses to be displaced laterally in a depositional downdip direction, forming overall outbuilding or progradatinal patterns.

Prograding Patterns

Sigmoid Pattern

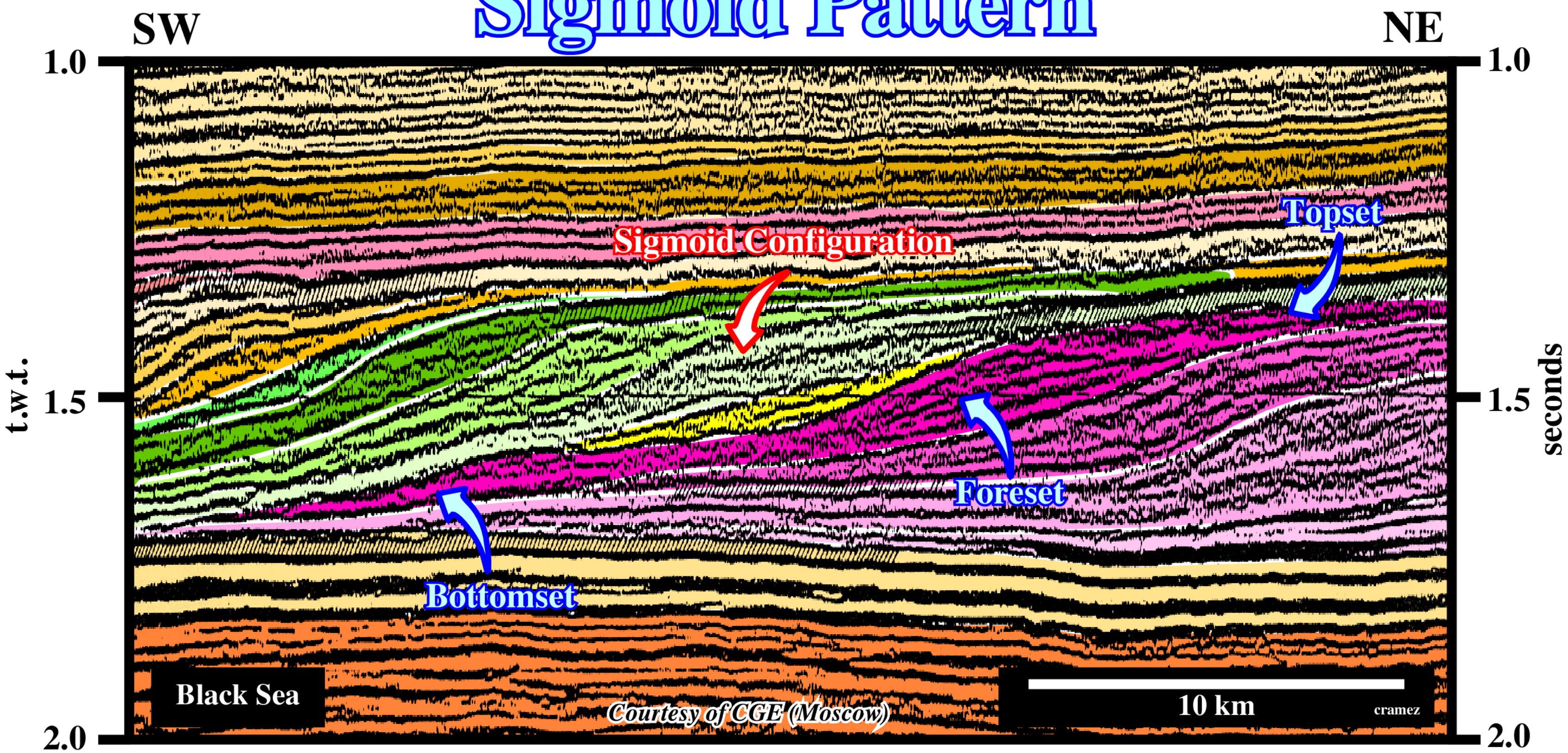
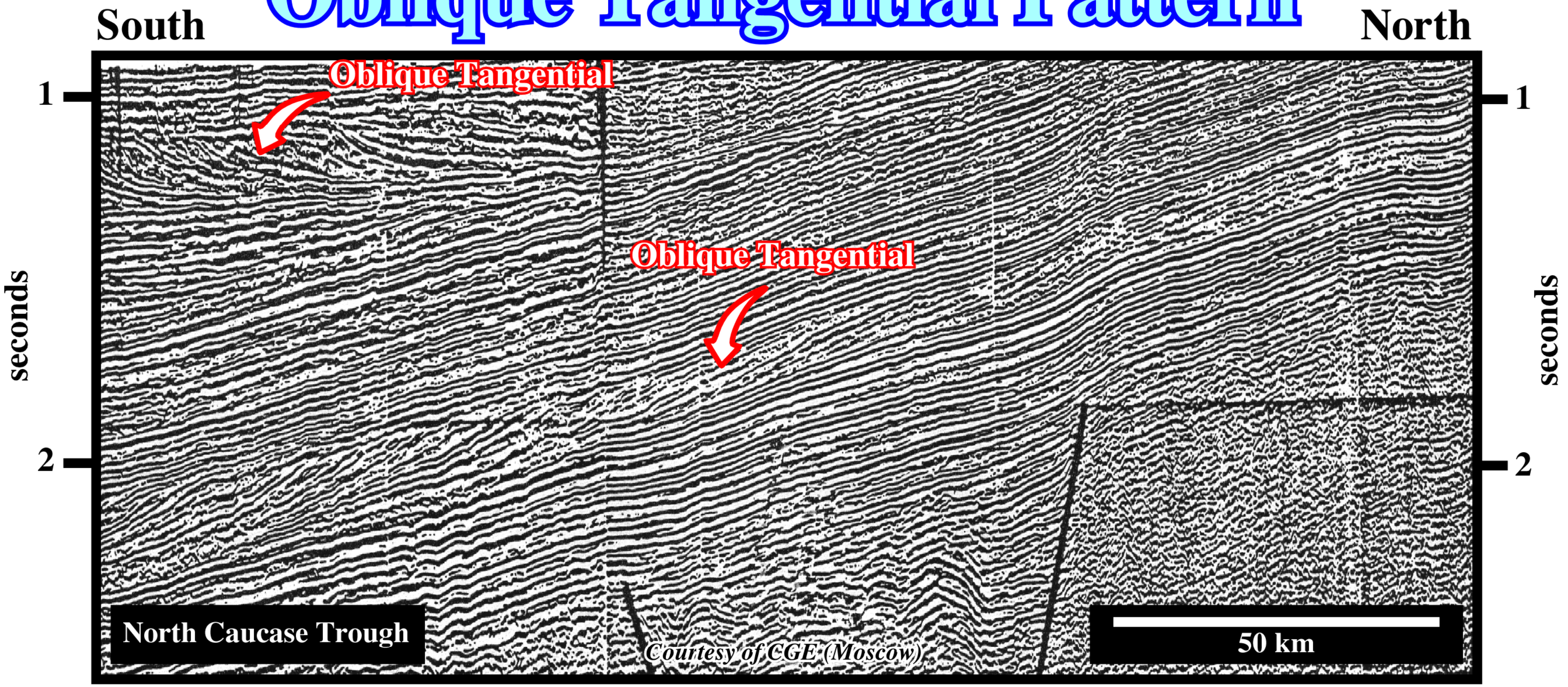


Fig. 108- As pictured on this line, in a sigmoid progradational configuration, depositional angles are quite low (usually less than 1°). On the other hand, the lower (bottomset) segments of the strata approach the lower surface of the facies unit at very low angles, and the seismic reflections show real or apparent downlap terminations as the strata terminates or become too thin to be recognized on seismic lines. This configuration implies relatively low sediment supply, and /or rapid rise in sea level to allow deposition and preservation of the topset units. A relatively low-energy sedimentary regime is interpreted. Indeed, very often bottomset segments match with potential source-rocks.

Prograding Patterns

Oblique Tangential Pattern



Courtesy of CGE (Moscow)

Fig. 109- On this line from North Caucase Trough principally oblique tangential progradation reflections are illustrated , which can be interpreted as a progradating clinoform pattern consisting ideally of a number of relatively steep-dipping strata terminating updip by toplap at or near a nearly flat upper surface of the stratigraphic unit. Successively younger foreset segments of strata build almost entirely laterally in a depositional downdip direction. They may pass laterally into thinner bottomset segments, or terminate abruptly at the lower surface at a relatively high angle. They build out from a relatively constant upper surface characterized by lack of topset strata and by pronounced toplap terminations of foreset strata. Depositional dips are characteristically higher than in the sigmoid configuration and may approach 10°.

Prograding Patterns

Oblique Parallel Pattern

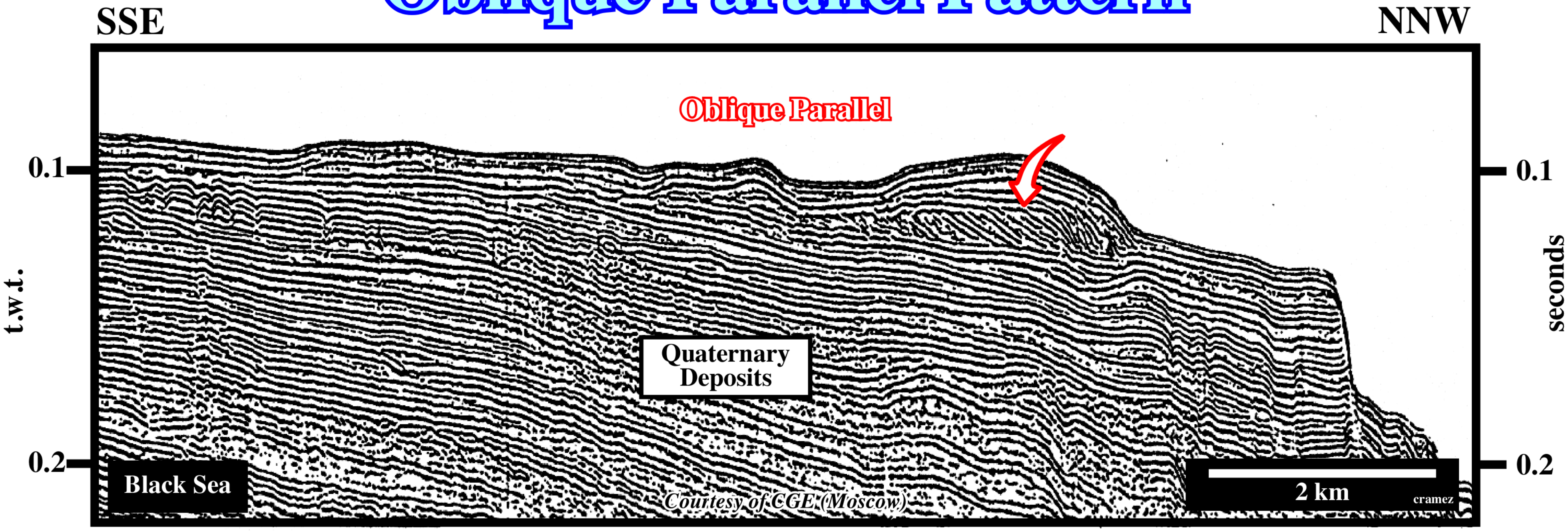


Fig. 110- In an oblique parallel progradational pattern, as illustrated above, the relatively steep-dipping parallel foreset strata terminate downdip at a high angle downlap against the lower surface. In sections parallel with depositional strike, reflections in these seismic intervals may range from parallel to low-angle oblique or sigmoid progradational, possibly with small channel-fill configuration. Notice that oblique progradational configuration implies depositional conditions with some combination of relatively high sediment supply, slow to no basin subsidence, and a stillstand of sea level to allow rapid basin infill and sedimentary bypass or scour of the upper depositional surface. A relatively high-energy sedimentary regime is indicated.

Prograding Patterns

Sigmoid - Oblique Pattern

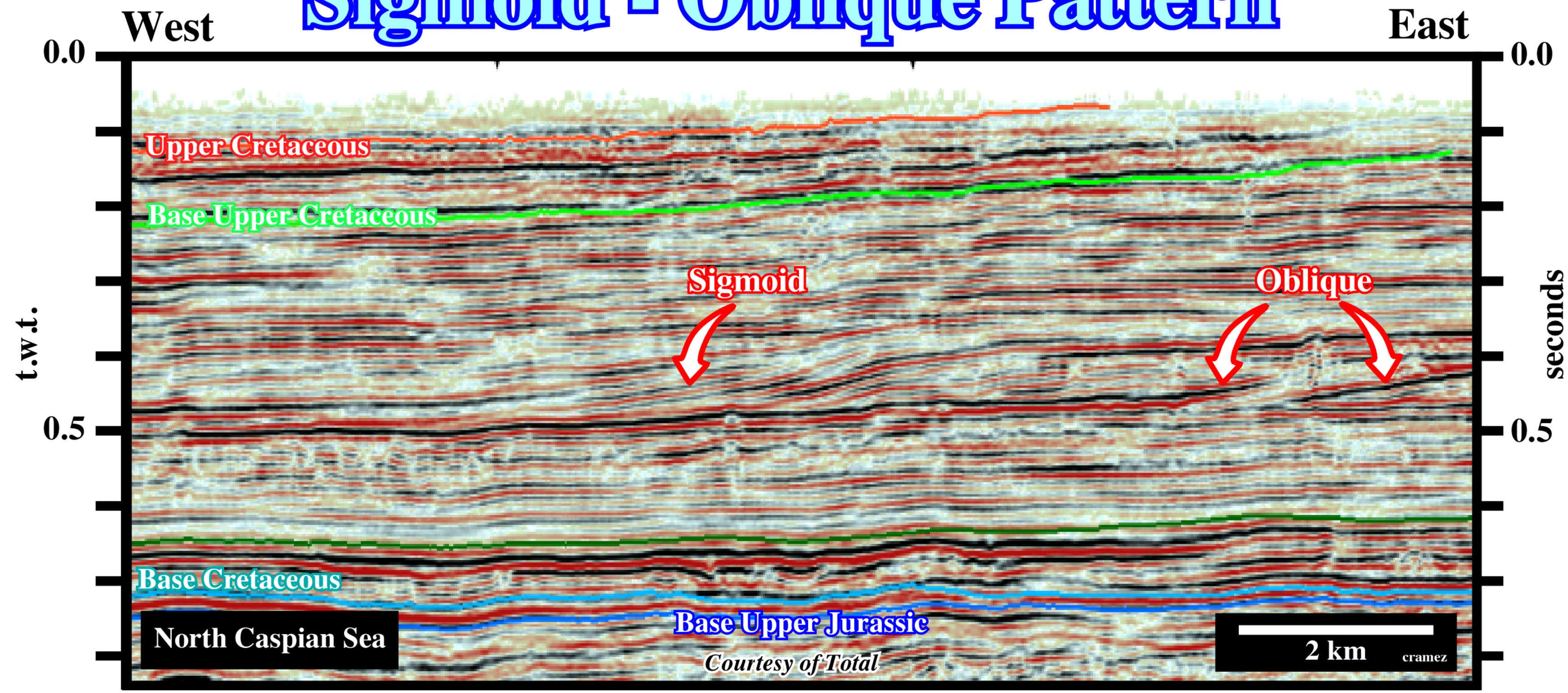


Fig. 111- Complex sigmoid-oblique progradational patterns are prograding clinoforms patterns of a combination of variably alternating sigmoid and oblique progradational reflection configurations within a single seismic interval. The upper segments (topsets) are characterized by complex alternations of horizontal sigmoid topset reflections and segments of oblique configuration with toplap terminations. This variability implies strata with a history of alternating upbuilding and depositional bypass in the topset segment, within a high-energy depositional regime. This reflection configuration illustrates short segments of toplap within a seismic sequence rather than at its upper boundary. The short segments of toplap indicate a number of smaller scale depositional intervals whose boundaries are below seismic resolution except where toplap is prominent. The smaller scale units are commonly interpreted as discrete lobes of a prograding unit.

Prograding Patterns

Shingled Pattern

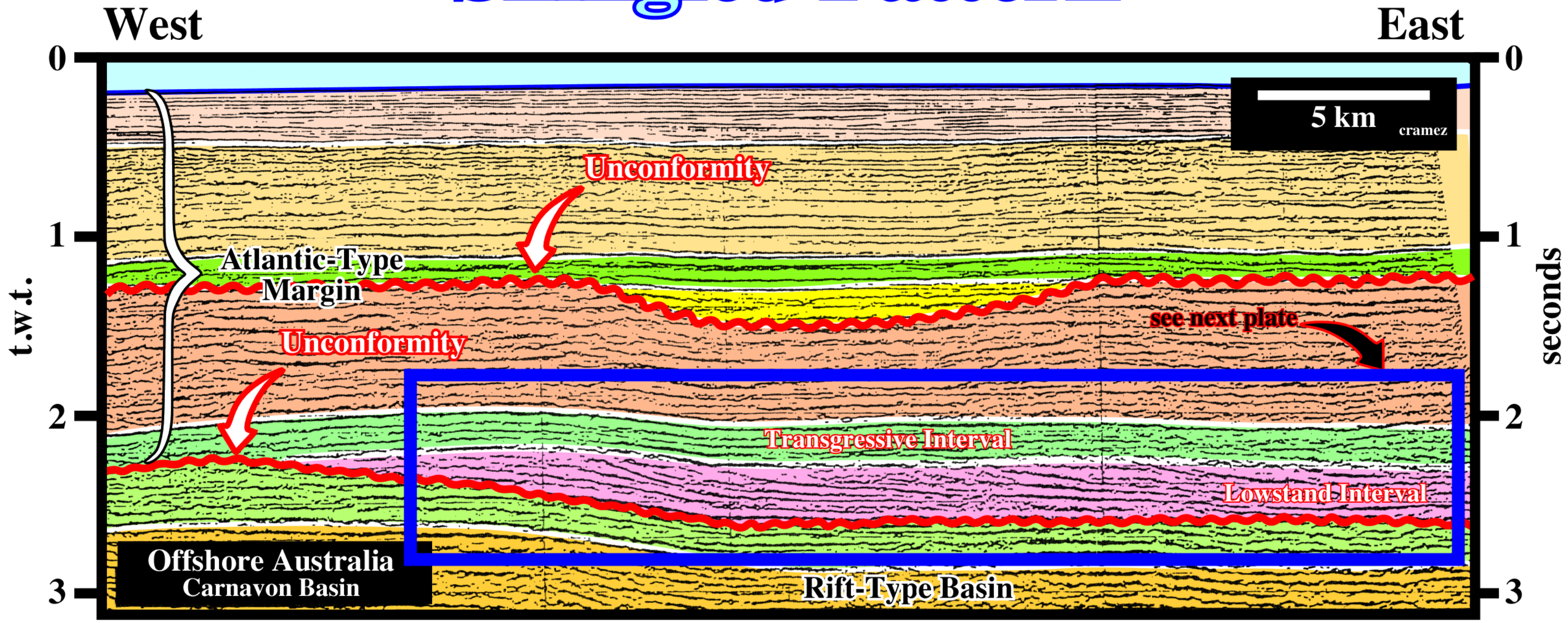


Fig. 112- A shingled progradational reflection configuration is a thin prograding seismic pattern, commonly with parallel upper and lower boundaries, and with gently dipping parallel oblique internal reflectors that terminate by apparent toplap and downlap. As illustrated on this seismic line, from Carnavon basin (offshore West Australia), successive oblique internal reflectors within the lowstand seismic interval (purple) show little overlap with each other. The overall pattern resembles that of the parallel oblique progradational configuration, except that the thickness of the interval is just at the point of seismic resolution of the oblique beds. See the facies interpretation of the lowstand interval, where shingled progradational reflections are present, on the next figure.

Prograding Patterns

Shingled Pattern

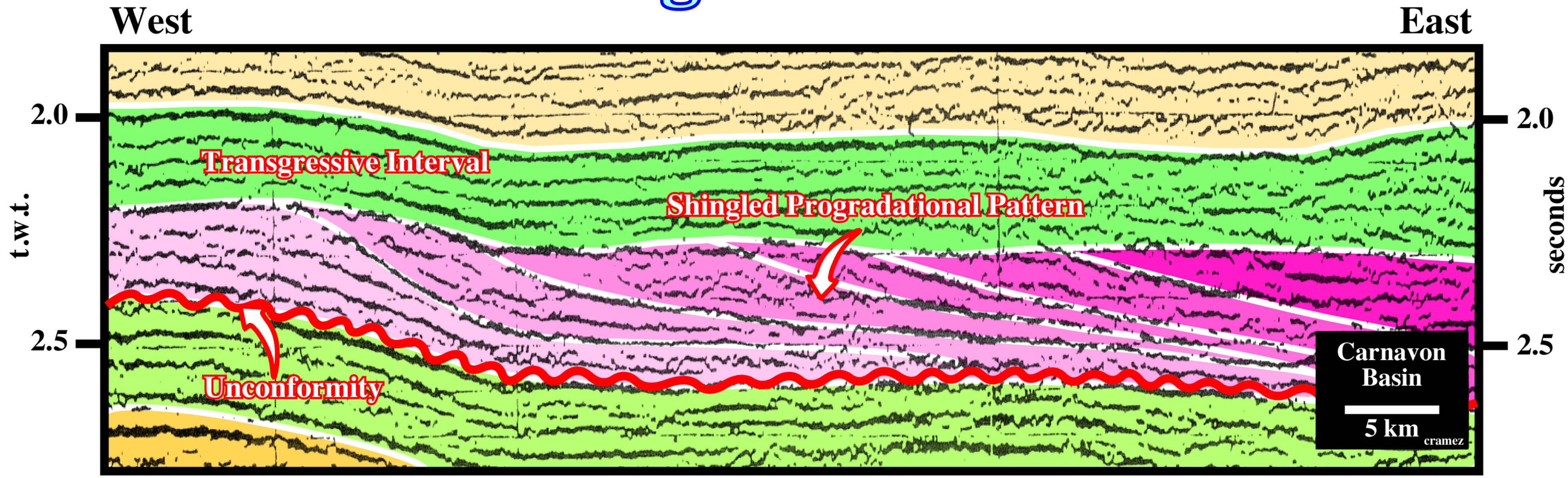


Fig. 113- Shingled seismic configurations are most common in seismic intervals interpreted as shallow water or deep water prograding depositional systems. This line, which is a detail of the seismic line illustrated on fig. 112, illustrates the shingled progradational reflection pattern associated with proximal turbidites. In fact, this interval was drilled and sandstone turbidite lobes, with shingled progradational patterns, were found. On electric logs such turbidite reservoirs have a characteristic cylindric signature, that is to say, the upper and lower limits are quite sharp. In additional, a stacking of several shingled turbidite lobes is often found in a single well.

Prograding Patterns

Hummocky Clinoforms

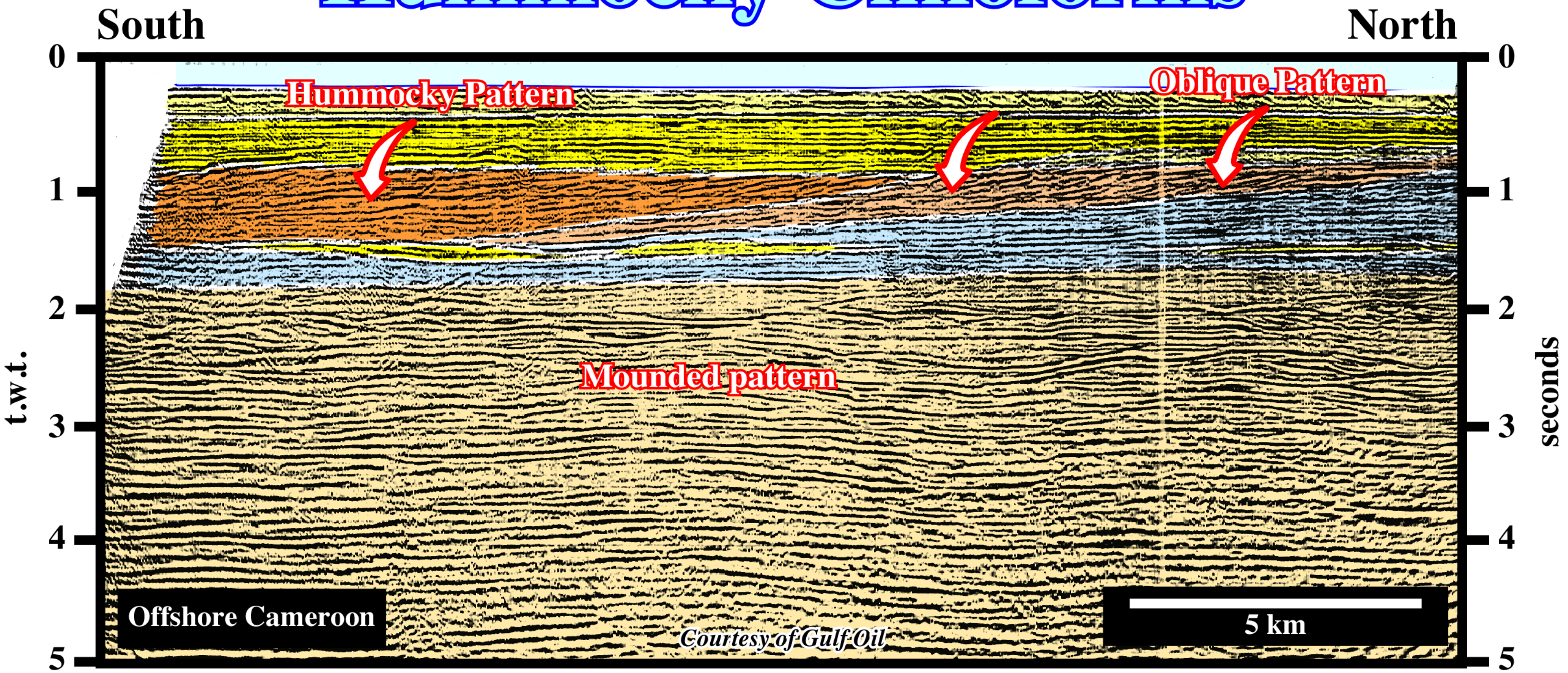
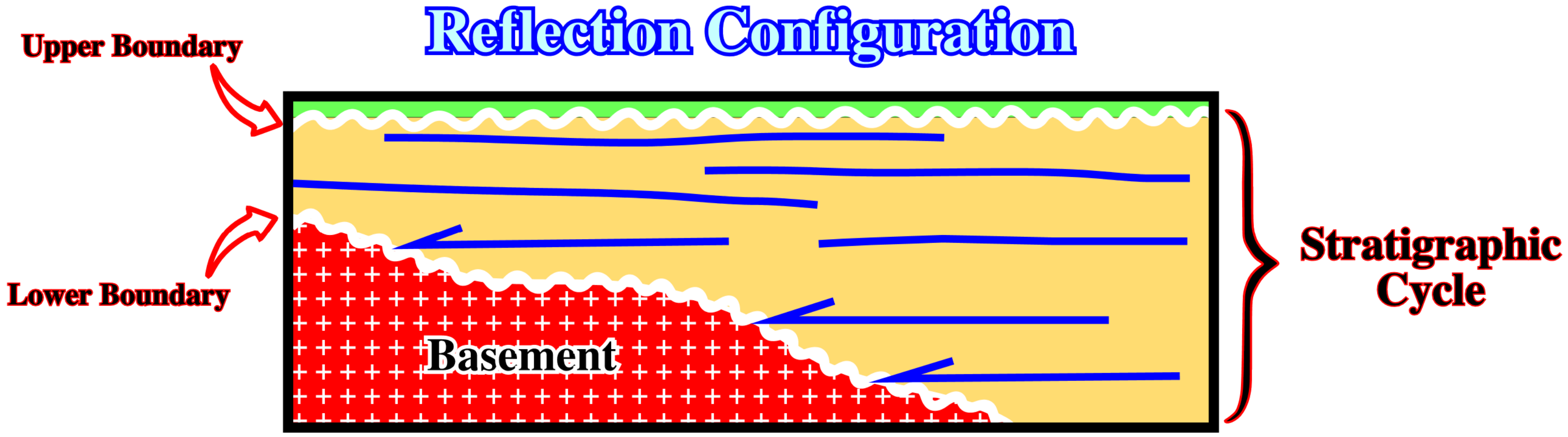


Fig. 114- A hummocky clinoform reflection configuration consists of irregular discontinuous subparallel reflection segments forming a practically random hummocky pattern marked by nonsystematic reflection terminations and splits. Relief on hummocks are low as the limits of seismic resolution are approached. As illustrated above, this pattern commonly grades laterally into larger, better defined clinoform patterns, and upward into parallel reflections. Reflection pattern is generally interpreted as strata forming small, interfering clinoform lobes building into relatively shallow water in a prodelta or interdeltaic position.

Significance
of
Geometric Configurations

The morphology of the boundaries of stratigraphic cycles can be used to interpret environments. Facies (lithology) predictions requires a wider geological and geophysical understanding, as we will see in the next volume. However, as all geologists know the lithology encountered in onlapping and progradational seismic intervals varies according to water depth, balance between rate of sedimentary supply and rate of relative rise of sea level. Which in turn are controlled by both subsidence and global eustatic variation. A few typical possibilities will be review.

Concordant Sand-Shale Interval



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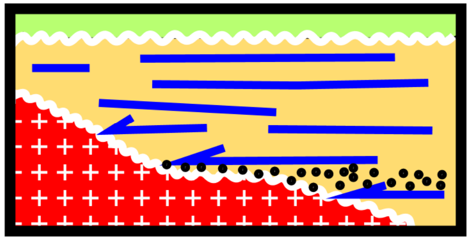
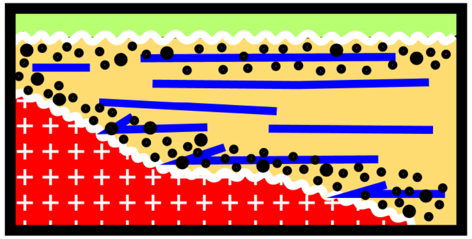
Concordant Sand-Shale Interval



Deep Shales

Deep Sea Sands



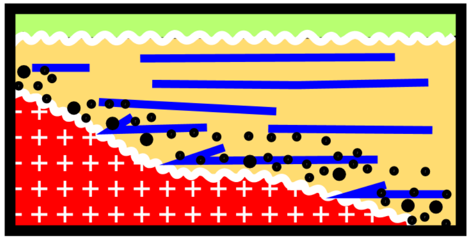
Littoral Sands

Marine Shales

Littoral Sands

R

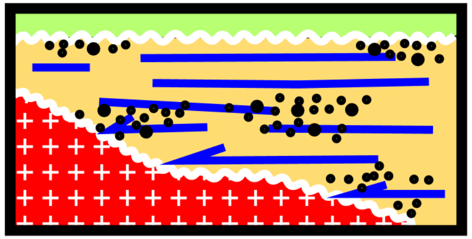
T



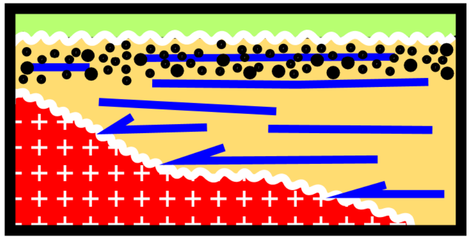
Marine Shales

Littoral Sands

Transgression



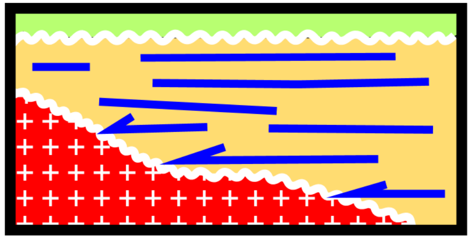
Continental Sands
(Alluvial Plain)



Littoral Sands

Marine Shales

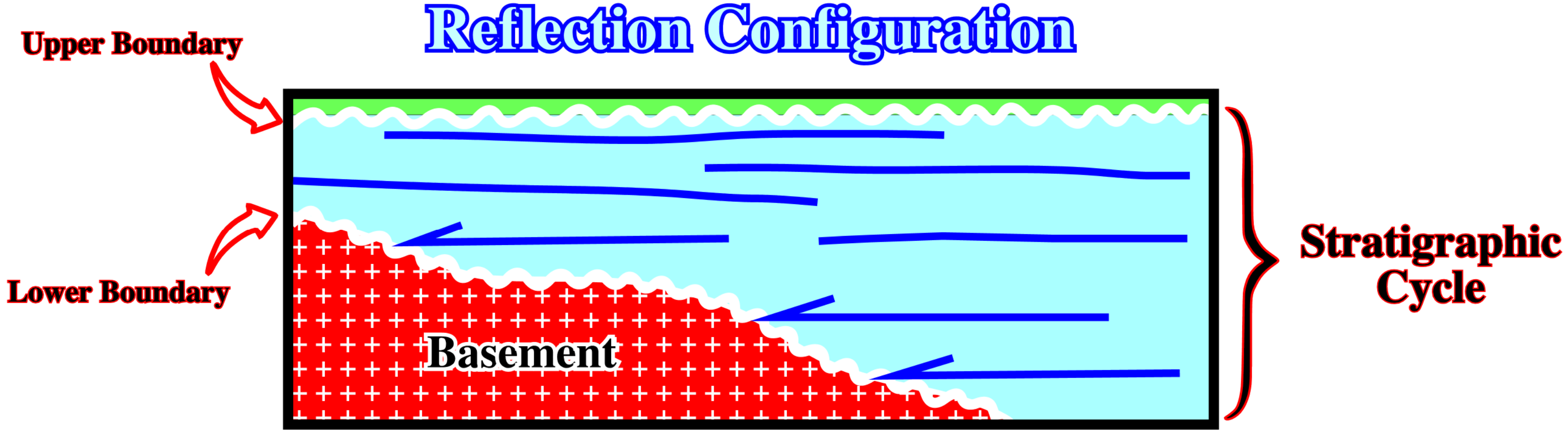
Regression



Marine Shales

Onlapping Carbonate Interval

Reflection Configuration



Upper Boundary

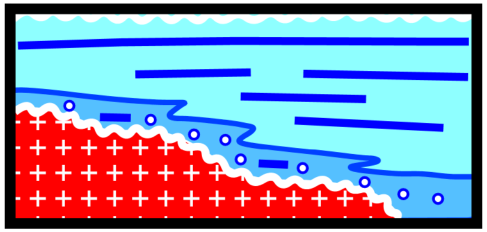
Lower Boundary

C- On

P

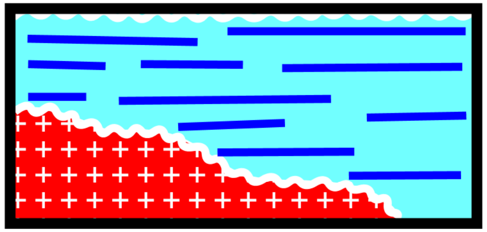
Internal Configuration

Onlapping Carbonate Interval

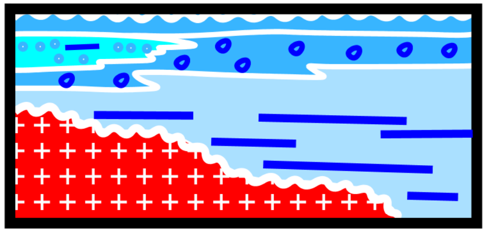


Micrite Limestone

**Oolithic Limestone
Bioclastic**

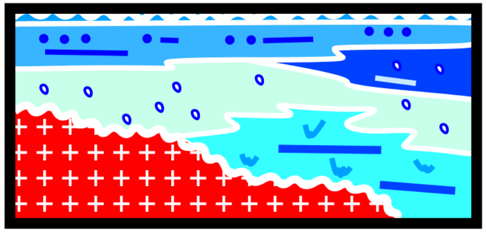


**Deep Micrite
Limestone
Shale Prone**



**Oolithic Limestone
Bioclastic**

Micrite Limestone



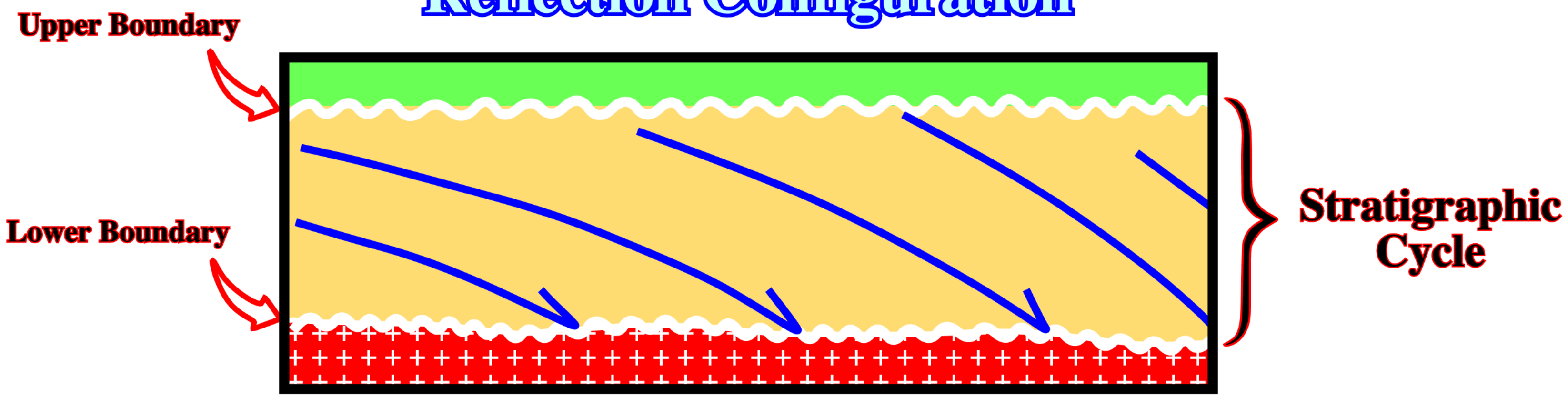
Laminated Algal Limestone

Bioclastic Limestone

Micrite Algal Limestone

Prograding Sand-Shale Interval

Reflection Configuration



Upper Boundary

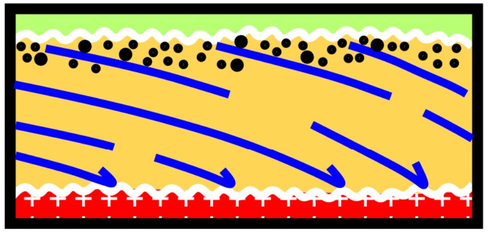
Lower Boundary

Top - Dow

Sig / Obl

Internal Configuration

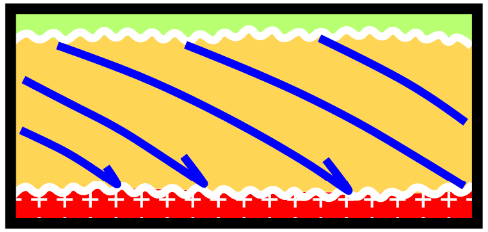
Prograding Sand-Shale Interval



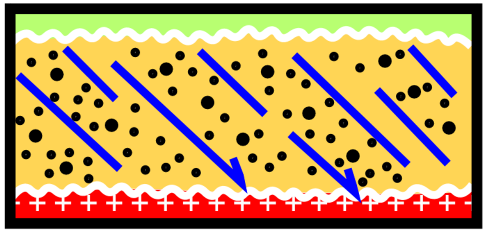
Littoral Sands

Marine Shales (slope)

Regression

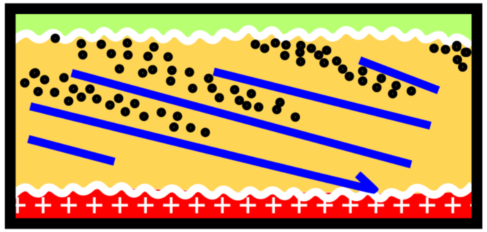


Marine Shales (slope)



Continental Sands
Alluvial Fan

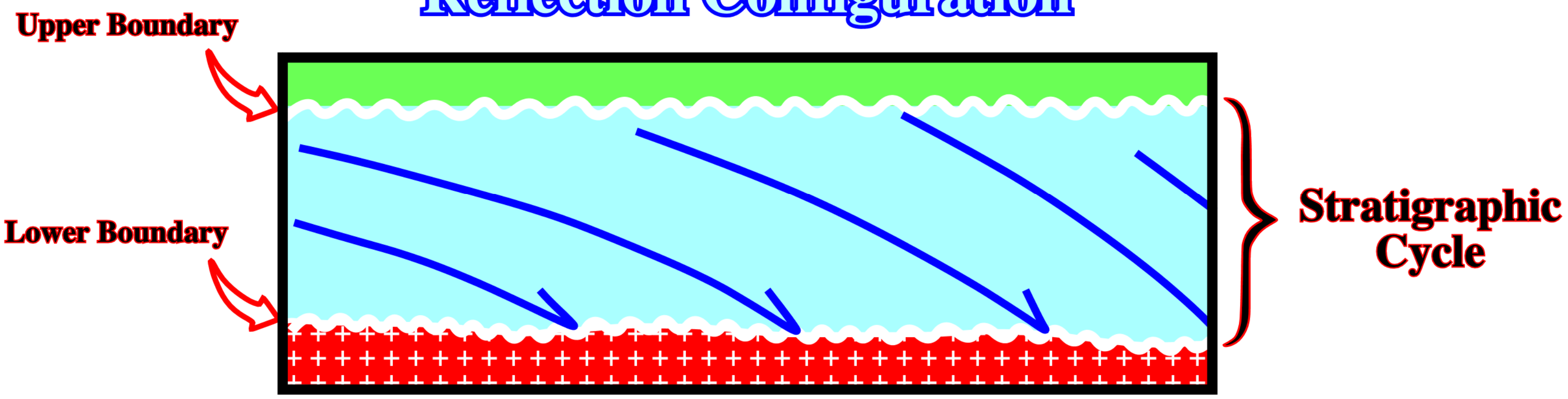
Regression



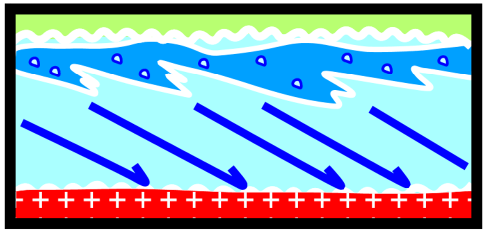
Offshore Bars

Prograding Limestone Interval

Reflection Configuration



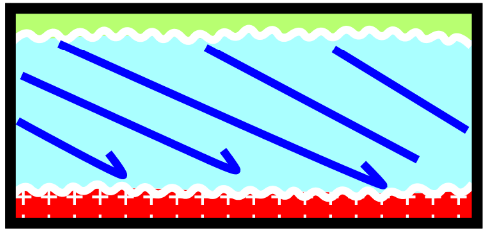
Prograding Sand-Shale Interval



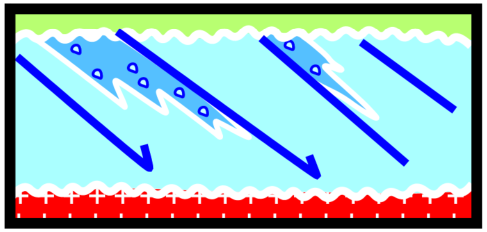
Bioclastic Limestone

Micrite Limestone

Regression



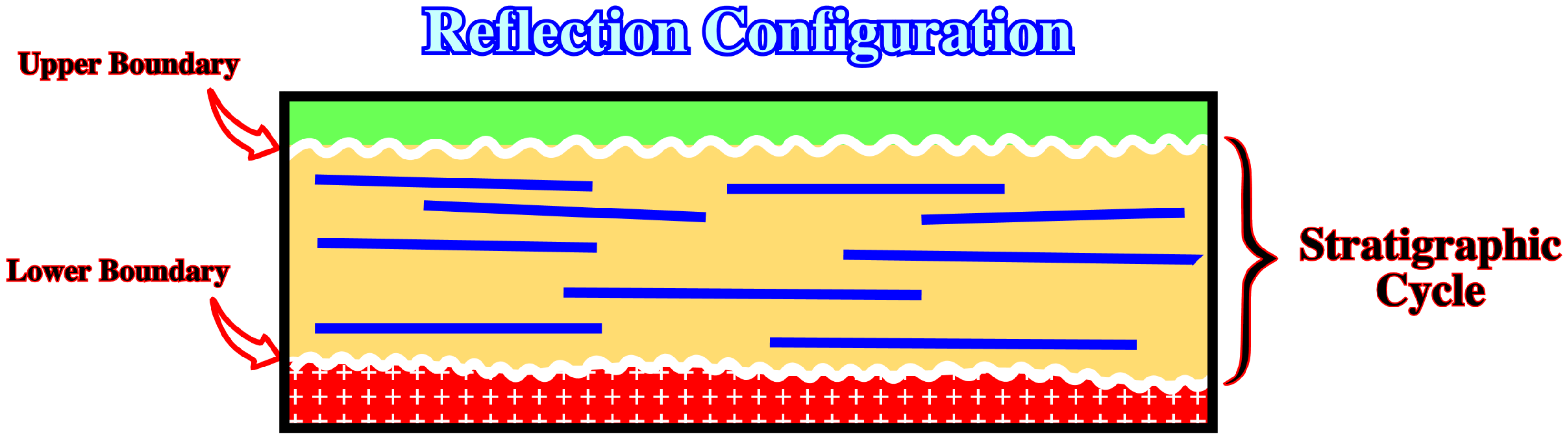
Deep Micrite Limestone

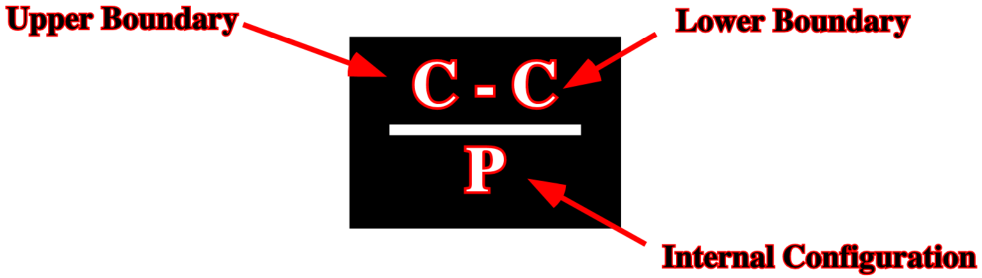


Micrite Limestone

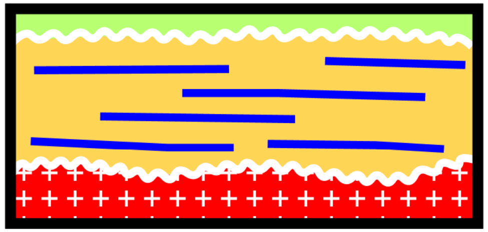
Bioclastic Limestone

Concordant Sand-Shale Interval

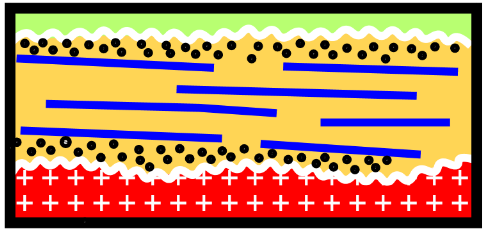




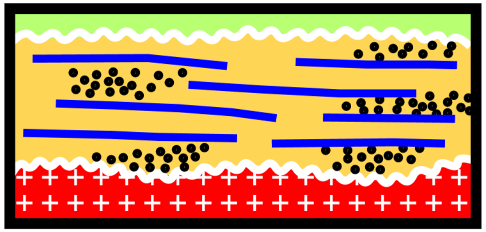
Concordant Sand-Shale Interval



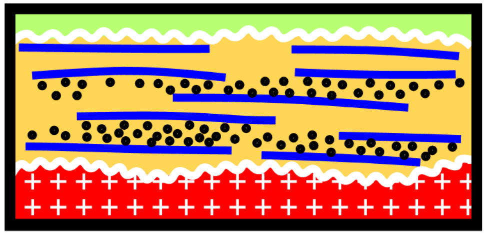
Marine Shales



Littoral Sands
Offshore Bars
Beaches



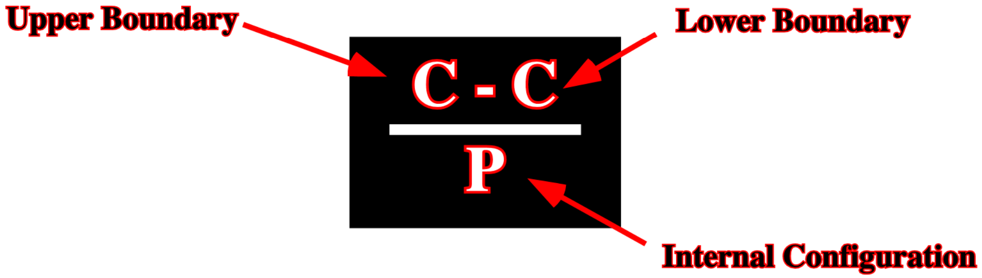
Continental Sands
Point Bars
Alluvial Fan



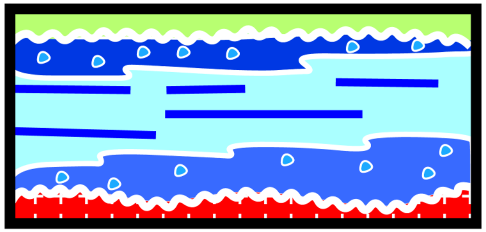
Marine sands
Turbidite fans

Concordant Carbonate Interval

Reflection Configuration

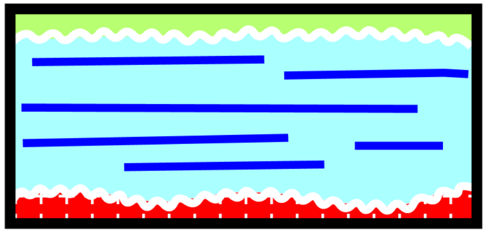


Concordant Carbonate Interval

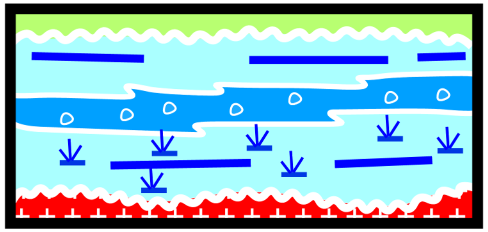


Oolithic Limestone
Micritic Limestone
Oolithic Limestone

R
T

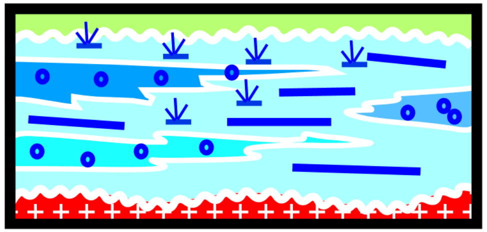


Deep Micritic Limestone



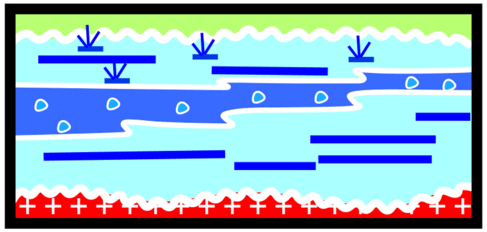
Micritic Limestone
Oolithic Limestone
Laminated Algal Limestone

Transgression



Shallow Water

Oolithic Limestone
Laminated Algal Limestone
Oolithic Limestone



Laminated Algal Limestone
Oolithic Limestone
Micritic Limestone

Regression

Diachronous Surfaces

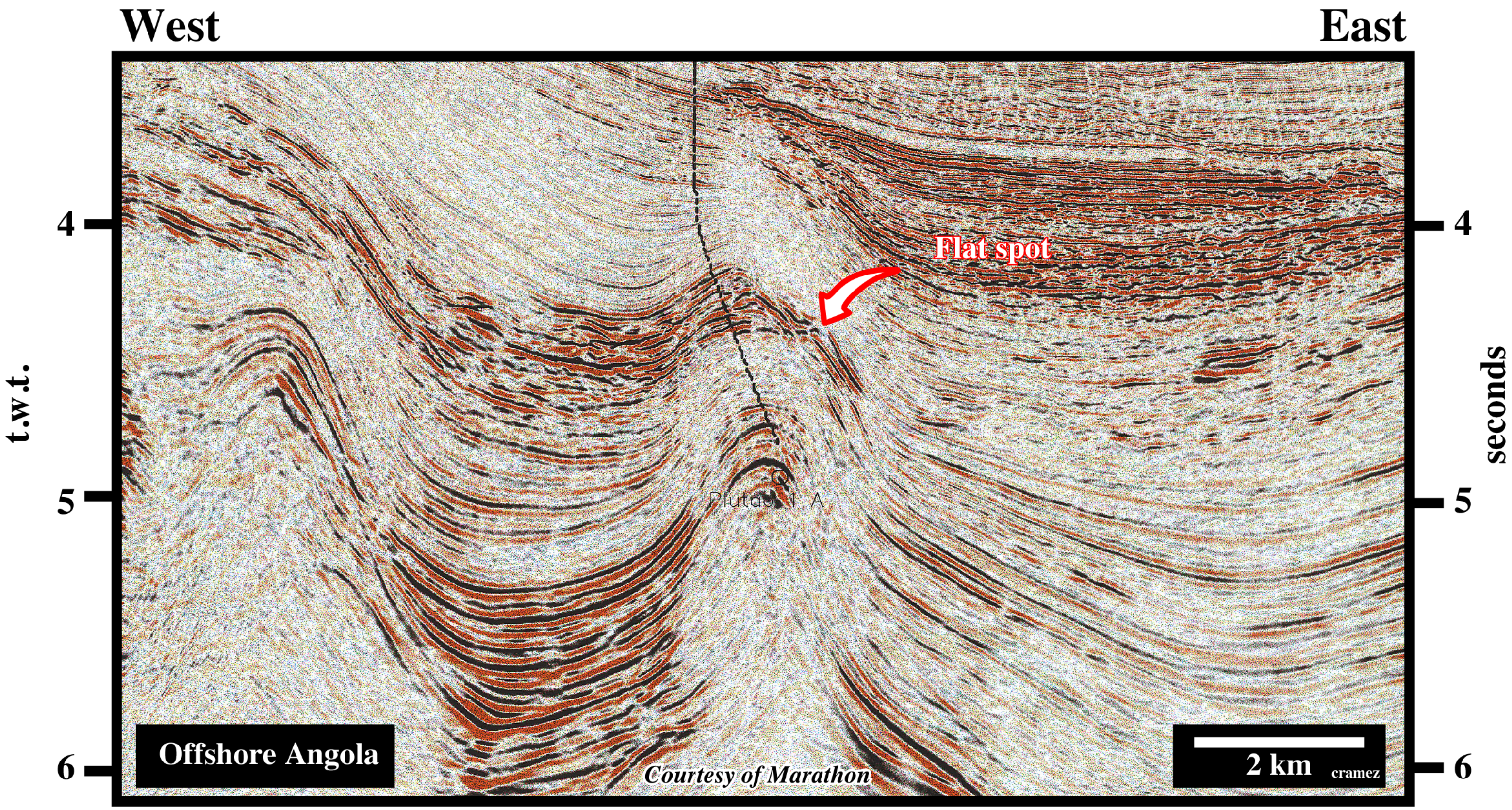
Diachronous surfaces are continuous boundaries crossing strata or seismic reflectors.

Diachronous surface examples are:

- **Fluid Contacts**
- **Permafrost**
- **Gas Hydrate Layer**
- **Low Angle Fault Trace**
- **Low Angle Igneous Dike**
- **Deep Desert Weathering Surface**
- **Karstic Solution Base Level**

Diachronous Surfaces

Fluid Contacts



Courtesy of Marathon

Fig. 115- On this seismic line from the northern deep-water Angola, a diachronic reflection is easily recognized at around 4.3 seconds. This anomalous reflection was interpreted as a flat spot, that is to say, as the reflection induced by the interface hydrocarbonous /water. The well (Plutão) was mainly based on such interpretation. Successfully, such a hypothesis was corroborated by drilling, which put in evidence a significant (may be economical) oil column. Take note that in spite of the oil discovery, in epistemological terms, explorationists did not increase their knowledge since the advanced hypothesis was not refuted.

Diachronous Surfaces

Permafrost

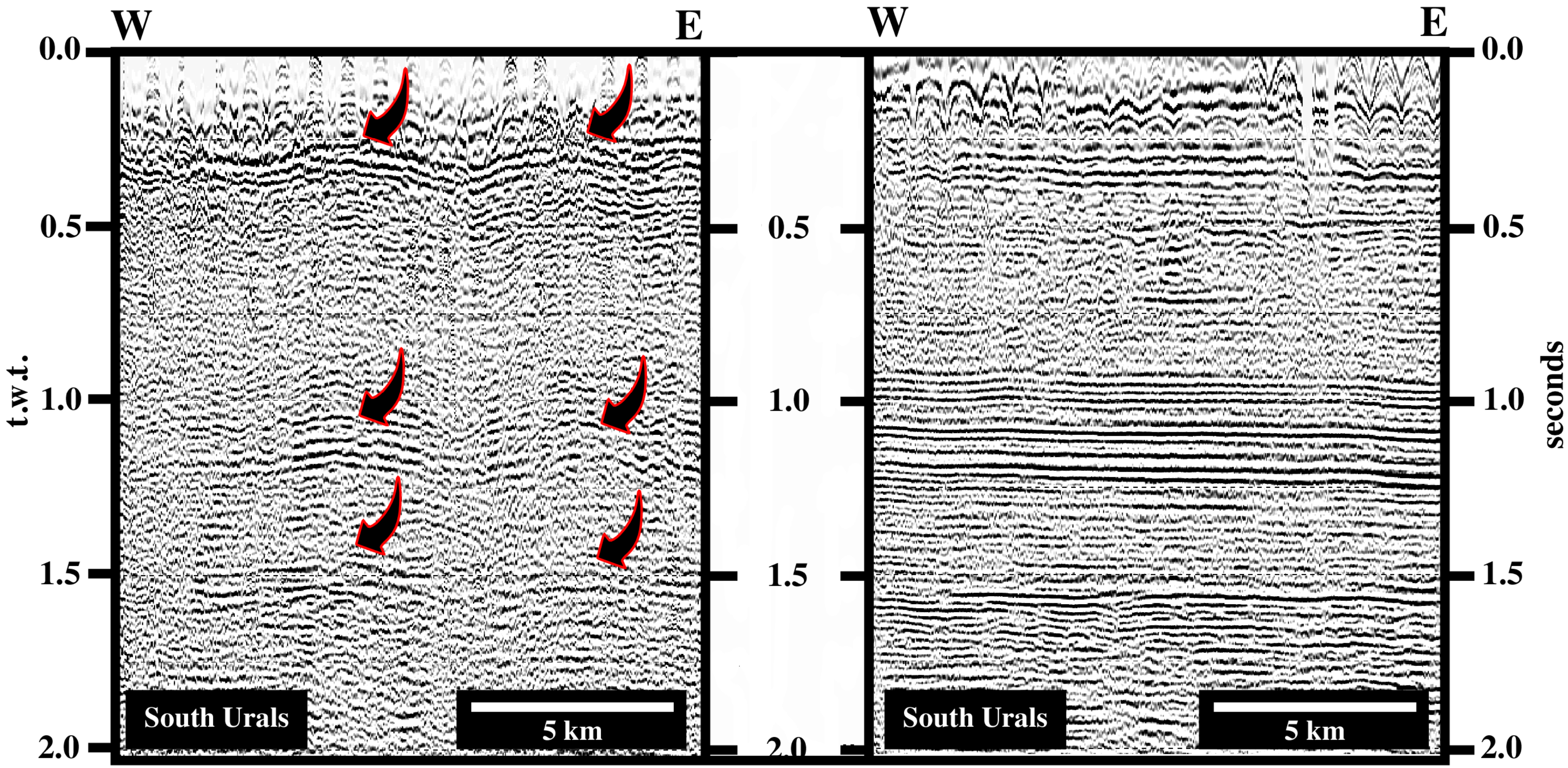


Fig. 116- Comparing both seismic lines it is easy to understand that permafrost induced diachronous surfaces (see also volume I). Indeed, on the left (permafrost effect not corrected), the reflectors do not correspond to chronostratigraphic lines. They correspond to seismic pitfalls. On the right line, on contrary, the reflectors correspond to real chronostratigraphic lines since the permafrost (ice ground) effect was corrected.

Diachronous Surfaces

Gas Hydrate Layer

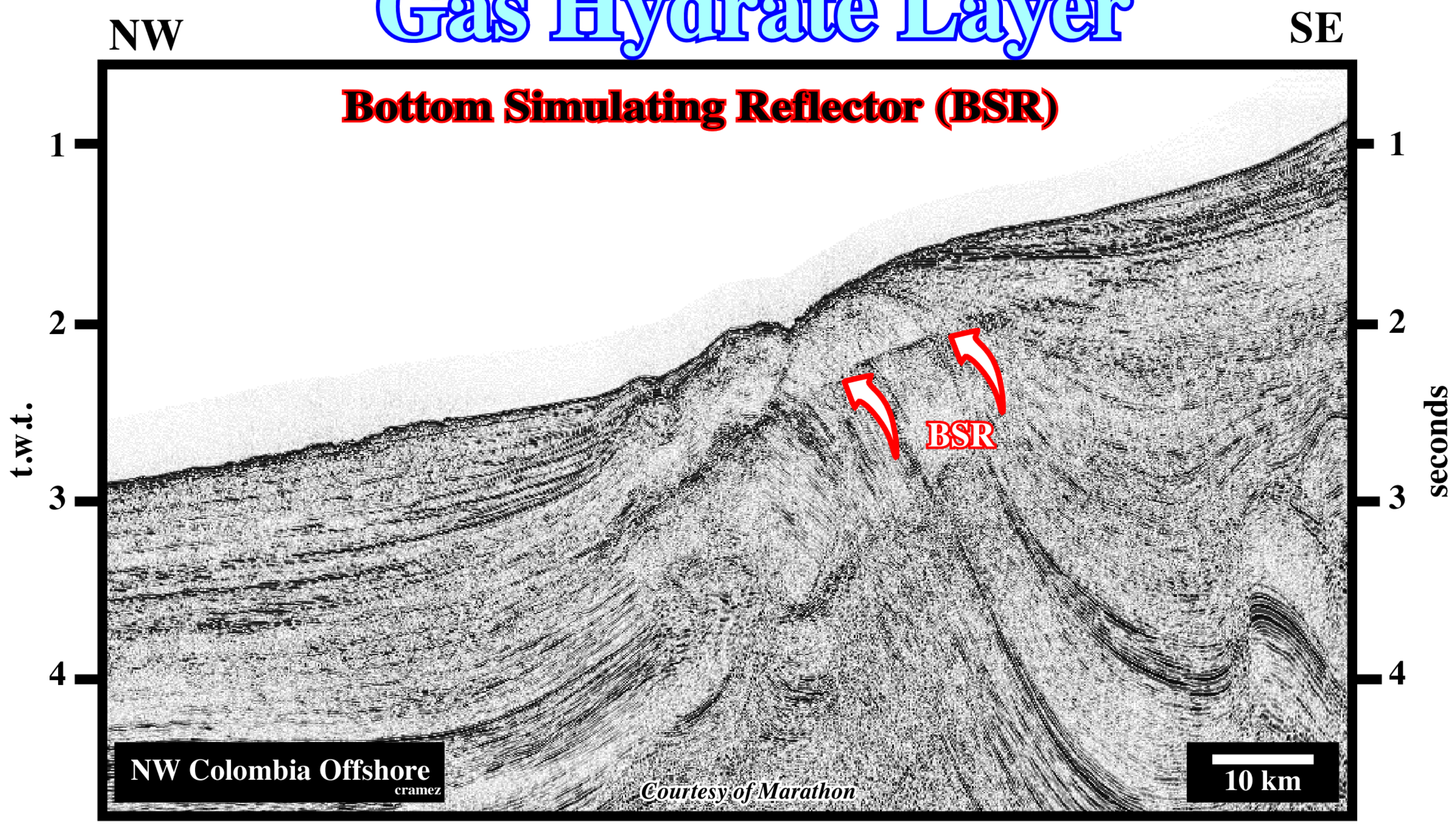
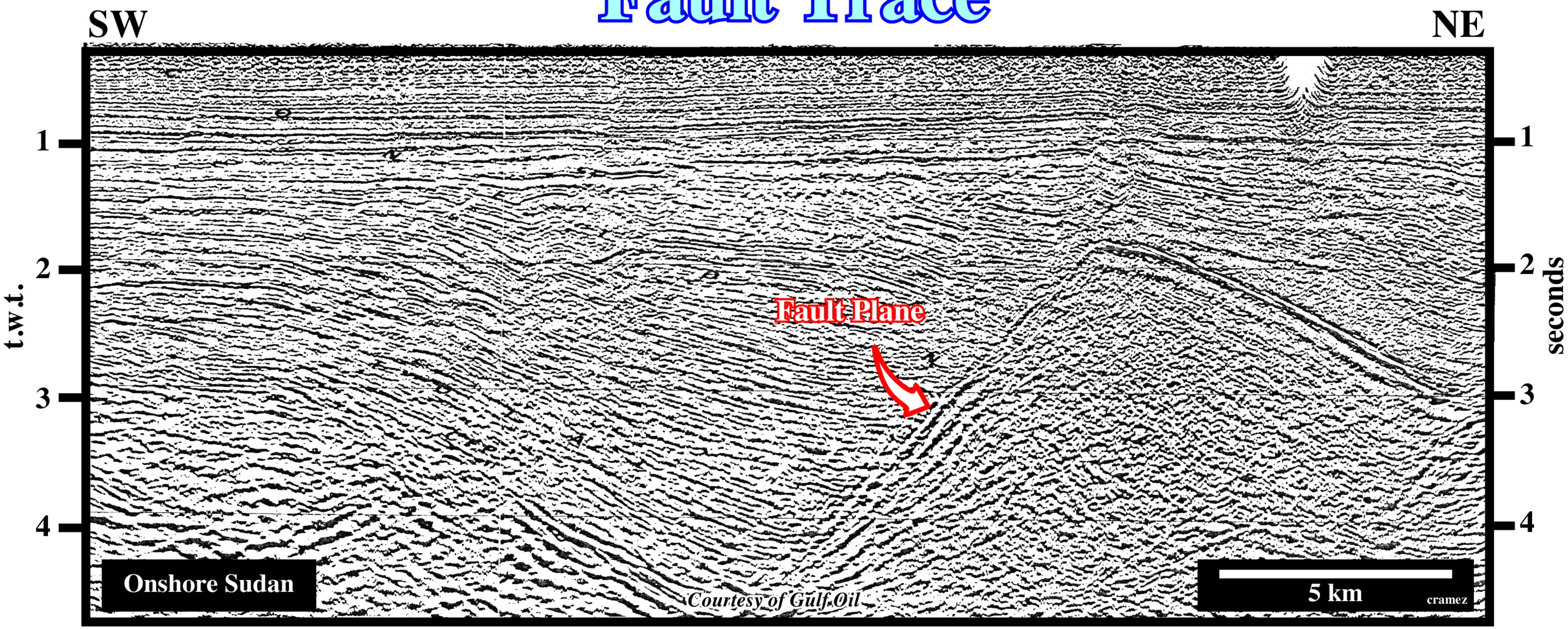


Fig. 117- On this line from offshore Colombia a diachronous seismic reflector is easily recognized roughly 0.5 seconds below sea floor. The bottom simulating reflector (BSR) seismic reflector is caused mainly by gas bubbles at the base of the stability zone, which accordingly cannot act as a seal because the porosity is more than 95% filled by water. Das hydrate stability zone (GHSZ) occurs in oceanic sediments over the first few hundred meters below the seabed. In this zone, any methane from organic material, including any seepages from below, is converted into solid hydrate, and is locked in place in the sediments. The origin of methane is poorly understood, with even its biogenic origin is being challanged.

Diachronous Surfaces

Fault Trace



Courtesy of Gulf Oil

Fig. 118- Generally, fault planes do not have seismic reflectors associated. However, there are three main exceptions that all seismic interpreters know: (i) when the fault put in juxtaposition sediments and basements, (ii) when the fault plane is filled by salt and (iii) when the fault plane is injected by volcanic material. In this example, the diachronous reflector is associated with a fault plane, which puts in juxtaposition rift-type basin sediments and a Precambrian basin (granite-gneiss). This seismic line, from the onshore Sudan, depicts the northeastern flank of the Unity giant oil field. The discovery well was located on the left end part of the line.

Diachronous Surfaces

Low Angle Fault Trace

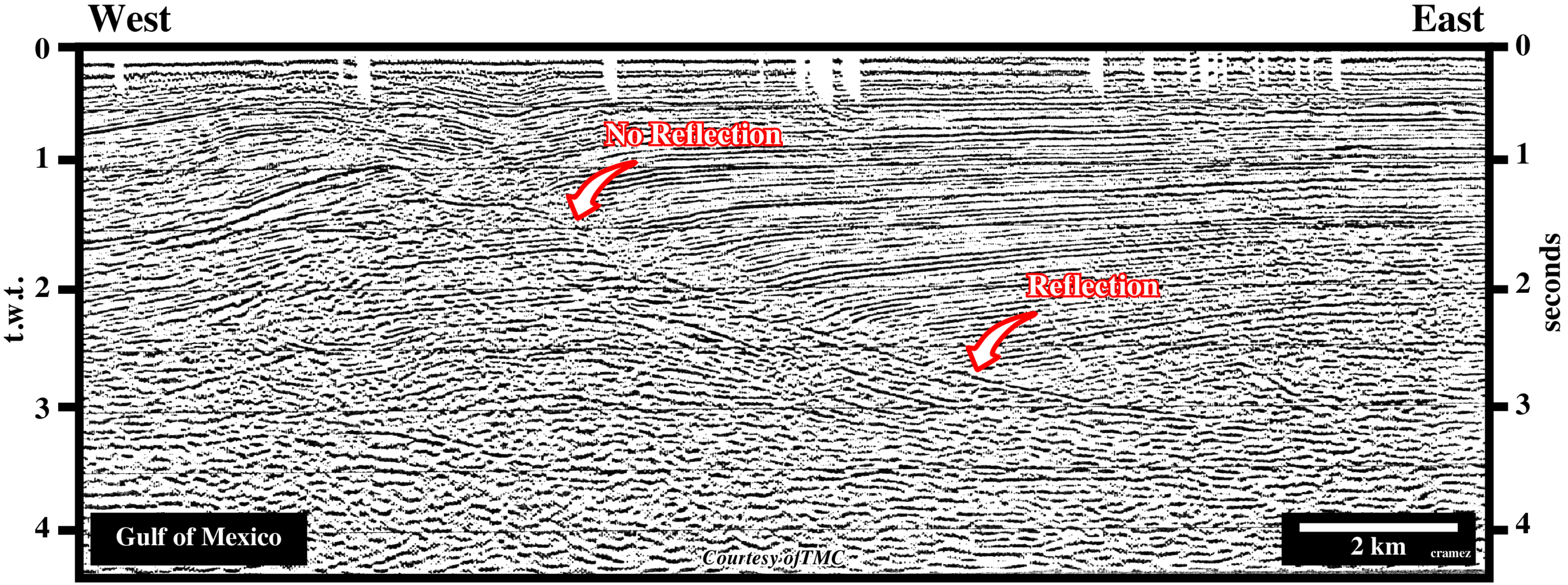


Fig. 119- On this seismic line from the Gulf of Mexico, a listric growth fault, that is to say, a fault contemporaneous with the sedimentation flattens in depth and clearly shows that a diachronous seismic reflection is created in the lower segment of the fault plane, where it has a high hade (low angle), while in the upper segment with a low hade (higher angle) there is no associated reflection. The interpretation of such a feature is directly associated with the seismic reflection method as saw previously (volume I).

Diachronous Surfaces

Low Angle Igneous Dike

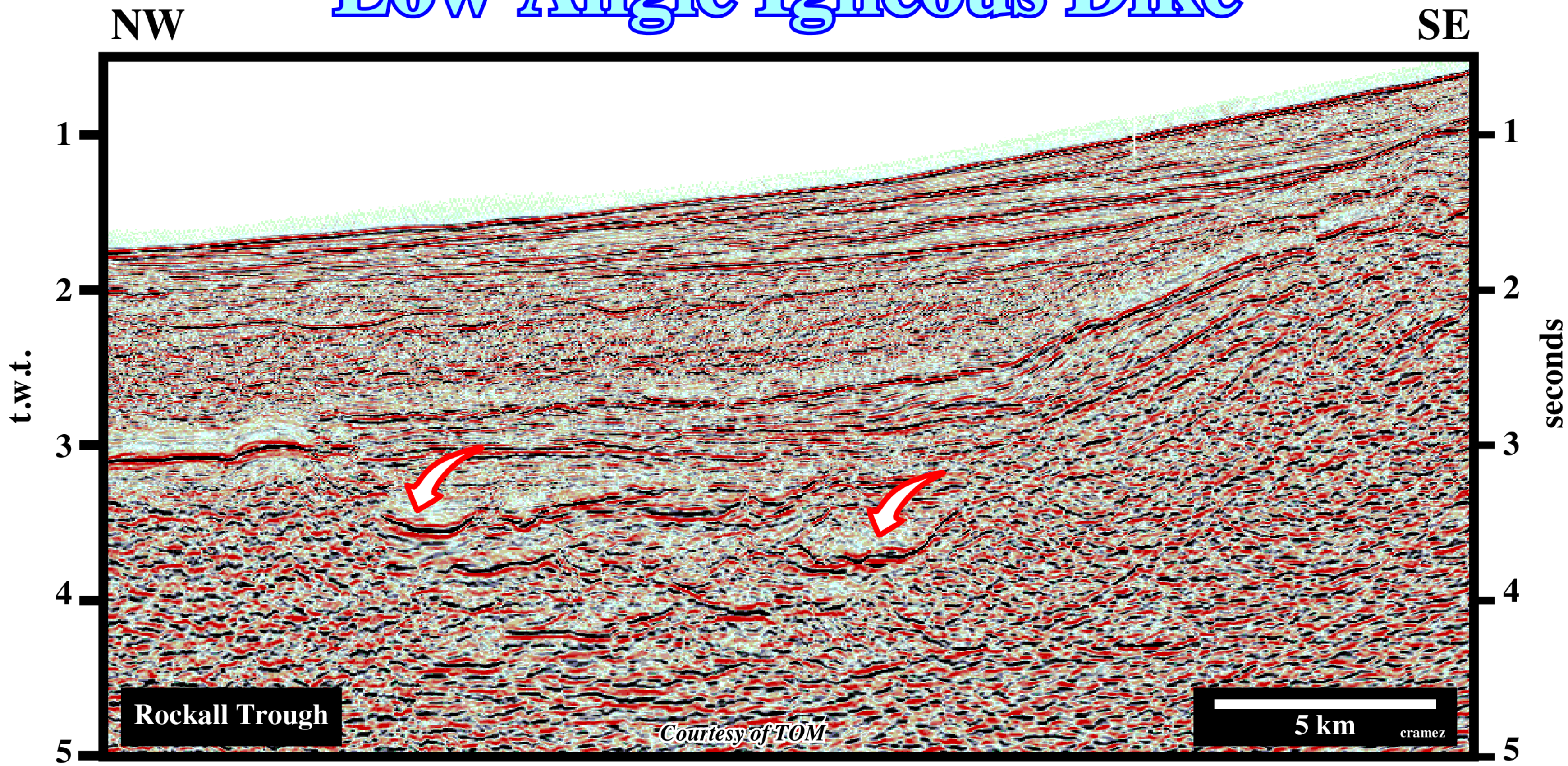
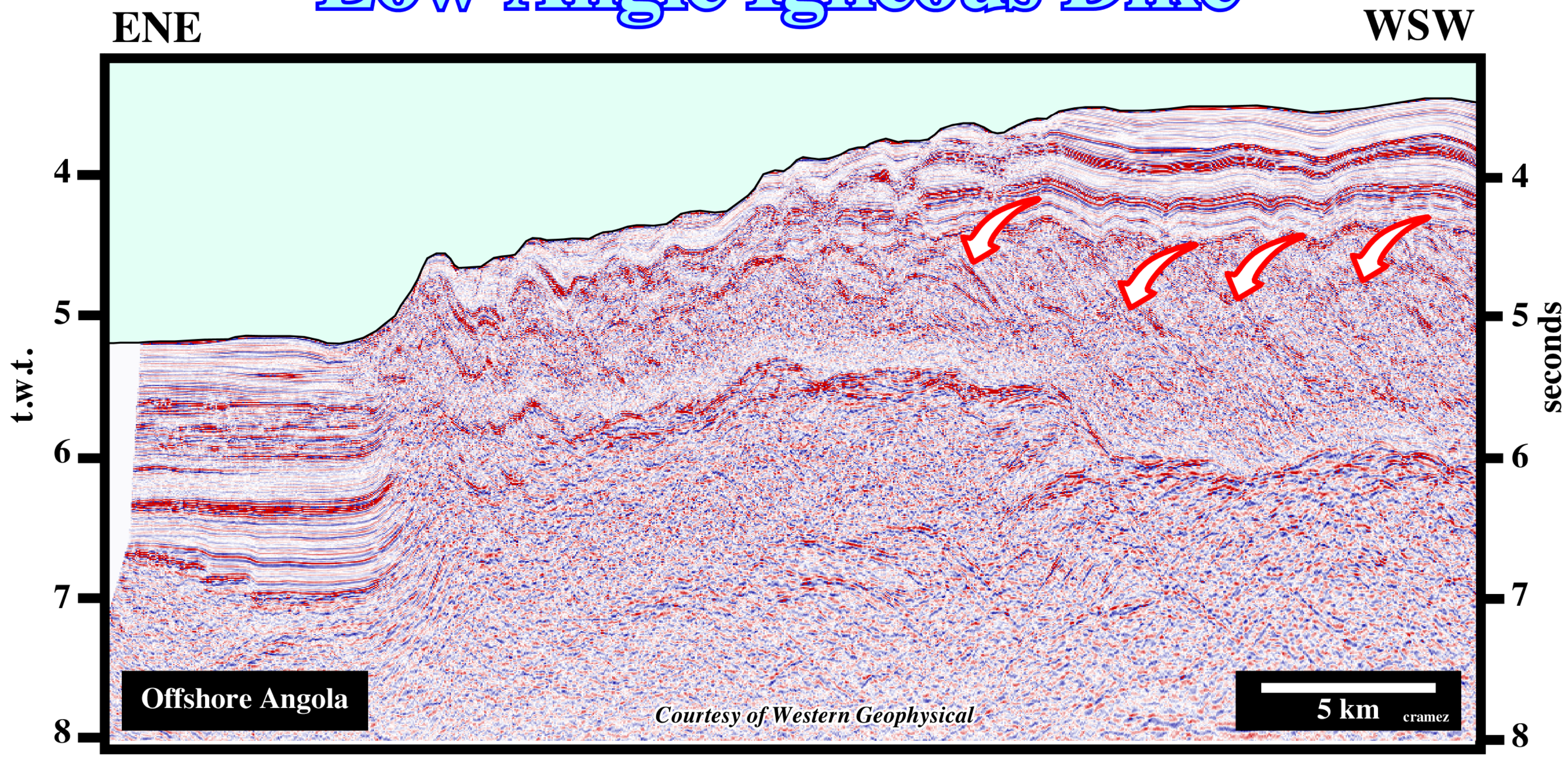


Fig. 120- Igneous dykes are quit frequent in the North Atlantic, particularly in the Rockall Trough. Indeed, on this seismic line, they can easily be recognizeed, not only by their anomalous amplitude but by their diachronous geometry.

Diachronous Surfaces

Low Angle Igneous Dike



Courtesy of Western Geophysical

Fig. 121- In the deep-water Angola, it is well known that the salt layer was thickened by thrusting, that is to say, by the lateral stacking of successive gravity induced thrust faults, which give an apparent outbuilding of the salt layer. Diachronous landward high dipping reflections, as depicted on the right part of this line, have been associated with the fault planes. However, recent exploration wells showed that such fault planes are filled by volcanic material, which seems to be scraped from the volcanic floor over which displacement took place.

Diachronous Surfaces

Deep Desert Weathering Surface

Fig. 122-

Diachronous Surfaces

Karstic Solution Base Level

Fig. 123- A