U38-0837: Post-Rift Deformation of Passive Margins

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ABSTRACT

A variety of post-rift deformations occur across basins on the passive margins of the Atlantic and Indian Oceans. These deformations are most pronounced in deep water settings, but are also observed in shallow water and onshore. The resulting structures range in scale from local uplift and inversion to regional exhumation.

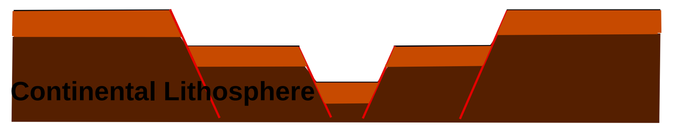
Small scale compression is observed on the margins of the North Atlantic Ocean, and on the Australian Northwest Shelf of the Indian Ocean. The effects include small scale doming and minor inversion of normal faults. These features occur near fracture zones and transform faults. The reorganization of sea floor spreading appears to be coeval with the development of these compressional features. Although ocean plates appear to behave as first-order, large-scale rigid plates, these observations suggest that fracture zones and transform faults subdivide ocean plates. The smaller plates deform in response appropriate ridge-push stresses.

In the Equatorial Atlantic long transform faults offset the ocean crust, and appear to be intermittently active into the Holocene. Strike-slip deformation is inferred from positive and negative flower structures found on both the African and South American margins. Movement on the transform faults appears to result from minor changes in sea-floor spreading along the mid-ocean ridge.

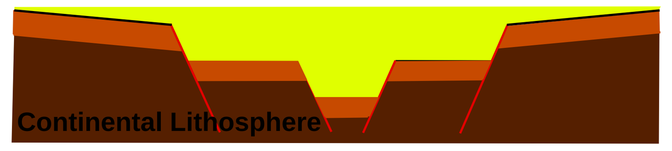
On a larger scale, Neogene regional doming is observed in Scandinavia and North America. These features do not appear related to changes in sea floor spreading. A wedge of sediments shed from these domes is found in the adjoining ocean basins. The base of these sediments appears to precede the onset of glaciation. Mantle flow is inferred to be downward beneath the older portions of the ocean basins, and/or upward beneath adjoining continental domes.

These observations suggest that mantle upwelling processes continue to effect passive margins long after continental rifting and the onset of sea-floor spreading. It is well known that the rate of upwelling varies after rifting, as seen in ocean floor ages. The lateral flow of mantle away from the mid-ocean ridges is inferred to also vary, resulting in deformation seen on both oceanic and continental crust.

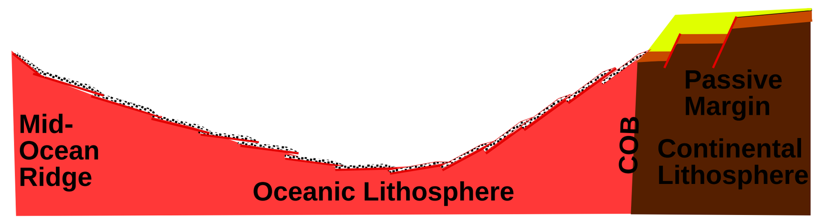
1. SIMPLE MODEL OF RIFT MARGIN DEVELOPMENT



1. Passive margins form by extension of continental lithosphere.

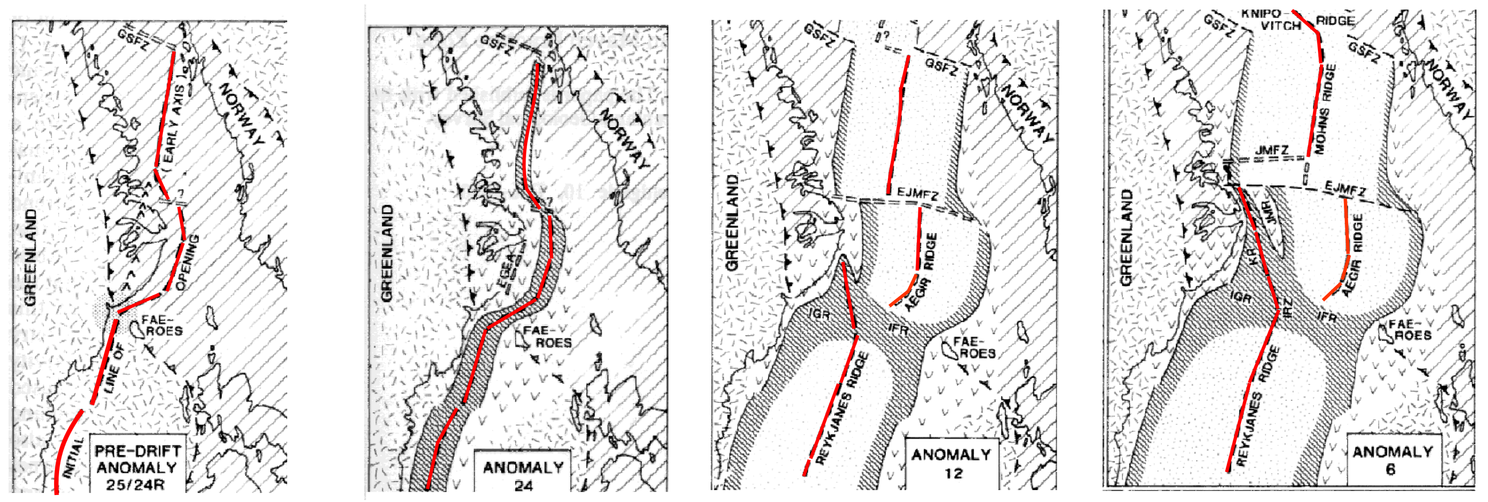


2. Post-rift sediments fill the resulting basin, often with little post-rift faulting.



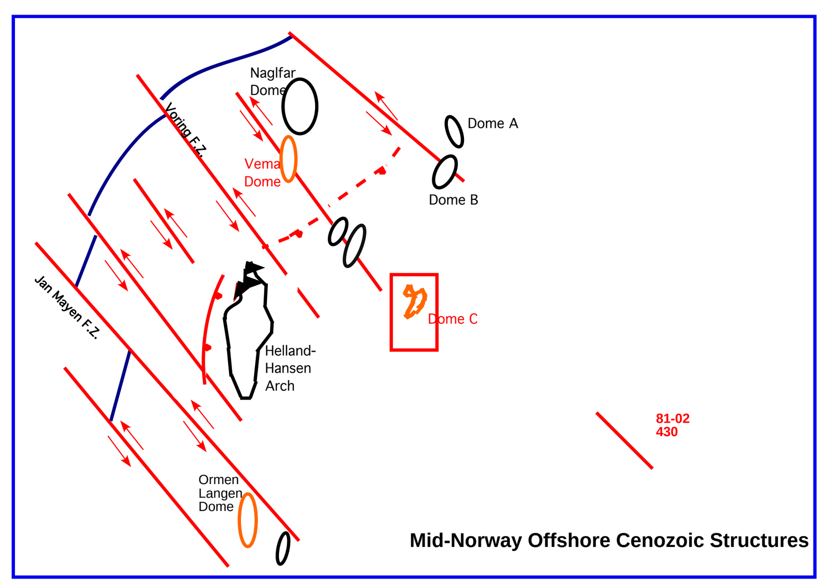
3. If sea-floor spreading occurs, then thermal uplift followed by thermal subsidence may effect the passive margin. No faulting is expected to occur in the passive margin as the plate grows at the mid-ocean ridge.

A. NORTH ATLANTIC MARGIN

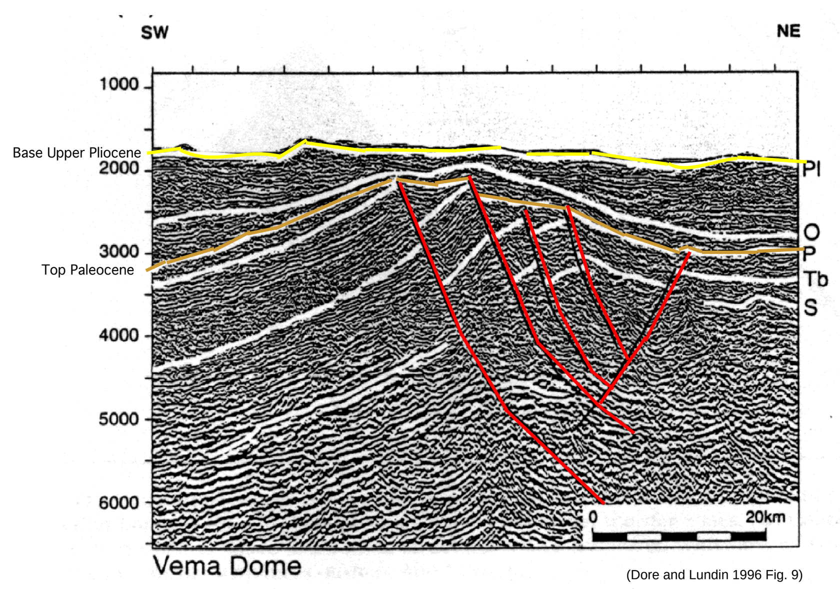


Model of the opening of the Northeast Atlantic proposed by H. C. Larsen (1988) showing development of two seafloor spreading centers.

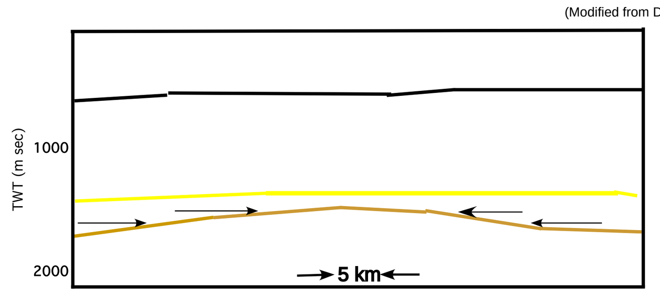
Sea floor spreading in the Northeast Atlantic was preceded in the Paleocene by large scale volcanic eruptions. The volcanism was concluded within 2 to 3 million years (White, 1988). These eruptions occurred at the onset of rifting from south of Greenland to the Barents Sea. Sea floor spreading commenced at Anomaly 25/24 (Late Paleocene). South of Iceland it occurred along the Reykjanes Ridge. North of Iceland, seafloor spreading was marked by ridge jumps to the east. The effects of the ridge jumps can be seen in compressive structures located off mid-Norway.



(Modified from Dore and Lundin 1996 Fig. 11c)

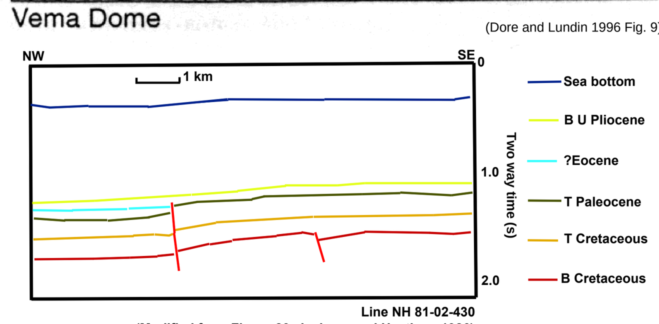


(Dore and Lundin 1996 Fig. 9)



Line B-18-83 over Dome C

(Jackson and Hastings 1986 Fig 25)

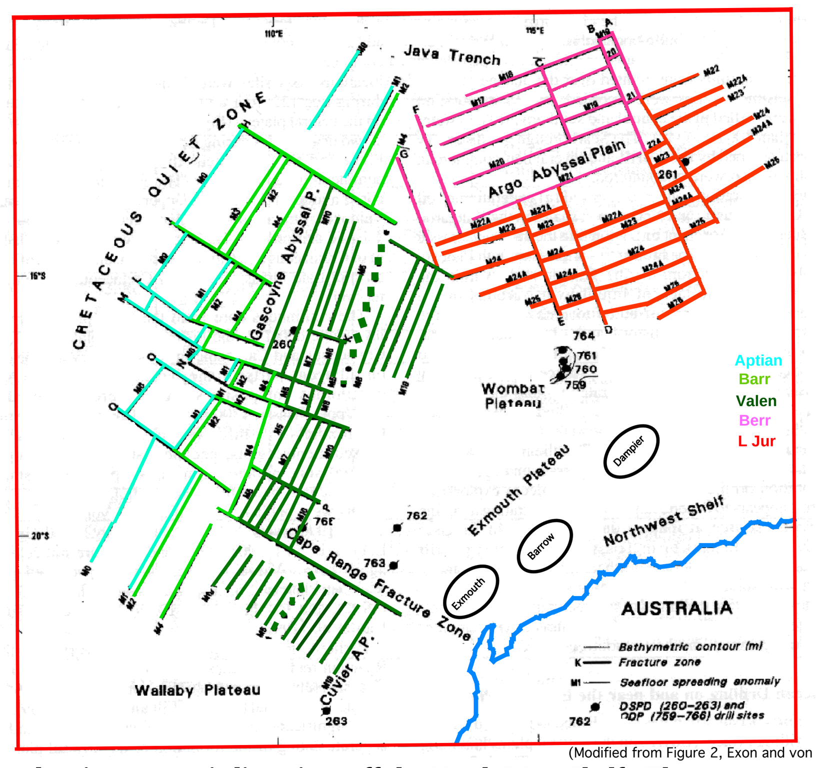


(Modified from Figure 23, Jackson and Hastings 1986)

Early seismic surveys conducted over the mid-Norway margin demonstrated the presence of inversion features (Boen et al 1984). Dore and Lundin (1996) and others investigators, have published detailed studies of these features (Dore et al 1999). They describe several large compressional domes, many apparently located above fracture zones extending from transform faults. These faults are inferred to move in right lateral manner, coeval changes in the geometry of the mid-ocean ridges.

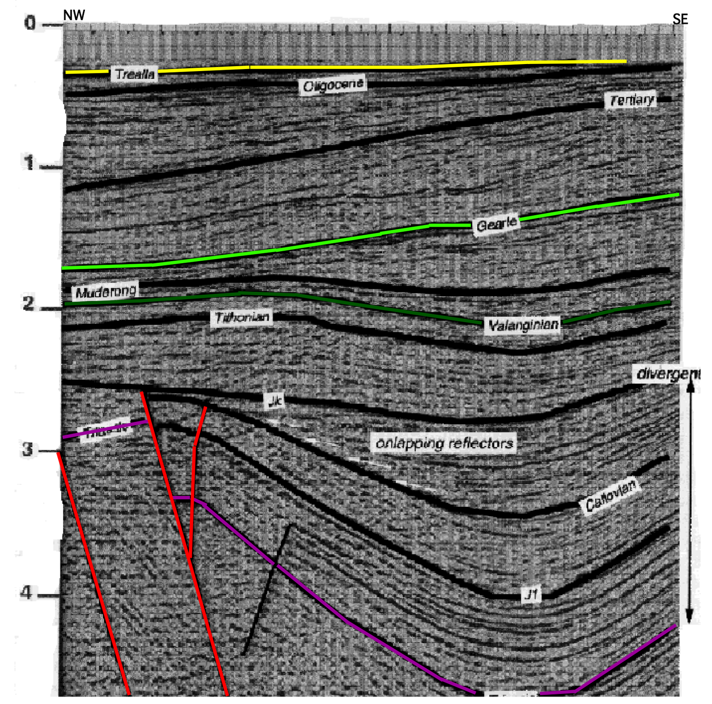
B NORTHWEST AUSTRALIAN MARGIN

The Exmouth, Barrow, and Dampier sub-basins began to open in Late Triassic-Jurassic time (Karner and Driscoll 1999). Regional subsidence of the Exmouth Plateau occurred in the Tithonian-Valengian. During the Turonian, sea floor spreading again reorganized in the Indian Ocean concurrent with major inversions on the Exmouth Plateau and in the sub-basins. Inversion was most intense over accomadation zones at the terminations of the sub-basins. These zones align with transform faults



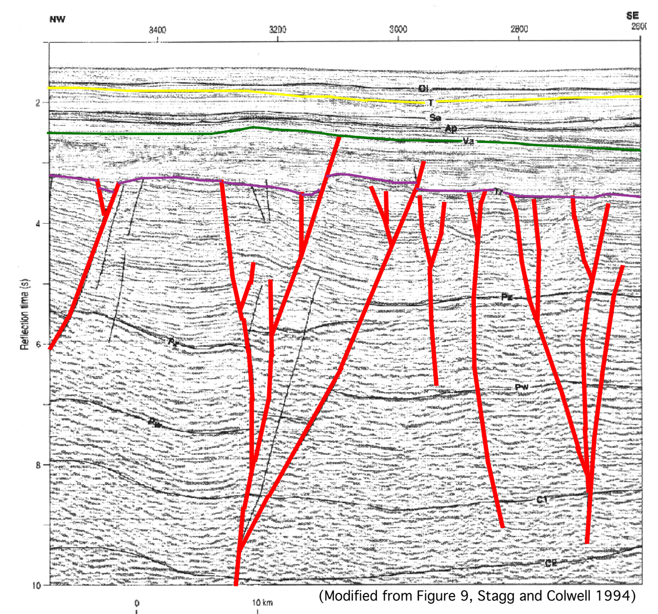
(Modified from Figure 2, Exon and von Rad, 1994)

Map showing magnetic lineations off the North West Shelf. The transform faults appear to allign with accomadation zones of the sub-basins.

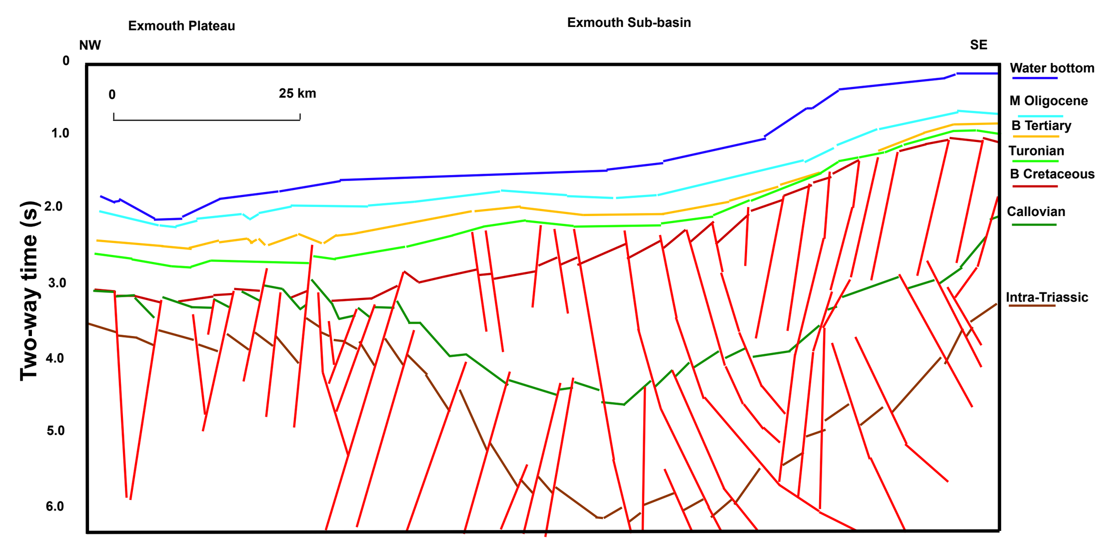


(Modified from Figure 12, Karner and Driscoll 1999)

Figure 1 Interpreted section AGSO101-09 Dampier sub-basin



(Modified from Figure 9, Stagg and Colwell 1994)



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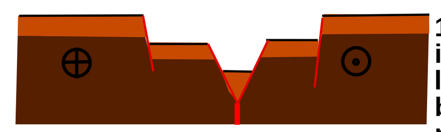
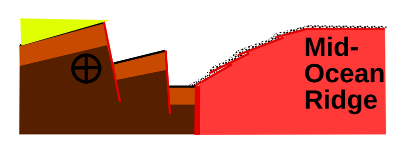
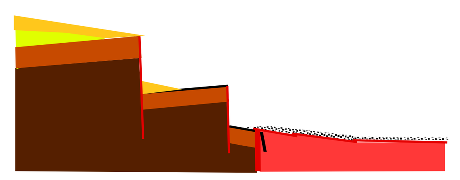
2. SIMPLE MODEL OF TRANSFORM MARGIN DEVELOPMENT



1. Transform margins form by initial wrenching of continental lithosphere, creating grabens bounded by strike-slip and normal faults.

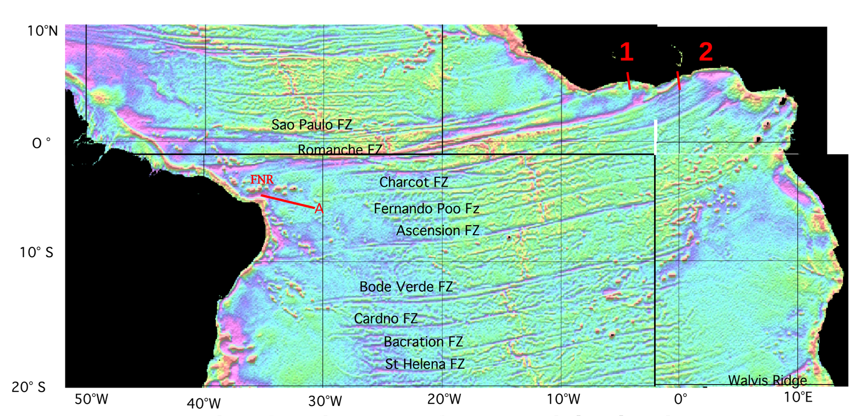


2. Sea-floor spreading places a mid-ocean ridge against continental lithosphere. Thermal uplift of continental margin effects sedimentation.



3. Continued sea-floor spreading moves the mid-ocean ridge away from the continental block. Thermal subsidence of both the ocean crust and the adjoining continental block may be accompanied by minor faulting, and will effect sedimentation patterns. Movement on the transform fault at the continent-ocean boundary is assumed to occur only between active mid-ocean ridges.

A. EQUATORIAL ATLANTIC TRANSFORM MARGINS



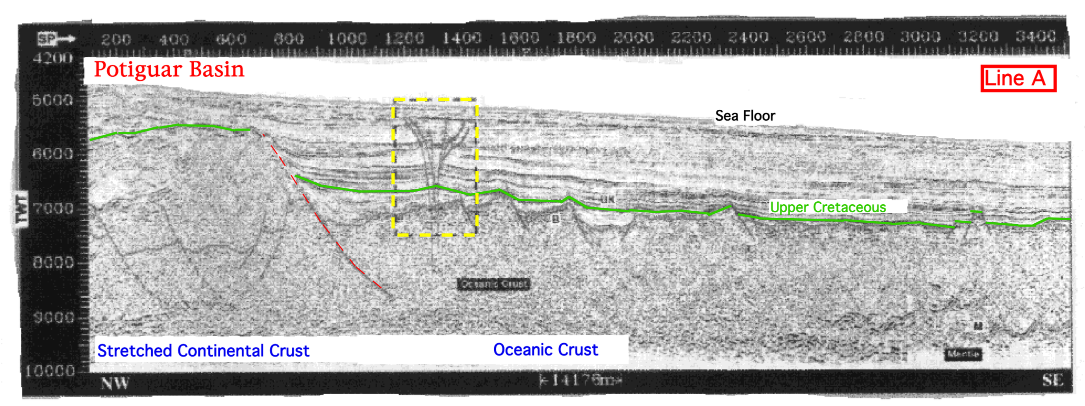
Marine Gravity Map of Equatorial Atlantic

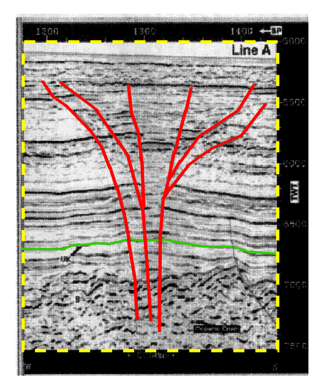
(Modified from Sandwell et al. 1996)

The South Atlantic opened between Africa and South America during the Late Jurassic (132 MA). The pole of rotation changed during the Late Aptian (102 MA) and during the Santonian(80 MA). The mid-ocean ridge north of the Walvis Ridge is thought to jump 200 km to the east at 80 Ma. A major phase of inversion is recognized at this time in West Africa (Fairhead and Binks 1991). Subsequent ocean spreading included a minor reorganization of the Equatorial Atlantic during the Miocene (Bonatti et al 1994).

Wrench related structures can be recognized on both margins of the Equatorial Atlantic. The features appear to be closely associated with the long transform faults , and to be coeval with changes in sea floor spreading.

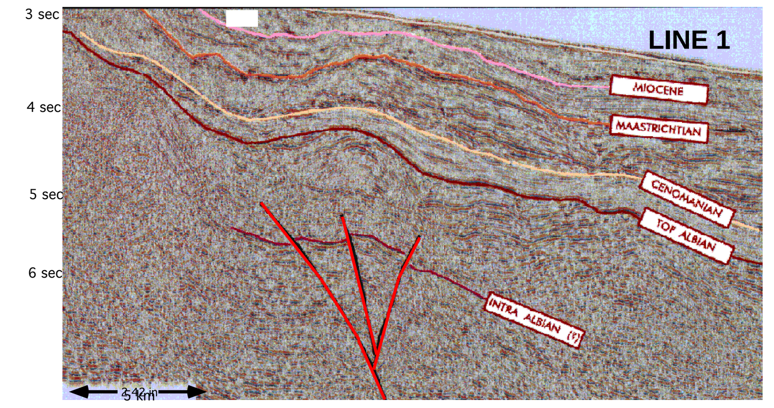
B. SOUTH AMERICAN MARGIN





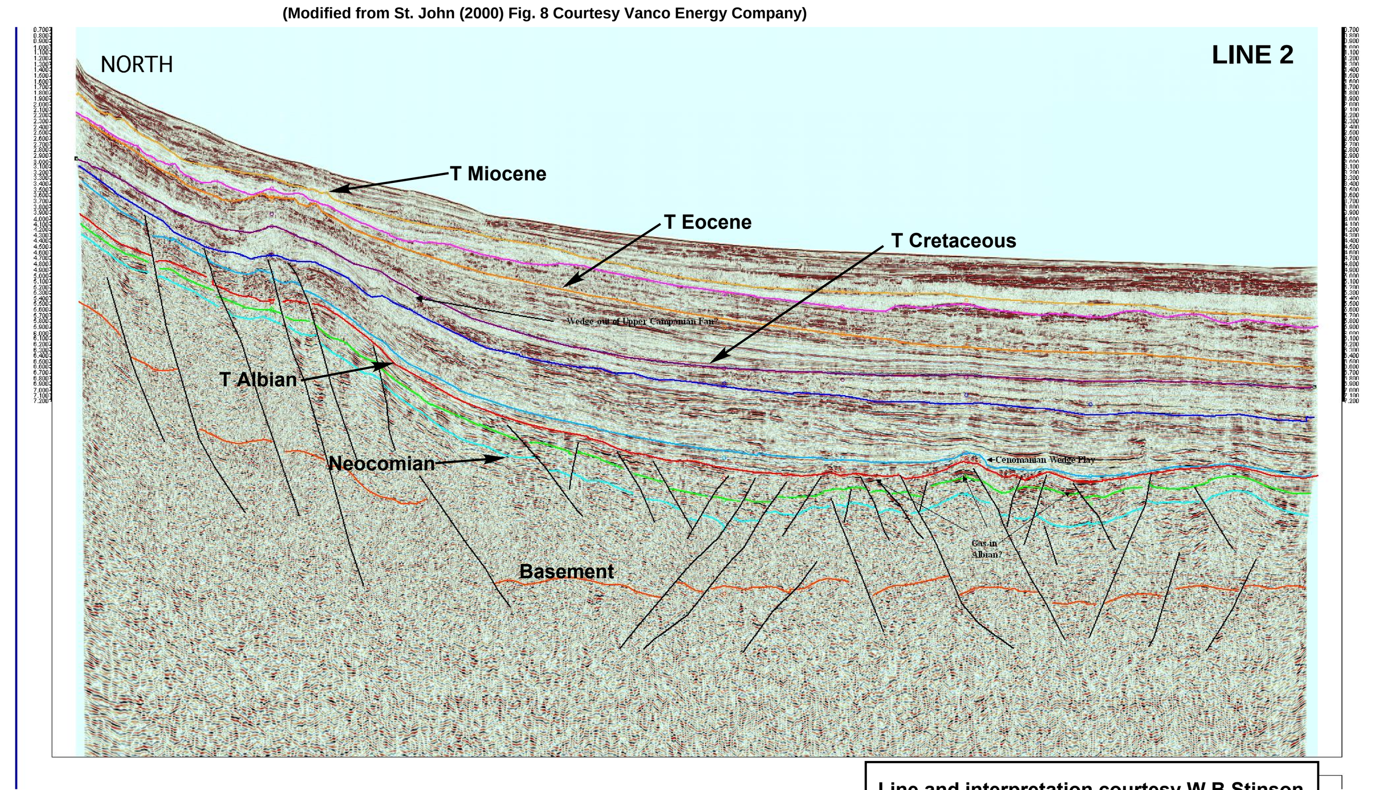
Line A crosses the extension of the Charcot Transform Fault on the Brazilian margin. A positive flower structure is interpreted to occur just southeast of the COB, effecting sediments as young as Early Miocene (Gomes et al. 1999). The Miocene deformation may be coeval with subtle changes in sea-floor spreading within the Equatorial Atlantic ridge system.

C. WEST AFRICAN MARGIN



(Modified from St. John (2000) Fig. 8 Courtesy Vanco Energy Company)

Thin, relatively flat-lying sediments of Cenozoic age overlie deformed Upper Cretaceous and older sediments beneath the C'ote D'Ivoire shelf. South-flowing rivers draining the West African margin deposited thick sedimentary units into the opening Atlantic rift basins. Wrench movements on transform faults during the late Cretaceous and Miocene deform the rift and post-rift interval.

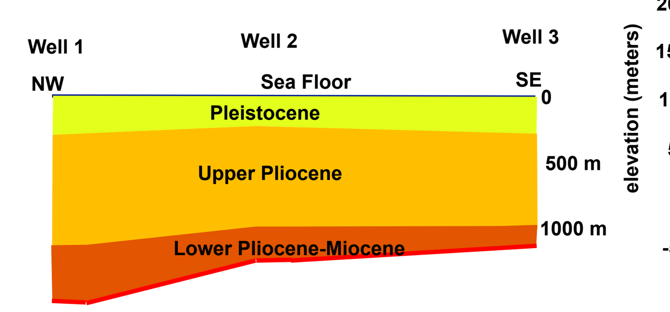


Line and interpretation courtesy W B Stinson

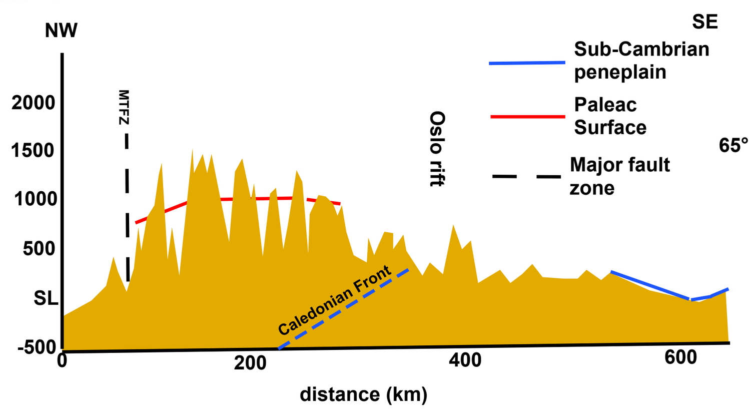
The paleo-Volta River also sourced sediments into the opening Atlantic rift basins during the Early Creaceous and ?Jurassic. Two episodes of post-rift deformation are inferred. The south end of the section shows upper Cretaceous sediments on lapping the top Albian reflector. The north end of the section shows late Miocene sediments on lapping an older ?Miocene reflector.

Both inversion structures are inferred to result from movement along the Romanche Fracture Zone during changes in Equatorial Atlantic sea floor spreading.

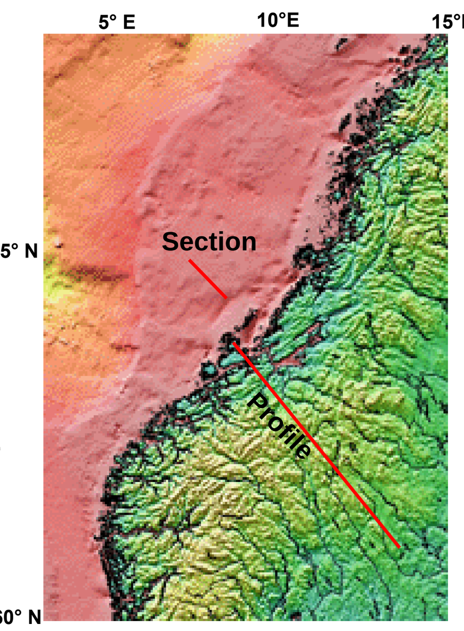
3. LATE POST-RIFT MARGIN UPLIFT



Modified from Figure 26 Jackson and Hastings 1986
Section



Modified from Figure 7 Lidmar-Berstrom and Naslund 2002
Profile



Post-rift thermal uplift of rifted margins is commonly recognized, and the uplifted hinterlands typically serve as a provenance for post-rift sediments. The Norwegian margin shows this pattern, as do other Atlantic passive margins. Onshore several peneplains have been inferred. The Sub-Cambrian peneplain is known in Fennoscandia (Lidmar-Berston and Naslund 2002). Vendian, Cambrian, and Ordovician sediments are found above this surface, and the basal Caledonian thrust is inferred to ride upon it locally. It is deformed into several long wavelength regional domes. The Paleac Surface formed during the Mesozoic and subsequently arched during the Paleogene. This episode is inferred here to represent post-rift thermal uplift of the North Atlantic rift margin.

The Norwegian offshore margin is underlain by a thick succession of Neogene sediments, whose lowest interval predate glaciation onshore. These sediments are deposited unconformably upon Paleogene sediments. The unconformity is correlated with the Paleac Surface (Riis 1996). Doming of the Paleac Surface with stream incision are inferred to source the offshore sediment package. Similar features have been identified on the western margin of the Atlantic in Greenland and North America (Stroeven et al 2002, Vogt 1991).

4. DISCUSSION

The passive margin rifts on the flanks of the Atlantic and Indian Oceans developed prior to the opening of the ocean basins. The rifts show the effects of initial continental lithospheric rifting, post-rift thermal subsidence, and post-rift sedimentation sourced from uplifted margins. Industry seismic and well data show compressional features on several margins. The compressional deformation appears to be vary as a function of distance from the mid-ocean ridges at the time of deformation, and thus are most intense in present deep water settings. The compressional deformations appear to be coeval with changes in sea-floor spreading geometry, especially where new mid-ocean ridges develop and older ridges cease spreading. Mantle flow must vary over time to produce these effects.

Fracture zones extending landward from transform faults appear to localize the compressional deformation of the rifted basins. Fracture zones also appear responsible for strike-slip deformation interpreted on transform margins. Minor changes in mid-ocean ridge geometry appear to be coeval with small scale flower structures interpreted on seismic data acquired on transform margins. Fracture zones appear play a major role in these styles of deformation, suggesting the fracture zones subdivide the ocean plates into small units.

Neogene doming on the Atlantic margin does not appear immediately related to rifting or sea-floor spreading. Mantle circulation patterns may provide a unified explanation for these features, with doming associated with small scale upwelling and the offshore depocenters associated with small scale downwellings. A suitable data base to constrain such models remains to be assembled.

Acknowledgments
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References Cited

Boen, F., Eggen., S. and Vollset J. 1984 Structures and basins of the margin from 62° N and their development. In Spencer, A. M. (ed.) Petroleum Geology of the North European Margin, Petroleum Society 253-270.
Bonatti, E., Ligi, M, Gasperini, L, Peyve, A., Raznitsin, Y, and Chen, Y. J. 1994 Transform migration and vertical tectonics at the Romanche fracture zone, equatorial Atlantic Journal of Geophysical Research 99:21779-21802
Dore A. G., Lundin, E. R., Jensen, L. N., Birkeland, O., Eliassen, P. E., and Fichler, C. 1999 Principle tectonic events in the evolution of the northwest European Atlantic margin. In Fleet., A. J. and Boldy, S. A. R. (Eds.) Petroleum Geology of Northwest Europe: Proceedings of the Fifth Conference.. Geological Society, London, 41-61.
Dore A. G. and Lundin, E. R. 1996 Cenozoic compressional structures on the NE Atlantic margin: nature, origin and potential significance for hydrocarbon exploration Petroleum Geoscience 2: 299-311.
Fairhead, J. D. and Binks, R.M. 1991 Differential opening of the Central and South Atlantic Oceans and the opening of the Central African rift system. Tectonophysics, 187: 191-203.
Gomes, P. O., Gomes, B. S., Palma, J. J. C., Jinno, K., and de Souza, J. M. 1999 Ocean-continent transition and tectonic framework of the oceanic crust at the continental margin off NE Brazil: results of the LEPLAC Proect. In Mohriak, W. and Talwani, M (eds.) Atlantic rifts and continental margins Geophysical Monograph 115, American Geophysical Union: 261-292.
Gowers, M. and Lunde, G. 1984 The geological history of Traenabanken. In Spencer, A. M. (ed.) Petroleum Geology of the North European Margin, Petroleum Society (Graham and Trotman) 237-252.
Jackson, J. S., and Hastings, D. S. 1986 The role of salt movement in the tectonic history of Haltenbanken and Traenabanken and its relationship to structural style. In A. M. Spencer (ed.) Habitat of Hydrocarbons on the Norwegian Continental Shelf Norwegian Petroleum Society (Graham and Trotman) 241-258.
Karner, G.D., and N.W. Driscoll, 1999. Style, timing, and distribution of tectonic deformation across the Exmouth Plateau, northwest Australia, determined from stratal architecture and quantitative basin modelling. In: "Continental Tectonics", Mac Niocaill, C., and P.D. Ryan (eds), Spec. Publ. Geol. Soc. Lond., 164, 271-311
Larsen, H. C. 1988 A multiple and propagating rift model for the NE Atlantic (extended abstract). In Morton A. C. and Parson, L. M. Early Tertiary volcanism and the opening of the NE Atlantic. The Geological Society of London Special Publication 39: 157-160.
Lidmar-Bergstrom K. and Naslund, J. 2002Landforms and uplift in Scandanavia In Dore et al (eds)Exhumation of the North Atlantic Margins. Geological Society Special Publication 196: 103-116.
Lundin, E. R. and Dore, A. G. 1997 A tectonic model for the Norwegian passive margin with implications for the NE Atlantic: Early Cretaceous to break-up Journal of the Geological Society, London, 154: 545-550.
Morton, N. 1992 Late Triassic to Middle Jurassic stratigraphy, palaeogeography and tectonics west of the British Isles. In J. Parnell (ed.) Basins on the Atlantic Seaboard. The Geological Society of London Special Publication No. 62: 53-68.
Riis, F. 1996 Quantification of CEnozoic vertical movements of Scandinavia by correlation of morphological surfaces with offshore data. Global and Planetary Change 12:331-357.
Rosendahl, B. R. and Groschel-Becker, H. 1999 Architecture of the continental margin in the Gulf of Guinea as revealed by reprocessed deep-imaging seismic data. In Mohriak, W. and Talwani, M (eds.) Atlantic rifts and continental margins Geophysical Monograph 115, American Geophysical Union: 85-104.
St. John, B. 2000 The role of transform faulting in the formation of the hydrocarbon traps in the Gulf of Guinea, West Africa. Offshore West Africa 2000 Conference, Abidjan, Cote d'Ivoire, preprint.
Sandwell, D., Smith, W. H. F., and Yale, M. 1996 Marine gravity from satellite altimetry Scripps Institute of Oceanography-IGPP http://topex.ucsd.edu/marine_grav/mar_grav.html
Stagg, H.M.J., Colwell, J.B., .1994, The structural foundations of the Northern Carnarvon Basin, Purcell, P.G. and Purcell, R.R., (Ed.), The Sedimentary basins of Western Australia: Proceedings of Petroleum Explortion Society of Australia Symposium, Perth, 349-372.
Stroeven, A., Fabel, D., Harbor, J, Hattestrand C., Kleman, J. 2002 Reconstructing the erosion history of glaciated passive margins In Dore et al (eds)Exhumation of the Northa Atlantic Margins. Geological Society Special Publication 196: 153-168.
Vogt, P. 1991 Bermuda and Appalachian-Labrador rises: common non-hotspot processes? Geology 19:41-44.
Wagner, T., and Pletsch T. 1999 Tectono-sedimentary controls on Cretaceous black deposition along the opening of Equatorial Atlantic Gateway (ODP Leg 159) In Cameron et al (eds) The Oil and Gas Habitats of the South Atlantic, Geological Society, London, Special Publication 153, 241-265.
White, R. S. 1988 A hot-spot model for early Tertiary volcanism in the N Atlantic. In Morton A. C. and Parson, L. M. Early Tertiary volcanism and the opening of the NE Atlantic. The Geological Society of London Special Publication 39: 3-14.