II CENTRAL & NORTH ATLANTIC CONJUGATE MARGINS CONFERENCE

LISBON 2010

Rediscovering the Atlantic: New Ideas for an old sea…

PROGRAM & SHORT ABSTRACTS

Edited by:

RUI PENA DOS REIS & NUNO PIMENTEL

Impressão: Impressões e Soluções, Laboratório de imagem, LDA.
Design Gráfico: Gabriel Barberes
Lisboa, Outubro 2010
Tiragem: 300 ex.
ISBN: 978-989-96923-4-3

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A New Kinematic Plate Reconstruction of the North Atlantic between Ireland and Canada

Ady, B. E. [(1)]; Whittaker, R.C. [(1)]; Alvey, A. [(2)]; Roberts, A. M. [(2)]; Kusznir, N. J. [(3)]

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(2) Badley Geoscience, Spilsby, Lincolnshire, UK
(3) Department of Earth Sciences, Liverpool University, Liverpool, UK

In comparison with other continental margins, the North Atlantic deep water basins of Ireland and Eastern Canada are very lightly explored with only a small number of wells drilled. Understanding the tectonic history of the conjugate margins of Newfoundland and Ireland is critical for evaluating their hydrocarbon potential, yet existing plate tectonic models for the North Atlantic are inadequate. Over the next two years GeoArctic Ltd., in collaboration with a team of leading researchers from academia, government, and industry on both sides of the Atlantic, will develop a *Kinematic Plate Reconstruction of the North Atlantic between Ireland and Canada*. The project team includes researchers from Badley Geoscience Ltd., Memorial University of Newfoundland (MUN), University College Dublin (UCD), the Dublin Institute of Advanced Studies (DIAS), the Geological Survey of Canada (GSC), and others. The project is due for completion in June 2012.

The integrated workflow developed for the project combines 4D deformable plate techniques and seismic, magnetic and geological interpretation with the analytical techniques of 2D or 3D gravity inversion, flexural backstripping, fault analysis and forward modelling. The project will use 2D and 3D structural modelling and gravity inversion to calculate crustal stretching in order to develop a new deformable plate model that will remove overlap and under-fit between plates. The new model will be useful in furthering our understanding of the major controls and mechanisms for North Atlantic basin formation and evolution.

Constraint on the lithosphere structure of the southern edge of the Galicia Bank: comparison with adjacent margin segments

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In the scope of the Portuguese Continental Shelf Extension Program, the EMEPC held a joint seismic reflection/refraction survey during June/July 2006 (6 OBS recovered east of ~12.5º W), extended to the west in November 2008 (6 OBS recovered, ~12.5º W to ~14.25º W). The wide-angle survey comprised the acquisition of a seismic refraction/wide-angle reflection line with a total length of 357 km, that is nearly coincident to the MCS near-vertical reflection line IB02. This line crosses the south-western edge of the Galicia bank (Vasco da Gama seamount) and the northern Iberian abyssal plain area.

We compared the crustal and shallow mantle structure, imaged along the IB02 transect, to other long transects that cross the west Iberia margin, namely IAM9, CAM (southern Iberia abyssal plain segment) and IAM5 (Tagus abyssal plain segment). To perform this comparison we considered multichannel seismic reflection data, wide-angle reflection velocity models, magnetic and free-air anomaly, profiles and models. It is well known that the clustering of the crust and shallow mantle structure, according to the seismic facies in the basement and its topography, crustal thickness, P-wave velocity and velocity gradient, density and magnetization, defines three domains in the west Iberian margin: (i) continental domain; (ii) transitional domain; (iii) oceanic domain.

The continental domain imaged along IB02 presents a crust already thinned to one third of its original thickness and the Moho shows the same geometry as in other places of the Iberian margin, where the crust thins from ~30 km to less than 5 km. In the transitional domain the magnetic anomalies are weak, the velocity-depth profiles do not resemble those of continental or oceanic crust and a region of anomalous P-wave velocity exists in the deep basement. These signatures are generally present in all other transects, especially those from the Galicia bank and southern Iberia abyssal plain segments where they have been interpreted, following extensive DSDP and ODP drilling in the northern area, to a zone of exhumed sub-continental mantle. From north to south a few differences come up when we compare the width of this region, the topography, reflectivity and magnetization of the basement and the presence or absence of crustal interfaces. These differences are certainly important when interpreting the structure, lithological nature and processes of margin evolution.

Salt Structures and the petroleum potential of continental margins in west Iberia, Newfoundland and South Atlantic

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Sedimentary basins with significant salt tectonics are main target areas for hydrocarbon exploration on multiple continental margins. Salt structures can form competent structural and stratigraphic traps, at the same time promoting the flow of fluids in adjacent regions to their flanks. A comprehensive set of (2D) seismic-reflection profiles from west Iberia, tied to borehole data, permitted the mapping of deep-offshore regions where salt structures are evident. Their geometry, age and importance in the tectono-stratigraphic record of offshore basins are compared with their counterparts in Newfoundland and South Atlantic (Espirito Santo Basin, Brazil and Nigerian Margin, West Africa).

In essence, developed salt structures not strictly related to Cenozoic inversion are only observed, on the western Iberian margin, north of 39^0 15'N. They comprise Late Triassic-early Jurassic evaporites and shales in their interior, which were not deposited uniformly north of the latter parallel. Onshore, salt pillows predominated in a structural style resembling that of the Jeanne D'Arc Basin, also in a proximal position on the Canadian margin. Direct comparisons with basins in Newfoundland show salt structures to be more developed in the deep-offshore, with developed salt diapirs and salt stocks observed in some places. Thus, the structural styles observed in deep-offshore basins are similar to those recorded in deep-offshore basins in the Scotian Shelf and in the Salar Basin, to cite two examples.

Similarly to the South Atlantic, post-rift tectonism affecting the salt-rich basins in west Iberia resulted in intense deformation of post-salt sequences, with toe-thrusts, local pop-up features and extensive inversion of salt-related basins occurring in deep-offshore basins. However, halokinesis was moderate in western Iberia, with no allochthonous salt deforming the base of the continental slope.

This analysis proposes the presence of salt in depth to contribute to the formation of structural traps in deep-offshore basins but, at the same time, to be responsible for the inversion of older halokinetic structures. As demonstrated for the shallow-offshore region (Lusitanian Basin), Newfoundland Basins and South Atlantic, the petroleum potential of such structures will depend on: a) timing of tectonic inversion, b) relative thickness of overburden sediment above the salt. Considering the existence of a significant tectonic activity in west Iberia during the Late Cenozoic, deep-rooted inversion structures covered by thick overburden units will present the largest potential for hydrocarbon accumulation.

Faulting of salt-withdrawal basins during early halokinesis: Structural controls on reservoir distribution in South Atlantic Conjugate Margins

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Three-dimensional (3D) seismic-reflection data were used in the analysis of submarine channel systems in the Espírito Santo Basin, Brazil. In the study area, pervasive normal faulting of pre-Oligocene strata was triggered during early halokinesis (Stage A) but initially hardly controlled the initial evolution of a channel system (RDCS) which, at the time, incised the continental slope axially within a salt withdrawal basin. In a second stage (Stage B) crestal/radial faults controlled erosion over growing salt structures, whilst synclinal and channel-margin fault sets dissected overbank strata to the RDCS. In the later part of Stage B, channel sinuosity decreased sharply in response to fault activity and associated seafloor destabilization. Vertical propagation of blind faults was triggered in a third stage (Stage C) - in association with crestal collapse of buried salt anticlines and regional diapirism - but synclinal and channel-margin faults did not propagate vertically above a regional unconformity marking the base of Stage C strata.

We have assessed the importance of faulting during early halokinesis on the 4D development of the RDCS. Statistical analyses of observed fault sets show that synclinal faults are in average 2.3 times longer than the crestal/radial types but record 60% of the throw (average 83 m) experienced by the latter. Significantly, the analysed axial fault sets are shown to have contributed to local cannibalisation of the seafloor, to vertical stacking of channel-fill strata and to structural and depositional compartmentalisation of potential reservoir successions. As a result, channel systems show marked differences in mean values for sinuosity, height and width in relation to five (5) main phases of channel development.

The structural setting in the study area differs from productive areas offshore Espírito Santo (e.g. Golfinho field), West Africa and Gulf of Mexico. It reveals - in distal parts of the Brazilian margin - the existence of local controls on submarine-channel architecture and structural compartmentalisation prior to the principal stages of diapirism, which are dated as Miocene to Holocene.

Structural Evolution and Timing of Continental Rifting in the Northeast Atlantic (West Iberian Margin)

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This abstract presents regional (2D) seismic-reflection profiles, outcrop and borehole data that indicate the bulk of Late Jurassic-earliest Cretaceous subsidence to have occurred in the present-day continental slope area. Five (5) principal regressive events (and their correlative basal unconformities) reflect tectonic uplift and relative emersion in proximal basins are correlated with major rift-related tectonic events occurring on the deeper margin. Direct comparisons with the Peniche Basin of northwest Iberia reveal that a significant portion of lower-plate margins is uplifted and eroded during the last stages of continental rifting. Such process was repeated at different times (and in different areas) as the locus of rifting and continental break-up migrated along the future passive margin. As a result, in west Iberia two distinct rift axes are recognised, a first axis extending from the Porto Basin to the Alentejo Basin and a second axis located on the outer proximal margin north of 380 30'N. In northwest Iberia, a similar episode of progradation occurred in the Porto Basin during (Aptian) continental breakup but stratigraphic data show, in contrast, a relative deepening across the break-up unconformity. Further south, on the continental shelf, a regional hiatus denotes erosion or non-deposition during from the Berrasian to the Aptian.

A key aspect revealed on seismic data is the marginal position of the inner proximal margin during continental rifting, with a Slope Fault System (SFS) separating the inner proximal margin from highly-extended tilt-blocks in the deep-offshore (Figure 1). Normal fault lineaments as the SFS – a structure suggestively equivalent to a 'rift-border fault' sensu Khalil and McClay (2001) - are commonly associated with the migration of rifting towards distal parts of continental margin occurring prior to continental break-up and subsequent formation of oceanic crust. Thus, in west Iberia subsident half-grabens/graben basins evolved in axial parts of the deep-offshore rift axes, while proximal regions effectively formed the rift-shoulder area to subsident tilt-blocks in the outer margin.

We propose subsequent phases of tectonic quiescence, widespread erosion and sediment progradation on the inner proximal margin as marking the abandonment of extensional basins east of the SFS, and the subsequent onset of syn-rift extension on the outer proximal margin. In addition, we conclude that: a) principal depocentres in deep-offshore basins are separated from proximal basins by a slope-bounding fault system (SFS); b) five regression episodes (S1 to S5) should reflect major tectonic events occurring on the deeper margin.

Growth of the Atlantic Basin, opening of the Gulf of Mexico, and movement along the Late Jurassic Mexico-Alaska Megashear

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Late Jurassic widening of the Atlantic Ocean basin and opening of the Gulf of Mexico (GOM) were accommodated by the Mojave-Sonora megashear (MSM) that bounded the southwestern and western margin of the North America plate. The inferred trace of the MSM, which is constrained by previously recognized regional elements such as transtensional basins, offset or overlapping magmatic belts, and terrane juxtapositions, is now recognized to extend along the continental margin to Alaska.

The longer, continental-scale fault thus defined, which is called the Mexico-Alaska megashear (MAM), linked the axis of Atlantic ocean-floor spreading and the developing Gulf of Mexico with a northward-facing subduction zone above which the Kobuk Sea floor, formerly in western Alaska, was consumed beneath the Togiok-Koyukuk arc at a right, restraining, step. The MAM accommodated at least several hundreds of km of movement between 168 and 148 Ma.

Passive Margin and Continental Basin: the necessity of the Holistic approach

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The formation of the sedimentary basins and continental passive margins have long been explained by numerous physical models, usually built on only one passive margin considered as the reference. However, passive continental margins are so diverse that the existence of a unique thinning process must be re-considered and discussed. However, the recurrence of some general features (abrupt thinning, large transitional domain, whatever the nature of the crust oceanic, continental or mixed) pleads in favour of general rules.

No margin presents all the features needed to support a general model, but each margin supplies pieces of the jigsaw. Understanding the thinning process can therefore only be reached using a holistic approach, comparing many different margins. The main, and most difficult, trick is to distinguish and to decipher local (as probably the presence or absence of a sag basin) and general characteristics (the abrupt thinning for instance). The thinning of passive continental margins is usually explained by models using pure stretching or simple shear, with or without depth-dependent thinning process. These models imply hypothetical extensional structures and large horizontal movements between the two conjugate margins. The holistic approach implies to combine geometrical description with precise plate kinematic reconstructions. This approach allows us to propose some general rules for the early thinning process, among which a high position of the system, throughout the entire process of thinning and a lost of lower continental crust are the most important. The diversity of the final structural morphologies observed seems to be a matter of tectonic heritage, geodynamic context and probably mantle heat segmentation.

The not-so-passive post-rift tectonic evolution of the Morocco continental margin: Implications for offshore terrigenous reservoirs and for the evolution of passive continental margins

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The early post-rift evolution of the Morocco continental margin (Late Jurassic – Early Cretaceous) is characterized by important tectonics and, in particular, vertical movements. Km-scale exhumation and erosion in onshore Morocco produced large amount of terrigenous sediments which were transported by a fluvial distributary system and deposited offshore subsiding basins. Coeval sediments form major potential reservoirs in the offshore of NW Africa and are also found on the conjugate Nova Scotia margin.

Building on the initial work we performed in the past, our new apatite (U-Th/He) and Fission Track data document that Middle Jurassic to Early Cretaceous exhumation and erosion affected also the High Atlas, the Anti Atlas and, further to the S, the Reguibate shield (1-3 km). The area experiencing exhumation was elongated in N-S direction and partly coincided with the “West Moroccan Arch”. In the region of the Essaouira basin, the upward moving area was separated from the more distal parts of the passive margin by a domain of continuous subsidence presently in the coastal and continental shelf domains. Such subsiding domain changes in dimensions and depth moving towards the S.

Generalized subsidence in the transitional domain in the Essaouira Basin allowed for the preservation of Jurassic to Cretaceous sediments in which syn-sedimentary structures are preserved documenting the tectonic regime during the early post-rift stage. Structural studies in these areas document an overall contractional regime during exhumation in contrast with the general lack of tectonic activity assumed for passive margins. In the coastal areas of Morocco, shortening triggered and interacted with the growth of salt diapirs. Most of these diapirs entered the diapiric phase long before the onset of Atlas orogeny.

Rocks eroded from the exhuming area were routed by a fluvial system and shed into the subsiding margin forming of submarine deltas such as the Tan Tan delta.

The results of the work we have conducted in the Morocco rifted margin complement the increasing body of data from other passive continental margins world-wide documenting the importance of vertical movements during the early post-rift stage.

Early seafloor spreading in the South Atlantic Ocean: M-series isochrons north of the Rio Grande Fracture Zone?

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South of the Rio Grande Fracture Zone (RGFZ), which intersects the South American and African continental margins at the northern limits of the respective Rio Grande Rise and Walvis Ridge hotspot tracks, Mesozoic magnetic isochrons (M-series), M11 to M0 (~136 to ~125 Ma), have been identified and mapped by several workers since 1979. We have examined new marine magnetic data, recently acquired in tandem with long-offset, long record seismic reflection data by ION-GXT over offshore Brazil, and correlated similar anomaly features north of the RGFZ,. We have integrated these results with our earlier work, that utilized open-file magnetic anomaly data offshore South America and Africa, to interpret and map magnetochrons M4, M2 and M0 (~130, ~128 and ~125 Ma) north of the RGFZ, over both offshore Brazil and Angola.

Recent tectonic reconstructions of the South Atlantic between Africa and South America have partitioned the ocean basin into Equatorial, Central, and Austral segments, with the RGFZ being the boundary between Central and Austral segments. Diachronous opening of the South Atlantic has been proposed in which seafloor spreading in the Austral segment, just before M7 (~132 Ma), was facilitated by an intraplate boundary in South America that extended northwestward to the Andean Cochabamba – Santa Cruz bend from the RGFZ. This was followed by sea floor spreading north of the RGFZ that began at M0 (~125 Ma). Unpublished evidence for this intraplate boundary is interpreted from remote sensing data; however the Parana flood basalts obscure much of the hypothesized boundary. Our results are not consistent with these tectonic models for the earliest opening of the South Atlantic but instead indicate that spreading was active north of the RGFZ as early as M4 (~130 Ma). Although the magnetic evidence suggests that the ocean basin may have opened from south to north, our interpretation does not require an intraplate boundary in South America to account for the early spreading history of the basin.

Middle-Upper Jurassic palynology of the Sagres region and the Carrapateira Outlier, southern Portugal

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The Algarve Basin corresponds to the southernmost geological province of mainland Portugal. It has an E-W strike and is represented onshore from Cap São Vicente to the Guadiana River on the Portuguese-Spanish border. More than 3000 m of essentially marine sediments accumulated during Mesozoic-Cenozoic times in the Algarve Basin. The Sagres region is the reference area for the Mesozoic fill of the Western sub-basin where Middle Jurassic strata outcrop in the cliffs at Mareta and Cilheta beaches. The Carrapateira Outlier is located 20 km north of the main Algarve Basin and consists of Upper Triassic to Kimmeridgian sediments.

The palynological study of the Jurassic successions in the Sagres region and the Carrapateira Outlier has yielded new biostratigraphical data based on dinoflagellate cysts and miospores.

The dinoflagellate cyst from the lower part of the Mareta succession are indicative of the Bathonian stage, due principally to the occurrence of *Ctenidodinium* spp., *Ellipsoidictyum/Valensiella* group, *Korystocysta* spp. and *Valensiella ovulum*. The uppermost strata of this succession match the Cilheta outcrop and yielded *Gonyaulacysta jurassica* subsp. *adecta*, *Korystocysta* spp., *Meiourogonyaulax caytonensis*, *Mendicodinium groenlandicum* and *Tubotuberella dangeardii*, and are indicative of the Callovian Stage. The dinoflagellate cysts from the Callovian, from further north in Europe, are normally significantly more diverse, maybe due to the relatively enclosed basin and/or preservational factors in southern Portugal.

The dinoflagellate cyst associations from the Carapateira Outlier are indicative of a Late Oxfordian/Early Kimmeridgian age due to the occurrence of species such as *Gonyaulacysta jurassica* subsp. *jurassica*, *Systematophora areolata* and *Systematophora penicillata*.

These results confirm, and refine, the existing macrofaunal age of these successions. However, the palynostratigraphical research in the Algarve Basin and Carrapateira Outlier is currently still in progress.

The diapirs of the Lusitanian Basin (Portugal): a brief overview

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The Lusitanian Basin constitutes one of the many basins formed during the opening of the North Atlantic. It is located along the western margin of the Iberian Peninsula and it has a rather complex history that comprises: i) at least two episodes of rifting during the Mesozoic – the first event of rifting spanning from the upper Triassic to the Hettangian and the second from the Oxfordian until the lower Berriasian; ii) two episodes of tectonic inversion in the Cenozoic - upper Cretaceous until the Palaeogene and Miocene; iii) three magmatic cycles which occurred at 200-180Ma, 145-130Ma and 94-72Ma of tholeiitic, transitional and alkaline nature. The rifting reactivated inherited faults from the Variscan basement in two main directions, NNE-SSW and ENE-WSW, sectioning the basin in three main areas.

A prominent feature of the basin is the existence of salt diapirs, as a result of lateral and vertical migration of the Hettangian evaporites of the Dagorda formation. These structures are distributed along the three sectors of the basin and are closely associated with the structure of the basement and the igneous bodies of the second and third magmatic cycles. The largest diapiric structures are salt walls located on the central sector of the basin, along two NNE-SSW parallel lineaments. The diapirs outcrop in the intersection of roughly orthogonal faults. Several factors about diapirism in the Lusitanian basin are not consensual among authors. From that lack of agreement stems three models regarding the time/tectonic setting in which occurred the diapirism: a first which states the existence of halokinesis and diapirism during the rifting events, a second that defends the diapirism at a later period, namely during the Miocene tectonic inversion of the Basin, and a third in which there is no halokinesis during the rifting periods, but rather a ductile response of the overburden to the brittle deformation of the basement, with the evaporitic layer accommodating the transition between two types of deformation and tectonic style. This proposal also states that the triggering mechanism for the diapirism is the onset of the third magmatic cycle.

During the Miocene tectonic inversion, most of the existing diapirs were reactivated as tranpressive structures, occurring also diapir rejuvenation and generation of thrust fronts above the level of detachment of the Dagorda Formation.

Erosional Unconformities, Megaslumps and Giant Mud Waves: Insights into passive margin evolution from the continental slope off Nova Scotia

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The deepwater Cenozoic geological history off Nova Scotia is understudied, both in terms of passive continental margin evolution and hydrocarbon potential. Interpretation of seismic reflection data and sparse hydrocarbon exploration well data reveals regional seismic stratigraphic units that are correlated to the well-studied U.S. Atlantic margin. Whereas U.S. margin studies benefit from numerous scientific drilling program wells, the present study of the Scotian margin benefits from superior high-quality seismic reflection data coverage which provides insight into deposition patterns and seismic geomorphology not previously attainable.

The global greenhouse to icehouse transition that occurred during the middle Cenozoic marked a major shift in geological and oceanographic conditions in the northwest Atlantic Ocean. During this transition, strong contour currents developed and sediment input to the North American Basin increased. These events were coeval with development of regional unconformities within the basin and along the basin margins. In many cases, however, the relationships between abyssal plain and continental margin unconformities and associated depositional elements are unclear. A Tertiary-age depocenter is recognized along the western Scotian margin. Results from this study show that regional canyon erosion was widespread in the study area during the Middle Eocene and Quaternary, but is also recognized during the Oligocene, Middle Miocene, and Late Miocene. Most canyons extend beyond the seaward range of data coverage, implying sediment transport across the slope and rise to the deep basin. Margin erosion by bottom currents is recognized on the continental rise during the Oligocene and on the continental slope and rise during the Middle Miocene and Pliocene, reflecting the changing circulation regime in the Northwest Atlantic. Mass-transport deposits, among the largest reported in the literature, appear to initiate on the steep foresets of shelf margin clinoforms, or along the lower slope in the vicinity of salt diapirs. Mass-wasting events contribute to the formation of regional and sub-regional unconformities and move vast amounts of sediment onto the lower continental slope and rise. Sediment drifts constructed during the Miocene and Pliocene form stacked sequences of giant sediment waves, or elongate mounded drifts. Their location, style, and evolution appear linked to the morphology of the underlying surface. In many cases, the unique morphology of sediment drifts aided in trapping gravity flows that otherwise would transit to the continental rise and abyssal plain. Sediment drifts, together with large mass transport deposits, form the dominant constructional features on the lower slope and rise, a result not previously recognized.

Foraminifera from the Lower-Middle Jurassic of the Lusitanian Basin (Portugal) – biostratigraphic and palaeocological significance

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The detailed study of benthic foraminifera of four reference sections from the Lower-Middle Jurassic transition of the Lusitanian Basin (Central Portugal) is presented. Murtinheira, S. Gião and Maria Pares sections are located in North Lusitanian Basin; Zambujal de Alcaria section is located in Central Lusitanian Basin, all representing different facies of the *sag* interval which follows the Late Triassic rifting episode.

Based on a previous biostratigraphic framework, well calibrated through the rich and diversified ammonite record, a total of 73 samples have been collected from the Upper Toarcian (Mactra and Aalensis Subzones; Aalensis Biozone), Lower Aalenian (Opalinum and Comptum Subzones; Opalinum Biozones) and Middle Aalenian (Bradfordenis Subzone; Bradfordensis Biozone) marly limestones, providing more than 30,000 specimens of benthic foraminifera, which have allowed the study of the assemblage composition and the analysis of their evolution throughout this time interval.

The assemblages' composition, the estimation of the relative taxa abundances and the data obtained from the calculation of several diversity indexes, together with the previous sedimentological and paleontological works, has permitted the recognition of *Astacolus dorbignyi* as index species for the studied stratigraphic interval, allowing accurate correlations with other North European basins. On the other hand, first occurrences, last occurrences and changes in relative abundances of taxa allow the recognition of some events displaying relevant biostratigraphic significance.

By analysing the relative abundances of apparently homogenous assemblages, three types of assemblages can be recognized:

- Assemblages developed in distal facies of shelfal basin environment (Murtinheira);
- Assemblages developed in transitional facies from internal to distal facies of shelfal basin environment (S. Gião, Maria Pares);
- Assemblages developed in internal facies of shelfal environment (Zambujal de Alcaria).

The diversity indexes results show that the assemblages' composition have changed throughout the studied time interval, ranging from instable conditions (Mactra Subzone-Lower Opalinum Subzone) to stable conditions (Upper Opalinum Subzone-Comptum Subzone).

The biostratigraphic and palaeoecological data resulting from this approach can represent a proxy to determinate both age and depositional environments assigned to core samples analysis from the Lower-Middle Jurassic boundary of the Lusitanian Basin.

Tectono-Stratigraphic relationships in the Palestina Graben, Araripe Basin, NE Brazil

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* Support *Bacias Interiores* Project, PETROBRAS/UFRN

The breakup of Western Gondwana, leading to the opening of the South Atlantic ocean, migrated northwards and reached NE Brazil by the end of the late Jurassic period. Along the continental margins, the first stages of this are underlain by a thick cover of the main rift stage (Hauterivian to early Aptian), followed by younger deposits of a late rifting and the drift stages. The Interior Basins province, in northeastern Brazil, samples an aborted branch the starting stage of the Neocomian rift, along the so-called *Cariri-Potiguar* Trend. The Araripe Basin, well known by its well preserved post-rift, aptian fossil records, rests on the neoproterozoic terrains of the Transversal Zone, Borborema Province, immediately to the south of the Patos strike-slip shear zone. This basin consists of a set of NE-trending asymmetric grabens and horsts filled with neocomian rift deposits overlying a pre-rift section of jurassic and early Paleozoic ages.

The Palestina graben, located in the eastern portion of the Araripe Basin, presents a half-graben geometry controled by the NW-trending extensional eocretaceous strain. Its SE border behaves as a flexural margin; the sedimentary pile is affected just by normal faults with small displacements. The eopaleozoic Mauriti Formation sandstones unconformably rests upon the Precambrian crystalline basement. The tectonic setting of the Jurassic sequence is still debatable, either as a pre-rift or the beginning stage of the Neocomian rift. Its deposits (the Brejo Santo Formation) originated in a distal floodplain related to ephemeral drainages, outcropping along the adjacent horst or at the SE border of the graben. The Rift sequence starts with the Missão Velha Formation, whose lower section is related to a braided to meandering fluvial system. Previously and still regarded by many authors as a pre-rift unit, its paleocurrent system controlled by the rift compartments, and the tectonic signature of synlithification deformation bands, lead to assign it to a Rift Initiation tectonic systems tract. The upper section of the Missão Velha Formation is separated from the latter by a major unconformity; this interval was originated by a braided fluvial system. Finally, the younger Abaiara Formation represents a deltaic system fed by a meandering fluvial system. The latter two units correspond to the Rift Climax tectonic systems tract.

The NW border of the graben is marked by normal faults with major displacements that control the general tilting of the layers to the NW. The interpretation of gravity data and a seismic line indicates that the main fault has a variable dip slip component, defining two deeper portions within the graben, in which the sedimentary column can reach thicknesses of up to 2 km. The NE-trending normal faults define an arrangement with penecontemporaneous E-W-trending strike-slip faults with sinistral shear sense. Both systems are controlled by the trend of the basement, Precambrian shear zones. An overall NW extensional regime of the rifting is locally combined modified by a transtensional deformation along the faults.

The thermal history and hydrocarbon source rock potential of the mid Carboniferous Quebradas Formation in SW Portugal and its correlatives in western Atlantic offshore basins

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The mid Carboniferous Quebradas Formation of the 'South Portuguese Zone' (SPZ) comprises 80m of post-mature black mudrocks with a mean TOC of 2.5% (based on 65 analyses). The TOC of this unit when within the oil window is estimated to have been *ca.* 3 – 4%. Lithostratigraphic units of similar facies and age such as the Holywell Shale, the Edale Shale and the Bowland Shale are important HC source rocks in the UK, having sourced a considerable proportion of the hydrocarbons in the East Irish Sea, East Midlands and Formby oilfields respectively. Palynofacies analysis of samples from the Quebradas Formation indicates a mixed kerogen content but slightly more oil-prone in its lower part.

At outcrop, the Quebradas Formation is strongly post-mature with vitrinite reflectance (R_r) *ca.* 4%, as it presumably also is throughout the SW part of the SPZ, where it is overlain by a thick sequence of post mature late Carboniferous turbidites, principally of the Lower – Middle Pennsylvanian Brejeira Formation. Illite crystallinity results from the Quebradas Formation and associated units suggest lower maturity than vitrinite reflectance. This is fully consistent with a short-lived thermal event, rather than gradual temperature increase during 'normal' burial. Analysis of the optic fabric of very thin coal lenses within the Brejeira Formation suggests that peak temperatures were attained before the Variscan (late Carboniferous – early Permian) deformation that has strongly affected the Carboniferous succession. This evidence restricts the age of the thermal event that has produced the high maturity of the Carboniferous to Moscovian – early Permian. Triassic rocks unconformably overlying the Carboniferous sequence are much less mature, with R_r *ca.* 1.2%.

Although the the Quebradas Fm has no HC source potential onshore due to its high maturity, Carboniferous rocks offshore may not have experienced the same extreme thermal history as the SPZ. The widespread distribution of mid Carboniferous black mudrocks throughout Western Europe suggests that these may be present in many offshore basins where Carboniferous rocks have been preserved.

Seismic stratigraphy and numerical basin modeling of the southern Brazilian margin (Campos, Santos, and Pelotas basins)

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An integrated approach of sequence stratigraphy, inverse-basin and forward stratigraphic modeling have been carried out on three seismic reflection profiles (~320 km each) in the Campos (CB), Santos (SB) and Pelotas (PB) basins, offshore Brazil. 21 calibration wells provided lithologic, bio-/chronostratigraphic ties for the Barremian-Holocene basin fill. Main results for each of the studied basins include: (i) twelve to fourteen seismo-stratigraphic units (3-50 m.y. of duration), containing smaller-scale stacking patterns and key stratigraphic surfaces; (ii) six subsidence trends (ST1 to ST6) controlling the Barremian-Holocene basin development; (iii) genetic subsidence model in time (thermo-tectonic, flexure and compaction components); (iv) processes controlling accommodation space: subsidence, eustacy and sediment supply; (v) impact of basin evolution stages and plate-tectonic reconfigurations on basin architecture: Barremian syn-rift, Aptian syn-rift sag in the CB, SB or post-rift in PB, and Middle Albian-Holocene drift. Forward modeling simulates the basin development and quantifies physical factors controlling sediment deposition. It incorporates a set of parameters (lithologies, ages and geometry of seismic units, flexural rigidity, eustatic sea-level, tectonic subsidence and sediment supply from inverse modeling), which allow to predict distribution of lithofacies, clastic and carbonate sedimentation rates, changes in sand/shale ratio, erosion and sediment transport.

After Barremian syn-rift brittle extension had ceased (subsidence trend ST1), depth-dependent lithospheric extension in the CB and SB controlled the syn-rift sag stage (trend ST2). Fault-bounded depocenters expanded; lacustrine environments evolved to salt basins in the Late Aptian, prior to continental break-up. In the PB, Barremian syn-rift volcanism (SDRs) and crustal thickening preceded post-rift Aptian clastic progradation in open marine environments. During the Late Cretaceous drift stage (ST3), decreasing subsidence characterized the thermal phase of "passive margins". Long-term retrogradation in the CB, PB contrast with progradation in the SB led by higher sediment supply. In the Tertiary (ST4-ST6), flexural subsidence controlled changes in accommodation space. Subsidence/uplift trends are highly variable between basins and along the shelf-basin transition. These variations are related to changes in sediment flux and resulting accommodation, linked to far-field stress and thermal re-adjustments of the crust. Salt deformation in the CB, SB was also a major control on sedimentation patterns. In the PB, the salt succession is absent; the basin development was largely controlled by differential flexural subsidence. In order to obtain a consistent model, simulated distribution of lithofacies and sedimentary processes are compared with initial qualitative sequence stratigraphic model, and inverse modeling results.

Density and depth distribution of serpentinised mantle on the Iberian, Newfoundland and Nova Scotia margins from comparison of seismic and gravity inversion Moho depths

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Basement sampling and geophysical studies reveal exhumed serpentinised mantle between thinned continental crust and basaltic oceanic crust in the continent-ocean transition zones (COTZ) of magma-poor rifted margins. Exhumed serpentinised mantle, of width 80 to 200 km, are believed to exist at the COTZ of Iberia, Newfoundland and Nova Scotia margins. We have made estimates of the density of serpentinised mantle at the Iberia, Newfoundland and Nova Scotia margins by comparing seismic and gravity inversion Moho depths for these margins. Seismic Moho estimates for IAM 9, SCREECH 3, SMART 1 and SMART 2 were used.

Within the COTZ of these margins, where serpentinised exhumed mantle is believed to exist, the reconciliation of seismic and gravity inversion Moho depth requires a mean density of serpentinised mantle of between 3000 and 3100 kgm^{-3}. These densities are consistent with seismological estimates of serpentinisation with depth for IAM 9 (Iberian margin) from Cole et al. (2000) and Skelton et al. (2005). The proposed density-depth relationship for serpentinisation on IAM 9 shows a surface layer of complete serpentinisation of thickness 1 – 1.5 km, beneath which serpentinisation decays exponentially with depth reaching approximately 5% at 5 km depth. The best fit between serpentinised mantle density determined by comparison of seismic and gravity Moho depth, and the parameterisation of Skelton et al. (2005), is achieved assuming a magnetite content of 4.5%. The average densities of serpentinised mantle determined from comparison of seismic and gravity Moho depths for SCREECH 3, SMART 1 and SMART 2 are also consistent with the serpentinisation-depth relationship determined for IAM 9.

This work suggests that average densities of serpentinised mantle are greater than that of continental or oceanic basement unless serpentinisation is shallower than 3 km depth, and that little serpentinisation occurs deeper than 5 km in which case the average density of serpentinised mantle is 3000 and 3100 kgm^{-3}. We believe that this work also suggests that it is unlikely that significant serpentinisation occurs under thinned continent crust at the COTZ, and that in any case, if it did occur, it would be denser than continental basement unless the crust was thinner than 3 km.

Diagenesis and Provenance of the sandstones of Rifte Tectonosequence of Araripe and Rio do Peixe basins, NE Brazil

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Diagenetic and provenance studies of sandstones belonging to the Rift Tectonosequence of the Rio do Peixe and Araripe basins. These basins are located in the interior of Northeast Brazil aligned along the *Trend*-Cariri Potiguar. Their origin is related to the Early Cretaceous rifting event. In terms of lithostratigraphy, the studied section corresponds to the Antenor Navarro, Sousa and Rio Piranhas formations of the Rio do Peixe Basin, and the Missão Velha and Abaiara formations of the Araripe Basin, outcropping in the central-west Cariri Valley.

A facies analysis was performed and identified nine distinct sedimentary facies for the Rio de Peixe Basin and ten sedimentary facies for the Araripe Basin, individualized according to the different rock types and their sedimentary structures. These facies associations to led paleoenvironments interpretations and their vertical succession allowed understanding the evolution of the depositional setting during the cronostratigraphic interval studied in these basins. Based on petrographic and diagenetic studies it was possible to characterize the texture and mineralogy of these sandstones, identifying their diagenetic stage and the grain framework provenance.

The petrographic study allowed to classify the lithotypes studied in both basins as quartzarenites. Such quartzarenites, in general, are rich in quartz, feldspar and lithic fragment grains, and at accessory levels tourmaline, sphene, zircon, epidote and other mineralogy. The diagenetic history of the studied rocks proved to be very complex, being characterized by a variety mineral of phases that succeeded each other during the eo, meso and telodiagenetic stages. According to the studied formation and the textural and compositional aspects of the rocks, some processes were more or less active, while others were even absent. The eodiagenetic stage is marked by mechanical infiltration of clays and early mechanical compactional processes. The mesodiagenetic phase is characterized by continuity of the mechanical compaction and the beggining of chemical compaction, with quartz and feldspar overgrowths, precipitation of kaolinite, alteration of framework grains to chlorite and illite, and finally, precipitation of opaque minerals. The telodiagenetic stage is represented by the oxidation of some grains, matrix and cements.

For the provenance analysis of the studied sandstones were used ternary diagrams whose vertices correspond to the percentage of quartz, feldspar and lithic fragments. This study allowed identifies the source area of these rocks as continental blocks. It was also possible, based on the chemical stability and mineralogical maturity of the rocks, recognize that the Antenor Navarro Formation of the Rio do Peixe Basin, and the upper section of the Missão Velha Formation of Araripe Basin have less maturity and stability when compared with the other studied formations. This information allowed associate the studied formations in each of the basins to specific stages of evolution of the rift stage.

Morphostructure of the S. Vicente Canyon, Marquês de Pombal Fault and Pereira de Sousa Fault (SW Iberia margin)

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The S. Vicent Canyon (SVC), Marquês de Pombal Fault (MPF) and Pereira de Sousa Fault (PSF) are located along the SW Iberian margin. The SVC appears to be controlled by the S. Vicent Fault (SVF), a steep NE-SW striking fault that outcrops along the southeast flank of the canyon, and possibly is the submarine prolongation of the 600 km long Odemira-Ávila fault..

The NNE-SSW trending MPF and the N-S trending PSF acted both as extensional faults during the Triassic-Early Cretaceous tectonic rifting phases of the North Atlantic Ocean in West Iberia. During the Late Cretaceous-Paleogene and the Neogene, this margin underwent two tectonic inversions related to the Alpine orogeny. The MPF was inverted as a thrust-fault, whereas the PSF continued to act as a normal fault.

The SVC, MPF and PSF area is characterized by moderate seismicity (magnitude events of M~5.0). However, higher magnitude historical and instrumental events have been recorded, such as the 1755 Lisbon tsunami and earthquake (estimated magnitude of 8.5 to 8.9) and the 1969 earthquake (Ms=7.9). Epicenters distribution shows a cluster in the SVC area attesting for the seismogenic and tsunamigenic potential of this sector of the SW Iberian margin

In order to better understand the SVC, MPF and PSF structures, the Meso-Cenozoic morphostructural evolution of this sector of the SW Iberia margin and the possible connection to present day seismicity it is necessary to identify the main tectonic phases from the Mesozoic up to Plio-Quaternary. To attain this objective, the main regional structures were mapped using 2D seismic lines and multibeam swath bathymetry data (SWIM compilation, as published by Zitellini et al., 2009). Although seismic data doesn't have the same detail and accuracy as the swath bathymetry, both interpretations are coherent and complement each other.

The integration of two surveys increased spatial coverage of this sector, allowing the mapping of the northern prolongation of PSF and the identification of faults that don't reach the sea floor. The MPF, SVF and PSF, with recent displacements, were confirmed as the responsible for the major morphostructures of this sector.

Mechanisms for Asymmetric Lithospheric Extension and Implications for the West Iberia-Newfoundland Conjugate Margins: A New Perspective from a Self-Consistent Asthenosphere-Lithosphere Numerical Model

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We use a finite-difference based, combined Lagrangian-Eulerian, thermo-mechanical numerical modelling approach to investigate some general conditions under which passive (rift or Atlantic-type) continental margins asymmetries may develop, and model the geodynamic evolution of the West Iberia-Newfoundland conjugate margins. In contrast to previous models of rifting, the present model maintains a self-consistent thermo-mechanical coupling between the "rigid" lithosphere and the convecting sub-lithospheric mantle during rifting. This is particularly relevant when modelling the long-term evolution of rift margins (10's to 100's of m.y.).

Two approaches have been successfully applied to generate regional-scale asymmetries during rifting: (1) a variable rift velocity (or several stages continental rifting) in a laterally uniform layered lithosphere; and (2) a pre-existing, weak detaching, dipping layer. The models predict, however, a distinct structural and tectonic framework associated with each of the mechanisms. Moreover, we found that the complex feed-back between the convecting asthenosphere and the stretching crust and lithosphere introduces a considerable degree of randomness in the rifting process, which may explain the strong segmentation observed along strike some well studied Atlantic-type margins.

In the case of the West Iberia-Newfoundland conjugate margins, a relatively simple, east-dipping detachment-like model is in excellent agreement with the observations. The model predicts both the prominent asymmetries associated with the early stages of rifting, when much wider and sediment rich basins formed on the Newfoundland side (e.g. the Jeanne d'Arc Basin), and the differences in the structural style and amount of post-rift subsidence observed in the distal margins. The proposed simple-shear model implies that the West Iberia Margin formed as an upper-plate conjugate, in contradiction with most conceptual models proposed to date.

Finally, the models show that by accounting for small-scale convection in the asthenosphere, with ongoing mass exchange and syn-rift erosion at the base of the lithosphere, depth-dependent stretching is pervasive and an intrinsic characteristic of the rifting process. We address the implications for the long-standing "upper plate paradox" and the thermal structure of rift margins.

Salt Tectonics and Sub-salt Exploration Plays in the Essaouira Basin, Morocco

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The Essaouira Basin forms part of the main Moroccan Salt Basin of the Central Atlantic Province. The salt is interpreted to have been deposited at ca. 200 Ma, as there are CAMP volcanics above and below the salt. The salt was particularly mobile in this basin, with large allocththonous sheets extruded, which are 1-2 km in thickness, and extrude up to 20 km away from vertical feeders. Sheet extrusion mainly occurred in the early Upper Cretaceous ca. 85 to 95 Ma. The salt canopy itself is interpreted to be folded on a wavelength of 10 km and amplitude of 700m, with a sediment cover of approximately 1.5 km of growth strata above the salt. This folding phase took place from late Oligocene? to Miocene times, and through to present day. The sea bed is folded, but is also undergoing extensional collapse where the sea floor has oversteepened. The recent folding has blown a lot of the shallow anticlinal traps and pre-salt targets are particularly attractive where the top seal will have remained intact.

There is a perceived lack of reservoir potential in the deep salt basin, after two recent dry holes. However, new seismic data has been acquired with a 10 km long streamer length and this has enabled very good imaging below the complex allocththonous salt sheets. We have identified several important channel input points which contain pre-Santonian sandstones. These reservoirs have undergone later folding below the allocththonous salt sheet. Numerous truncation and sub-salt anticlinal traps have been identified, and the basin is considered to have good potential for a working Jurassic (oil)-Early Cretaceous (reservoir) petroleum system. We will show some high quality seismic images of the pre-salt play, which has yet to be tested.

Initial rifting and break-up between Nova Scotia and Morocco: An examination of new geophysical data and models

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The margins off Nova Scotia and Morocco began forming during Late Triassic rifting and Middle Jurassic separation of the North American and African plates. Initial rifting formed small rift basins bounded by long, sinuous faults. Thick salt deposits accumulated in these early rift basins, later deforming younger sequences as the margins evolved. Images of deeper crustal structure show that faulting style and basin geometry vary along the margin, and beneath the central and northeastern Scotian margin the continental crust was thinned by up to 50% over 150 to 200 km distance prior to breakup and initiation of sea floor spreading. Thermal subsidence of the Scotian margin was also greater to the northeast, resulting in a thick (in excess of 10 km) post-rift succession and numerous salt structures that obscure basement and deeper structure.

Determining the nature and timing of rifting between Morocco and Nova Scotia has proved challenging. The margin to the south of Nova Scotia has clearly recognized characteristics of a volcanic-style rifted margin, including seaward dipping reflector (SDR) sequences that are interpreted as rift-related volcanic flows overlying basement. These SDRs are coincident with a strong linear magnetic anomaly, the East Coast Magnetic Anomaly (ECMA), which shares many characteristics with the West African Coast Magnetic Anomaly (WACMA). Seismic evidence for these reflector sequences is absent along most of the Scotian margin, and the magnetic anomalies on the Nova Scotia and Moroccan margins change character and fade in amplitude midway along the margins. The nature of the ECMA and WACMA is regarded as being critical to understanding the nature of rifting. Modelling of a new compilation of magnetic data is one approach being used to explain the source of the anomalies and the variations in rifting character along the margin. Other evidence, ranging from geophysical (gravity, magnetics, reflection and refraction studies) to geological (volcanic age dating, salt deposition, and Triassic/Jurassic stratigraphy) is also being evaluated to garner insight into the early stages of rifting and break-up.

The new interpretations and supporting evidence are being used to develop revised models for the early rifting between Nova Scotia and Morocco in order to provide a better framework for predicting palaeo environments and heat flow during the rifting process, both critical to understanding the hydrocarbon prospectivity.

Waveform tomography applied to long streamer MCS data from the Scotian Slope, offshore Eastern Canada

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Conventional seismic imaging of complex margin structures such as salt diapirs, mass transport deposits and sequence boundaries at the edge of the shelf is often challenging even using the most advanced techniques. Determining the nature of sediment reflectors is also of great importance for exploration purposes and requires imaging beyond reflection. Waveform tomography, which uses both phase and amplitude of the seismic wavefield, is a method that can produce high resolution velocity fields if refracted waves propagating through the target structures are recorded. Modern marine acquisition with long streamers now offers the ability to record far offset arriving refracted waves at great density using uniform sources. We use 2D MCS data acquired with a 9-km-long streamer over the Nova Scotia Slope in water depths of ~1600 m. Using a frequency domain acoustic code over frequencies from 10-25 Hz on two crossing profiles (45 and 30 km long), we detail how the limited refracted waves can constrain the velocity field above the depth of the turning waves (~1.5 km below seafloor).

Velocity inversions are particularly well resolved above the 1500 mbsf limit, where the high resolution velocity field also matches the lithology very closely and velocity models are consistent at the crossing point between the two tested profiles. Several important features are resolved by the waveform velocity model, which are not present in the initial travel-time model. In particular, a small increased velocity layer (<100 km/s) due to gas hydrates is imaged along the entire profile even where a characteristic BSR (Bottom Simulating Reflector, marking the thermal stability of hydrates) is not visible. Imaging gas hydrates continuously where the BSR cannot be identified by reflection imaging allows better estimates of the total volume of hydrates, important for their potential impact on climate. The depth of the BSR can also be used to estimate heat flow, information of potential importance for estimating petroleum system maturation in frontier areas.

The 'slope detachment zone' on the western Scotian Slope, offshore Nova Scotia: structural style and implications for margin evolution

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Regional 2D and 3D seismic mapping efforts reveal a ca. 350 km long structurally distinct region that runs parallel to, and outboard of, the Jurassic carbonate bank on the central and western parts of the Scotian Slope, offshore Nova Scotia. This region, defined here as the 'slope detachment zone' (SDZ), covers an area greater than 13 000 km2, is ca. 35 to 55 km wide, and is characterized by the distinct absence of allochthonous salt diapirs in present day water depths generally between 500 to 2500 m. Because it encompasses roughly 30% of the total area of the Scotian Slope in water shallower than 2500 m, improved understanding of this structural domain is of significant economic and academic interest (in terms of understanding deep water petroleum systems and margin evolution). The landward edge of the SDZ corresponds to the structural hingeline that parallels the Jurassic carbonate bank, separating a relatively stable platform to the north from significantly attenuated continental crust to the south; its distal limit, as defined here, corresponds to the landward edge of the 'slope diapiric province' comprised dominantly of allochthonous salt diapirs. Within the SDZ, strong decoupling is recognized between the structural styles above and below a seismically amorphous interval interpreted as a thin autochthonous salt layer. The deformation style above this layer (and its associated primary weld) is dominated by raft tectonics and associated thin-skinned detachment. Jurassic strata are commonly offset along low-angle listric growth faults that sole out in autochthonous salt. These faults define the headward parts of detached 'slabs' of Jurassic strata, and can be correlated laterally into distinct shear zones that define the edges of rafted blocks. Parts of the Jurassic carbonate bank foundered in a similar manner. In the southern parts of the SDZ, there is an increased tendency toward contractional structures, including detachment folds, reverse faults and thrust faults. Such structures continue into the 'slope diapiric province' to the south. Several scenarios could explain the distinct lack of allochthonous salt diapirs in the SDZ. However, there is little evidence to suggest that much salt moved seaward from the SDZ during sediment loading and detachment. Rather, significant sediment down-building took place along the southern boundary of the SDZ in the Jurassic and Cretaceous, accommodated by salt withdrawal along the landward edge of the 'slope diapiric province'. Hence the transition from the SDZ to the 'slope diapiric province' probably corresponds to a seaward increase in the original thickness of autochthonous salt in present day water depths >2000 m. The SDZ is therefore interpreted to coincide with the onlap edge of the original autochthonous salt basin and development of extensional and contractional structures is believed to have been prompted by tilting of autochthonous salt layer during Jurassic thermal or mechanical subsidence after continental break-up.

Offshore Nova Scotia: basin framework of the slope diapiric province

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Integration of ION-GXT's long-offset, long-record seismic reflection data (NovaSPAN™) with 2D gravity and magnetic models, as well as seismic refraction results from published sources, in the slope diapiric province of offshore Nova Scotia indicates a region of thin crust beneath the salt basin. Our results suggest that: 1) crystalline crustal thicknesses range between 5 and 12 km, 2) a prominent basement ridge bisects the region of thin crust, and 3) this region is roughly 60 to 100 km wide and appears to be offset between oceanic fracture zones.

A first order sequence stratigraphic interpretation of the supra-crustal interval across the outer shelf and into the deep basin shows a 2 to more than 16 km thick predominantly clastic aggradational wedge with interspersed Jurassic and Cretaceous carbonates and salt. Carbonate deposition, salt deformation, and tectonic setting across the Scotian margin suggest variable and highly dynamic structural basin styles and depositional environments throughout the Jurassic and Cretaceous. The meso- and deep crustal data show the Moho consistently dipping westward from circa 5 km below the "oceanic" crust to below 30-35 km beneath the continental crust. Furthermore, complex internal yet poorly understood structuring is evident throughout the deep crustal sections.

Recent tectonic interpretations, supported by seismic reflection and refraction data, suggest that the north-eastern part of the Nova Scotia salt basin is underlain by unroofed and hydrated upper mantle rocks. Consistent with these interpretations, our work indicates that the crystalline crust of this part of the basin is markedly different from that of the crust to the southwest. However magnetic data over Nova Scotia and its conjugate margin, Morocco, are characterised by prominent anomalies. If these sets of anomalies indeed are conjugates, then this implies that the thin crust may be oceanic.

Geophysical data suggest that the crust beneath the Scotian salt basin might be hyper-extended continental crust, oceanic crust, or unroofed and hydrated upper mantle. The presence of a salt basin over basement structuring suggests to us that salt deposition occurred over thinned continental crust that was deformed during rifting, however this interpretation may be modified with further work aimed at understanding the character of deep crustal reflections.

Development of synrift tectonic domains in the South Atlantic salt basins: comparison of extension implied by plate reconstruction with observations from regional seismic data

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The Brazil and West Africa salt basins were formed during the final stages of the rift to drift transition in the South Atlantic. Study of these salt basins has recently been greatly enhanced by ION/GXT's acquisition of nearly 40,000 km of high-quality, deep penetration 2-D seismic data. These data were processed using pre-stack migration to produce depth sections that give a unique view of the crust in this highly extended domain. This extension can be quantified using plate reconstructions of the South Atlantic that incorporate all potential field, geologic and regional data. Combining constraints on the amount and timing of extension from the plate reconstruction with meso-crustal imaging using the seismic data allows definition of several structural provinces with differing expressions of how extension was accommodated. Total extension varies along the conjugate margins, ranging from 200 km between northern Gabon and Sergipe Alagoas to more than 500 km between southern Angola and the Santos Basin. This means, for instance, that there was 500 km of motion between South America and Africa before the Santos was completely formed, i.e. before onset of sea floor spreading. Comparison with other areas of large-magnitude extension such as the Basin and Range in North America and the Iberia-Newfoundland rift in the North Atlantic are useful for understanding how such large amounts of extension could have been accommodated on the South Atlantic margins. Structural provinces include areas of significant volcanism where crust is entirely igneous, domains with large-magnitude extension accommodated by low-angle normal faults, areas of continental thinning resulting from faulting that cut through the entire crust, and areas where extension has possibly resulted in exhumation of lower crust or, in places, even mantle. The areas of low-angle normal faulting are significant because they also include thick pre-salt sedimentary basins that are proving to be significant hydrocarbon provinces. The edge of salt is in many areas a pronounced topographic escarpment, stepping up from extended crust to oceanic crust, with up to 2 km of relief in places. Salt was the final influence on some of the structuring, especially formation of these escarpments which we interpret as the isostatic consequence of deposition of thick salt on extremely thin crust.

Morphologies and emplacement mechanisms of the lava flows of the Central Atlantic Magmatic Province (CAMP) of Morocco

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The Late Triassic-Early Jurassic volcanism of Morocco comprises four Lava Flow Fields or formations, all emplaced into a subaerial environment during the development of an extensive Continental Flood Basalt province: the Central Atlantic Magmatic Province (CAMP). Eruption of CAMP basalts occurred at about 200 Ma on four continents and preceded the disruption of Pangea and the opening of the Central Atlantic Ocean. The Lower Formation is 55 to 173 m thick and corresponds to a succession of 2 to 9 individual flows. The Intermediate Formation reaches a maximum of 130 m and is composed of an eruptive sequence of 2 to 9 individual flows. The Upper Formation, with thickness varying from 15 to 76 m, is formed of one or two lava flow units. The Recurrent Formation is 5 to 50 m thick and is present only in the Central High Atlas as a single flow. The boundaries between these formations are marked by sedimentary levels (siltstones, sandstones, stromatolitic limestones) and paleosols that represent minor periods of volcanic inactivity. In most basins, the total thickness of the volcanic pile is 100 to 200 m. However, it may be as thick as 350 (as in the southern flank of the Central High Atlas), or just 8 to 50m in inter-basin areas. The CAMP lava Flows of Morocco can be grouped in two major categories: "compound pahoehoe flows" and "simple flows". The former category is found almost exclusively in the Lower and Intermediate Formations, while the second category dominates the Upper and Recurrent Formations. The larger lobes (and many smaller ones too) that form the compound pahoehoe flows display a characteristic three-tiered structure with a thin "basal lava crust", a dense "lava core", and an "upper lava crust". The former is locally characterised by the presence of "tumuli", "squeeze up" and horizontal "squeeze" structures. The second category is found exclusively in the Upper and Recurrent Formations. The simple flows appear as simple cooling units, without multiple lobes. Some of them are characterised by "rubbly tops" or "flow-top breccia". The basaltic lava flows of Moroccan CAMP, particularly the compound pahoehoe flows of the Lower and Intermediate Formations, show excellent and unambiguous evidence of endogenous growth or "inflation". In this sense they are similar to inflated pahoehoe flows observed in Hawaii, on the basaltic provinces of the Columbia River, and Deccan. The remarkable thickness of some flows and the abundance of compound flows in the CAMP basalts of Morocco strongly suggest the hypothesis of a slow emplacement during successive sustained eruptive episodes instead of a fast emplacement. The structural observations of CAMP flows emphasize the need for physical volcanological studies in Continental Flood Basalt provinces. It is probable that such studies will reveal the similarities as well as differences in the styles of eruption of flows from different provinces.

Regional Setting of the Late Jurassic Deep Panuke Field, offshore Nova Scotia, Canada II: Part 1 - Distant and fractal analogues and possible process controls for a thick carbonate platform flanked by a large delta

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Deep Panuke, discovered in 1998, is the only carbonate gas field in the eastern North America continental shelf. This shelf margin reef complex pool occurs between the northeast contemporaneous Sable Island paleodelta prograding ramp shelf and the southwest aggrading carbonate platform. This juxtaposition of a thick continuous carbonate platform so close to a large delta is extremely rare in the geological record and was thought to be unique. However at least two analogues are possible. The utility of analogues is not exact duplication; rather similar patterns may help infer similar control processes and principles at work. This better understanding aids future exploration and exploitation.

From north to south, the Panuke pattern to match in the uppermost Abenaki (Latest Jurassic-early Neocomian age) is a large delta burying the shallow carbonates and passing laterally from prodelta shales to diachronous deeper sponge reefs to starved sediments (coated ironstone = 'iron oolite') on a drowned shelf to continued shallow platform oolite and coral reef growth. The fractal analogue (self-similar at different time and space scales) is the North American eastern continental shelf margin itself. The Jurassic gigaplatform is mostly buried in siliciclastics until the deep Blake Plateau that is thinly covered in starved sediment with major evidence of seafloor diagenesis (and even minor deep-water coral reefs) where shallow carbonates drowned in the Aptian but continue growing off Florida and in the Bahamas.

Some relevant process controls are northward plate tectonic drift (paleo-latitude/climate changes), erosive-inhibitory oceanic currents (Gulf Stream), subsidence and eustatic sea-level changes. The distant analogue in both time and space is the Neogene northern Great Barrier reef system in the Gulf of Papua with the large Fly River delta siliciclastics input that buried a drowned Miocene carbonate platform and southward the world's largest barrier reef continues growing. For varied time including to the present day, proximal shelf margin reefs and outboard atolls continued growing. One encased in deltaic clastics reservoirs the undeveloped Pandora reef gas pool.

Control processes on carbonate platforms involved are in long term – plate motions northward and subsidence; in short term – rifting (pre-existing topography), eustacy, climate (variations through Neogene), oceanography (for instance Miocene phosphate inhibition of reefs and particularly East Australian Current that swept deltaics northward from carbonates), collision (change from passive to active margin of Papua-New Guinea). Both these analogues have lessons to help understand the Abenaki platform-Sable delta juxtaposition. Differing sea-water chemistry of Neogene aragonitic seas versus Jurassic-Cretaceous calcitic seas (much greater oolite) is a key difference.

Late Jurassic Source Rock Super-Highway on Conjugate Margins of the North and Central Atlantic (offshore East Coast Canada, Ireland, Portugal, Spain and Morocco)

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In the past decade, offshore Atlantic Canada has become an important petroleum province producing from Late Jurassic-Early Cretaceous synrift structures associated with Pangea breakup and opening of the North and Central Atlantic. The region's offshore basins had a complex geodynamic evolution including Mesozoic extension, salt tectonism, subsidence and localized compression and exhumation that have created numerous hydrocarbon trapping styles.

The largest hydrocarbon discoveries were made during the 1979-1984 period, when drilling in the high-risk, high-cost Atlantic waters was stimulated by the Canadian federal government's Petroleum Incentive Program (PIP). Currently, 55646 m^3/d (350,000 bopd) are produced from three oil fields of the Jeanne d'Arc Basin offshore Newfoundland, while 12.7 MM m^3/d (450 MM ft^3/d) flow daily from the five gas fields of the Sable Subbasin offshore Nova Scotia. The Hebron giant oil field on the Grand Banks and the large Deep Panuke gas field on Nova Scotia shelf are future petroleum developments on the Canadian margin.

The most important ingredient of the Atlantic Canada's petroleum system is the presence of rich Kimmeridgian-aged source rock. Due to deposition in different paleogeographic conditions, it is predominantly a restricted marine source in the Grand Banks basins and a terrestrial derived one on the Scotian Shelf and Slope basins. Initially indicated by wildcat wells, seismic mapping and basin-to-basin correlations, the presence of Late Jurassic rock successions in other Newfoundland offshore basins (Flemish Pass, East Orphan basins) was recently confirmed by drilling. In the Flemish Pass Basin the 2003 Mizzen L-11 well has intersected a Late Jurassic source rock and discovered reservoired oil, while in 2008 the Mizzen O-16 well, drilled 10 km to the north, was recently declared a significant oil discovery. The 2007 Great Barasway F-66 well in the East Orphan Basin intersected a Late Jurassic sequence that might contain source rocks. A second deep water well Lona O-55 was spudded during spring 2010 in the Orphan Basin.

This proves that these two basins were part of the Kimmeridgian-aged source rock super-highway partially following the Atlantic rift trend connecting the Scotian Basin to offshore Newfoundland basins and extending into the Porcupine, Rockall Trough and Slyne basins, West of Ireland and from there into the North Sea and Norwegian Sea basins and subbasins. While not directly proven by drilling, it is hypothesized that arms of this Kimmeridgian Sea extended into the Carson and Salar basins on the eastern Grand Banks divergent margin and from there into the Iberia conjugate margin basins. Moreover, during the Late Jurassic prerift stage, arms of the sea may have extended into Labrador Sea basins situated now on the slope and deep waters of both the Greenland and Labrador margins.

Keys to further oil and gas discoveries on conjugate margins of the North and Central Atlantic are:

1. Reconstructing the paleogeography of the intra-continental rifting in the north and oceanic rifting in the south;

2. Identifying and mapping, with regional seismic grids, the Late Jurassic source rock super-highway; and

3. Characterizing and connecting source rocks to crude oil in discoveries, shows and outcrops and correlating along and across the Atlantic margins.

Organic Maturation and Source-Rock Potential of the Mesozoic Algarve Basin – Southern Portugal

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The Algarve Basin is an important Mesozoic depocentre in southern Portugal. It is located south of the Upper Palaeozoic rocks of the Variscan basement and mainly comprises Jurassic and Lower Cretaceous carbonate lithologies. The basin extends from Cape Saint Vincent in the west to the Guadiana River on the Portuguese-Spanish border in the east.

This sedimentary basin was initiated by rifting associated with the opening of the North and Central Atlantic Ocean, following the breakup of Pangea. Lateral changes in facies and subsidence across the Algarve Basin, allow its division into the Western, the Budens-Lagoa, and the Eastern sub-basins. These relatively small depocentres are separated by major regional faults which were probably active during deposition. Sedimentation in the Algarve Basin started with Upper Triassic continental red beds and evaporites which unconformably overlie Upper Palaeozoic strata. These Late Triassic strata are overlain by Early Jurassic (Hettangian) volcanic rocks associated with the Central Atlantic Magmatic Province (CAMP). Following this magmatic event, Sinemurian to Tithonian marine carbonate sedimentation became well-established across the Algarve Basin. The dominant lithofacies are shallow water limestones and cycles of pelagic marls and limestones. The Early Cretaceous is represented by a mixed clastic and carbonate succession, deposited in nearshore and terrestrial settings. During the Late Cretaceous, a major basin inversion event occurred, related to Alpine tectonism and the emplacement of the Late Cretaceous syenite of Monchique (72.5 Ma) into Upper Palaeozoic strata. Therefore, no Upper Cretaceous strata are present in the Algarve Basin. Sedimentation resumed during the Miocene with bioclastic limestones which unconformably overlie the Jurassic and Lower Cretaceous successions.

Vitrinite reflectance values measured from the Algarve Basin are all within the oil-window, ranging between 0,82%Rm and 1.29%Rm. In the Western sub-basin the general trend observed is a decrease in vitrinite reflectance as sections become younger: 1.17%Rm for the Upper Triassic, 1.14%Rm for the Pliensbachian and 1.07%Rm for the Bajocian-Callovian. This suggests that the maturation process for this part of the basin may have been related to burial. The exception to this is the anomalous high value measured for the Aptian marls of the Porto de Mós, with values of 1,14%Rm. This value is tentatively related to a local elevation of the palaeogeothermic gradient of the basin related to Upper Cretaceous magmatism. In the Eastern sub-basin a similar trend for the maturation was also detected: 1.12%Rm for the Callovian, 1.08%Rm for the Oxfordian and 1.06%Rm for the Kimmeridgian. However, a slight higher value of 1.11%Rm was recorded for the Kimmeridgian-Tithonian sucession.

TOC values recorded from marls and mudstones of the Algarve Basin vary remarkably with the age of the strata: 1.02% for the Toarcian, 0.06-0.81 for the Bathonian-Callovian, 0.06-1.77 for the Oxfordian, 1.08-1.17 for the Kimmeridgian, 0.02-0.54 for the Berriasian-Barremian and 1.08-2.27 for the Aptian Porto de Mós Marls. The samples from the Toarcian, Kimmeridgian and Aptian marls gave values always above 1% TOC indicating therefore a good source potential in terms of quantity of organic matter.

A re-assessment of the organic maturation and palynostratigraphy of the wells Ruivo-1 and Corvina, offshore Algarve Basin, Portugal

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The exploration wells Ruivo-1 and Corvina, located in the offshore Algarve Basin, Portugal, were drilled in the mid 70's. The material still available from both wells was studied in order to assess its organic maturation levels and age using the biostratigraphy of dinoflagellate cysts.

Ruivo-1

This well was a total depth of 2100 m and intercepted lithologies assigned to the Miocene at the top and Upper Triassic at the bottom. Ten samples were collected from marls and marly limestones, between 1715 and 2070 m depth, from the interval belonging to the Jurassic. The organic residues are abundant, and comprise well-preserved palynomorphs together with plant and wood fragments. The dinoflagellate cysts recorded from samples between 1800 and 2030 m include *Batiacasphaera* spp., *Ctenidodinium* sp., *Ctenidodinium sellwoodii* Grp., *Ellipsoidictyum gochtii*, *Ellipsoidictyum/Valensiella* grp., *Gonyaulacysta jurassica* subsp. *adect*, *Impletosphaeridium* spp., *Korytocysta gochtii*, *Meiorogonyaulax caytonensis* Grp., *Pareodinia ceratophora*, *Sentusidinium* spp., *Systematophora areolata*, *Systematophora penicillata*, *Systematophora* spp. and *Tubotuberella dangeardii*. These associations are indicative of the Middle-Late Callovian. Was also recorded the species Nannoceratopsis deflandrei subsp. deflandrei, that marks the interval Toarcian-Aalenian, that appeared reworked into the Callovian sediments. Vitrinite reflectance from the Callovian sediments are within the oil-window, ranging between 0.8 and 1.0%Rm.

Corvina

This well intercepted a 2700 m depth succession with Miocene sediments at the top and Jurassic sediments at the bottom. Twelve samples were collected between 1595 and 2680 m depth, that yielded relatively abundant organic residues dominated by dinoflagellate cysts. Miospores observed include bisaccate pollen, *Callialasporites dampieri, Callialasporites turbatus, Callialasporites* spp., *Classopollis classoides* and *Perinopollenites elatoides*. The dinoflagellate cyst floras from these samples are indicative of the ?Early/Middle Oxfordian due principally to the occurrence of *Ctenidodinium ornatum*, *Compositosphaeridium polonicum*, H*ystrichosphaerina orbifera*, *Endoscrinium luridum*, *Gonyaulacysta jurassica* subsp. *jurassica*, *Rigaudella aemula*, *Surculosphaeridium vestitum*, *Stephanelytron redcliffense*, *Systematophora* spp., and *Wanaea acollaris*. The vitrinite reflectance values from this thick Oxfordian succession are within the oil-window and range between 0.9 and 1.1%Rm.

Hydrocarbon generation potential of the Pliensbachian organic-rich series of Peniche (Lusitanian Basin, Portugal): An organopetrographic and thermal maturation assessment integrated analysis

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The purpose of this study is to characterize the hydrocarbon generation potential of the organic-rich facies from the Lumpy marls and limestones (LML) and Marly limestones with organic-rich facies (MLOF) members of the Vale das Fontes Formation (Fm.) and the base of Lemede Fm. in the Lusitanian Basin reference section of Peniche. More than 30 rock samples of marly nature, covering a stratigraphic interval of 47m in outcrop, were analyzed using organopetrographic observation (transmitted white light and reflected UV/blue light) and organic geochemistry, namely Total Organic Carbon (TOC) and selected ratios of molecular organic compounds by CG-MS techniques, H32S/(R+S) and H30/M30. Vitrinite Reflectance (R_o%) and Spore Coloration Index (SCI) were analyzed in 5 representative samples spread evenly in the entire studied interval.

TOC in the studied interval is generally high, reaching up to 26%. Organopetrographic observation shows that the studied section presents a diversified set of palynofaciological associations, with some very rich TOC layers characterized by high abundance of type II kerogen in the MLOF member. Kerogen in the LML member is generally a mixture of variable proportions of type II and III kerogens. The studied samples of the Lemede Fm. contain dominant percentages of type IV kerogen, the rest of it being subordinated to type III kerogen. Concerning thermal maturity parameters, Ro% ranges between 0.45% and 0.5% and SCI values ranging from 3 to 3.5, according to the standard Robertson Research UK® SCI reference scale. H32S/(R+S) and H30/M30 varies between 0.10 to 0.82 and 0.39 to 0.61, respectively.

As conclusion, the organic-rich facies of the Vale das Fontes Fm. show an elevated hydrocarbon generation potential in most of the samples analyzed, due to generally high TOC values and types of kerogen present, being the part of Lemede Fm analyzed the least hydrocarbon-prone interval of all the members and formations sampled. The thermal maturation indexes all fall in the immature range, observation that is in agreement with previous studies using other methodologies.

Insights into Crust Evolution during Continental Rifting and Initiation of Organized Oceanic Spreading– A Fresh Look at Newfoundland and Iberia Gravity, Magnetic, and Seismic Data

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Iberia-Newfoundland conjugate margins are being studied in detail using seismic reflection, refraction and Ocean Drilling Program (ODP) drill holes data. Ability to calibrate interpretation of geophysical deep-water data with ODP well data made Iberia-Newfoundland conjugates into a laboratory where passive continent margins are extensively studied. Multiple models of formation of the highly extended conjugate rifted continental margin are proposed. Models that incorporate sub-crustal detachments and upper mantle unroofing are most popular. In our paper we revisit existing models and propose modifications based on a new interpretation of regional reflection seismic and seismic attributes integrated with mega-regional coverage of new high resolution gravity and magnetic data. Based on our observations rooted into the data we offer a new understanding of distribution of crustal provinces formed during continental margin extension and oceanic spreading initiation along non-volcanic margin. Furthermore, a poly-phase crustal response to evolving far-field stresses has being recorded in regional gravity and magnetic data and is calibrated with seismic data in this study.

Diagenetic Processes and Porosity Evolution Controls in Upper Jurassic Siliciclastic deposits of the Lusitanian Basin (Portugal)

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Sandstones and conglomerates of Upper Jurassic intervals of the Lusitanian Basin were studied in the attempt to quantify effects of diagenetic processes on their porosity evolution and reservoir properties. Samples were taken mainly from outcrops and also from wells and represent fluvial and turbidity deposits, related with coastal or transitional siliciclastic and carbonate environments.

The framework compositional plots of the Upper Jurassic sandstones reveal considerable variations between different areas in the basin. The framework grains are composed predominantly of plutonic rock fragments (granites, gneisses, schists and philites) common in the coarse proximal deposits.In some sandstones, carbonate rocks fragments (calcilutite and oolitic or bioclastic calcarenites) are present and are interpreted as resulting from intrabasinal erosion of exposed older carbonate platforms. The studied sandstones contain mainly secondary porosity. The average total porosity ranges from 3,35 to 13,7%. Total macroporosity is higher in the non-hybrid sandstones and lower in the hybrid sandstones. Macroporosity resulted from grain dissolution and intergranular secondary pores have also resulted from the partial to pervasive dissolution of carbonate cements.

The paragenetic sequence and porosity evolution pathways of the Upper Jurassic sandstones of the Lusitanian Basin were controlled by multiple factors that include variations in the sedimentary facies, climatic conditions and burial history. Fast burial history resulted in paragenetic sequences with strong compaction processes and important porosity destruction. The more extensive eogenetic carbonate cementation in the slow burial history sectors may have played a role in the preservation of higher porosity and intergranular volumes. Porosity enhancement by carbonate cement dissolution, due to telogenetic meteoric influx into the reservoirs of these sectors, could be significant compared to other sectors.

The best reservoirs of the studied Upper Jurassic siliciclastic rocks occur in non-hybrid sandstones and in slow buried sectors, where porosity was early cemented and enhanced by dissolution of carbonate cement during telogenetic influx of meteoric waters.

Spreading evolution of the Norway Basin and implication for the evolution of the Møre rifted margin and its intermediate conjugate system (the Jan Mayen microcontinent)

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The Norway Basin is an aborted oceanic basin formed during the onset of breakup between Norway and the coupled Greenland/Jan Mayen conjugate system in Early Tertiary (~55 Ma ago). The early history of the Norway Basin is traditionally characterized by a first phase of continental breakup resulting in the formation of volcanic margins observed on the mid-Norwegian and Faeroes margins and the proto-Jan Mayen microcontinent, still attached to Greenland at that stage. Around Oligocene time, sea-floor spreading along the Aegir Ridge decreased until it became extinct and the spreading axis "jumped" westwards to initiate the Kolbeinsey Ridge. The relocation of the spreading ridge from the aborted Aegir Ridge to the Kolbeinsey Ridge resulted in the complete separation of the Jan Mayen microcontinent from the Greenland Plate around 25 Ma ago. Based on a new aeromagnetic survey, we reevaluate the structure and spreading evolution of the Norway Basin from the continental oceanic transition region to the extinct Aegir Ridge and propose a more complex geodynamic history. Our interpretation documents a transform margin, an orthogonally rifted segment and an oblique-shear volcanic margin formed during the onset of breakup between the East Jan Mayen Fracture Zone and the Faeroe Plateau. The detailed fabric of the Norway Basin documented by the new data also indicates that two distinct tectonic phases have reshaped the basin before the cessation of seafloor spreading and abortion of the Aegir Ridge in Late Oligocene. After continental breakup, a phase 1 (from 52 to 48 Ma) marks the earliest phase of spreading probably initiated in the central part of the Møre margin. During that period, competing oceanic segments lead to the formation of overlapping systems and pseudo-fault development. We observe a significant change in the Norway Basin's oceanic spreading system in the late Early Eocene and, based on observations from surrounding areas, we suggest that this marked a major tectonic event in the Norwegian-Greenland Sea. During phase 2 (48-28 Ma) of Norway Basin's development, spreading rates decreased, spreading direction changed, and the number of rigid faulting with large displacement increased leading to the formation of new N-S oriented oceanic fracture zones. The fan-shaped development of the spreading system was initiated around C21 (~48-46 Ma) instead of C18-C17 (~40-38 Ma) or C24 (53.3-52.3 Ma) as previously proposed. This new observation also allows us to reevaluate the tectonic calendar of the Norwegian-Greenland Sea and discuss some implications on the syn- and post-breakup development of the surrounding continental margins and the evolution of the Jan Mayen microcontinent.

Cenozoic sediment supply from Western Scandinavia to the Norwegian shelf and North Sea Basin

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The rates of sediment input to the North Sea and the Norwegian Shelf varied significantly during the Cenozoic. During Paleocene and Eocene times The Shetland Platform and Scottish Highlands were the main sediment sources, while with the onset of the Oligocene more sediment was coming from the Scandinavian shield. This is believed mainly to be a consequence of varying erosion rates and/or changes in sediment catchments in Western Scandinavia and has previously been interpreted in terms of variable tectonic uplift of the area caused by a hitherto unknown tectonic agent. During Paleocene to Early Eocene times tectonic activity related to the final stage of opening of the North Atlantic was apparently controlling the sediment input in the North Sea as sediment pulses correlate well with tectonic events. Although there is no signs of Cenozoic tectonic activity onshore Scandinavia (igneous bodies, faulting), tectonic disturbance related to ocean opening could be responsible for deposition of thick Paleocene wedges along the western coast of Norway. During subsequent Cenozoic periods domal structures in the Norwegian shelf are a proof for mild and protracted compression. However, depositional patterns from offshore Scandinavia have been interpreted as a result of significant tectonic movements. In the absence of proofs for active tectonic agents we attempt to explain these sediment input variations as a result of climate fluctuations. The Eocene-Oligocene greenhouse-icehouse climate transition corresponds to an increase of sediment yield from the Scandinavian shield. Furthermore, several studies show a correlation between climate fluctuations, sequence stratigraphic surfaces and lithological changes in the North Sea. We suggest that a rapid cooling at the beginning of Oligocene (Oi-1 glaciation) changed the erosional regime in western Scandinavia from fluvial (inefficient in tectonically stable settings, almost regardless of the amount of precipitation) to glacial. Glacial erosion is much more effective and is apparently able to outpace tectonic processes responsible for development of high topography. Therefore, a hypothesis of climate control on erosion and deposition during the Cenozoic history of western Scandinavia and adjacent sedimentary basins emerges. This theory is further supported by higher sediment input and pronounced progradation patterns of the Molo Formation (deposited during Late Miocene-Early Pliocene cooling) and the spectacular prograding wedges of Naust Formation (with onset of deposition at around 2.8 Ma, matching the Pliocene 'climate crash').

The combined effect of sedimentation rate and salt tectonics on the Angolan margin

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The Angolan margin is an excellent example of a passive margin affected by salt tectonics. Both the Lower Congo and Kwanza basins are heavily influenced by salt movement. The interaction between salt movement and sediment deposition leads to extensional and structural domains characterized by salt diapirs, faults and folds.

In this study, physical laboratory experiments are used to examine the effect of sedimentation rate on the development of extensional and compressional salt tectonic features. The experiments were done using sand and silicone to simulate respectively the brittle behavior of the sedimentary layers and the ductile behavior of the salt layer.

The results show that sedimentation rate has an effect on the extent of the extensional and compressional domains. Low sedimentation rates result in a wider extensional domain than high sedimentation rates. Structural styles within each domain also depend on the sedimentation rate. Diapirs and rollovers are abundant in models with low sedimentation rates, whereas trust faulting is primarily seen in models with high sedimentation rates.

Experiments with high, low, increasing and decreasing sedimentation rates have been performed and the structural styles are analyzed and compared with each other.

The laboratory models are compared with the sedimentary history and seismic data from the Lower Congo and Kwanza Basins to test if sedimentation rates can explain variations in structural style.

The presentation is part of a Licenciatura project and is presented by two students from University Agostinho Neto doing their internships at Statoil's sand box laboratory in Luanda.

Kinematic and thermal analysis of the rifted NW African Margin: A passive margin with an active post-rift stage

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The post-rift evolution of NW African margin is marked by a Middle Jurassic to Early Cretaceous km-scale exhumation of several domains onshore Morocco, while offshore, widespread Lower Cretaceous terrigenous clastics are found. Continental exhumation took place after the appearance of oceanic crust in the Central Atlantic (thermal cooling stage) and prior to the onset of the Atlas shortening. The exhumed domains, namely the Meseta in the North, the High Atlas, the Anti-Atlas, and the Reguibate shield in the south, were intensively eroded. They show an outcropping Precambrian to Paleozoic basement unconformably covered by reduced Upper Cretaceous to Quaternary succession. The eroded material was routed by fluvial systems and shed to the subsiding basins offshore.

To provide a quantitative kinematic analysis of the evolution of the rifted Moroccan margin, we present 3 crustal sections crossing the rifted Moroccan margin in the regions of Doukkala to the north, Tarfaya, and Dakhla to the south. The sections link the exhumed areas onshore to the subsiding basins offshore. We conduct basin and subsidence analysis to test quantitative relations between amounts and distribution of thinning, and related vertical movements.

The large-scale evolution of the NW African margin fit in the classical scheme of passive margin evolution. However, the kinematic and thermal evolution of the different basins and the comparison between the different sections show a more complex story, characterized by plyphase rifting, differential thinning of the lithosphere, anomalous exhumation phases during the post-rift triggered by shortening, and submarine deltas such as the Tan Tan Delta.

The role of mantle small-scale convection in vertical movements during the early post-rift stage of passive continental margins: The case of Morocco-Nova Scotia conjugates

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Small-scale convection cells resulting in convective removal of the mantle commonly take place at the base of the lithosphere during the evolution of rifted continental margins. It is invoked to explain patterns of vertical movements not directly justifiable with simpler, purely isostacy-based rifting models.

In this contribution we analyze the importance of small-scale convection during the formation of the Central Atlantic. Observations from the Morocco-Nova Scotia conjugate margins indicate a tectonic evolution characterized by polyphase rifting, regions of attenuated crust with depth-dependent lithospheric thinning, mantle exhumation prior to formation of a mature mid oceanic ridge spreading centre, and substantial deformation and uplift in the eastern part of the system during the early post-rift stage. We present a quantitative framework for the evolution of the conjugate margin system integrated with forward thermo-mechanical models of passive margin formation. Extension of the lithosphere is modeled using a 2-D plane-strain finite element method for viscous-plastic creeping flows. Features that are important for predicting the observed characteristics include: 1) slow rifting (0.5 cm/year) leading to an asymmetric geometry of extension, 2) exhumation of mantle lithosphere, and 3) Upper crustal deformation and exhumation in the post rift.

Models show exhumation of the margin in the order of 2 to 4 km magnitude and 10 to 100 km wavelength. Combining the modeling results and the constrains from the natural system, two alternative scenarios were proposed for the evolution of the Morocco-Nova Scotia conjugate margins:

(a) rifting of a cold and strong lithosphere system which exhume the mantle and produce a significant flank uplift in the syn-rift phase. In this case, the erosion of the resulting topography takes place during the post-rift;

(b) rifting of a weak lithosphere system producing very reduced flank uplift in the syn-rift and the initiation of small-scale convective removal of mantle lithosphere after break-up, which results in buoyancy driven uplift.

The Eocene Salt Canopy of the NW Gulf of Mexico explained by the Mechanism of Squeezed Diapirs – A Numerical Modeling Study

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Salt canopies of variable sizes developed in the Gulf of Mexico (GoM) since the Palaeogene, and are now located at several different structural levels. Little is known about their emplacement and early evolution. The underlying structures may be shielded from seismic imaging or salt may have entirely evacuated from the original canopies. Allochthonous salt structures can have a major influence on the structural evolution of a basin, on the sediment deposition patterns and also on the development of hydrocarbon systems.

This study focuses on the evolution of an Eocene salt canopy located in the NW GoM. This canopy developed in the center of an up to 350 km wide salt basin. During Oligo-Miocene times, it acted as a detachment surface for large-scale gravity spreading. By localizing gravitational instabilities at an allochthonous level, the canopy likely postponed gravity-driven deformation above the distal part of the autochthonous salt basin until the late Oligocene, at which time the Perdido Fold Belt began to form here.

We investigate the circumstances under which the Eocene canopy could have evolved via the mechanism of squeezed diapirs. During such a process, shortening of a region containing pre-existing diapirs will be absorbed by the salt (the weakest part of the system), which is then expelled to the seafloor.

We use 2D finite-element models to study the evolution of an analogous canopy. The models comprise a viscous salt layer overlain by a frictional-plastic sedimentary sequence from shelf to deep water, thereby incorporating the dynamical interaction of gravity spreading caused by shelf progradation. Model experiments include sediment compaction, flexural isostasy, loading by the overlying water column, and parametric calculations of the effects of pore-fluid pressures in the sediments.

The models integrate two phases of the basin evolution: Phase 1 in which diapirs develop during sediment aggradation, and Phase 2 in which sediment progradation leads to gravity spreading, shortening of diapirs, expulsion of salt, and the development of a canopy.

The Phase 1 modeling presents a new mechanism for diapir initiation and evolution, which has remained a poorly understood aspect of salt tectonics. This mechanism is based on a sedimentation-type that preserves local bathymetric expressions (channel-levee system, turbidite deposits). These structures need to adjust isostatically relative to the salt layer. This local balancing can create sufficient pressure differences to drive diapirism. These diapirs can form in a neutral stress regime and long before they get squeezed by shortening.

The evolving model canopies show characteristics similar to the Eocene canopy of the NW GoM (lateral extent, structure of underlying strata, postponing of deformation above distal salt basin). They also share important characteristics with other canopies, such as the Eocene canopy of the northern GoM.

Mesozoic Tectonic and Stratigraphic Evolution of the Orphan Basin, with Special Emphasis on Regional Correlations with Flemish Pass and Northern Jeanne d'Arc Basins

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The tectonic framework and depositional settings of the Orphan Basin are studied using ~25,000 km of 2-D seismic reflection profiles and stratigraphic data from nine key exploration wells. The evolution of the region is recorded in five seismic distinct stratigraphic units (Z, A, B, C, X), each separated from one another by widespread regional markers U1-U4, representing prominent unconformities. Exploration well data showed that Units Z, A, B, C and X are correlated with the Pre-Cambrian/Paleozoic basement, ?Triassic/Jurassic, Early Cretaceous, Late Cretaceous and Tertiary successions, respectively. Similarly, the well data showed that U1, U2, U3 and U4 markers are correlated with the Top Paleozoic, Top Jurassic, Mid-Cretaceous and Base Tertiary Unconformities, respectively. The well data further showed that the seismic Units A, B+C, and X are broadly correlated with three regional tectonic episodes, where each episode includes a period of extension, followed by a period of protracted uplift associated with sectoral break-up, and a period of sustained thermally-driven subsidence.

On the basis of stratigraphic and structural architecture of the successions imaged between the Top Paleozoic Unconformity and the Base Tertiary Unconformity, the study area is divided into five tectonic provinces: the Western and Southwestern Basin Margin, the Eastern Basin Margin, the White Sail Fault Zone, the West Basin and Ridge Province, and the East Basin. The Bonavista and White Sail Fault Zones were developed during the ?Jurassic (may be as early as Triassic if evaporates are present in the Orphan Basin), as prominent basin-bounding faults. Several large faults paralleling the White Sail Fault Zone also developed during this time. The extensional tectonic activity continued in the study area throughout the Cretaceous, but slowly culminated in the late Cretaceous / Early Tertiary as indicated by the absence of growth strata within the Tertiary succession associated with the faults, and tip points of these faults being situated in the Early Tertiary successions.

The seismic data documents that faults in the northern and northeastern segment of the Orphan Basin display greater growth, rotation and tilting of the mid-Late Cretaceous successions than those observed in the western and southern segment of the basin. These observations together with the large fan-shaped fault splays of the White Sail Fault Zone collectively suggest that the Flemish Cap probably experienced a progressive clockwise rotation of 25º-35º during the Late Jurassic – Late Cretaceous. This rotation and extrusion of the Flemish Cap is largely accommodated by the Cumberland Belt Fault Zone in the south and the Charlie Gibbs Transfer Zone in the north.

From the Solar System to the Reservoir: understanding the influence of Plate Tectonics, Paleogeography, and Paleoclimate on Pre-Salt Petroleum Systems of the South Atlantic

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The nature of the break-up between the African and South American plates had a profound influence on petroleum system elements in the South Atlantic Ocean. Scalable earth models and multi-disciplinary basin analysis are critical to determine the fundamental controls on source rock, reservoir distribution and geo-histories of the pre-salt plays. Our workflow integrates mega-regional to pore-scale observations with quantitative modeling to better understand the evolution of the South Atlantic pre-salt petroleum systems.

Offshore Brazil, in both the Campos and Santos basins, pre-salt depositional systems were dominated by carbonate platform trends underpinned by basement highs; however, differences in depositional environments resulted from differences in the underlying rift tectonics of each basin. The Campos carbonate platform was formed on a basement high connected to the rifted craton. As a result, the Campos Basin Pre-Salt has a complex mixing zone of siliciclastic and carbonate sediment. The carbonate platform in the Santos basin formed over an outer basement high resulting from extreme crustal asymmetry in the Santos rift system. The Santos platform was therefore isolated from significant siliclastic input.

Integrated basin analysis has proven to be an important technique for play prediction. Our workflow integrates mega-regional to pore-scale observations with quantitative modeling to better understand the evolution of the South Atlantic pre-salt petroleum systems.

Rifted margin crustal thickness and OCT location for the Central Atlantic from gravity inversion: Evidence for breakup rift segmentation and micro-continent formation

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Satellite gravity anomaly inversion, incorporating a lithosphere thermal gravity anomaly correction, has been used to map Moho depth, crustal thickness and continental lithosphere thinning factor for the Central Atlantic continental margins. Continental lithosphere thinning factors and crustal thickness from gravity inversion provide independent predictions of ocean-continent transition (OCT) location, margin asymmetry, micro-continents and breakup basins. Crustal thickness maps from gravity inversion, restored to early post-breakup Jurassic times (160-170 Ma) using published plate reconstruction rotation poles, show evidence of segmentation of breakup rifting of the early Central Atlantic between the Moroccan and conjugate New England - Nova Scotia margins resulting in failed breakup basins and micro-continent formation on the African side. Further south, restorations of crustal thickness from gravity inversion suggests an early Central Atlantic rift linkage, north of the Bahama Banks, into the NE Gulf of Mexico, which was abandoned in favour of breakup between the Bahama Banks and West Africa by 150 Ma.

Superposition of illuminated satellite gravity data onto crustal thickness maps from gravity inversion provides improved determination of pre-breakup conjugacy and breakup trajectory of the North American and West African margins. Restorations to Jurassic time show an intriguing conjugate continuity of the Cretaceous New England sea-mounts and Miocene south-western Canary Island volcanism. The location of this volcanism and breakup rift segmentation appear to be controlled by the northern boundary of the West African Craton. Early post-breakup oceanic crust shows a rapid increase in North American plate oceanic crust thickness southwards across the New England sea-mount chain.

Input data used in this study is satellite gravity, digital bathymetry and NOAA-NGDC sediment thickness. Gravity inversion to determine Moho depth and crustal thickness variation is carried out in the 3D spectral domain and incorporates a lithosphere thermal gravity anomaly correction for both oceanic and continental margin lithosphere (Chappell & Kusznir 2008). Failure to incorporate a lithosphere thermal gravity anomaly correction gives an over-estimate of crustal thickness predicted by gravity inversion. A correction is made for crustal volcanic addition due to decompression melting during breakup and sea-floor spreading.

Deep Crustal Structures of the Central Atlantic Ocean conjugate margins: Combined Approach of Seismic, Gravity and Magnetic Investigations

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The deep crustal structure of the Northeast American margin has been intensely investigated in the 1980s by means of seismic reflection and wide-angle studies. New data about the West African margin system allow us to better understand the conjugate evolution of the Central Atlantic Ocean margins. The joint-interpretation of the seismic data available both on the Northeast American and West African conjugate margins highlighted four major structural zones: the continental platform domain (1), little or no thinned; limited by a hinge line from which the continental crust thins rapidly from 32 km to less than 10 km on a 60 km wide transition zone (2). At the foot of the continental slope, an atypical oceanic/transitional domain (3) corresponds to a crust with high Vp-waves velocities (>7.4 km/s) observed at its base. To the west, the oceanic domain (4) is clearly interpreted as a typical oceanic crust.

The potential field signature of the margin is characterized by a strong regional magnetic anomaly, so-called the East Coast Magnetic Anomaly (ECMA) located near the hinge line. Plate reconstructions suggest that the ECMA also coincides with a similar West African Coast Magnetic Anomaly (WACMA) observed on the conjugate margin. The ECMA is thought to mark the continent-ocean transition, and is often considered to represent the magnetic signature of thick volcanic sequences and underlying mafic intrusions emplaced during the onset of breakup and typically expressed on seismic as Seaward Dipping Reflectors (SDRs).

However, the presence of a thick carbonate platform, observed on MCS profiles does not allow a proper seismic imaging of deep crustal structures on the conjugate African system. Consequently, potential SDRs are not clearly identified all along the margin and fundamentally the origin of these coastal magnetic anomalies remains enigmatic.

Herein, we attempt to integrate our different seismic results with gravity and magnetic modeling at a regional scale in order to test different basement structures alternatives leading to a better qualitative and quantitative estimation of the whole rift and margins architecture.

The meaning of the magnetic anomalies and the possible identification or not of a true conjugate volcanic system on both side of the Central Atlantic Ocean is crucial to better assess the large scale geodynamics processes and rifted margin mechanisms involved during the formation of the continent-ocean transition.

Variations in crustal structure across the Nova Scotia continental margin and its conjugate

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The Nova Scotia rifted continental margin lies in a transitional segment between the volcanic US East Coast margin to the south and the non-volcanic Newfoundland margin to the north. The East Coast Magnetic Anomaly (ECMA) and the associated seaward dipping reflectors (SDR), both well-known volcanic margin phenomena, are observed off Georges Bank on the south-western part of the margin but quickly reduce in magnitude to the northeast. A comparison of seismic observations across different parts of the margin also shows a parallel decrease in syn-rift volcanism as defined by three previous cross-margin refraction profiles (SMART-1,2,3). The margin changes from volcanic to non-volcanic between the southern line (SMART-3) and the central line (SMART-2). Existing data between the central and the northern line show a wide continent-ocean-transition (COT) zone characterized by a pervasive layer with velocities of 7.3-7.9 km/s, intermediate between crust and mantle, that we interpret as partially serpentinized mantle. The nature of the crust overlying the partially serpentinized layer was, however, difficult to define as it was under-sampled due to sparse receiver spacing.

In November 2009, a new refraction profile was acquired by the Offshore Energy and Technical Research (OETR) Association of Nova Scotia along a coincident deep reflection profile (NovaSPAN line 2000) to the northeast of SMART-1. The profile was obtained using 100 ocean-bottom seismometers and with particularly dense spacing (2.5 km) within the COT that gives greatly improved resolution in this region. It also extends 125 km seaward of the reflection profile to better constrain the oceanic crust. Data were analysed using the same modelling technique as for the SMART survey. Preliminary results show very similar structures to those determined for SMART-1. Therefore, all the profiles in the central and the northern margin are consistent with the lack of volcanism and the presence of thin oceanic crust. These results aid in determining a detailed kinematic reconstruction of the rifting and breakup of the complete Nova Scotia-Morocco conjugate margins. Asymmetry in oceanic crustal thickness is, however, observed across a near conjugate to NovaSPAN 2000 on the Moroccan margin (SISMAR-4) after plate reconstruction. Either a ridge jump or post-spreading volcanism may be required to explain such asymmetry.

A global perspective of the tectono-stratigraphic evolution of Triassic basins of the Central and North Atlantic realm

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The break-up of the Pangean Megacontinent in the present day area of the North Atlantic commenced along a narrow extensional zone during Permo-Triassic times. Permian rift processes are generally considered to be related to collapse during the later part of the Hercynian/ Variscan orogeny but the Triassic rifting style is more complex and the presence of an over-riding first-order control equivocal. It is clear that basement terranes and terrane boundaries provide pre-existing areas of structural weakness that have a significant influence on the location, timing, orientation and extent of rifting during the Triassic. Plate stresses associated with the opening of neo-Tethys, the residual Permian thermal subsidence and the southward-propagation of the Arctic rift system were then applied to this inhomogeneous basement structure. The style of rifting observed is the result of the combination of these factors.

We present a compilation of published stratigraphic, sedimentological and structural data, as well as combined individual mapping, to investigate the tectono-stratigraphic evolution of the Triassic basins in the Central and southern North Atlantic domain, estimate the timing of rifting and evaluate the role of larger-scale rift processes. All of the Triassic basin fill successions in this study display a similar sedimentological evolution and are dominated by continental deposits. The sequence commences with a lower sand-prone phase characterised by fluvial, alluvial-fan and fluvio-aeolian sediments. This sequence is overlain by an upper fine-grained, mud-prone unit which may include evaporites and is interpreted as representing deposition in playa/ lacustrine dominated environments.

Although the sedimentological evolution of the basins studied is similar, the onset of basin filling is strongly diachronous, and the timing and duration of the phases of fluvial and playa deposition vary from one basin to another. In latest Triassic times, the basins in the Nova Scotian/ Moroccan domain record the earliest marine transgression into the rift system from the north and east whilst the southern basins remained in a continental setting.

Published seismic reflection data show that many Triassic rift basins have geometries typified by large-scale tabular sedimentary sequences, local depocentre changes and subtle thickening of sequences toward faults. Subsidence is considered to be driven by lower crustal flow within a high heat-flow region.

The peculiar tectono-stratigraphic evolution of the eastern margin of Northeast Brazil, and its African Counterpart

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Despite the quantity of research regarding the conjugate evolution of the East Brazilian and West African margins, few have attempted to solve the challenging questions that arise from the Pernambuco, Paraíba and Natal Platform basins, in northeast Brazil. To date, most research has focused on Santos-Campos-Segipe/Alagoas (Brazil) and its comparison with Angola-Congo-Gabon (Africa) basins. The reason for this discrepancy in data coverage is likely due to the lack of onshore and offshore data.

The Pernambuco Basin is bound by the Maragogi High to the south and the Pernambuco Shear Zone (PEZC) to the north. The Paraíba Basin is bound by the ZCPE and by the Patos Shear Zone (PAZC) to the north. The Natal Platform is bound by the ZCPA and by the Touros High, to the north. The opening of the Atlantic in this region began with the development of the Cupe sub-basin (Aptian), south part of the Pernambuco Basin. The rift in this area was influenced by the Santa Helena hotspot, which affected the Pernambuco basin, thinning the crust, creating the Pernambuco Plateau, also bound to the north by the PEZC.

The Paraíba and Natal Platform basins, north of the PEZC, shows a high basement profile, with a thin sedimentary cover. The platform ends abruptly against the oceanic plate, forming a steep slope bypass zone. The absence of deposits older than Turonian in the onshore region indicates a very restricted situation, and possibly that, during the rift process this sector remained as a structural high with all the deposition being pushed to its African counterpart. This sector of the Brazilian margin holds such a peculiar evolution that we called it the "Exception Zone". It also represents the point which divides the Brazilian margin in two branches - a transforming margin, without salt, and a distentional salt-bearing margin. It is possible that the continental piece formed by the large shear zones (PEZC, PAZC), which form the Brazilian Northeast Transversal Zone (NETZ), acted as an accommodation zone and redirected the rift axis from the center of the Borborema Province (BP) to its edge. The effect of the shifted rift, surrounding the BP, was the separation of BP from the African plate. The absence of crustal thinning was probably caused by the crust thickness along the Paraíba and Natal Platform basement, at the edge of the BP.

The correlation of Pernambuco Basin with its African counterpart, Rio Muni Basin, shows a good correlation for sedimentary fill and tectonic evolution. However, for the sector formed by the PEZC and the Touros High, Paraíba and Natal Platform basins, with its counterpart, Douala to Niger Delta Basins, the comparison shows a complete asymmetrical situation regarding their sedimentary fill and tectonics. The petroliferous potential for the Paraíba and Natal platform basins is still undetermined, but it is clearly different from the Pernambuco Basin and its Plateau to south of the PEZC.

Deep to surface processes of the French Guiana transform margin, eastern Demerara plateau

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Transform margins represent an important part of the equatorial Atlantic margins. They usually present a very steep ocean-continent boundary inherited from the vertical transform fault along which opening occurred. A marginal Ridge is bounding the continental domain. This is expressed on bathymetry by important bathymetric gradients (in average greater than 20°) along the continental slope. Therefore erosional processes and especially slope instabilities prevail in those settings. Also, these margins usually have trapped organic matter during rifting. The geometry of syn- and post-rift sequences fundamentally differs from that of "divergent" passive margins, and this has consequences on surface processes and fluid migration patterns.

The Demerara plateau located offshore French Guiana has been surveyed in 2003 (GUYAPLAC cruise, part of the french EXTRAPLAC program) using multibeam bathymetry and imagery (EM12), 6 traces seismic data and 3-5 kHz echosounding. The analysis of this dataset has revealed several original patterns from depth to the surface:

- first, no clear marginal ridge seems to characterize this transform margin, especially approaching the divergent sections,
- second, the distal part of the continental margin seems to have been lately tilted seaward (Eocene?)
- third, very important slumped masses affect the surface of this tilted area (last 500 meters of sediments on nearly 150 km²) strongly eroding the Demerara plateau,
- finally a giant pock-mark field occurs on the seafloor in the same area. There, the association of slumping and fluid-escape structures suggests that fluid overpressure can be a key factor in the recent evolution of this system.

We present here a detailed analysis of this original transform margin, that may be considered as an end-member of transform margin structural diversity.

Identification and classification of the ocean-continent transition (OCT) at magma-poor margins using new gravity and re-processed magnetic data integrated with wells, seismic reflection and seismic refraction data.

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Crustal types along strike of magma-poor rifted margin have unique gravity and magnetic signatures. When these data are integrated with wells and seismic data, the lateral density and magnetization contrasts are clearly observed, identified and classified for each crustal type. The result is a method to differentiate and document crustal types (composition and structure) related to magma-poor ocean-continental transition zones. Verification of these crustal types is demonstrated using a full 3-D crustal gravity model.

Gross Depositional Environment offshore Nova Scotia: methodologies and preliminary results

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The Play Fairway Analysis (PFA) programme initiated by OETR (Offshore Energy Technical Research Association of Nova Scotia) is fundamentally based on the creation of Gross Depositional Environment (GDE) maps for key intervals. These maps are created through a thorough integration of paleo-environment data from wells with seismic facies analysis.

The methodology is essentially based on a rigorous sequence stratigraphic approach. The major innovation in this PFA study was the creation of a systematic sequence stratigraphic framework offshore Nova Scotia. This analysis was based on 20 key wells of which 6 had new biostratigraphic analyses.

The information from these key wells was extrapolated using seismic stratigraphy. Accurate well to seismic ties were established through careful calibration of sonic and density data together with well established well/seismic correlations methods. In order to ensure the highest possible resolution for calibration to the wells, key seismic lines were reprocessed to improve bandwidth and imaging. These well data were extrapolated using a large seismic database (~70,000 km of 2D and ~30,000 sq km of 3D).

The PFA workflow imposes a rigorous and disciplined integration process. This is designed to ensure that the various input elements of the study are internally consistent. The integration process is continual throughout the programme and is tested fully during the creation of the GDE maps. These maps necessarily have to honour all the data and interpretation that feeds into the process (from the most basic tectonic history, through biostratigraphy, depositional processes as evidenced by sedimentological studies, seismic stratigraphy and, in this instance, salt kinematics).

The PFA project included some 14 horizons that were mapped seismically for structural and stratigraphic control. Of these, 9 surfaces have significance for understanding the most prospective Cretaceous and Jurassic plays. The GDE maps for the most important intervals are interrogated for predictions of distribution of reservoirs, sources and seals.

This paper presents the overall methodology and illustrates the workflow with an example of source rock distribution.

A revised biostratigraphic and well-log sequence stratigraphic framework of the offshore Nova Scotia Margin, Canada

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As part of a Play Fairway Analysis (PFA) of the Scotian Margin, offshore eastern Canada, we have conducted quantitative multi-disciplinary biostratigraphic studies of the Upper Triassic-Cenozoic sections in 6 wells: Bonnet P-23, Chebucto K-90, Cohasset L-97, Glenelg J-48, Glooscap C-63 and South Griffin J-13.

These wells were chosen to provide good spatial coverage and stratigraphic penetration, plus correlation with the seismic grid.

Using the results from these new wells as calibration, we have also evaluated pre-existing biostratigraphic data and interpreted the well-log sequence-stratigraphy of 14 additional wells using a consistent event scheme. Our study provides accurate ties and clarifies the origin of seismic horizons mapped across the area within the PFA project. Key to the dating of some horizons has been integration of the palynology and micropalaeontology (most commonly used for biostratigraphy on the Scotian Margin) with available nannofossil and calpionellid data. By integrating the biostratigraphic, lithofacies, well log and seismic data, we have enhanced resolution over previous efforts and thus have a better understanding of unconformities and major flooding events in the region. As part of the PFA, this work will help generate new momentum in the search for hydrocarbons on the underexplored Scotian Margin, especially in deeper water.

A crust and basin study of the Nova Scotia margin and its ocean transition based on densely spaced ocean bottom seismic observations

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A crustal and basin seismic study of the Nova Scotia shelf/slope and its transition to the oceanic crust of West Atlantic was performed in November 2009. One 400 km long NW-SE oriented seismic profile was observed by 100 Ocean Bottom Seismographs (OBSs) spaced at 2,5 to 10 Km intervals. Inline shots were spaced at 120 m and fired by a tuned air gun array of 50 l volume. By using a first-break tomography an initial velocity model was obtained limited at depth due to the penetration of diving waves. This was improved by layered tomography. Reflected arrivals were picked and assigned to specific layers in a top to bottom procedure by a list-square approximation, thus defining thickness of layers and optimizing the velocity distribution. The final velocity model was obtained by forward modeling, computing synthetic travel times and amplitudes. Upon completion of this procedure, the velocity model was used to depth-migrate the diving waves and reflected phases.

Four different geological sections have been recognized. The first, starting at the north western end of the profile and extending for its first 70 km, consists of a continental crust of 33 to 27 km thickness. An upper, middle and lower crust, very similar in structure and velocities to those observed further south across the Canadian continental margin, were resolved. Sediments in this part of the profile have a maximum thickness of about 4,5 km. The second section, of 100 Km width, consists of a stretched continental crust thinning from 27 to 19 km, including more than 9 km thick sediments. Here the continental crust is terminated. For the following 90 km the crust consists of an igneous intrusion with Vp-velocity ranging between 7.2 and 7.3 Km/s. This intrusive body is covered by a layer with Vp-velocities of 5,1 to 5.4 Km/s. The irregularity of the velocity distribution within this layer indicates that this also consists of igneous intrusions that have experienced intense serpentinization. The next 140 km of the profile are floored by thin oceanic crust of about 4 km thickness, which is covered by 4 to 5 km thick sediments.

Several salt bodies were identified within the sedimentary sequence and cover most parts of the stretched continental crust up to the edge of the igneous intrusions. This part of the basin belongs to the salt province that strikes parallel to the Canadian continental shelf.

The conjugate margin of Nova Scotia, which is the Moroccan margin north of Agadir, differs from that of the Canadian side since the stretched continental crust of the Moroccan margin is followed by seafloor spreaded oceanic crust without any igneous intrusions and serpentinized units.

This project was financed by OETR, Canada.

Hydrocarbon prospectivity of a new deepwater petroleum province, offshore Senegal

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The Senegalese portion of the greater Northwestern african coastal MSGBC Basin, located offshore and south of the Dakar peninsula and north of Gambia, is under-explored. This study identifies the elements of a petroleum system and points to the exploration potential of the untested, deepwater portion of the Senegalese basin margin. 3D seismic data (2050 km2) acquired in 2007 reveal the existence of a long-lived carbonate platform and associated incised canyons with genetically related down-slope debris aprons/turbidites.

Seismic interpretation and multidisciplinary geologic studies indicate that the offshore region can be subdivided into two main para-sequences: the Pre-Senonian unconformity section and the syn-post Senonian unconformity section. The pre-Senonian age section includes the long-lived carbonate platform of Jurassic to Cenomanian age. Uplift and subaerial exposure of the platform during Late Cretaceous time led to karstification and erosion that we believe are key to development of fracture-related permeability in the carbonate reservoir. Uplift was likely associated with differential rotation induced by withdrawal of Triassic age salt in the southern MSGBC. Erosion is marked by the Senonian age unconformity that is easily recognizable on seismic and yields seismic evidence of karstified topography. In contrast, the syn-post Senonian age section consists mainly of stacked Santonian age fans with multiple stacked amplitudes on seismic, and an overlying Tertiary age succession. Detailed rocks physics and attribute analysis indicate that the turbidites are a mixed lithology of reworked carbonate material and paralic siliciclastic sediments. The paralic sands were transported from the shelf into the basin through incised valleys that also are clearly observable on seismic.

3D basin modeling was used to determine the timing of generation and spatial extent of the petroleum kitchen for the well-documented Turonian age source shale that was deposited along the West African margin. Generation began during Maastrichtian time and continues through present-day, and the down-slope debris aprons and turbidites, as well as the karstified carbonate platform, are located either within or adjacent to the present-day kitchen.

Drawing on analogues from recent discoveries in Late Cretaceous age turbidites offshore Ghana, we believe that the Senegalese offshore basin is an exciting new deepwater province along the northwest African margin.

Mesozoic magmatism at the West Iberian Margins: timing and Geochemistry

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The West Iberian Margins (WIM), including the Lusitanian and Algarve basins, preserve evidence of three Mesozoic magmatic cycles related with different phases of the Atlantic evolution and the kinematics of the Iberian plate.

The **1st cycle** (202-198 Ma), linked to the initial opening stages of the Central Atlantic, is coeval with magmatic events in the North American conjugate margin, in South America and NE Africa; together they constitute the Central Atlantic Magmatic Province (CAMP). In Iberia, this cycle produced continental tholeiites that post-date the deposition of the first syn-rift terrigenous sediments of the Algarve Basin and, also, the 530-km-long Messejana-Plasencia dike. Smaller occurrences also outcrop in the Lusitanian and Alentejo basins at Sesimbra and Santiago de Cacém, respectively.

The **2nd cycle** occurred in the Jurassic-Cretaceous transition (147-141 Ma) and is restricted to the central part of the Lusitanian Basin (Soure-Óbidos region). Here, hypabissal rocks of transitional affinities (moderately alkaline to sub-alkaline) occur spatially associated with salt diapirs. This cycle is coeval of the rift migration from the Lusitanian basin axis to West of the Berlengas islets; this is associated with an extensional phase affecting the Grand Banks and the Iberian margin in the Jurassic – Cretaceous transition.

The **3rd cycle** was the most voluminous. It occurred during late Cretaceous (94 to 72 Ma), was alkaline in nature and comprised two pulses. The first (94–88 Ma) occurred during the opening of the Bay of Biscay and consequent rotation of Iberia and is located between 38º26’ and 39º00’ N. The second pulse (75–72 Ma) has a wider geographical distribution (N 37º to N39º), includes the intrusive massifs of Sintra, Sines and Monchique as well as the volcanism of the littoral Algarve lamprophyre-basanite suite and the Lisbon Volcanic Complex. This last pulse is contemporary with the initial stages of the Alpine orogeny in Iberia that led to the tectonic inversion of the Mesozoic basins.

Magma generation in the WIM records the mantle response to the opening of the Atlantic from the onset of continental rifting (1st cycle), close to continental break up (2nd cycle) and, finally, the late Cretaceous evolution of Iberia (3rd cycle). The geochemical magmatic evolution from tholeiitic (202-198 Ma), trough transitional (147-141 Ma), to alkaline (94-72 Ma) expresses the increasing role of the sub-lithospheric mantle source(s). The geochemical properties of some of these magmas still show traces of the modification of sub-continental lithosphere during Hercynian orogeny.

Provenance of reservoir sandstones in the Flemish Pass and Orphan Basins (Canada): detrital zircon dating using the laser ablation method

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The Flemish Pass Basin is located in the northeastern Grand Banks of Atlantic Canada, and forms an elongate oblique slip transfer system connecting late Jurassic to early Cretaceous rifting in the Jeanne d'Arc Basin to the south with the Orphan Basin to the northeast. Detrital zircons have been analysed from reservoir sandstones from three wells in the northern Flemish Pass Basin, and one in the western Orphan Basin, using the laser ablation method to shed light on sandstone provenance (Mizzen L-11, Mizzen O-16, Baccalieu I-78 and Blue H-28).

Results of the laser ablation study are very consistent from well to well. There are three primary detrital zircon $^{207}Pb/^{206}Pb$ age populations in Lower Cretaceous (Berriasian) and Upper Jurassic (Tithonian) sandstones, which are approximately 340-460 Ma, 530-680 Ma, and broadly Grenvillian. A secondary age population in late Jurassic sandstones ranges from 300-325 Ma. The 340-460 Ma zircon grains are interpreted to be derived from the Central Meguma belt of the Appalachian orogen. The 530-680 Ma zircons are indicative of sandstone provenance from the Avalon Belt of eastern Newfoundland, or alternatively from pre-Variscan granites of Flemish Cap and Iberia, which were connected in Jurassic times. The secondary population in Jurassic sandstones of 300-325 Ma zircons is equivalent to Variscan granite ages, and is interpreted to be indicative of Iberian sediment provenance. The Grenvillian age population can arguably have been derived from North American or Iberian sources, or both.

Reconstructions of the North Atlantic indicate that the continental basement of Flemish Cap and Iberia formed a continuous landmass prior to late Jurassic to early Cretaceous rifting. The Flemish Cap forms a steep borderland to the northern Flemish Pass Basin, and was exposed for much of the Jurassic, forming a proximal source for sediment derivation. It is underlain by ca. 697 Ma granodiorites, which likely contributed detritus to the Flemish Pass Basin in late Jurassic times.

Late Jurassic sandstones from the Flemish Pass Basin also contain elongate, prismatic zircon grains with concordant ages that cluster at 141 Ma. These are likely cavings in the wells from early Cretaceous tuffs. They are of volcanic origin and are interpreted to be rift related. The age of volcanism is consistent with the ca. 140 Ma volcanics of the Bonavista C-99 well, located on the western margin of Orphan Basin.

Petroleum systems modelling offshore Nova Scotia, an integrated approach

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The goal of the Play Fairway Analysis (PFA) programme initiated by OETR (Offshore Energy Technical Research Association of Nova Scotia) is to estimate the volume and distribution of the Yet To Find (YTF) hydrocarbons offshore Nova Scotia. The intention is to predict the scale of the remaining exploration opportunity and to describe the risks associated with each play fairway.

The approach described in this paper is to construct 1D, 2D & 3D petroleum systems models based on input from Gross Depositional Environment (GDE) maps produced by the play fairway interpretation. The GDEs provide inputs for distributions of source rocks, seals and reservoirs as well as calibration for their stratigraphic history.

The source rock distribution information from the GDEs is integrated with an extensive investigation of the geochemistry of known source rocks and fluids offshore Nova Scotia. A key component of the PFA was a major geochemistry project that reviewed a very large number of wells (~40 wells) which were sampled for potential source rocks as well as hydrocarbon liquids. A full range of geochemistry analyses were conducted including RockEval, vitrinite reflectance and GCMS (to assess the molecular signature of source rocks and hydrocarbons).

The petroleum systems approach then integrated the geochemistry and play fairway mapping to produce 3D models (of varying resolutions) that describe the generation, migration and trapping of hydrocarbons through geologic time. This gives a natural way to estimate the likely scale of the YTF for each play identified by the PFA.

Calibration of this model with exploration history data and integration of analogues and interpretation uncertainty, leads to the production of Common Risk Segment (CRS) maps for each play fairway. These maps summarise the play risks associated with each play and are a convolution of risk maps for each individual play element (seal, source/charge and reservoir).

The paper presents the overall approach illustrated using preliminary results of the modelling work.

Seismic Stratigraphy of the Suriname margin, South America

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The Suriname continental margin, South America, is in a critical position to record final Atlantic rifting and opening of the Atlantic Gateway. As such, it represents the youngest portion of the Atlantic, providing an ideal location to study early Atlantic post-rift stratigraphy and sedimentation patterns. The area is a recent exploration frontier with 2D and 3D MCS reflection data available. The outer portion of the margin (Demerara Rise) was recently drilled during Ocean Drilling Program Leg 207 and several offshore exploration wells were drilled in the area. These wells provide groundtruth for seismic interpretation.

A stratigraphic succession of eight seismic units was defined, based on regional correlation of key seismic horizons. The lowest unit consists of complex patterns of faulting and folding observed in the pre-Albian succession; interpreted to represent sedimentation during subsidence following late stage trans-tensional rifting between the Demerara Rise and its conjugate; the Guinea Plateau of West Africa. Final separation between South America and Africa in the Albian created a regional unconformity (C reflector) across the breadth of Demerara Rise (DR) and onto the Suriname margin proper. The sedimentary sequence above the C horizon, from Cenomanian to Recent, forms a 400 to 1000 ms-thick cap across the plateau that is largely flat-lying and uninterrupted by faults. It thickens landward to be >4000 ms-thick underlying the continental slope. The base of this succession, between the “C” and “B” horizons consists of 90-125 m-thick sequence of black shale across the DR. The sequence between the “B” and “A” reflection events is variable in thickness across the outer DR because it is heavily eroded, probably by intensified bottom currents during the Oligocene and again in the mid-Miocene. The sedimentary section above the “A” horizon is nearly absent on the outer DR but thickens inboard. It forms a sequence of progradational clinoforms under the Suriname shelf and slope, with several correlated horizons marking sequence stratigraphic boundaries. The shelf break advanced seaward by nearly 20 km to its present day location between mid-Miocene and Recent. Little evidence of tectonic effects is recognized along this margin since initial breakup and subsidence; thus, the Cenozoic stratigraphic architecture was developed principally by high sedimentation rates interacting with global sea level positions.

Continental slope sediment distribution and characterization: case studies from the Scotian and Suriname margins

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The Scotian margin endured a number of unsuccessful hydrocarbon exploration attempts because of insufficient understanding of continental shelf-to-slope and slope geologic processes. The Shubenacadie H-100 and Shelburne G-29 wells were drilled on mounded seismic morphologies, interpreted as depositional fans. In post-drill analysis, it is apparent that these structures are erosional remnants of canyons cutting across the slope. More recently, the Torbrook C-15 well was drilled into a presumed Tertiary fan; a mass transport deposit was encountered.

The above examples highlight a global need to recognize and understand continental shelf-to-slope and slope sedimentary processes. This investigation addresses this issue through study of Cenozoic analogues on the Scotian and Suriname margins wherein there is sufficient data resolution and fewer complicating factors such as sediment compaction, structural faulting and mobile salt deformation. For the Scotian margin, application of conventional sequence stratigraphic methods has proven difficult to apply; the margin is largely aggradational with dominance of erosive processes. Such processes include numerous episodes of canyon cut and fill, mass transport reworking and re-deposition, and along-slope sediment erosion and transport by deepwater contour currents. These poorly understood processes dominate over sediment input and sea level controls and greatly impact the preserved stratigraphic record with significant spatial and temporal variations.

By contrast, the Suriname margin is relatively simple in its Cenozoic depositional architecture. This margin is the last vestige of the proto-Atlantic, forming in the mid-Cretaceous. As such, its modern latitudinal position and post-rift history are equivalent to Nova Scotia’s in the Jurassic. In the case of Suriname, off-shelf sediment transport driven by an interplay of sediment supply and sea level position dominates control of Cenozoic sedimentation, leading to rapid margin progradation and construction of a well developed sequence stratigraphy.

Despite these distinctions between margins, there are consistencies in depositional patterns that provide the basis for a stratigraphic framework. For example, a major Oligocene canyon cutting period and a mid-Miocene bottom current intensification period are recognized along both margins. Control events such as these provide stratigraphic markers that permit broad age control and a degree of correlation.

Geodynamic keys of the Santos Basin

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Understanding genesis of the very peculiar 600 km wide Santos Basin - São Paulo plateau system and its narrow conjugate Namibe Margin is an old geodynamical and structural problem. Several hypotheses were proposed which imply the same amount of horizontal movement.

We propose to investigate the consequences of this movement. The new kinematic history of this system that we present here, based on interpretation of seismic profiles and dedicated kinematic constraints, has strong geodynamical consequences:

1) there is no need for a ridge jump;

2) the Namibe margin evolved as a transform passive margin;

3) the opening direction of the Santos Basin - São Paulo plateau system is oblique to general opening motions of the South American and African plates and

4) this opening is younger that those of the other basins of the central segment of the South Atlantic.

Combined rigid/deformable plate tectonic reconstructions for the Central Atlantic margins

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Passive continental margins are characterised by a transition zone from continental rifting to oceanic crust accretion. The exact location of the continent-ocean boundary (COB) is often difficult to predict because of the similar physical properties of oceanic crust and highly extended continental crust. Magmatic intrusions have an effect on the calculation of crustal thickness, which adds further uncertainty to the definition of the COB.

The Iberian and Newfoundland conjugate margins are zones where anomalously large amounts of crustal extension have occurred. Within these regions, the formation of continental ‘rafts’, comprising highly attenuated continental crust, poorly defined oceanic crust and exhumed mantle, is characteristic. In these regions the reconstruction of plate boundaries to their pre-drift positions without the modelling of deformation history results in a very large amounts of continental plate overlap (of North America, Iberia, Greenland and Europe Plates, including the Hatton Bank). There is an additional complexity at the northern margin of Iberia and in the Aquitaine Basin resulting from compression during the closure of the Tethys Ocean and the related Alpine-Pyrenean orogenies.

To remove the deformation effects produced by overlap in the reconstructions, an ArcMap™ extension has been developed (Plate Wizard™). The program creates displacement vector maps that allow restoration of the plate margins by ‘warping’ the mapped extended regions. The program also allows the restoration of the geometries of geo-referenced datasets that can be intersected with the plates defined by the model.

To date, a self-consistent global, plate tectonic model has been achieved, that incorporates stretching factors and scales deformation for the Cenozoic and Mesozoic for the entire Atlantic margin. Restoration to the pre-rift geometries of the margin in these areas can be refined further by detailed modelling of tectonic evolution and the extent of crustal deformation. Furthermore, by resolving deformation geometries to pre-drift positions, the imprints of earlier rifting, strike slip, and collisional histories are more clearly defined.

Thermal modelling of the central Scotian Slope, offshore Eastern Canada: Seafloor heat flow data, hydrocarbon maturation potential and the effects of salt on heat flow

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Six of the twelve deepwater Scotian Slope explorations wells were drilled between 2002 and 2004 as a result of the global push towards deeper water exploration. The Jurassic-Cretaceous Verrill Canyon Formation has been inferred as the prominent source rock for the entire Scotian Basin based on previous wells on the shelf. However, the maturation of these shales through standard vitrinite reflectance analysis is largely unknown for the outer slope basins, as few of the deeper water wells penetrate the Verrill Canyon Formation and none reach beneath the upper Jurassic sediments. In an attempt to provide additional constraints on the thermal structure of the central Scotian Slope 48 seafloor heat flow measurements were acquired in July 2008. The data show significant lateral variations in seafloor heat flow associated with the presence of large salt diapiric structure with high thermal conductivity. However, measurements in regions unaffected by salt record relatively uniform seafloor heat flow values of ~42-45 mWm^{-2}. The crustal heat flux history of the basin consistent with these values is calculated using uniform and depth dependant extensional models. Crustal stretching factors (β) across the rifted continental crust underlying the Scotian Slope, which are required for extensional modelling, are constrained from previous seismic refraction velocity models (Wu et al. 2006).

To further define the maturation potential of sedimentary sequences within the slope basins, dynamic 3D thermal models are produced as constrained by available seismic data, well data, seafloor heat flow data, and crustal rift models. Initial results assuming no radiogenic heat production, or radiogenic heating in only within the sediments, predict that the inferred Late Jurassic source rocks occur within the wet gas or late oil window, depending on whether the models are matched to the landward or seaward measured heat flow data. To match all observed seafloor heat flow, requires increasing radiogenic heat production associated with thickening crust in the landward direction. These models predict that the maturation of the inferred Late Jurassic source rocks increases from the late oil to wet gas window in the landward direction.

Long-term post-orogenic evolution of N Atlantic conjugate margins constrained by on- and offshore data

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Late Palaeozoic into early Mesozoic collapse and rifting processes began to dismember the Caledonide orogen immediately after its formation. This evolved into protracted continental rifting affecting the area between the N American-Greenland and Eurasian cratons, producing the deep late Palaeozoic and Mesozoic sedimentary basins on the continental shelves of north-western Europe and east Greenland. After a phase of intense tectonism involving early Paleocene magmatism in widely separated areas throughout the N Atlantic realm, the rifting process finally led to ocean formation and extensive flood basalt production in late Paleocene-early Eocene.

The eastern (Norway) and western (NE Greenland) margins of the present-day N Atlantic Caledonides differ in several respects. The inland topography is generally more pronounced in western Scandinavia than in NE Greenland. Furthermore, late Palaeozoic and Mesozoic basins are exposed along the E Greenland margin while they generally remain buried on the Norwegian margin. Also the proximity of the Jurassic-Cretaceous central rift zone to the present land areas varies significantly within the N Atlantic. At the NE Greenland and Vøring margins there are wide late Paleozoic-early Mesozoic basins and platforms. In contrast, Jurassic-Late Cretaceous rifting is in close proximity to the present land areas along the Møre margin and the Lofoten-Vesterålen archipelago. Furthermore, fission track data show characteristic patterns. For example, the correlation of fission track age at sea-level with distance to the coast is prominent in western Scandinavia, but apparently absent in NE Greenland.

We hypothesise that these differences could be related to asymmetric margin development and investigate cause and effect in N Atlantic rifting history and topography evolution using a numerical model of the lithosphere-asthenosphere system. The coupled equations of motion and heat transfer are solved in the Bussinesq approximation. Being based on a dense distribution of Lagrangian particles, the method allows arbitrarily large strain, enabling the combined simulation of mantle convection and localised strain (faults) in the mantle lithosphere, crust and sediments. The model is tested against observed sediment structures, crustal and lithospheric thickness, magmatism and low-temperature thermochronology.

Comparative analysis of the Porcupine Median Volcanic Ridge with modern day Pacific Ocean seamounts – further evidence of an amagmatic Mesozoic basin history for the South Porcupine Basin, offshore Ireland.

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The Mesozoic Porcupine Median Volcanic Ridge (PMVR) is located in the frontier deepwater South Porcupine Basin (SPB) some 200 km off the southwest coast of Ireland. The PMVR is important because it provides a potential insight into the Mesozoic basin development of the South Porcupine Basin in the context of a magmatic/amagmatic history. The PMVR also forms the edifice for the Lower Cretaceous Dunquin carbonate platform exploration prospect, which is considered one of the largest un-drilled exploration targets offshore NW Europe. The composition of the PMVR remains unknown and previous workers have suggested that it is composed of volcanic, sedimentary or metamorphic (serpentinitic) rock. Here, we measure PMVR gross geometry and morphology, which was derived from mapping of recently acquired two dimensional long offset seismic reflection data and compare/contrast the results with those of modern day potential analogues in the Pacific Ocean. This kind of analysis should provide an objective process-based analysis versus more common detailed and subjective seismic interpretation methods. The results of these analyses illustrate that the PMVR does not fall into the well established morphological relationships which have been developed for volcanic seamounts as seen in potential modern day analogues. Therefore, if such models are to be pursued, new genesis processes must be developed for the ancient which are different to those observed in the modern day environment. We however believe that these analyses support our view that the PMVR is of a sedimentary origin. If this view is correct and the SPB has experienced an amagmatic Mesozoic basin history, the potential positive implications for the hydrocarbon prospectivity of the basin are significant and far reaching. In addition, there may be similar implications for other hyper-extensional basin systems along the conjugate margins of the Central and North Atlantic.

Mesozoic subsidence and uplift history of an exposed Atlantic rifting margin - the Lusitanian Basin (Portugal)

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The Lusitanian Basin (Portugal) is located on the Western Iberian Margin of the North Atlantic. The sedimentary infill documents its evolution since the first Late Triassic intra-continental rifting, the second Oxfordian marine rifting, until the Early Cretaceous Atlantic opening with break-up and sea floor spreading in three northward migrating steps. The Late Cretaceous and Tertiary inversion, related to the tensions between the Iberian, NW African and European plates, promoted intense uplift and exposure of the full stratigraphic succession. The analysis of this succession, mostly based on detailed studies of large-scale outcrops, complemented by the integration with some km-thick well data, allowed the build-up of a coherent tectono-sedimentary model for the basin.

This work analyses the expression of the Mesozoic rifting and drift episodes, in terms of the sedimentary volumes *versus* accommodation space creation during defined time intervals. The subsidence has been estimated from isopach maps for each 2nd Order Trangressive-Regressive Sequence (based on well and outcrop data), together with subsidence curve calculations in specific wells. These estimations also considered the effects of two major uplift events, identified and quantified in erosional unconformities.

The interpretation of the quantitative data and its spatial distribution allows the understanding of the different basin's sectors evolution, with distinct subsidence and uplift episodes. In fact, this particular Atlantic margin, presents a non-homogeneous and diachronic behavior, including: i) significant transient uplift intervals; ii) important lateral time-migration of tectonic subsidence; iii) distinct subsidence and uplift for contiguous tectonic blocks, even for the same rifting episode. These conditions are responsible for different maturation timings in different sectors of the basin and also for important erosional events with significant volumes of sediments being carried towards the off-shore. The overall subsidence – uplift evolution may be described in these main steps:

1. Intense initial tectonic subsidence in narrow blocks, associated with the first rifting (Carnian-Norian?); **2**. Moderate ramp-like subsidence during post-rift (Early - Middle Jurassic); **3**. Heterogeneous and moderate uplift (few hundred meters) in NE-SW oriented blocks (Calovian – Early Oxfordian) preceding the second rifting; **4**. Heterogeneous and intense tectonic subsidence (from hundreds to few thousand meters) in NE-SW oriented blocks, during the second rifting (Late Jurassic); **5**. Moderate subsidence (few hundred meters) during the post-rift (Early Cretaceous); **6**. Intense uplift (up to two thousand meters) in northern and central sectors, while the southern sectors remained subsident, associated to the North-Atlantic break-up (Late Aptian); **7**. Low subsidence (hundred meters?), associated to the drift (Late Cretaceous); **8**. Northern low subsidence and southern uplift in distinct tectonic blocks, related to the basin's inversion (latemost Cretaceous and Tertiary).

The integration of these data with the regional geodynamic context gives a better picture of the signature of the North Atlantic opening at the Western Iberian Margin.

Nova Scotia Play Fairway Analysis Upper Jurassic–Lower Cretaceous Depositional Systems

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This presentation focuses on a key sequence of interest on the Scotian margin from a hydrocarbon standpoint: the Upper Jurassic and Lower Cretaceous clastics. It presents new data on interactions between uplift events inferred from the geological record onshore Nova Scotia and Newfoundland and the resultant depositional systems in the Scotian Basin. Mineralogy studies have provided evidence for sediment provenance. Depositional environments have been inferred from studies of conventional cores, informed by seismic correlation. Reservoir quality depends in part on regional variation in diagenesis, influenced by both detrital supply and depositional setting. Predictions are made about the type of deposition and reservoirs in areas poorly tested by wells on the southwest and southeastern part of the margin.

The continent to ocean transition across the SW Iberian margin: The effect of syn-rift geometry on post-Mesozoic compression

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The southwest Iberian margin, located in palaeogeographic proximity to the Western Tethyan domain, the Central Atlantic and the conjugate margin of South Newfoundland (Canada), is an ideal area to clarify the geological processes leading to continental extension, breakup and posterior post-rift compression.

The interpretation of 2D seismic data from the margin, tied to exploration boreholes and outcrops reveals that the inherited syn-rift geometry and rheology of both deep continental crust and overlaying sediments, plays a major role in the positioning and typology of the distinct structural styles resulting from the post-rift Late Cretaceous to present day basin inversion. Accordingly, in SW Iberia three major post-rift compressional sectors are coincident with the syn-rift segmentation, i.e. the inner proximal, outer proximal and distal margin; these are broadly aligned NNW-SSE.

Compression at the inner proximal margin is expressed by localized reverse faulting of syn- to post-rift sequences, significant uplift and erosion. Shortening at the outer proximal margin is characterised by thin-skinned deformation, often rooted at deep viscous early syn-rift evaporitic successions, which includes reverse faulting, backward propagation narrow anticlines, backthrusting and the formation of incision surfaces. Deformation at the distal margin is characterised by impressive thick-skinned transpressive geometries, which include broad anticlines (e.g. Marquês de Pombal High), "piggy-back" deformation, deep thrusting and reverse faulting, uplift and erosion.

Consequently, the thick-skinned shortening expressed at the distal margin broadly depicts the position of the Ocean-Continent Transition, where the extremely thinned continental crust is the preferred location to accommodate local shortening resulting from the interplay between the thick continental crust to the East and the oceanic crust to the West.

The investigation of the main structural compressive sectors and styles allowed estimating the age of compressive events at the deep margin of Southwest Iberia. Compression is interpreted to have initiated as early as the latest Cretaceous, but is most significant through a period of time spanning the middle Eocene and the Late Oligocene-Miocene to recent times. Moreover, data reveals that shortening along and across the margin is neither synchronous nor similar.

Multiphased syn-rift segmentation on the SW Iberian margin

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The Alentejo Basin is a key province to clarify some of the unclear aspects of the syn-rift evolution and the geometry of non-volcanic passive margins. Its palaeogeographic proximity to neighbouring provinces such as the West Tethys, North Africa and the conjugate South Newfoundland margin, increases the potential to answer some of these aspects.

The interpretation of an extensive 2D seismic dataset imaging the transition from the continental to the oceanic domains, tied to exploration boreholes, dredges and outcrops allowed to address the relative timing of syn-rift events on the margin, the geometry of the continental crust during syn-rift extension and their relation to the position of the Ocean-Continent Transition.

The syn-rift segmentation of the southwest Iberian margin reveals distinct extensional structural styles, each one defining different sectors that are also recognised in northwest Iberia: 1) an inner proximal margin, showing limited subsidence of closely spaced tilt blocks overlaying a thick continental crust; 2) an outer proximal margin, characterized by stacked growth strata deposited over a thinned continental crust, and revealing continued subsidence from the Late Triassic to Late Jurassic, and 3) a distal margin comprising thinned continental crust, with deeply-rooted fault blocks and thick Late Triassic to Late Jurassic growth strata, defining large sub-basins. Each of these segments records differently the three major extensional pulses (Syn-rift I, II and III), leading ultimately to breakup West of the Tagus Abyssal Plain. Syn-Rift I (Late Triassic-Hettangian) is widespread and coeval with the initial wide rift mode recorded throughout the North Atlantic. Central Atlantic Magmatic Province related magmatism and growth strata of Sinemurian to Callovian age (Syn-Rift II), mainly expressed on the outer proximal and distal margins, relates to extension across North Africa and on the conjugate margin of South Newfoundland. The final extensional event recorded prior to breakup at SW Iberia (Syn-Rift III) occurs from the Oxfordian to the Tithonian (Berriasian?). From the earliest Cretaceous onwards, post-rift strata blanketed the SW Iberian margin, whereas North of 38ºN, syn-rift continental extension continued at the conjugate segments of Lusitanian and Jeanne d'Arc Basins.

The formation and evolution of crustal blocks at rifted margins: new insights from the interpretation of the Jan Mayen microcontinent.

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The conjunction of high-quality seismic surveys, deep sea drilling, and progress in numerical modelling changed the way of thinking about how continents rift and oceans form. In particular the discovery of exhumed continental mantle and hyper-extended crust in deep water rifted margins has led to a paradigm shift in research into the evolution of rifted margins. Although rifted margins now appear to be more complex and their architecture more diverse than previously thought, their study worldwide shows that there are in fact a limited number of structures observed in seismic images that characterize their architecture. These "building stones" include crustal blocks of various sizes, often referred to as microcontinents, continental ribbons, H-blocks, extensional allochthons and outer highs. The processes controlling the formation and individualization of these blocks during extensional deformation are still little understood despite the fact that these processes are keys to understand rifted margins evolution.

In this contribution, we summarize the characteristics of these crustal blocks. We propose, using the example of the North Atlantic, that these blocks are the result of specific rift processes that correspond to the sequential evolution from stretching, to thinning and exhumation of the continental lithosphere. Then, based on a new geophysical dataset, we present a new seismic interpretation together with magnetic and gravimetric modeling of the Jan Mayen microcontinent. These results permitted to better define the architecture of Jan Mayen and propose a new scenario for its evolution. It also helps to better constrain the rifting evolution of the Norwegian-Greenland Sea.

Characterization of sills associated with the U reflection on the Newfoundland margin: Evidence for widespread early post-rift magmatism on a magma-poor rifted margin

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Drilling during ODP Leg 210 penetrated two post-rift sills (dated as ~105.3 and ~97.8 Ma) in the deep sediments overlying ‘transitional’ basement of the continent-ocean transition zone on the magma-poor Newfoundland margin. The sill emplacement postdated the onset of seafloor spreading by at least 10-15 m.y. These sills have been correlated with strong reflections in seismic reflection data by means of synthetic seismograms. The shallower of the two sills is generally coincident with the U reflection which is observed throughout the Newfoundland Basin, and strong reflectivity in the sub-U sequence suggests that a number of other sills are present there. However, the lateral extent of the sills and their relation to the U reflection away from Site 1276 has not been documented. Likewise, the cause of the magmatism and the relationship between the sills and other contemporaneous magmatic features has been uncertain.

We used multichannel seismic reflection data and synthetic seismograms to investigate the nature, magnitude, and extent of this post-rift magmatism in the deep basin. Features observed in seismic profiles that we attribute to sill injection include high-amplitude reflections with geometries characteristic of intrusions such as step-like aspect; abrupt endings, disruptions, and junctions of reflections; finger-like forms; differential compaction around possible loci of magma injection; and disruption of overlying sediments by apparent fluid venting. Interpreted sills occur only over transitional basement that probably consists of a mixture of serpentinized peridotite and highly thinned continental crust, and they cover an area of ~80.000 km^2. From analysis of synthetic seismograms, we estimate that sill intrusions may comprise ~26% of the sub-U high-reflectivity sequence, which yields a crude estimate of ~5.800 km^3 for the total volume of sills emplaced by post-rift magmatism. This is significant for a margin usually described as 'non-volcanic'. We discuss competing theories regarding the source of the magmatism, which is still uncertain, like the Canary-Madeira plumes or rift-drift related tectono-magmatic processes.

Lithospheric extension in the presence of small-scale convection: Implications for post-rift subsidence and stratigraphy

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The plate model of Parsons & Sclater provides a generally accepted, quantitative framework for the thermal subsidence-evolution in extensional basins. It predicts an asymptotic evolution of the geotherm towards a steady state of a constant lithospheric thickness and ceased subsidence. This is formulated by assuming that the temperature at a fixed depth (the asymptotic thickness of the lithosphere) is constant. It is implicitly assumed, that this temperature is maintained by sub-lithospheric, small-scale convection, but the dynamics controlling this process are not considered.

Here, we apply a two-dimensional, numerical, thermo-mechanical model of the lithosphere and upper mantle to asses the effects of small-scale convection. Given a particular mantle rheology, our model shows small-scale convection, and converges over time towards a self-consistent, quasi-steady-state. Extension of the convecting equilibrium model causes the formation rifts or continental margins which cools and subsides as predicted by the plate model. However, in contrast to the plate model, the elevated asthenosphere is not instantaneously decoupled from the convecting upper mantle below, and cooling is thus not entirely conductive above the former base of the lithosphere. This causes significantly protracted cooling and subsidence. This model exhibits improved consistency with subsidence data from several rifted margins and intracontinental basins. Furthermore, our model shows that the long-term subsidence pattern in the presence of small-scale convection is superimposed by vertical movements at periods of 2-20 Myr due to convection dynamics at the base of the lithosphere. We show that these movements are a recurrent and potential cause for the development of stratigraphic sequences at similar time scale. Since such sequences are commonly assumed to be caused by eustatic variations, our results have important implications for inferences on the latter. Our results are furthermore important for the assessment of hydrocarbon potential of sedimentary basins in terms of stratigraphic correlation and thermal maturation.

Opening of the Atlantic and development of the Iberian intraplate rift basins during the late Jurassic-early Cretaceous

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This paper deals with a comparative approach of the Iberian intraplate rift basins development during the late Jurassic-early Cretaceous times. In this paper we review the tectonic and sedimentary evolution of these basins. To do it a restoration of the basins at chron M0 (125 Ma) was performed.

The Iberian intraplate rift basins was a part of the network of rifted basins of the northwestern PeriTethyan platform that evolved during the break-up of Pangea, and gave rise to the opening of the Alpine Tethys and the North Atlantic. These basins developed in the late Permian-Triassic rifting cycle during which the Tethys and Arctic-North Atlantic rift systems propagated westwards and southwards, respectively (Ziegler, 1988). During the early and middle Jurassic, the evolution of the Iberian intraplate rift basins was governed by post-rift thermal subsidence. Late Triassic to Mid-Jurassic alkaline magmatism took place in the Iberian Chain.

Rifting resumed during the late Oxfordian and persisted till the early late Albian times. This rifting cycle can be subdivided into three discrete rifting pulses which controlled the development of the study basins. This second rifting cycle coincides with rifting activity in the North Atlantic domain, culminating in the mid-Aptian separation of Iberia from North America and Europe and the opening of the oceanic North Atlantic and Bay of Biscay basins. During the late Albian to the Maastrichtian times the Iberian Basin subsided in response to post-rift thermal re-equilibration of the lithosphere.

During the mid and late Cretaceous the study area underwent alkali basaltic volcanism, metamorphism, and thermal heating associated with high thermal gradients. Hg-Sb bearing deposits were also formed during this time. The volcanic system occurs as a WNW–ESE belt of alkali basaltic character along the northern Iberia offshore, the Basque-Cantabrian Range and the Pyrenees. It displays strong lateral variations in thickness and facies and is complexly interfingered with deep-sea sediments. These volcanic rocks occurred in an extensional geodynamic context (Albian-Santonian) generated by the drifting of the Iberian plate with respect to the European plate.

The evolution of the Iberian intraplate rift basins was coeval with the development of the North Atlantic margin basins, the Aquitaine Basin, and the Mesozoic part of the Ebro Basin.

Modelling of the Jurassic and Cretaceous erosive stages in the Lusitanian Basin

Santos, F. O.; Mendes, M.; Russo, J.; Pimentel, N.

The Lusitanian Basin is located on the Iberian Western Margin, forming a NNE-SSW oriented elongated depression, where the sediment column reaches, at its deepest, approximately 5 km. It is bounded to the East by the Porto-Coimbra-Tomar Fault, which separates it from the Hesperian Massif, to the South by a NNE-SSW oriented fault, stretching from Golegã to the Setúbal Canyon, and to the West by a Hercynian horst, presently materialized by the granitic and metamorphic rocks of the Berlengas archipelago.

The evolution of the basin is intimately related to the first attempts of North Atlantic rifting, beginning in the Upper Triassic up to the Aptian in Lower Cretaceous. The reactivation of pre-existing Variscan structures as well as the development of others, more recent and due to the Middle Triassic initiated fracturing of Pangea, conditioned its evolution.

The basinal erosive processes were controlled by several rifting episodes of the North Atlantic, which provided different subsidence and sedimentation rates with differential known uplifting phenomena, and consequently different erosion rates, along the extent of the Lusitanian Basin.

This project was conceived by identifying the K-J unconformities in the geological maps (scale 1:50000) covering the area of research. Using a more recent legend, the lithostratigraphic units were uniformed so that differently named but contemporary formations could be analysed. This same reason was what led to the creation of a comprehensive legend for the K-J interval. It was necessary to outline on a GeoMap app structural map the relevant faults of the area using ArcGis and geological maps (scale 1:50000 and 1:500000). The coordinates of the identified points showing some kind of the afore mentioned unconformities were projected and plotted as GIS in a way that it is possible to recognize what kind of K-J unconformity exists in each one, how severe is the erosion and the type of erosive event. Isopachs maps compiled from well and outcrop data were also used in mapping and plotting the lateral variations.

In the end, 3 great K-J unconformities were identified: i) DC1, during the Berriasian and defined in the Iberian Segment of the Basin, ii) DC2, during the Barremian and identified in the Tejo Segment, and iii) DC3, during the Aptian, and by far the most relevant at a regional level, in the Galiza Segment. According to the data, the uplifting processes were more intense to the North, with some of the erosion values reaching well over 1500 meters, than on the South, where the sedimentary gap never surpasses a few hundred meters.

Modeling of Cretaceous uplift and erosion events in the Lusitanian Basin (Portugal)

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The Lusitanian Basin is located on the Western Iberian Margin, forming a NNE-SSW elongated depression, with around 300km x 150km, where the sediment column reaches, at its deepest, approximately 5km. The evolution of the basin is intimately related to the successive attempts of North Atlantic rifting, since the Upper Triassic break of Pangea until the Lower Cretaceous break-up. The reactivation of pre-existing variscan fractures, in the basement and propagating into the sedimentary cover, has strongly conditioned its Mesozoic (mostly distensive) and Cenozoic (mostly compressive) evolution. Besides the Mesozoic sedimentary infill, with variable subsidence and sedimentation rates, basin-scale uplift and erosion events took also place, with differential rates in different areas of the basin. The main erosive events occurred during the Cretaceous, related with the successive break-up events at the Western Iberian Margin.

The present study aimed to identify and characterize these Cretaceous events, based on the analysis of published 1:50.000 geological maps of the basin, implying a re-analysis of the lithostratigraphic charts of old and recent maps. On each map, unconformities between Cretaceous units and older Cretaceous or Jurassic units have been identified and multiple points have been marked. The thicknesses of the missing sequences have been estimated, based on time-interval isopach maps of the basin's infill, previously compiled from well and outcrop data. The geographical coordinates of those over thousand points were plotted in ArcGIS, with different colours/symbols for the age of the unconformity, the age of the underlying unit and the estimated erosion/uplift. This plotting has been overlaid to a map with the main regional faults, aiming to relate it with the main structural trends of the basin.

Three major Cretaceous unconformities have been identified: DC1 of Berriasian age, DC2 of Barremian age, and DC3 of Aptian age. According to the compiled data and resulting maps, the following conclusions may be drawn: i) uplift and erosion thicknesses are in the order of a few hundred meters in the southern sector of the basin, whereas in the northern sectors they attain more than 1500 meters; ii) unconformity DC3, of Aptian age, is by far the most relevant unconformity in the basin; iii) uplifting processes tended to migrate in time and to increase in amplitude northwards; iv) the age and intensity of unconformities is clearly related to the successive episodes of the North Atlantic break-up, migrating northwards along the Western Iberian Margin: DC1 related to the Iberian Segment, scarcely present in the southern sector; DC2 related to the Tejo Segment and present in the central sector; and DC3 related to the Galiza segment and mostly present with the higher values in the northern sector.

Contribution to the knowledge of petroleum generative potential of Late Sinemurian – Pliensbachian of the Lusitanian basin -northern sector (Portugal)

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The Late Sinemurian – Pliensbachian interval of the Lusitanian Basin is characterized by marly limestone deposits sometimes with organic-rich layers (Black shales). The study of these levels in outcrops located in the northern part of the Lusitanian Basin using some geochemical parameters such as total organic carbon (TOC) and Rock-Eval pyrolysis, allowed the definition of its petroleum generative potential with high stratigraphic accuracy.

There are two stratigraphic intervals particularly rich in organic matter positioned in the Oxynotum(?)–Raricostatum zones (Polvoeira Member of Água de Madeiros Formation) and at the top of the Ibex-upper part of Margaritatus zones (top of the Vale das Fontes Formation). These intervals are characterized by a high frequency of TOC values greater than 1% and/or several high values that can reach about 10%. The Rock-Eval pyrolysis parameter S2 is frequently above 10 mg HC/g rock, with an average value of 16.67 and highest value of 43.81 mg HC/g rock in Raricostatum Zone and highest value of 35.96 mg HC/g rock in the Margaritatus Zone. The values of HI obtained for these intervals, very often larger than 150 mg HC/g TOC, show potential for generation of oil and gas-oil.

Contrasts between the two main Jurassic source rocks in the western margin of the Lusitanian Basin (Portugal)

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The Lusitanian Basin (LB) is a small, North-South elongated basin, located on the western side of the Iberian Massif and, as other Mesozoic Peri-Tethyan basins, its origin is linked to the opening of the Atlantic Ocean. In the Jurassic sedimentary record of this basin, several organic-rich intervals are distinguished; two of them correspond to the main Jurassic source-rocks relevant for hydrocarbon exploration. The aim of this work is to characterize the organic content and associated parameters of these sediments, by palynofaciological observation and organic geochemistry analysis of more than 100 samples from on-shore outcrops in the west of the basin, contextualizing these occurrences in the Mesozoic sedimentary evolution of the LB.

The first organic-rich interval is the hemipelagic Marly-limestones with organic-rich facies member of the Vale das Fontes Formation, age constrained to the Lower Jurassic (Pliensbachian, top Ibex–Margaritatus zones). This hemipelagic series, with weak lateral facies variation at a basinal scale, represents deposition in a north-westerly dipping low energy carbonate ramp environment. Most of the organic-rich facies (some are true black-shales with TOC reaching 26%) are recorded in the distal areas of the basin, at Peniche and S. Pedro de Moel (western zone) while, in the most proximal sector (eastern zone), such facies are not recorded. The organic matter is composed of a mixture of marine and continental components, preserved in a marine depositional environment.

The second interval corresponds to the Cabaços Formation which, although poorly age constrained due to the lack of good index fossils, is dated from the early(?)/middle Oxfordian. This formation corresponds to the first sedimentary infill after the Middle-Upper Jurassic disconformable basinwide hiatus. Basinal lateral facies variation is strong. The studied Pedrógão section (located around 20 km NNE of S. Pedro de Moel), encompasses upper Callovian marine facies unevenly overlain by the Oxfordian Cabaços Formation, composed of fresh to brackish water facies with subaerial exposure, grading upwards into marginal- to restricted- marine facies. Here, the organic-rich facies are mainly restricted to the base of the Cabaços Formation and have a continental character, punctuated by minor marine incursions.

The Jurassic Carbonate Reef Trend Offshore Nova Scotia

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An Upper Jurassic carbonate bank extends for over 650 kilometers across Nova Scotia's offshore from the Sable Island area, southwest to the U.S. border. With only 21 exploration wells drilled into this bank since 1970, one commercial field has already been discovered along the reef margin. EnCana's Deep Panuke Offshore Gas Development Project will begin producing up to 892 Bcf of recoverable gas in 2011. With 630 kilometres of under explored bank edge remaining, more discoveries are anticipated. The carbonate bank can be divided into 3 geologically distinct sections. The Shelburne segment extends 120 km north east from the US border, has no wells and is poorly imaged on seismic. This transitions into the central Acadia segment which continues for 400 km and is characterized by erosion above the prominent bank edge. There is also faulting and collapse along this bank edge which is penetrated by 7 wells. The Panuke segment defines the north eastern portion of the bank and has prominent bank edge morphology that extends 120 km before transitioning into a carbonate ramp geometry north of Sable Island. Here, the influx of Jurassic clastics from the Sable Delta system overwhelmed carbonate production. The Panuke section is penetrated by 14 exploration wells and includes Nova Scotia's only commercial carbonate reservoir to date. This 3500m subsea reservoir is contained along the reef margin and consists of high porosity, fractured, dolomitized carbonates along with vuggy, cavernous limestone zones. This development occurs in water depth of approximately 50 m.

Syn- to Post-Rift Transitions on passive margins: The case of the western Iberian margin (NE Atlantic)

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A comprehensive set of 2D seismic reflection lines, borehole data from more than 50 Industry wells, stratigraphic information from key outcrops, and published DSDP/ODP data, was used in the analysis of syn-to post-rift transitions offshore West Iberia, Northeast Atlantic. In this work, we chiefly use wireline, stratigraphic and seismic data to document the tectono-stratigraphic changes occurring when of continental break-up in strata below and above a regional 'break-up' unconformity.

The progressive filling of proximal basins (Porto, Lusitanian and Alentejo Basins) during the latter stages of Late Jurassic syn-rift reflects a relatively low sea-level (lowstand) and the progressive abandonment of the former Late Jurassic rift axes. Stratigraphic data from key outcrop and well locations show shallow-marine to continental deposits denoting progradation towards the main axis of rifting, to the west. Shallowing-upwards sequences are intercalated with carbonate units deposited in slowly subsiding basins with no relevant topographic features. Continental break-up in southwest Iberia resulted in the sudden influx of siliciclastic material in onshore and shallow-offshore basins, interpreted to represent a forced regressive event accompanied by: a) westward tilting of the proximal margin, which sourced westward-prograding units; b) complete abandonment of syn-rift depocentres, which were blanketed by post-rift successions. Significantly, a period of widespread erosion is also recorded on the modern continental shelf and slope of southwest Iberia.In Northwest Iberia, a similar episode of progradation occurred in the Porto Basin during (Aptian) continental breakup. However, the inferred forced regression across the break-up unconformity was marked by prograding reflections of Albian age denoting shallow-marine environments, not continental deposits.

We suggest the differences between the two sectors as resulting from differences in the geological processes leading to continental break-up. Regions where continental break-up occurred relatively close to the rift-shoulder areas show widespread regional hiatuses and an abrupt shallowing of sedimentary facies across the break-up unconformity. Also, areas where break-up occurred closer to the rift-shoulder should contain the larger thickness of syn- and post-rift reservoirs, a character reflecting shorter distances between sediment source areas and adjacent depocentres on the continental margin.

New techniques for sand provenance – Combined isotopic tracing of detrital zircon and tourmaline

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Sandstone units hosting oil and gas reservoirs in sedimentary basins are often difficult to trace in the subsurface, particularly where drilling and seismic data are limited. Heavy minerals present in the sandstones can provide distinctive fingerprints of the clastic sources of the sandstones, which may be used to reconstruct paleo drainage pathways into the basins and correlate sandstone formations. Traditional approaches in clastic heavy mineral studies have emphasized ratios of particular minerals with similar hydrodynamic properties, and in situ uranium-lead geochronology of zircon. More recent studies of sand provenance have investigated in situ uranium-lead geochronology of detrital monazite and in situ lead isotope geochemistry of detrital feldspar. Here we explore the potential of hafnium isotope geochemistry of detrital zircon and lead isotope geochemistry of detrital tourmaline for sandstone source tracing.

Heavy minerals are pre-concentrated using bromoform (specific gravity = 2.85 g/cm^3) in order to separate the heavy mineral fraction from matrix light minerals such as quartz and feldspar. An epoxy grain mount is made directly from the 63 μm – 177 μm heavy mineral concentrate to avoid any potential bias produced by magnetic separation and hand picking of mineral populations. An integrated scanning electron microscope/Mineral Liberation Analyzer (SEM/MLA) allows for automated identification and chemical analysis of all heavy mineral grains within the grain mount. The MLA identifies the position, chemical and physical characteristics, and relative abundances of all heavy mineral phases of interest present in the concentrated subsample. In-situ isotopic analyses of identified detrital zircon and detrital tourmaline grains are made by laser ablation multicollector inductively coupled plasma mass spectrometry (LA-MC-ICPMS). The Hf isotope characteristics of analyzed detrital zircon grains can be combined with in-situ U-Pb LA-ICPMS analyses from the same zircon grain. This information, integrated with the Pb isotope geochemistry of detrital tourmaline from the same sample can be used to even further refine the provenance for a particular sandstone unit. Example data from petroleum reservoir sandstones of the offshore Newfoundland Grand Banks and potential source rocks from on land Newfoundland stream and till deposits will be presented.

New techniques for sand provenance – Combined isotopic tracing of detrital zircon and tourmaline

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The Upper Jurassic Petroleum System: evidence of secondary migration in carbonate fractures of Cabaços Formation, Lusitanian Basin

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The petroleum exploration in the Lusitanian Basin began in the last century, especially after 1938, when several geological and geophysical data was acquired. Occurrences of petroleum impregnating surface rocks (seeps), and other hydrocarbon shows in the subsurface indicate the presence of active petroleum systems, in both the northern and southern parts of the basin.

Two main source rock intervals are recognized in Lusitanian Basin: Lower Jurassic (Sinemurian and Pliensbaquian) and Upper Jurassic (Oxfordian). The aim of this work was to characterize geochemically the origin and thermal maturation of oil impregnated in carbonate fractures of Cabaços Formation locate at Torres Vedras Region (Turcifal Sub-basin) and then to associate the oil to a petroleum system based on oil-source rock correlation.

The oil samples collected in carbonate fractures was analyzed using traditional geochemical techniques, including whole oil stable carbon isotopic composition ($\delta\,^{13}C$ - MS Finnigan MAT 252), liquid chromatography (MPLC), whole oil gas chromatography (GC), and gas chromatography coupled with a mass spectrometer of saturate compounds (GC-MS, m/z=191 e m/z=217).

The geochemical results of MPLC show a predominance of resins and asphaltenes with 51%, associated to 22% of saturates and 27% of aromatics. The values of $\delta^{13}C$ for whole oil are around -24.9‰. According to gas chromatography data, the organic composition represents a typical signature of non-biodegraded oil, characterized by the abundance of *n*-alkanes and low pristane/n-C_{17} and phytane/n-C_{18} ratios. Sometimes, the absence of light *n*-alkanes and isoprenoids can be attributed to evaporation under conditions of prolonged exposure. Saturate biomarkers weren't affected by processes of secondary alteration. The relatively more abundant compounds among terpanes (m/z 191) are C_{29} 17α(H)□□, 21β(H)-30-norhopane (H_{29}), C_{30} 17α(H), 21β(H)-hopane (H_{30}), 17α(H)-22,29,30-trisnorhopane (Tm) and C_{24} tetracyclic (TET_{24}). Moreover, the distribution of steranes (m/z 217) displays a predominance of C_{29} steranes, pregnane (C_{21}) and homopregnane (C_{22}).

The organic geochemistry parameters of this oil, like low pristane/phytane and diasteranes/regular steranes ratios associated with high H_{29}/H_{30}, TET_{24}/26 Tri, H_{35}/H_{34} ratios and carbon isotopic signature enriched in ^{13}C, are compatible with the composition of extracts from Cabaços Formation, represented mainly by marine organic-rich black limestone intervals (Oxfordian). The good oil-source rock correlation corroborates the presence of an Upper Jurassic Petroleum System in the Turcifal Sub-basin domain, central sector of Lusitanian Basin. It is important to mention that the geochemical characteristics of the Upper Jurassic Petroleum System are easily recognizable when compared to Lower Jurassic Petroleum System.

This type of occurrence suggested secondary migration via fractures probably associated with fissured carbonate reservoirs of Cabaços Formation. Similar reservoirs were tested in some wells drilled in the Torres Vedras region which recovered oil in fractures at the same formation. Due to the short distance between source rock and reservoir, and also the network of fractures and faults observed in the outcrops, this petroleum system can be considered of high generation efficiency and drainage.

The Upper Jurassic Petroleum System: evidence of secondary migration in carbonate fractures of Cabaços Formation, Lusitanian Basin

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The aim of this work is to characterize geochemically the origin and thermal maturation of the oil impregnated in carbonate fractures of Cabaços Formation that occur in outcrops at Torres Vedras Region (Turcifal Sub-basin) and then to associate to petroleum system based on oil-source rock correlation.

The oil samples collected in carbonate fractures were analyzed using traditional geochemical techniques, including whole oil stable carbon isotopic composition (□^{13}C - MS Finnigan MAT 252), liquid chromatography (MPLC), whole oil gas chromatography (GC), and saturate biomarkers by gas chromatography coupled with a mass spectrometer (GC-MS, m/z 191 e m/z 217).

The geochemical results of MPLC show a predominance of resins and asphaltenes with 51%, associated to 22% of saturates and 27% of aromatics. The values of □^{13}C for whole oil are around -24.9‰. According to gas chromatography data, the organic composition represents a typical signature of non-biodegraded oil, characterized by the abundance of *n*-alkanes and low pristane/*n*-C_{17} and phytane/*n*-C_{18} ratios. Sometimes, the absence of light *n*-alkanes and isoprenoids can be attributed to evaporation under conditions of prolonged exposure. The saturate biomarkers weren't affected by process of secondary alteration. The relatively more abundant compounds among terpanes (m/z 191) are C_{29} 17□(H)□□, 21□(H)-30-norhopane (H_{29}), C_{30} 17□(H), 21□(H)-hopane (H_{30}), 17□(H)-22,29,30-trisnorhopane (Tm) and C_{24} tetracyclic (TET_{24}). Moreover, the distribution of steranes (m/z 217) displays a predominance of C_{29} steranes, pregnane (C_{21}) and homopregnane (C_{22}).

The organic composition of this oil associated with high H_{29}/H_{30}, TET_{24}/26 Tri, H_{35}/H_{34} ratios and ^{13}C enriched carbon isotopic signature, are compatible with the composition of extracts from Cabaços Formation, represented mainly by marine organic rich black limestones intervals (Oxfordian). The good oil-source rock correlation corroborates the presence of Upper Jurassic Petroleum System in the Turcifal Sub-basin domain, central sector of Lusitanian Basin. The low thermal maturation founded for this oil, based on low Ts/(Ts+Tm), $C_{29}Ts/H_{29}$ and C_{29} S/(S+R) ratios, indicates that the kitchen area reached at least to beginning of oil window in the catagenesis.

This type of occurrence suggested secondary migration by fractures probably associated with fissured carbonate reservoirs of Cabaços Formation. Similar reservoirs were tested in some wells drilled in Torres Vedras region recovering oil in fractures (DPEP).Due to the short distance between source rock-reservoir and also the network of fractures and faults observed in the outcrops, this petroleum system can be considered of high generation efficiency and drainage.

The Mesozoic Orpheus rift basin, offshore Nova Scotia and Newfoundland, Canada: Synrift and early postrift evolution of a well-imaged North Atlantic rift basin

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The Mesozoic Orpheus rift basin of offshore eastern Canada formed during the breakup of Pangaea prior to the opening of the North Atlantic Ocean. Using a dense grid of high-quality 2D seismic data, we have identified three distinct tectonostratigraphic packages associated with the early development of the basin. Information from nearby wells (albeit limited) and the onshore Fundy basin suggests that the tectonostratigraphic packages represent prerift rocks (Paleozoic strata and basement), Middle Triassic to Early Jurassic synrift strata, and Early to Late Jurassic postrift strata. The middle part of synrift package is likely halite. High-amplitude reflections that cut the synrift package are likely igneous sheets associated with the earliest Jurassic Central Atlantic Magmatic Province (CAMP). The regional angular unconformities that separate and bound the tectonostratigraphic packages are, from oldest to youngest, the rift-onset, breakup, and Late Jurassic/Early Cretaceous postrift unconformities.

Both deep-seated tectonic activity and the presence of salt profoundly affected the structural evolution of the Orpheus rift basin. Rifting began no later than the Late Triassic, producing a series of east-striking, south-dipping basement-involved faults with normal separation that bound the Orpheus basin on the north. During the early stages of rifting, the basin was broad with few faults. Most basement-involved faulting began during the deposition of the halite unit, causing pronounced thickening of the salt toward the south. The salt began to flow after its deposition, forming fault-parallel salt anticlines and salt-withdrawal synclines. Movement on basement-involved faults during rifting produced fault-propagation folds in the synrift section above the salt. Postrift shortening occurred during the Early to Middle Jurassic, producing salt-cored detachment folds, detached thrust faults, and regional uplift and erosion. A period of tectonic quiescence followed shortening, leading to widespread deposition atop the breakup unconformity. Postrift salt movement resumed during the Middle to Late Jurassic, producing fault-parallel salt-cored highs and salt-withdrawal lows. Uplift and erosion during latest Jurassic to early Cretaceous produced a widespread unconformity.

Provenance of Mesozoic sandstones of the Flemish Pass and Orphan Basins, offshore Newfoundland – the view from isotopic studies of detrital zircon and tourmaline

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Late Jurassic to Early Cretaceous potential reservoir sandstones from three industry exploratory wells in the Flemish Pass and Orphan Basins were studied for provenance analysis. The sandstones from this study formed during intracratonic rifting that preceded the breakup between North America and its European conjugate margins and seafloor spreading in the North Atlantic. Most were deposited during the Tithonian and Neocomian North Atlantic Rifting stage, during which rifting intensified between Iberia and the Grand Banks and the deposition of important reservoir sandstones occurred regionally.

Heavy mineral fractions were isolated from cuttings samples from six syn-rift sandstone units. The studied sandstones range in age from Tithonian to Albian. For comparison to on land sources in Newfoundland, seven samples of glacial tills and nine samples of stream sediments were collected across the Island. Three traditional heavy mineral approaches were used to determine provenance and make correlations: (1) U-Pb geochronology and petrography of detrital zircons, (2) detrital heavy mineral grain counts and ratios, and (3) geochemistry of detrital tourmalines. In addition, two newer approaches – Hf isotope geochemistry of zircon and Pb isotope geochemistry of tourmaline were also used.

The data indicate that the predominant first-cycle sediment sources included the Neoproterozoic arc-phase igneous rocks of the Avalon Zone as well as the Ordovician to Devonian magmatic rocks and metasedimentary rocks present in the Central Mobile Belt. There is abundant petrographic and heavy mineral evidence to support significant recycling of material from cover sequences in these tectonic zones as well, likely including Early and Late Paleozoic sedimentary rocks which are ubiquitous in both zones. Such a source signature requires uplifted source areas to be present in the west, including parts of the Bonavista Platform, Interior Newfoundland, Northeastern Newfoundland Shelf, and potentially parts of the Irish conjugate margin, including the Porcupine Bank. Thus, paleodrainage orientations and delivery of coarse clastic detritus into the Flemish Pass and Orphan Basins was predominantly from the west during the Late Jurassic to Early Cretaceous, as seafloor spreading began between the Grand Banks and Iberia. Based on this information, one would expect to find reservoir facies sandstone units of this age concentrated along the western margins of the Flemish Pass and Orphan Basins, with deteriorating reservoir grade towards the east.

Jurassic reef exploration play in the southern Lusitanian Basin, Portugal

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A well-developed shelf-edge reef trend is observed on reprocessed 2-D and newly acquired 3-D seismic data from the western margin of the Turcifal sub-basin in the southern Lusitanian basin of Portugal. There appear to be three stacked reef tracts ranging in age from Dogger to Malm along this margin. The youngest reef complex (Oxfordian) is coeval with the Abenaki reef trend of the eastern Canada offshore (Panuke Deep gas field). Plate reconstructions place the Lusitanian basin in an Upper Jurassic reef belt extending from the Canadian Scotian shelf area of the proto-Atlantic, around the Iberian cratonic block, and along the northwest margin of the Tethys Ocean. Mohave Oil and Gas Corp. drilled the only well into the shelf-edge complex (TVR G-1 well). That well, based on limited 2-D seismic data only, failed to encounter reef core facies. It penetrated mostly clean micritic limestones interpreted as backreef facies, but did drill 200m of cemented grainstones and packstones with coral and other fossil debris. That verification of reef environment prompted acquisition of 3-D seismic data to accurately map the reefs and associated facies. Additional drilling is planned after interpretation of the 3-D dataset is complete.

Oxfordian reef facies have been penetrated in wells in the neighboring Bombarral sub-basin, with up to 100m of water-bearing porosity (Campelos-1 well). A well drilled downdip from an exhumed oil deposit in reef rock and overlying sands, on the northwest flank of the Serra de Montejunto trend, penetrated 450m of scattered heavy oil and tar in reef and near-reef facies (Pragança-1 well). Mohave encountered a 1m zone of reef-derived, bioclastic grainstone at 212m depth in a shallow core hole at Abadia Dome. The zone was saturated with heavy oil, and whole core analysis indicated 23% porosity with horizontal permeability of 1500 mD and vertical permeability of 950 mD. Outcrop studies of Upper Jurassic coral communities have been conducted along the eastern margin of the Arruda sub-basin to the east, an area dominated by greater siliciclastic influx.

Source rocks for the system are documented from outcrop and well samples. Regionally, the basal Oxfordian carbonate unit is a bituminous limestone with up to 6% TOC, and overlying Kimmeridgian silty shales also range up to 6% TOC. At the Torres Vedras anticline in the northeast corner of the Turcifal sub-basin, live oil (25º API) has been recovered in shallow wells from fractured non-reef Oxfordian limestones and from overlying thin, fine-grained Kimmeridgian sandstones.

The TVR G-1 well penetrated good seal facies consisting of 20m of transitional, thin micritic limestones and dark silty shales, capped by at least 30m of dark silty shale with >50 API units Gamma Ray signature. An ancillary play is associated with Kimmeridgian prograding clinoforms which traverse the reef front and spill into the forereef basin.

Hydrocarbon potential of Mass Transport Deposits on the Central Atlantic Conjugate Margins- An Evolving Play Concept

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Mass transport deposits (MTDs) form a significant portion of the sedimentary section of most continental margins. For example, MTDs comprise up to 40% of the Cenozoic section along the eastern Canadian margin. MTDs are commonly recognised as a geohazard in offshore hydrocarbon exploration, documenting evidence of seafloor instability. However, MTDs are now becoming recognised as potential hydrocarbon exploration targets. Drilled MTDs have contained gas (Shipp & Gibson, 2009) and while these are often geohazards to deeper drilling, they do prove petroleum systems with effective reservoir, trap and seal facies.

The lack of recognition of MTDs as potential hydrocarbon targets was in part due to their deposition in deep water, with large run-out distances down slope onto the abyssal plain, the heterogeneity of these deposits, and their typical chaotic seismic character. There was also the belief that MTDs would have poor reservoir quality with the assumption of very fine grained sediment.

There are potential risks associated with the exploration of MTDs. Reservoir heterogeneity can create baffles and barriers to effective fluid flow contributing to reservoir risk. In drilling and production operations MTDs are a risk where top seal, and internal baffles and barriers can create zones of overpressure that are difficult to predict, particularly in gas-charged systems that are difficult to image seismically. Sand deposited by high density turbidites can act as a "thief" zone, bleeding off production.

MTDs follows the ever evolving concepts of new exploration plays; from the novel idea of sediment bypass across the shelf and slope to deeper waters; drilling through overpressure zones to find new zones of hydrocarbons; and sub-salt plays along passive margins. The potential of MTDs will continue to grow as exploration expands along the slope systems of continental margins.

Sequence stratigraphy and development of the Tarfaya Basin, Morocco

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Although sufficiently mature source rocks (Early Jurassic, Late Cretaceous) and suitable reservoir facies (e.g. Late Jurassic, Early-Middle Tertiary) exist in the Tarfaya Basin (TB), past exploration has yielded few oil/gas shows and no commercially producing wells (Morabet et al. 1998). In order to better understand the basin and HC systems development of the TB, an integrated approach has been applied including numerical modeling of source and sink areas. Key methodologies include sequence stratigraphy, thermochronology, biostratigraphy, source-to-sink analysis, geochemistry and basin modeling. This contribution focuses on sequence stratigraphy which will be the key concept for future numerical modeling in the sink area. The model is based on i) well correlation, ii) seismo-/sequence stratigraphic interpretation and, iii) data from outcrop analogues.

The Mesozoic to Cenozoic basin development includes 5 major basin stages i) Permian to Pliensbachian rift- and sag, ii) Toarcian to Cenomanian drift, iii) Turonian to Early Eocene drift with initial Atlasian deformation, iv) Middle-Late Eocene drift with major Atlasian compression; v) Late Eocene to Early Miocene drift with major Atlasian uplift and inversion. At least 92 sequences (3rd order) have been identified in the Lower Jurassic to recent Tarfaya shelf margin so far.

The Late Permian to Liassic rift, sag and early drift basin fill (260-180 Ma) includes alluvial, limnic, evaporite and carbonate ramp depositional environments. In the area of the recent shelf margin, the Lower Jurassic basin fill contains five sequences showing coastal plain mudflats with alluvial intervals until the Early-Middle Toarcian and carbonate-evaporite ramps in the Late Toarcian. The Middle and Late Jurassic carbonate shelf ramp is subdivided by at least 28 sequences. 30 Early Cretaceous and up to 15 Late Cretaceous sequences comprise fluvio-deltaic and inner-outer shelf environments. Offshore, the Cretaceous is bounded by a major erosional unconformity, triggered by continental margin collapse. The Paleocene siliceous to carbonate and Eocene mainly clastic basin fill includes seven sequences. Significant sediment bypass across the shelf top and margin took place during the Early to Middle Paleogene. A major regression coincides with shelf margin and upper slope collapse in the Oligocene. The Neogene basin fill covers 14 sequences. The resolution of the sequence stratigraphic model reaches reservoir-scale.

The Acquisition of Deep, Long Offset Seismic Data Provides New Information on the Stratigraphic and Structural Development of the NE Greenland Margin

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The NE Greenland Shelf is the conjugate margin to the Lofoten and Vøring Margins of Mid-Norway and it lay south of the Barents Shelf prior to break-up. In order to fully understand the evolution of these margins and the opening history of the North Atlantic Ocean the lesser-known NE Greenland margin requires further exploration and additional data. Deep long-offset seismic data were acquired in 2009 as the first stage of a larger survey designed to cover the NE Greenland Shelf. The data currently extends between the Jan Mayen Fracture Zone in the south to the Greenland Fracture Zone in the north, covering the southern part of Danmarkshavn Basin, the Thetis Basin, and the Northeast Greenland Volcanic Province.

Earlier attempts to acquire seismic data in the area have been hampered by heavy ice coverage. This was overcome by employing a proprietary streamer and deployment technology to acquire data below the pack ice. In addition to this an icebreaker was used to clear first-year ice for the primary acquisition vessel, allowing the seismic program to remain focused on geologic targets. A total of 5,283km of seismic data were successfully acquired in the first phase of the survey and there are plans to return to acquire more data in 2010, focused on the northern Danmarkshavn Basin.

Pre-stack depth migrated (PSDM) seismic lines were used for the interpretation which was tested iteratively against gravity and magnetic modeling. The seismic data images intra- and sub-basalt reflectors in the volcanic province and on the marginal high where seaward dipping reflectors are interpreted. Several of the lines cross the Continent Ocean Transition (COT) where they clearly show deep reflectors at around 10 km which may represent the Moho. These deep reflectors plunge west to about 22-25 km depth towards Greenland continental crust.

The data show a very thick sedimentary sequence in the southern part of the Danmarkshavn and Thetis Basins which is at least 9 km thick. Both basins are interpreted to include a thick Mesozoic section. Older Paleozoic sediments are also thought to be present in the Danmarkshavn Basin and subcrop along the Danmarkshavn Ridge, a prominent structural high separating the two basins. Extensive syn-rift faulting is interpreted along the eastern and western margins of the Danmarkshavn Ridge and large scale folding and doming have affected the area since break-up, leading to the development of potentially large hydrocarbon traps. These observations, together with comparisons with the conjugate Mid-Norway margin, reinforce previous interpretations that the area has excellent hydrocarbon potential. Information gained from the new deep long-offset seismic survey in NE Greenland also provides input for a revised plate tectonic model of the North Atlantic.

Nova Scotia Play Fairway Analysis
Why and What For

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The OETR (Offshore Energy Technical Research) Association has initiated an industry standard Play Fairway Analysis program. This program serves as a pivotal role in stimulating industry interest in exploration of Nova Scotia's offshore petroleum resources by providing explorers with critical information about prospectivity and resource potential to aid in decision making.

The play fairway program addresses three key issues:

1. Plate tectonic reconstruction: Establishing the relationship between rifting and salt deposition has developed models for potential syn-rift and early post rift depositional environments and the development of source rocks.

2. Forensic Geochemistry: The program has undertaken a systematic evaluation of geochemical source rock and hydrocarbon typing data. An important component of this work includes fluid inclusion studies from hydrocarbon traces found in the salt. This analysis, combined with the reconstruction work provides evidence for a restricted marine Lower Jurassic source rock covering much of the margin.

3. Sequence stratigraphic framework: The program of work has re-evaluated the biostratigraphy of 20 key wells which were then integrated with the seismic interpretation, and tectonic models. A comprehensive sequence framework for the basins has been established

Leading academic researchers based in Halifax have contributes substantial elements to the overall program. Of particular note are the plate tectonic and salt modelling projects being done at Dalhousie University; and the biostratigraphy and reservoir quality projects being done at St Mary's University. All projects will also build on the extensive high quality thinking and knowledge that exists in the Geological Survey of Canada (GSC) and the Canada-Nova Scotia Offshore Petroleum Board (CNSOPB).

The Play Fairway Program has integrated the results of these individual projects to develop an industry standard play fairway analysis and atlas. This includes Gross Depositional Environment (GDE), and Common Risk Segment (CRS) maps on each key sequence.

This technical program is being accompanied by a marketing campaign focussed on attracting leading exploration companies to explore in Nova Scotia.

Synsedimentary Tectonism on Wedge Top Basins: Offshore Rharb Basin (Northwestern Morocco)

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The Rharb Basin is located onshore and offshore northwestern Morocco. The basin was created as result of the formation of the Gibraltar Arc and is the more external unit of the Rif Cordillera. Northwestern Morocco evolved from a classic Mesozoic passive margin into an active margin due to the convergence of the Eurasia and African Plates and the westward escape of the Alborán microplate during Late Miocene time. The Gibraltar Arc represents the westernmost segment of the Alpine–Mediterranean Belt and connects the Betic Cordillera with the Rif Cordillera. The external domain includes sedimentary allochthonous units derived from the South Iberian and North African passive margins and results from a piggy back sequence of emplacement from top to bottom and from hinterland to foreland.

Two regional NW-SE offshore sections have been interpreted, converted to depth and restored to illustrate the evolution of the area. Seismic lines show a thick tertiary section overlying the Prerif Nappe. This is an olistostrome sequence giving an irregular upper surface. This paleorrelief was covered by a thick Miocene sedimentary sequence that produces instability of the incompetent Prerif Nappe. The extensional faults are rooted into the Prerif Nappe.

The restoration of the two lines show that in the first stages the Miocene sediment loading triggered the extensional and gravitational processes. The Miocene depocenter is limited by a master western dipping fault. Fault activity is more important in the south where it has also control the deposition of the base of the Lower Pliocene. To the north, the activity of this fault decreases and deposition of the base of the Lower Pliocene seems to be controlled by differential compaction and subsidence (onlap relationships).

During the upper part of the Lower Pliocene and up to the Holocene, fault activity is shifted to the west and the main depocenter and sedimentation processes are related to a master east dipping fault. However, the sedimentation of the upper part of the Lower Pliocene is filling a small pod with onlap relationships to both sides.

Gravity spreading and extension began with the deposition of the Miocene sequence above the incompetent Prerif Nappe. Normal listric faults are rooted in this incompetent unit. Fault movement produced tilting and block rotation and probably toe thrust inside the Prerif Nappe. Sedimentation is mainly controlled by these normal faults and shifting of the sedimentation can be observed from East to West.

The palinphastic restoration has been very helpful to identify the movement and activity of the main faults present in the area. This activity has controlled the accommodation space for the turbidite deposition, knowing its evolution allows interpreting the location of the reservoir facies for the exploration prospects in the area.

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